FTA-MA-26-7022-97-1
DOT-VNTSC-FTA-97-7

U.S. Department
of Transportation
Federal Transit
Administration

Subway Environmental Design Handbook, Volume II
Subway Environment Simulation Computer Program, Version 4
Part 1, User's Manual

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

Final Report
December 1997

OFFICE OF RESEARCH, DEMONSTRATION, AND INNOVATION

NOTICE

NOTICE

NOTICE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No.0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1997

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
Subway Environmental Design Handbook, Volume II
Subway Environmental Simulation Computer Program
- SES Version 4, Part I User's Manual

5. FUNDING NUMBERS

6. AUTHOR(S)
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Parsons Brinckerhoff Quade & Douglas, Inc.
One Penn Plaza / 250 West 34th Street
New York City, NY 10119 *

8. PERFORMING ORGANIZATION REPORT NUMBER
FTA-MA-26-7022-97-1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Department of Transportation
Federal Transit Administration
400 Seventh Street, SW
Washington, DC 20590

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
DOT-VNTSC-FTA-97-7

11. SUPPLEMENTARY NOTES

* Under contract to:
U.S. Department of Transportation
Research and Special Programs Administration
Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

* Under contract to Parsons Brinckerhoff:
ICF-Kaiser Engineers, Inc.
1800 Harrison Street
Oakland, CA 94612

12a. DISTRIBUTION / AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Subway Environment Simulation (SES) Version 4 is an upgrade to Version 3 (1982). It includes enhancements to the program input, code and documentation. A number of changes were made to make the code conform more closely to PC applications of FORTRAN 90 and to use its specialized features such as the PARAMETER statement, pagination and the date-time stamp on each page of the output. A Windows-based SES Input Manager, SESIN, was written to enable the less-experienced user to more quickly construct, modify, correct and run SES input data files. SESIN permits the user to create, view and change SES input data files using menu-driven dialog boxes with tables, list boxes and other standard Windows data entry features. Known anomalies in the program were written out or reduced in severity. The Users Manual was converted to electronic form for easier maintenance and future updates. Some improvements were made in the text and the references were brought up to date. A chapter outlining the SES part-scale and full-scale validation work, including that of the fire model from the full-scale Memorial Tunnel Fire Ventilation Test Program, was added.

14. SUBJECT TERMS
Subway Environment Simulation, SES, Tunnel Ventilation, Fire-Life Safety, Environmental

Control Systems, Emergency Ventilation, Tunnel Design

15. NUMBER OF PAGES
620

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Forms 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

PREFACE TO SES VERSION 4

Version 1 of the Subway Environment Simulation (SES) computer program was completed in 1975. Since then, the SES has been used to analyze approximately 26 underground rail transit systems as well as six mainline rail tunnels on five continents. To meet the evolving needs of the industry, SES Version 2 was completed in 1976 and Version 3 was completed in 1982. SES Version 3 well withstood the test of time. Beginning in about 1991, personal computers (PCs) and their compilers evolved to the point where they equaled mainframe computers in their ability to perform day-to-day engineering analyses. However, PC compilers were not the same as mainframe compilers and some rather daunting problems had to be overcome when running converted versions of the SES on PCs. Another issue was that the SES User's Manual had been hand-typed in 1974-1975 and was cumbersome to update. Finally, the program input was difficult unless one had experience with text editors. To overcome the latter problem, ICF-Kaiser Engineers (ICF-KE) began the development of a Windows-based SES Input Manager in 1993, but was unable to finish the work.

Recognizing these issues, the Volpe National Transportation Systems Center authorized Parsons Brinckerhoff Quade and Douglas, Inc. (PBQ&D) to develop SES Version 4 in 1996. PBQ&D then subcontracted the development of the Input Manager to ICF-KE. The SES Version 4 work order tasks were:

- Validate the fire model
- Adapt the SES to run on modern computing machinery
- Correct known problems
- Update the documentation

The work began in October 1996 and was completed in September 1997.

The SES computer program fire model was validated using the Memorial Tunnel Fire Ventilation Test Program. References 17 and 18 of Chapter 15 explain the Froude Number methodology and the full-scale validation work to date and discuss future improvements and how they may affect the SES.

A number of changes in the SES source code were made to take advantage of the features of FORTRAN 90. These included the use of the PARAMETER statement to enable easier and less error prone changes to the SES program memory and the printing of the date, time and page number on each page of the output. Appendix I ("New Features in SES Version 4.0") of this Manual contains a complete list of these improvements.

The SES Input Manager (SESIN), was written by ICF-KE. SESIN provides a modern, interactive, Windows-based interface for developing and editing ASCII format SES input data files and for initiating execution of an SES simulation. SESIN permits the user to view and enter SES input data using menu-driven dialog boxes with tables, list boxes, and other standard Windows data entry features. Files prepared or edited with SESIN are fully compatible with files prepared by the traditional editor method, and files prepared by either method may be run with either the DOS or Windows-based version of SES. A program for running multiple SES files was also written and is accessible either from SESIN or directly from Windows. For the less-experienced user, SESIN can significantly reduce cost and increase the accuracy of the SES input file creation. SESIN is described in Chapter 11 of this manual.

The first five years of PC-based SES analyses identified a number of anomalies in the SES program. They were reported by PBQ&D, ICF-KE, New York City Transit, et al. Some of them had been existent in the SES program since Version 1 and others arose because of the differences between PC and mainframe FORTRAN. Much effort was spent to eliminate them. One of them, the so-called unbalanced flow problem, was reduced in severity but not completely eradicated. Appendix I of this manual briefly identifies the problems and documents the changes made.

The SES User's Manual was converted to electronic form for easier maintenance and future updates. Some improvements were made in the text and the references were brought up to date. Chapter 15 outlining the SES validation work to date was added. The individual validation reports are referenced. A chapter on sample calculations was added. Since the SES Programmer's Manual was not updated, Appendix I was added to the User's Manual to form a bridge between the SES Version 3 Programmer's Manual and SES Version 4. Because of a lack of use, the chapters on sensitivity studies and sample problems were deleted.

As was the case with the development of SES Versions 1, 2 and 3, the development of SES Version 4 involved a coordinated team effort.

The PBQ&D team included:

Project Management	W.D. Kennedy
Advisors from the past	J.A. Gonzalez
	J.W. Guinan
	S.S. Levy
SES Interface with SESIN	C.C. Chan
	D.P. Elpidorou
Program updates	D.P. Elpidorou
	W.D. Kennedy
	S.K.L. Li
Documentation	D.P. Elpidorou
	G.D. Huang
	M.J. Karaa
	W.D. Kennedy
	A. Lambrou
	G. Lemmon
	T.P. O'Dwyer
Testing	D.P. Elpidorou
	G.D. Huang
	S.K.L. Li

The ICF-KE team included:

Project Management	P.C. Miclea
Advisor from the past	R.E. Murphy
Programming of SESIN	D.M. McKinney
SES Interface with SESIN	D.M. McKinney
Documentation	D.M. McKinney
	P.C. Miclea
Testing	D.M. McKinney
	P.C. Miclea
	R.E. Murphy

The development team wishes to acknowledge the assistance of:

- W.T. Hathaway and A. Thompson of the Volpe National Transportation Systems Center for program monitoring and direction.
- J.A. Harrison and A.G. Bendelius of PBQ&D and J.H. Bergersen of ICF-KE for project management and support.

PREFACE TO SES VERSION 3

In the first half decade, since its completion in 1975, the Subway Environmental Design Handbook and Subway Environment Simulation (SES) Computer Program have been used in the study and design of ten subway systems on three continents.

As the supply of energy for personal transportation decreases and the demand for more and improved mass transit increases, it is evident that the usage of the SES Program will continue and grow.

In order to meet the demands of the future, Parsons Brinckerhoff Quade & Douglas under a contract from the Volpe National Transportation Systems Center (VNTSC) or Volpe Center has revised and updated the SES Program to increase both its flexibility and accuracy. This work has led to the development of SES Version 3. The work effort encompassed a 20-month period which involved research, programming, and related maintenance. The following is a summary of program improvements.

Subway Fire Model

A model for the evaluation of the airflow direction, quantity, and air temperature during a major subway fire has been incorporated into SES Version 3.

Among the elements included in the fire model is the ability to simulate throttling effect. This pressure loss is caused by the rapid expansion of the air flowing past the fire site. Also, as a consequence of the law of conservation of mass, the viscous pressure losses in the section of the tunnel downstream of the fire increase, tending to reduce tunnel airflow. Density differences between the hot gases and the ambient air give rise to pressure differentials which can either augment or retard the tunnel airflows, depending on the direction of ventilation (uphill or downhill). The effects of these density differences on exhaust fan performance have also been accounted for in the model.

Another element included in the fire model is that of wall surface temperature response. Accurate modeling of the transient heating of the wall surface at the fire site is an important factor in determining the conditions downstream of the fire, as it improves the accuracy of the predicted air temperatures which are subsequently used to calculate the buoyant pressure differential.

The fire model is intended for use in a trial-and-error fashion to determine the size of the emergency ventilation system capacity. The iteration is between the tunnel air velocity (past the fire site) predicted by the SES Fire Model and a design air velocity criterion which precludes the movement of smoke and hot gases against the ventilating air stream ("backlayering"). The air velocity criterion is a function of the fire heat rate, the tunnel width and grade, and the temperature of the hot gases leaving the fire.

The original and current version of the SES is essentially a one-dimensional, incompressible, turbulent, slug-flow model. The throttling and buoyancy effects, which are primarily caused by changes in density, are conveniently accounted for by noting that changes in density are inversely proportional to changes in the absolute temperature of the air.

The SES Fire Model has been designed with the ability to simulate the "overall" effects of a tunnel fire on the ventilation system. This level of detail is considered sufficient for evaluating the adequacy of an emergency ventilation system and is consistent with the state-of-the-art in mining ventilation programs with the capability of simulating fires.

Program Enhancements

The option has been added to punch a set of "initial condition" cards utilizing the results of one computer simulation as the starting point for subsequent simulations. These items can be punched: train data, airflow rates, wall temperatures, air temperatures, humidities and estimates of air conditioning loads.

The ability to simulate adjacent air conditioning zones (controlled zones) has been added. This change simplifies the simulation of air-conditioned stations with more than one design temperature requirement.

The simulation of direct current traction motors has been improved. The new procedure can model series-wound or separately-excited motors. The computation of motor current, line current, and heat generation has been improved, particularly for trains operating at partial throttle. Also, the instantaneous value of the line current is now printed.

The capability of simulating an energy storage device on board a train has been added. This device (a flywheel assembly) stores energy during a braking cycle and provides electrical energy to the propulsion system during acceleration. While the input to the model is in units associated with flywheels, it may be possible to simulate other energy storage devices by appropriate manipulation of the input.

The steady-state heat rejection rate (both sensible and latent) from trains and the power consumption by the vehicle auxiliaries have been modified to linear functions of the number of passengers on board the train. The previous version assumed these values to be constant.

The summary output has been expanded to show the average sensible and latent heat gains within each line segment by the following categories:

1. Train propulsion/braking system heat
2. Train auxiliary system and passenger heat
3. Segment steady-state heat gains
4. Segment unsteady-state heat gains including viscous heating
5. Heat removed/added by segment environmental control system
6. Heat sink
7. Heat captured by trackway exhaust systems

. A summary of the electrical power consumed by the train has been added. This summary gives the power consumed over a user-specified length of track during the summary time interval. The summary provides a good estimate of the total propulsion and auxiliary energy requirements with sufficient accuracy for use during the preliminary design of power distribution systems.

The effectiveness of the trackway exhaust system has been subdivided into two separate heat-capture percentages — one applied to the heat from the train's propulsion system, and the other applied to the heat from the train's auxiliaries. This modification facilitates the modeling of subway systems having both an over-trackway and under-platform exhaust systems, or only one of them.

The capability to simulate impulse fans (also known as induction fans) has been added. This type of fan operates on the principle that a high-velocity air jet injected along a plane nearly parallel to the longitudinal axis of a tunnel can induce a lower velocity airflow in the trainway.

The subroutines used to solve the Dynamic Humidity Response Matrix (DHRM) and the Dynamic Thermal Response Matrix (DTRM), used by the Heat Sink Subprogram to determine the long term temperature and humidity throughout the system, have been replaced by one that is much faster and more accurate.

A mechanism whereby the user can vary the simulation time increment, and change the size of the integration step for the Aerodynamic and the Thermodynamic Subprograms has been added. The proper use of this feature can substantially reduce computer time and cost.

The format and labeling of The SES supplementary output which is useful to an individual who requires more information about the system being modeled than is normally used by a designer, has been improved to allow someone familiar with the individual mathematical models (documented in the Subway Environmental Design Handbook, Volume II, Part 2: Programmer's Manual) to make use of this information.

The removal of multiple entry points from the program code and the use of alternate means for specifying memory requirements have increased the compatibility of the program with CDC and DEC computers.

In addition to program enhancements, the User's and Programmer's Manuals have been extensively updated and revised to reflect and explain the changes in the program, and, where applicable, the developments of recent research in the area of subway transportation. It is hoped that these improvements will make the increased power of SES Version 3 easier to use and understand.

As was the case with the original development of the SES, the development of Version 3 involved a coordinated team effort. The members of the team and their major areas of contribution are listed below.

Project Management/Numerical Methods	W.D. Kennedy
Fire Model	J.A. Gonzalez
Programming & Program Organization	J.W. Guinan
Enhancements and Documentation	J.A. Gonzalez
	J.W. Guinan
	W.D. Kennedy
	S.S. Levy
	H.C. Maa
	M.G. Sherman

The development team wishes to acknowledge the assistance of:

- R.E. Murphy of Kaiser Engineers for contributions in developing the conceptual requirements of the fire model.
- E.J. Murphy of the City of Philadelphia for contributions in developing the train performance model.
- N.E. Meltzer of the TSC for program monitoring and direction.
- N.H. Danziger of Parsons Brinckerhoff Quade & Douglas, Inc. for valuable guidance and overall supervision.

PREFACE
(TO THE ORIGINAL SES PROGRAM)

The Subway Environment Simulation (SES) Computer Program is a product of a four-year research and development project in the area of subway environmental control sponsored by the U.S. Department of Transportation's Urban Mass Transportation Administration and the Transit Development Corporation, Inc. The project produced a two-volume Subway Environmental Design Handbook: Volume I is subtitled "Principles and Applications," and Volume II consists of the "Subway Environment Simulation (SES) Computer Program, Part 1: User's Manual" and the "Subway Environment Simulation (SES) Computer Program Part 2: Programmer's Manual." The SES, an analytical design tool, made possible the formulation of many of the manual computation techniques and data contained in Volume I.

Volume I, "Principles and Applications," describes the design process for subway environmental control from establishing criteria and system conceptual design through heat load analysis and equipment selection. It covers a range of parameters including temperature, humidity, air quality, air velocity, and pressure transients. Typical values, and design guides for stations, subway structures, and vehicles are also presented.

The two parts of Volume II are presented as separate documents. Part 1, the User's Manual, is organized in a manner to provide two convenient decision points for those wishing to assess the usefulness of the program in handling a specific problem. Chapter 1, Management Overview, is intended to provide a convenient summary of the types of information which can be obtained from the program, allowing a preliminary assessment of its usefulness. If a reading of the Management Overview indicates the program may be of potential interest, then management and senior technical personnel may obtain additional general decision-making information from Chapter 2, Technical Introduction and Program Description. Chapter 2 describes in general terms the four major sub-programs (Train Performance, Aerodynamics, Temperature/Humidity, and Heat Sink/Environmental Control) and briefly describes the input data required for program operation. It is intended to be sufficiently detailed to allow a more informed decision regarding the usefulness of the program in a particular situation.

Whereas Chapters 1 and 2 focus on what the program is capable of doing and what is required for its use, the balance of the User's Manual is keyed to the specific needs of the subway design engineer. Chapters 3 through 8 provide detailed instructions for preparing input data for the simulation of a specific problem, with emphasis on reducing engineering data to the appropriate input format. Chapter 9 is intended to assist the user in determining the level of accuracy and detail required for a particular program application, and it describes a number of user-oriented input and output options which designers may or may not wish to exercise in any given situation. Chapter 10 provides a detailed description of the input forms and their specific data requirements and constraints.

Chapters 13 and 14 of the User's Manual provide information which will be of assistance to those directly involved in the application of the program and a number of sample problems are provided to illustrate by specific example the applications and options of the program. Also included in these chapters are the results of parametric studies with the SES program which may assist the user in specific areas of program application. Chapter 15 documents the findings of a comprehensive series of field tests designed to verify the program.

The Programmer's Manual, which is designed for use by computer personnel, contains information concerning programmer options and procedures. It also provides descriptive information regarding the operating characteristics and structure of the SES Program, which permit a programmer to make changes in the organization and computer space requirements of the program. The Programmer's Manual includes flow diagrams of each of the program subroutines and derivations of the mathematical models on which the program is based. Engineers desiring to use the program as it stands should not require any of the information contained in the Programmer's Manual; the Programmer's Manual should be consulted only by computer support staff for information concerning the adaptation of the program to a specific machine and to estimate computer run times for various system configurations.

The user of the SES Program is also referred to Volume I of this Handbook for general information on subway environmental analysis and control. The second chapter of Volume I presents methodologies for establishing human criteria for the subway environment; the third chapter presents methodologies for manual computations which will in many cases form a prelude to the use of the SES Program; and the fourth chapter of that volume contains procedures for the selection of environmental control equipment. The manual computations described in Volume I are best suited for preliminary design, whereas the SES Program is generally more appropriate for final design.

A brief note regarding the philosophy underlying the organization of this manual may be useful to potential users. Considering the size and complexity of the SES Program as well as the range of engineering disciplines involved, the most useful means of describing the program and making it usable was a matter of considerable concern among the members of the program development team. Two basic approaches were identified and considered. One approach would have been to organize the program description to follow the sequence of the input forms and to describe each input item separately. However, the input forms were structured and sequenced in a manner most efficient for the development of data and the running of the program. The resulting input form organization does not present the most logical sequence in which to methodically introduce the user to the basic concepts and structure of the program. The alternative approach, and the one eventually selected, was to describe the various components of the program in an order tailored to human understanding rather than computer data inputs, while at the same time cross-referencing each section of the discussion to the appropriate input forms. As a result, input forms are mentioned in the text in an order not necessarily the same as the sequence in which they are organized for the computer. It is believed that this approach will be the most sympathetic to the readers of the User's Manual, providing both a logical exposition of the major characteristics of the program and a computer-efficient organization of the input data forms.

The SES Program and the program documentation presented in this volume are the results of a coordinated team effort which extended over the life of the four-year research and development project. The members of this development team and the major area of contribution by each are shown below.

Principle Contribution	Member
Aerodynamics	W. D. Kennedy
Thermodynamics	
Temperature/Humidity	T. E. Hoover
Heat Sink	W. W. Hitchcock
Environmental Control	S. S. Levy
Train Performance	J. W. Guinan
Program Documentation	D. I. Stillman

This development team gratefully acknowledges the technical support of T.C. Chen and W.W. Metsch and the administrative guidance of N.H. Danziger and S.S. Greenfield of Parsons Brinckerhoff Quade & Douglas, Inc.

TABLE OF CONTENTS

SES User's Manual

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

1. MANAGEMENT OVERVIEW

1.1 Background

The Subway Environment Simulation (SES) Computer Program is a designer-oriented tool which provides estimates of airflows, temperatures, and humidity, as well as air conditioning requirements, for both operating and proposed multiple-track subway systems.

The capabilities of the SES program are comprehensive, permitting the user to simulate a variety of train propulsion and braking systems; various systems of environmental control (including forced air ventilation, station air conditioning, and trackway exhaust); airflows in any given network of interconnected tunnels, stations and underground walkways; any desired sequence of train operation (including the mixing of trains with different operating characteristics and schedules); various steady-state and non-steady-state heat sources; emergency situations with trains stopped in tunnels and air movement solely by mechanical ventilation and buoyant forces; and a special feature to simulate the long-range thermal impact of the possible reduction in the heat-absorbing capacity of tunnel walls after many years of system operation.

The SES program was developed by Parsons Brinckerhoff under the aegis of the Volpe National Transportation Systems Center (Volpe Center) of the United States Department of Transportation. The SES program was field validated in Montreal, Pittsburgh, San Francisco, Toronto, Washington and the Memorial Tunnel and has been applied to transit systems in Atlanta, Baltimore, Boston, Bucharest, Buenos Aires, Buffalo, Camden, Caracas, Chicago, Copenhagen, Dallas, Detroit, Frankfurt (Airport), Guangzhou, Hiroshima, Hong Kong, Honolulu, Istanbul, Izmir, Jersey City, London, Los Angeles, Manila, Minneapolis, Montreal, Newark, New York City, Philadelphia, Pittsburgh, Portland, San Francisco (BART, CalTrain, MUNI), San Juan, Seattle, Seoul, Shanghai, Singapore, St. Louis, Taipei, Teito, Toronto, and Washington, as well as the Flathead, Hong Kong West Rail, Lotschberg, Moffatt, Mount Shaughnessy, Mount MacDonald/Rogers Pass and Stampede rail tunnels and Amtrak's New York rail tunnels and a proof-check of the English Channel Tunnel ventilation concept. Its tropical climate applications include Hong Kong and Singapore.

1.2 Design Applications

As indicated above, the SES program has been validated in model tests and in actual practice. It is applicable to a variety of subway operating and design configurations and has been demonstrated to be a cost-effective tool for evaluating the performance of most types of environmental control strategies. Examples of situations in which the program can provide important design information include the following engineering questions:

- What is the most effective size, configuration, spacing and location for ventilation shafts and/or fan shafts in the system in terms of overall system environmental conditions (temperatures, humidities, air velocities and the movement of smoke and gases during a fire emergency) and power requirements for environmental control?

- What are the impacts of various operating schedules, vehicle headways, vehicle speeds, and train sizes on vehicle power demand and system temperatures, air velocities, and pressure transients?
- What is the impact of vehicle air conditioning on overall heat rejection in the system and on the temperatures and humidities in stations and tunnels?
- What are the comparative impacts of various vehicle propulsion and braking systems on overall system temperature?
- What is the effect of track vertical alignment on system temperatures and power consumption? What are the long-term trade-offs between lowering track sections between stations and the costs of power for propulsion and environmental control?
- What are the energy consumption implications of vehicle air conditioning alone versus air conditioning the entire system?
- What are the long-term and short-term effects of heat sink? How much heat can be absorbed by the tunnel walls? What rate of heat absorption can be sustained for 30 years or longer?
- What effect does evaporation from wetted walls have on the overall system temperatures and humidities?
- What effects does operating the mechanical ventilation fans have during normal scheduled train operation?
- What are the acceleration profiles of vehicles at various parts of the system? How much time is required for a vehicle to traverse the length of the system?
- What are the effects of emergency control procedures on the subway environment? (For example, what are the purge times for smoke in the system?)
- What effect does the heat release from an emergency fire in the system have on the overall environmental conditions?
- What are the dynamic temperature and airflow conditions that prevail during a fire emergency?
- What ventilation system capacity is adequate to control the spread of smoke and heat during a fire emergency?

The above noted examples of program applications are by no means exhaustive. Indeed, the program is capable of estimating the environmental effects and implications of varying many of the design parameters of a multi-track subway system.

2. TECHNICAL INTRODUCTION AND PROGRAM DESCRIPTION

2.1 SES Description

The SES computer model provides a dynamic simulation of the bi-directional operation of multiple trains in a multi-track subway and permits continuous reading of the air velocity, temperature, and humidity throughout any arrangement of stations, tunnels, ventilation shafts, and fan shafts. In addition, the program has been designed to provide readings of the maximum, minimum, and average values for system air velocities, temperatures, and humidities during any preset time interval. The program computes estimates of the station cooling and heating capacities necessary to satisfy given environmental criteria, as well as the percentage of time during which specified environmental criteria are exceeded. Although a simulation can extend over any period of subway operations, the primary focus of the SES is on short-term simulations, such as the peak rush hours, when the load on the environmental control system is the greatest. Both the input/information required by the program and the output produced are tailored for the use of design engineers concerned with practical environmental problems.

2.2 Computation Sequences

The SES program comprises four interdependent computation sequences: a train performance subprogram, an aerodynamic subprogram, a temperature/humidity subprogram, and a heat sink/environmental control subprogram. In addition, a special option of the program enables the simulation of the aerodynamic and thermodynamic effects of a fire. Figure 2.1 provides an overview of the program organization. These subprograms use a mutually shared set of system descriptive parameters, and operating together they provide a continuous simulation of the dynamic phenomena which govern the quality of subway environment. The train performance subprogram determines the speed, acceleration, position, and heat rejection of all trains in the system on a continuous basis. The aerodynamic subprogram uses these computed train parameters, coupled with the geometric arrangement of the system and the ventilation performance data, to compute continuous values for the air velocity in all stations, tunnels, and ventilation shafts. In turn, the temperature/humidity subprogram uses these computed airflow parameters together with the train heat release data generated in the train performance subprogram to compute the convective dispersal of sensible and latent heat throughout the system. It is thereby able to continuously determine the temperature and humidity at all locations. Finally, the air velocities computed in the aerodynamic subprogram are used by the train performance subprogram to determine the airflows adjacent to the trains, providing means to compute the vehicle aerodynamic drag. The subway ventilation and heat load data from these subprograms, together with information on daily and annual changes in outside conditions, are used by the heat sink/environmental control subprogram to compute the long-term conduction of heat between the subway air and the structure and soil surrounding the subway as well as the heating or cooling capacities required to satisfy design conditions in specified areas of the subway. This integrated calculation procedure makes possible continuous simulation of the complex interactions among the dynamic phenomena operative in a subway system. In the following sections, the theoretical basis for each of the subprogram models is outlined and the fundamental logic for each of the four subprograms is described.

2.2.1 Train Performance Subprogram

The operation of trains provides a forcing function for the air movement in an underground transit system, and the heat dissipation from transit vehicles may account for as much as 90 percent of the heat released to the system. Consequently, a knowledge of the location, speed and acceleration of the trains within the subway system is essential to determine the rate and location of subway heat release as well as the system airflow regime.

The SES train performance subprogram provides the engineer with several options for simulating the operation of trains within a subway of which the most comprehensive is the implicit train performance. This option provides the engineer with a complete simulation of all aspects of train operation in the system. This option represents both the highest level of sophistication in the SES train performance computations and the greatest flexibility in evaluating trade-offs between train operations (headway, speed, etc.) and subway environment. The SES implicit train performance option differs from most conventional train performance computations in two important respects: (a) the SES subprogram has been designed specifically to accommodate accurate, continuous computation of the total heat released by trains, passengers and ancillary equipment such as air conditioning, and (b) the SES program permits the direct computation of the aerodynamic drag acting on each of the trains in the system, using continuously computed aerodynamic parameters. Conventional train performance programs are not ordinarily concerned with the continuous evaluation of vehicle heat release, and in evaluating vehicle aerodynamic drag these programs ordinarily settle for a semi-empirical relationship based on train velocity and blockage ratio (the ratio of the train frontal area to that of the tunnel cross section). The actual aerodynamic drag on a train fluctuates continuously as it encounters variable annular airflows resulting from changes in tunnel diameter, ventilation shaft location, mechanical ventilation, and the pressure caused by other trains. The basic logic governing the computation of train acceleration capability requires calculation of the train resistance, the available tractive effort, and the acceleration resistance. The train resistance is defined as the arithmetic sum of all the external forces which must be overcome in order to start, accelerate, and maintain the operating speed of a subway vehicle and consists of mechanical resistance, grade resistance, curve resistance, and air resistance. Train mechanical resistance is a summation of the journal friction (a function of train weight) and rolling friction (a function of speed and weight).

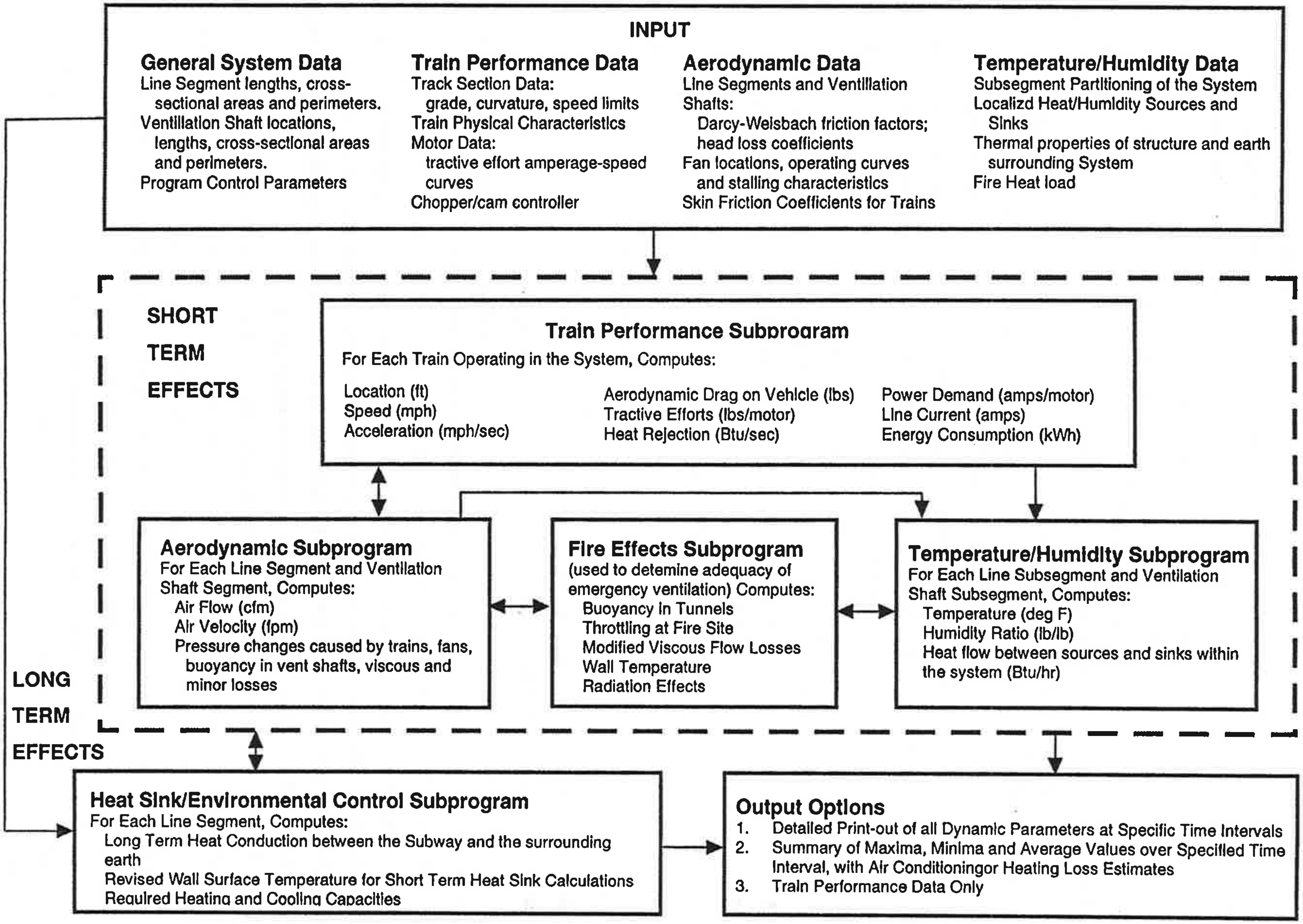


Figure 2.1 Parameters and Organization of Subway Environmental Simulation (SES) Computer Program

Grade resistance (which may be either positive or negative) is determined from the slope of the track using an expression which includes the grade angle with the horizontal. Curve resistance is an additional friction term which represents the increased effort required to negotiate turns resulting from the increase in friction between the wheel flanges and the rails, and this term is computed as a function of track radius of curvature. The air resistance or aerodynamic drag is a function of the air velocity in the tunnel relative to the train, the train blockage ratio, tunnel wall friction, and the configuration of the cars. The available tractive effort for a given transit vehicle and the resulting acceleration and maximum velocity capability depends almost entirely upon the performance characteristics of the motor employed. Manufacturers of motors for rapid transit vehicles ordinarily provide standardized motor characteristic curves in which the tractive effort and speed are related to motor current for various values of motor field strength. Using data from these curves, the SES computes the precise tractive effort capabilities of vehicles powered by these motors as they travel through the system. The acceleration resistance is a combination of the forces required to accelerate the mass of the train (including passengers) and its equivalent mass of rotating parts, including wheels, axles, gears, and motor armatures. The implicit SES train performance option continuously computes values for the train resistance, the tractive effort, and the acceleration resistance of each vehicle in the system and from this determines the rate at which each train can accelerate, assuming no slippage at the wheel/rail interface.

The most important train-related heat release to the system can be traced to the vehicle braking cycle. For a train using a dynamic braking system, the speed reduction of the vehicles is brought about by using the motors as generators to produce electrical power which may be regenerated back into the traction power supply system, used to create stored energy (flywheels) or dissipated to a grid of undercar resistors. The rate at which energy is dissipated to these dynamic-braking resistor grids is approximately equal to the net rate of decrease in kinetic and potential energy of the braking train, corrected for the proportion that can be regenerated or absorbed by flywheels. This energy loss can be computed directly from the vehicle deceleration rate, velocity, total mass and the regeneration effectiveness or the flywheel characteristics. The implicit SES train performance option computes the instantaneous power dissipation to the braking resistors and the manner in which the resistors warm up and subsequently transfer the heat to the subway air. This computation directly accounts for the thermal inertia of the braking resistors, relating the heat storage and heat release to the surrounding air to the resistor thermal properties, weight and configuration, air turbulence and velocity, and resistor temperature.

In operation, the implicit train performance option first checks to see whether or not trains should be added to or removed from the system (according to the train operating schedule specified by the user), after which it computes the individual train resistance for each train. The program then determines whether the train should accelerate, coast, decelerate, or maintain speed, using a brief computation which extrapolates the current operating mode of each train to determine if continuation of the train's current course will cause it to overrun a speed restriction or approach a stop too rapidly. If continued acceleration is indicated, the program computes the velocity-dependent tractive effort capabilities of the train and then calculates the acceleration which will occur over the preselected computation time interval.

Should a reduction in train speed be found necessary, the program computes a deceleration rate based on the user-specified braking rate. Finally, if the speed of the train exactly matches a system speed restriction, no acceleration occurs and the train uses only the power necessary to maintain this speed. When the train is on a downhill grade, the speed restriction is maintained by braking when necessary. The program next computes the heat energy being dissipated by the individual motors of each vehicle. For the case of a cam-controlled train, this consists of the motor current squared times the sum of the internal motor resistance and the external acceleration grid resistance. For the case of a thyristor-controlled train this consists of the motor current squared times the internal resistance, plus the line current squared times the thyristor inefficiencies. The program provides a summation of traction and auxiliary energy requirements on a substation basis, which can be used for the preliminary design of the traction power supply system.

During the braking mode, energy is dissipated from both the change in train kinetic energy and the change in train potential energy (due to elevation). If regeneration or flywheels are being simulated, the energy dissipation is reduced accordingly. During station stops the SES continues the computation of heat release to the system from the passengers, equipment, and the warmed resistor grids. The program also computes the change in passenger loading at each station stop, thereby accounting for changes in total train weight and the corresponding effects in acceleration and braking energy dissipation, as well as changes in vehicle energy consumption and heat release from on-board auxiliaries and passengers.

The computed values for the position, speed, and acceleration of all trains in the system as well as their individual rates of heat rejection are necessary for the operation of the aerodynamic and temperature/humidity subprograms. However, the train performance subprogram can also be operated independently to evaluate the comparative performance of transit vehicles, or propulsion motors, or both, by suppression of the computation and printing of environmentally related information. The airflows and air velocities of the aerodynamic subprogram would still be computed, of course, as these data would be necessary to compute aerodynamic drag for the train performance subprogram.

2.2.2 Aerodynamic Subprogram

The airflow through a subway system affects the comfort of subway patrons both directly and indirectly. Air movement is directly responsible for the convective transfer of heat and humidity through the system, and the cooling effects of moving air can directly influence the comfort of persons in non air-conditioned vehicles and in station areas. Furthermore, the buildup of excessive air pressures in stations from train piston effect has been known to constitute a separate operating problem, sometimes causing doors at entranceways to swing hazardously or become difficult to open. Airflow indirectly influences the heat content of subway air in two respects: (a) the aerodynamic drag on vehicles resulting from air motion relative to the train affects the power consumption (and heat rejection) of the vehicle motors, and (b) the rate of heat transfer into the surrounding deep-heat sink is dependent upon the air velocity at the air-wall interface.

Airflow in a subway is generated by two primary sources: the piston effect of trains moving through confined tunnels and mechanical ventilation by fans. The mathematical model which has been developed to describe this flow for a subway assumes the flow to be unsteady, turbulent, incompressible, and effectively one-dimensional. The unsteady nature of airflow in subways precludes the use of approximate analyses based on the assumption of steady-state flow, because the air velocities generated by trains with arbitrary operating schedules moving through tunnels of varying shape and size must fluctuate continuously. Steady-state flows may only develop in the absence of train movement.

The present model includes consideration both of near-field phenomena (flow in the immediate vicinity of the train) and far field effects (flow at a distance far enough from the train that no transverse perturbations are present other than those ordinarily associated with normal turbulent inertial flow). Far-field flow is mathematically similar to typical inertia flows, whereas near-field flow must be described using formulations which include the aerodynamic drag acting on trains and the localized pressure rise which accompanies fan operation. As noted earlier, the computation of aerodynamic drag is an essential component of the subway simulation because this factor determines both the air resistance that trains must overcome in order to accelerate and the amount of energy that is imparted by the moving trains to the surrounding air. In general, the drag experienced by a train in a single-track tunnel increases with train speed and decreases with frequency of train operation (shorter headway).

Using information describing the position, acceleration, and speed of trains provided by the train performance subprogram, the location of each of the trains with respect to the subway is determined. The train operation information is then used to compute the net forcing function on the system airflows - the difference between energy added to the flow from train drag and fans and that removed due to the friction and minor losses. In this computation, the piston effect of each train is independently computed by evaluating the piston effect components on the system from the front, side, and rear of the train. The aerodynamic differential equations are then integrated forward in time using a modified version of the Runge-Kutta numerical integration technique. The standard output for the aerodynamic subprogram provides continuous readings for the aerodynamic drag on each train and for the air velocity (in feet per minute) and flow rates (in cubic feet per minute) in all tunnels, stations and ventilation shafts. Using the summary option, the subprogram can also provide output in the form of peak and average values of air velocity and total reading for airflow over any specified time interval.

2.2.3 Temperature/Humidity Subprogram

The temperature and humidity of the air throughout a subway system reflect the heat added or removed by underground equipment, trains, and patrons, as well as by the rate of heat exchange across the system walls and by mixing with external ambient air. An analytical treatment of this dynamic heat regime must provide a means to describe these phenomena mathematically in an operating system. The acceleration and braking of trains produces the main source of sensible heat in an operating subway system, but sensible and latent heat are also added by electrical equipment, patrons, and in certain instances, the surrounding earth. Heat is removed from the system mainly by the expulsion of warm system air through ventilation shafts and by heat conduction across the tunnel walls into the surrounding heat sink. Heat may also be added or removed by mechanical means such as heating and air conditioning.

In developing an analytical description of the heat regime, it was concluded that the system could be treated as one-dimensional, meaning that the air temperature and humidity can be considered uniform over any cross section. Axial conduction heat transfer in the system air was assumed to be negligibly small in comparison with the heat convected by moving air. The heat contributed by viscous dissipation resulting from air friction against the system walls, while usually small, can optionally be considered as a variable heat source.

Three fundamental processes can occur to alter the temperature and humidity in each of the subsegments: (a) sensible and latent heat can be directly added or removed by sources and sinks within the subsegment; (b) heat can be exchanged across the tunnel walls; and (c) there can be a net difference in the heat content between air flowing into the subsegment and air flowing out. An equation for the rate of change in temperature and humidity of each subsegment is therefore a combination of the analytical expressions for these three processes. The quantity of air flowing into each subsegment at any given time is computed by the aerodynamic subprogram and this airflow is used by the temperature/humidity subprogram together with values for subsegment temperature and humidity to compute the net difference between heat content of the air entering and leaving the subsegment. Rejection of heat from moving trains, computed simultaneously in the train performance program, is proportioned over the subsegments containing trains. Next the temperature/humidity subprogram sums the quantities of sensible and latent heat removed or added in each subsegment by patrons, auxiliary equipment, and station heating or air conditioning. Latent heat can be removed from or added to the system by condensation on, or evaporation from, system walls. In the case of simple condensation or evaporation, an equivalent amount of sensible heat is added to or removed from the system by the program. The heat transfer across the walls of the system is computed using the wall temperature and convective heat transfer coefficient which is a function of the subsegment air velocity, density, viscosity, thermal conductivity, and tunnel diameter. The value for subsegment wall temperature is computed in a separate operation using an analytical technique based on the diurnal and annual variation in outside ambient temperature, the deep heat sink temperature, and the degree of subway utilization. This analytical approach provides the wall surface temperature as a function of the time of the day and the time of the year. The heat transfer across the system walls has been found to have significant effect on the air temperature throughout the system.

The train locations, which were computed by the train performance subprogram, are used to determine the specific subsegments which contain some portion of each train. Each subsegment is then analyzed in detail, computing the rate of heat transfer to the tunnel walls, and, if trains are present, the amount of sensible or latent heat released into the subsegment by the trains. The airflows computed in the aerodynamic subprogram are used to determine those in each of the tunnel, station, and ventilation shaft subsegments. The values for heat flow across each subsegment boundary, for the sources and sinks of heat in each subsegment, and for the velocity-dependent coefficient of heat transfer across the system walls form a separate differential equation describing the rate of change of sensible and latent heat in each subsegment. These differential equations for the rate of change in air sensible and latent heat content are developed for each subsegment in the system, thus forming a system of equations which is integrated using a modified Runge-Kutta numerical integration technique resembling that used for the aerodynamic equations. This provides the time-dependent values for temperature and humidity throughout the stations, tunnels, and ventilation shafts of the system.

2.2.4 Heat Sink/Environmental Control Subprogram

There are three key independent factors which influence subway air temperature: system ventilation as determined by geometrical configuration, train operations and mechanical systems; system heat load, which relates directly to utilization of the subway; and outside ambient temperature. A fourth factor affecting subway air temperature is the heat transfer between the air and the surrounding structure and earth. In contrast with the first three factors, an interdependence exists between this heat transfer (commonly referred to as a "heat sink" effect) and the air temperature: the subway air temperatures directly influence the heat conduction history of the surrounding earth, since the rate of heat flux between the subway air and the walls is dependent on the convective heat transfer coefficient and the temperature difference between the air and the wall surfaces. One purpose of the heat sink/environmental control subprogram is the evaluation of this interdependent behavior.

During the relatively short-term simulation periods of the SES aerodynamic and temperature/humidity subprograms, the surface temperature of the subway structures is essentially constant. However, subway wall temperatures ordinarily experience daily and annual fluctuations because of variations in outside conditions and subway operating schedules. There may also occur a gradual increase in the average wall surface temperature over a period of years either as a result of prolonged internal temperatures above outside ambient conditions or because of increases in system utilization. Thus, to accomplish its purpose, the heat sink/environmental control subprogram must address not only the air-wall temperature interdependence, but also the conduction of heat in the earth as influenced by the daily, annual, and long-term variations in the subway air temperature. Whereas the short-term simulation evaluates subway airflows and temperature on a second-by-second basis, the heat/sink environmental control subprogram evaluates a phenomenon which is measured in terms of hours, days and years. Thus, this subprogram involves a shift in time scales and the link with the short-term simulation is accomplished through a process involving the averaging of short-term simulation results.

The heat sink computation scheme in this subprogram is geared to produce as output the wall surface temperature for each of the geometrical subsegments into which the subway tunnels and stations are partitioned, corresponding to the time of the day and year that the short-term simulation is intended. To perform this computation, the subprogram requires data on structure and earth thermal properties, earth temperature at a point far removed from the subway, and daily and annual variations in outside conditions. In addition, the subprogram requires detailed information on subway ventilation, heat loads, and areas of the system which are maintained at specified design temperatures with environmental control equipment. Thus, the use of the heat sink/environmental control subprogram requires that the aerodynamic and temperature/humidity subprograms first be applied in a short-term simulation. The SES is organized so that the required data transfer is accomplished internally in the program. The user can specify that the program execute a short-term simulation, transfer the required ventilation and heat load data to the heat sink/environmental control subprogram for the detailed wall surface temperature computations, and then transfer the calculated wall surface temperatures back to the short-term simulation portion of the program to continue the analysis.

The computation of the heating or cooling loads required to maintain design temperature and humidity conditions in specified areas of the system (such as stations) is an integral part of the heat sink/environmental control subprogram. The relationship between the heat sink and environmental control computation schemes is two-fold: first, many of the data requirements in terms of averaged short-term SES computations of subway ventilation and heat loads are shared; and second, an interdependence exists because of the exchange of air between the controlled and uncontrolled areas of the system.

For user-specified areas within the subway where the temperature and humidity are to be maintained at design conditions, the environmental control computation scheme evaluates the heat which must be added or removed to achieve the desired conditions, on the average, during the design point operation addressed by the short-term simulation. This evaluation is performed for each of the geometrical subsegments into which the controlled area is partitioned, and includes calculations of sensible and latent heat gains from trains, sensible and latent heat gains from stationary sources (such as lighting, patrons, third rails, etc.), sensible heat transfer between the air and the structures (heat sink), and sensible and latent heat gains or losses attributable to the exchange of air between the subsegment and adjacent areas such as tunnels and stairways (convective load).

The interdependence with the heat sink computation for uncontrolled areas of the system is reflected by the evaluation of the convective load. The subprogram analyzes this interdependence by assuming that the airflow from controlled to uncontrolled areas of the system are at design temperature and humidity conditions. The heat sink computation scheme uses these airflow, temperature and humidity data in assessing the behavior of the heat sink in the uncontrolled areas of the system. In turn, the environmental control computation scheme is provided with a temperature for the air entering the controlled area from the uncontrolled area which reflects the estimated effects of the overall convective air and heat exchange process.

The SES organization is such that the computed heating or cooling load requirements can be transferred internally to the short-term simulation portion of the program to continue the analysis. By continuing the short-term simulation, the user can determine whether the computed loads satisfactorily achieve the desired design conditions in the controlled areas. A continuation of the simulation also provides data on the transient temperature and humidity excursions from the average design conditions caused by the unsteady nature of the airflows and heat loads throughout the subway.

2.3 Fire Model

2.3.1 Description of Model

The SES Program has the ability to model the effects of a subway fire. When the fire model is "turned on" as described below, the following aerodynamic and thermodynamic factors are considered by the program:

A fire in a tunnel has the effect of throttling the ventilating airflow. This effect is caused by the rapid expansion of the air flowing past the fire site. Also, as a consequence of the law of conservation of mass, the velocity of the hot gases downstream of the fire increases inversely proportional to the density (or equivalently, directly proportional to the absolute temperature of the gases), hence increasing the viscous pressure losses in this section of the tunnel. These pressure changes will reduce the tunnel airflow. The density differences between the hot gases and the ambient air give rise to pressure differentials which can either augment or retard the tunnel airflows, depending on the direction of ventilation (uphill or downhill). The elevated air temperatures produced by a fire cause the tunnel walls to heat up. This transient heating of the wall surface is an important factor in determining the conditions downwind of the fire. Allowing the wall surface temperature to respond properly improves the accuracy of the predicted air temperatures which are subsequently used to calculate the buoyant pressure differential.

The model treats the wall as a one-dimensional concrete slab of infinite thickness with uniform thermal properties and an arbitrary time-dependent heat flux at the wall surface. This approach is appropriate because: (a) temperature changes resulting from heating at the wall surface will be confined to within a short distance of the wall surface, and (b) the wall surface temperature is of interest rather than the temperature at some depth below the surface.

The heat conduction equation is solved by using an approximate integral method. This method was chosen because it requires relatively little computation time and provides good accuracy (results range from three percent to nine percent of the theoretical value).

Heat is transferred to the wall by convection and radiation. Radiation will be the dominant mode of heat transfer at the fire site, while downwind of the fire, both modes will be nearly the same order of magnitude. At the site of the fire, heat is radiated uniformly from the interior of the burning vehicle through the windows and opened doors directly to the tunnel wall. The interior temperature of the vehicle is assumed to be at an "effective fire temperature". Both the effective fire temperature and the total area of the openings are input items. Downward of the fire site, the hot smoke is assumed to be radiating to the tunnel wall as a "black body" at a temperature equivalent to the "bulk" subsegment air temperature. Only radiation effects in the transverse direction from smoke to tunnel wall are considered.

The changes in air density associated with elevated temperatures degrade the performance characteristics (pressure vs. volume flow curve) of the exhaust fans. These effects have been accounted for in the model.

2.3.2 Application of Model

The fire model is intended for use in a trial-and-error fashion to select the emergency ventilation system capacities. The interactions are between the tunnel air velocity (past the fire site) predicted by the SES Fire Model and a design air velocity criterion which precludes the backing of smoke against the ventilating air stream (backlayering). This "critical" air velocity criterion is a function of the fire heat release rate, the tunnel width, the average tunnel grade, and the temperature of the hot gases leaving the fire. A typical application of the fire model consists of the following steps:

- Perform an SES simulation to predict the tunnel air velocity and the hot air temperature.
- Determine the critical air velocity using the methodology given in Chapter 9 of the SES User's Manual.
- If the predicted air velocity exceeds the critical air velocity, the ventilation system is considered adequate.
- If the predicted air velocity is less than the critical air velocity, change the system and repeat the process.

Note that the SES is essentially a one-dimensional, incompressible, turbulent, slug-flow model. The throttling and buoyancy effects which are primarily caused by changes in density are conveniently accounted for by noting that changes in density are inversely proportional to changes in the absolute temperature of the gas (air), a quantity which is computed by the program. Therefore, the effects of density changes have been accounted for in the computations without actually converting computations in the program from an incompressible to a compressible flow model. As a result, the airflow quantities printed out by the program are "referenced" to the ambient air density. This notion of basing the computations on a reference air density has been used in mining ventilation computer programs and in a program prepared at Michigan Technological University for the U.S. Bureau of Mines.

The SES Fire Model has been designed with the ability to simulate the "overall" effects of a tunnel fire on the ventilation system. This level of detail is considered sufficient for evaluating the adequacy of an emergency ventilation system and is consistent with the state-of-the-art in mining ventilation programs with the capability of simulating fires. However, the model does have its limitations. As previously mentioned, the SES is a one-dimensional model. Therefore, the results of a fire simulation will indicate whether or not the ventilation airflows are sufficient to prevent backlayering, but not the extent of back-layering (a two-dimensional phenomena) if it is predicted to occur. In addition, the early stage of a fire, before the ventilation system is activated, generally cannot be simulated since this period is dominated by buoyant recirculating two-dimensional airflows.

3. GEOMETRY

The first task for a user of the SES program is to prepare a schematic diagram of the physical system to be simulated. This schematic diagram will facilitate considerably the preparation of the geometry descriptive data, and will assist the user in understanding the operational requirements of the program. In broad terms, the subway system must be divided into: (1) sections in which airflows must be uniform, (2) nodes which signify the connecting points of these sections, (3) segments which have uniform geometrical properties (and therefore uniform air velocities), and (4) subsegments which are subdivisions of segments and which are assumed to have uniform temperature and humidity conditions. These four geometrical properties (sections, nodes, segments and subsegments) are the basic geometrical building blocks of the simulated subway system. An actual physical subway system must be converted into a schematic representation using these four geometric units before the user can proceed further with the simulation, since all other input data required by the program must be referenced to these parameters.

A brief description of these four geometrical properties will be provided here, to be followed by an example of the reduction of an actual system to a schematic representation using these building blocks.

3.1 System Description

The term "system" is used to describe the entire track and tunnel network, both above and below the ground. The above-ground portion of the system may be either at grade, on a elevated structure, or in a trench-like open cut. The below-ground portion, or tunnel system, is composed of a network of tunnels and passageways. Some parts of the tunnel system contain tracks for train operation; some are designed to allow passengers and employees to enter, exit, and move about within the system, and other parts permit the exchange of air with the atmosphere.

The analysis of a system which is composed of two or more separate tunnel systems must be performed in two or more parts since airflows and temperatures occurring in one tunnel system do not influence other systems. The independent simulation of each tunnel system does not introduce any error into the results. The user may simulate each tunnel system with track on each route extending outside the tunnel portion of the system so that the train operation within the tunnel system can be arranged to be the same as if the entire system was simulated as a whole.

The basic geometrical unit for the simulation of the below-ground portion of the system is the segment. There are two categories of segments: line segments and ventilation shaft segments.

Line Segment

A line segment is a continuous length of station or tunnel which has the following geometric properties "uniform" over its length: type (tunnel or station), length, cross section area, perimeters and roughness length.

Since a line segment is a physically uniform length of tunnel, the velocity of airflow in a line segment will also be constant over its length at any given instant in time, when no trains are present within it.

Ventilation Shaft Segments

A ventilation shaft is a structure that permits movement of air or patrons between the below-ground tunnel system and the outside atmosphere, and may be any stairway, walkway, or tunnel. A ventilation shaft cannot contain tracks for train operation, but may contain a fan. It is important to note that within the SES program, the term "ventilation shaft" is an inclusive term for both the structures that are designed for the movement of air and the structures for passenger movement such as stairways and walkways. In most cases a ventilation shaft connects between a point in the system and the atmosphere. However a ventilation shaft may also be connected between two points within the system, as would be the case for a passageway between parallel tunnels. Ventilation shafts differ from line segments in four ways: (1) Trains cannot operate in ventilation shafts, (2) Fans can be placed in a ventilation shaft (provided it is not a stairway), (3) Neither steady nor unsteady state heating or cooling sources can be located within a ventilation shaft, and (4) The viscous friction between the air and the ventilation shaft walls is assumed to be negligible compared to the "minor" head losses, and is therefore ignored in the ventilation shaft airflow calculations. ("Minor" head losses refers to those losses caused by other than frictional effects, such as turns. Minor does not refer to the magnitude of the losses.)

Ventilation shaft structures may be assigned one or more segments, each of which may have a different area or perimeter. Furthermore, ventilation shafts are sometimes constructed of segments which are connected at various angles in order to satisfy physical clearance problems and alignment with surface geometry, reflecting the fact that, in general, gratings are preferably located in the sidewalk rather than in the street.

Each ventilation shaft segment has the following uniform properties: length, area and perimeter. These properties are defined in a manner identical to those of line segments. The following additional properties must be defined once for each ventilation shaft: section type, grate-area, and design maximum outflow air velocity at grate.

Section and Nodes

A section is a length of tunnel within which the air moves at a uniform flow rate. It may contain one or more contiguous segments. If these segments are of different cross-section area, the air velocity will change for each segment, but the bulk airflow rate will be uniform throughout the section. A line segment may comprise all or part of any given section, but it cannot be part of more than one section. A section is bounded at both ends by a node, which serves as a reference point where one or more sections may be joined. There are two types of sections: a line section, which is composed of line segments; and a ventilation shaft section which is composed of ventilation shaft segments.

The aerodynamic portion of the SES simulation program computes an airflow rate for each line section and ventilation shaft section in the system. The rate of airflow in the section is a function of train piston action, fans, buoyancy, viscous damping, "minor" head losses and inertial effects. These factors are all considered in the calculations of the airflows which are continuously varying over the simulation interval.

A section may be connected to other sections or to the atmosphere. In addition, sections must not terminate at a "dead end," that is, it must not have a closed end which does not permit air to flow either into or out of the section. When simulating a system which is composed of a tunnel network, there must be a flow path available from any node to all other points in the tunnel system. This flow path may pass through one or more sections, but may not pass through the atmosphere. In short, the tunnel system must be an interconnected network of sections, each with a uniform airflow rate at any given time. Examples of possible sections are shown in Figure 3.1.

A "node" is a reference point which is used to relate the interconnections of the sections in a system. A node must be defined at each junction of three or more sections as well as at each portal and opening to the atmosphere. A node may also optionally be located at a junction of two sections if the user wishes.

A "portal" is formed when a line segment is terminated at the atmosphere. Since line segments may have trains operating in them, trains can enter or leave the tunnel system through portals. The point where a ventilation shaft terminates at the ground surface is called an "opening to the atmosphere."

Nodes may have from one to five sections attached. (This upper limit may be changed as described in Appendix A.) However, a node with a single section attached is always either a portal or an opening to the atmosphere.

The airflows at each node must satisfy the law of conservation of mass. That is, at any instant, the amount of air flowing toward the node is always equal to the amount of airflow leaving the node. The law of conservation of thermal energy is also maintained. The thermal energy flowing toward the node is always equal to that leaving the node.

NOTE: In the following discussion, and throughout this manual, the term "fan" refers to a conventional supply/exhaust fan, unless otherwise specified.

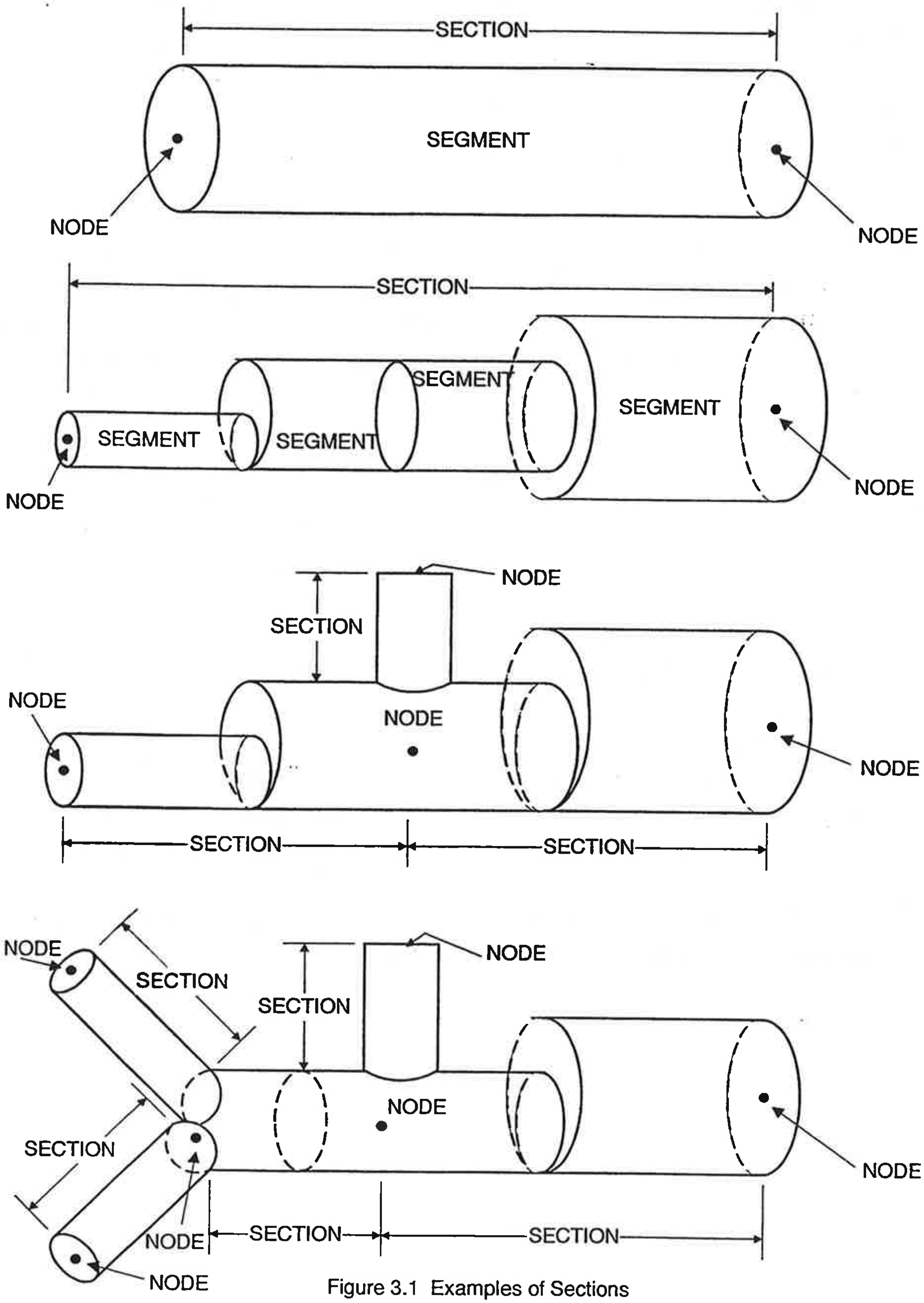


Figure 3.1 Examples of Sections

3.2 Schematic Diagram

As an aid to setting up the system geometry and understanding the interrelation between the sections in the system, the user is advised to prepare a schematic or line diagram of the system. In the schematic diagram, each section is represented by a line and the intersections of sections (at nodes) are also identified. Each of the sections and nodes are then numbered for purposes of identification in the program. Each section number is unique to that section; that is, no other section in the system can have the same identification number. Sections need not be consecutively numbered (although this is advisable to assist in data review as the print out supplies the information within the sections sequentially according to the section identification numbers); the user may choose any number as long as the number has not been used previously and lies between the limits of 1 and an upper limit described in Appendix A. There is no relationship between section numbers and their physical location within the system. These numbers are used solely for identification, and the physical arrangement of the sections is described in the geometry data.

In a manner similar to section numbers, the node identification numbers need not be consecutive, but they must be unique. Node numbers do not describe the physical location of the sections within the system, but are only a means of referring to a particular node.

Unlike sections and nodes, segment <u>identification numbers</u> are not limited by the limit in Appendix A, but may range from 1 through 999. However, the <u>total number</u> of segments is limited to the amount specified in Appendix A. Section, node and segment identification numbers are entirely independent. Therefore sections, nodes and segments may, if desired, be referenced by the same identification number.

<u>Sample System</u>

Figure 3.2 provides an isometric sketch of a sample subway system which is used as the basis for the preparation of the schematic diagram of the system also shown in Figure 3.2. This figure shows several of the geometrical situations that one would expect to encounter in a subway. In the schematic diagram the nodes are represented by numbered points, the sections are represented by numbered lines, and the segments are represented by portions of the numbered lines used to describe the sections. It can be seen that the system shown has been represented by 18 sections and 18 nodes.

The system shown in Figure 3.2 contains three portals which are located at nodes 1, 2 and 12. These nodes can be immediately identified as either portals or openings to the atmosphere since only one line section is attached to them. The system contains six ventilation shafts which provide connections to the atmosphere. They have been designated as section numbers 5, 8, 11, 13, 15, and 17. These vent shafts all terminate at nodes with only one section attached. All portals or openings to the atmosphere must be represented by nodes with one section attached. This system contains one station composed of portions of sections 12 and 14.

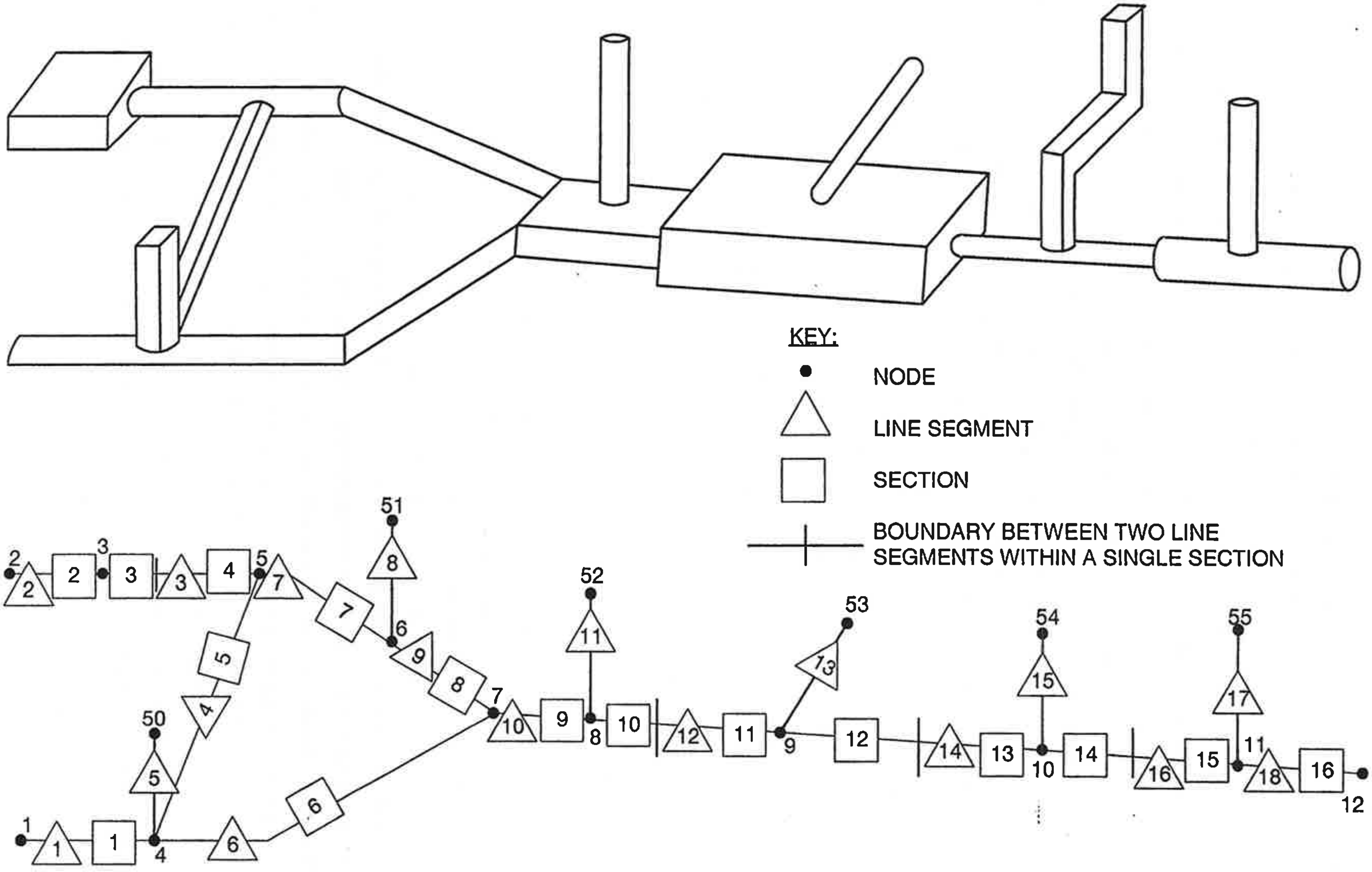


Figure 3.2 Sample System and Corresponding Schematic Diagram

The stairway which is located at the center of the station is connected to node number 9, which divides the station into two lines segments — one in line section 12 and other in line section 14. Both section 12 and 14 are composed of two line segments — a station segment and a tunnel segment.

The system shown in Figure 3.2 contains both double-track tunnels and single-track tunnels. A double-track tunnel contains two or more tracks on which trains may operate. A tunnel is considered to be double-track if there is either no dividing wall between the trackways, or if a dividing wall of sufficient porosity is present so as to not significantly affect the bulk airflow rate in the section. Frequently trackway dividing walls are constructed with regularly spaced openings through the wall. These openings are placed for safety and access purposes; however, they also allow air to flow between the trackways. Porosity, which is a measure of the "openness" of the wall, is defined as the ratio of the open area of the holes to the area of the entire wall.

Scale model tests (Ref. 1) have shown that tunnels with porosity values from 0 to approximately 5 percent should be treated as two separate parallel segments with discrete openings between them. The airflow in the parallel tunnels exhibits some degree of asymmetry for porosity values on the order of 5 percent and greater, but the piston-action bulk tunnel airflow is essentially the same as if no dividing wall exists (see Ref. 1 for details). Thus for normal operation simulations, tunnels with porosity over 5 percent can be adequately simulated as one double-track segment. (For emergency operation simulations, even tunnels with less than 5 percent porosity should be simulated as one double-track segment. See Chapter 9 for a more detailed discussion of emergency operations, and special cases.)

Referring to Figure 3.2, it can be seen that node 4 has four sections attached to it. In this case, three line sections and one ventilation shaft section meet at the node. Node 3, which is located at a junction of only two sections has been placed in the system at the user's option. If this node were not present, sections 2 and 3 would be combined into one section. This node was inserted in order to facilitate future modifications of the program to allow a new section, such as a ventilation shaft, to be added. Addition of a ventilation shaft to an existing node requires only the definition of an additional ventilation shaft section which connects a new node, open to the atmosphere, and the existing node.

If an existing node is located at the point where a new ventilation shaft is to be connected into a system, the user need only define the new ventilation shaft to be connected to this existing node and enter the properties of this new shaft in the ventilation shaft data. The user will have fewer modifications to the input data than if a node was not placed in the original tunnel system in anticipation of the future addition of a vent shaft at that particular point. If no node exists at the point where the user wishes to add a ventilation shaft, there will be fewer modifications to the input data if the user adds the new node and the new vent shaft at the interface between two segments, rather than in the middle of a segment. The reasons that fewer modifications to the input data will be required if the new vent shaft is placed at the interface between two segments are as follows: When a new node is placed between two segments at the segment interface, it creates only one additional section and no additional segments. If the new node and vent shaft are placed in the middle of a segment, the segment in which they are to be located must be broken into two segments. Therefore, when the new node and vent shaft are placed in the middle of a segment, one additional section and one additional segment will be created. It is always a good idea for the user to anticipate any possible future additions to the system as a great deal of time would be saved should modifications be necessary.

The cross passage represented by section 4 (see Figure 3.2) must be represented as a ventilation shaft segment if it is to contain a fan, or as a line segment if it is to include any steady-state heat loads. If calculations are desired to determine the heat created by viscous friction along the walls and for evaporation from the wall surface, the cross passage must be represented as a line segment. It is suggested that cross passages between tunnel sections be represented as ventilation shaft segments, while cross passages within stations be represented as line segments (unless they are expected to contain a fan). Stairways and actual ventilation shafts may also be represented as line segments if desired.

3.3 Preparation of Geometry Data

System line sections must be described on Input Form 2A and system ventilation shaft sections on Form 2B. (Each of the required input items necessary to perform a SES simulation are discussed in this manual. The order in which these input items are described does not always correspond to the order in which the input items are entered in the input forms.)

The input information required is the <u>section number</u>, a <u>starting node number</u>, an <u>ending node number</u>, the <u>number of segments</u> in the section, and the <u>initial airflow</u> rate. Although the selection of the starting and ending node is entirely arbitrary, the program output reports airflows as positive if flowing from the starting node to the ending node and as negative if flowing in the reverse direction.

The line sections may be entered on Form 2A in any order desired; it is not necessary that the section numbers be sequential. The same is true of the ventilation shaft sections entered on Form 2B. Since a line section may be composed of one or more line segments, the number of segments in each section must also be entered.

Line segments are described on the Form 3 series of input forms and ventilation shaft segments are described on the Form 5 series of input forms. The order in which line segments are described on Form 3 must correspond to the order in which the line sections were described on Form 2A. In other words, if the user was simulating the system described in Figure 3.2 and had entered the line sections on Form 2A in increasing numerical order beginning with line section 1, the line segments would also have to be entered in increasing numerical order beginning with line segment 1 on Forms 3A through 3E. Similarly, ventilation shaft segments must be described on Form 5 in the order that the ventilation shaft sections are described on Form 2B.

If a section contains more than one segment, the segments must be entered on the input forms in the order in which they occur within the section. The segment closest to the <u>starting node</u> must be entered first.

Limits on the number of sections, segments, and nodes which can be used are discussed in Appendix A. Methods for modifying these limits are described in the Programmer's Manual. The geometrical properties of a segment are defined as follows:

Line Segment Type. In the program input, line segments are divided into two basic types: station segments and tunnel segments. A station segment contains a trackway exhaust system (TES) operating at the heat capture efficiencies entered on Form 1G (refer to section 5.7). A tunnel segment does not contain a TES. Each of these two basic types is subdivided as follows:

A station segment may contain either 1) A TES which captures heat from the train propulsion and braking (prop/brkg) system only, 2) A TES which captures heat from the train auxiliaries and passengers (aux/pass) only, or 3) A TES which captures heat from both the propulsion and braking system and auxiliaries and passengers (prop/brkg and aux/pass).

A tunnel segment may either 1) contain an impulse fan system (IFS) or 2) not contain an IFS. A tunnel segment containing an IFS is referred to in the program output as a special tunnel. The program allows for the input of up to six IFS's, each one identified by a different line segment type. A summary of line segment types is given here.

Line Segment Types

Type	Title	TES	IFS
1	Tunnel	No	No
2	Station	Yes - (prop/brkg and aux/pass)	No
3	Station	Yes - (prop/brkg)	No
4	Station	Yes - (aux/pass)	No
9	Special Tunnel	No	Yes - IFS Type 1
10	Special Tunnel	No	Yes - IFS Type 2
11	Special Tunnel	No	Yes - IFS Type 3
12	Special Tunnel	No	Yes - IFS Type 4
13	Special Tunnel	No	Yes - IFS Type 5
14	Special Tunnel	No	Yes - IFS Type 6

NOTE: Line segment type numbers 5,6,7,8,15 & 16 are reserved for future use. An input of any of these will default to a type number 1 line segment.

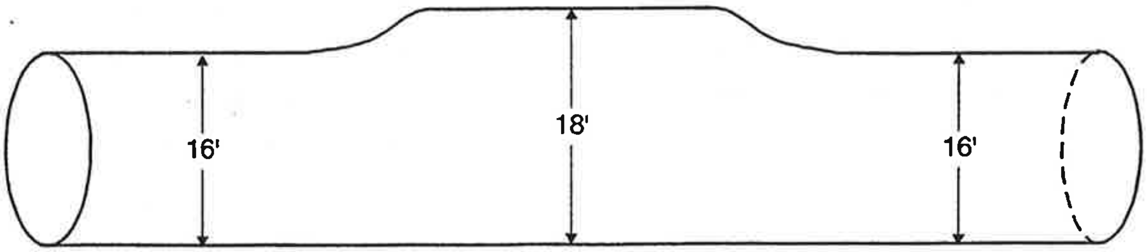
Assignment of line segment type is a function of the equipment within the line segment rather than the location of the line segment. A station segment would usually be used to designate platform areas in stations which have trackway exhaust systems. Segments without trackway exhaust would be designated tunnel segments even if they were physically located within the station box.

Length. The length of a line segment is measured in feet along the longitudinal axis of the segment.

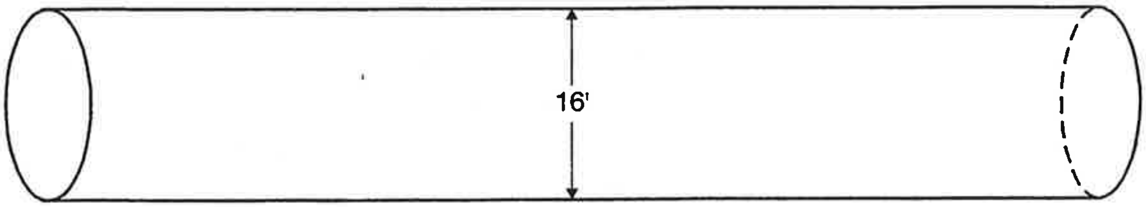
Cross-Section Area. The cross-section area is the unobstructed area of the inside of the tunnel which intersects a plane perpendicular to the longitudinal axis of the segment. In other words, it is the inside area of the tunnel which is open to permit airflow within the tunnel. This area is computed by taking the gross tunnel inside area and subtracting from it the area of any fixed obstructions such as catwalks, cable ducts, tracks and ballast, station platforms, etc. In stations, the passengers who are waiting to board trains can also be considered to be an obstruction to the airflow, and the cross section area of the tunnel may be reduced by an amount the user feels represents the average area obstructed by the passengers. In many cases, the cross section area of the segment can be measured from the plans by using a planimeter. The cross-section area of trains is not subtracted in computing the segment cross section area. The cross-section area is measured in square feet.

The degree of latitude in the "uniformity" of the properties of a line segment which would be acceptable for a given simulation is dependent upon the detail and accuracy desired. Users who are interested in a preliminary evaluation of a system may wish to neglect variations in "uniformity" which should be considered in a more detailed simulation. The flexibility of the program allows a user to obtain a degree of detail appropriate for the intended uses of the results. The following example illustrates the options open to users in describing the geometry of a system:

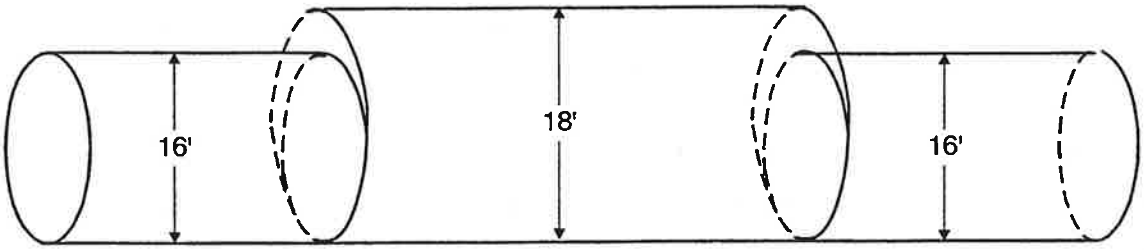
> Example 3.1. A portion of a tunnel might be shown in the plans with a variation of the diameter along its length. This portion could be described as a single line segment of average area if the user is performing a simulation for the purpose of a preliminary evaluation. However, the accuracy of the simulation results may be improved by entering the physical details more accurately. Figure 3.3 depicts a sample configuration which might be described in two different ways depending upon the accuracy which is required.



PORTION OF SUBWAY TUNNEL AS SHOWN ON DRAWING



PRELIMINARY SIMULATION - ASSUME TUNNEL TO BE UNIFORM



ACCURATE DETAILED SIMULATION - CREATE THREE SEPARATE SEGMENTS

Figure 3.3 Degrees of Accuracy for System Geometry

Vent Section Type. Although the term "ventilation shaft" is meant to include both structures for air movement and passenger movement, a distinction is made between the two uses in coding the ventilation shaft type. A ventilation shaft designed for air movement is designated as Type 1, and a ventilation shaft intended for passenger movement is designated as Type 2. (A Type 2 ventilation shaft is labeled as a "stairway" in the simulation output.) Fans may optionally be located in Type 1 vent shafts. For further details on the simulation of fan operation, see Section 4.4 of this manual.

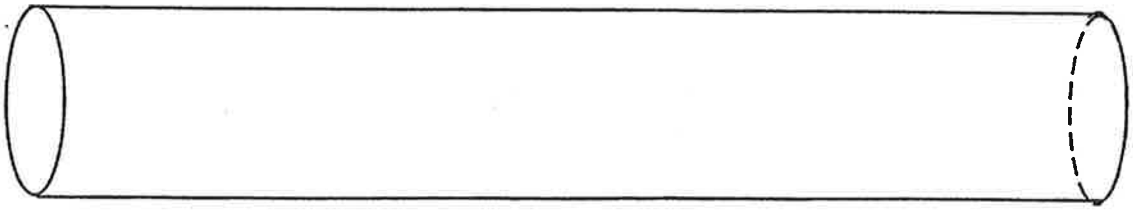
Grate Free Area. This is the unobstructed area of the ventilation shaft opening to the atmosphere. The "free area" is the gross area minus the area of any obstructions to the airflow, such as sidewalk gratings. The grate free area is measured in square feet.

<u>Design Maximum Outflow Air Velocity At Grate</u>. This is the rate of air velocity which the designer feels should not be exceeded at the ventilation shaft grating. This air velocity is computed using the airflow rate and the "grate free area". "Outflow" refers to the flow of air out of the ventilation shaft in the atmosphere. This airflow may be either "positive" or "negative" in the ventilation shaft, depending upon which direction has been defined as "positive" by the user.

Using the data describing the length, perimeter and head loss coefficients for each ventilation shaft segment, the program computes an "equivalent" ventilation shaft which is composed of one "segment" whose dimensions are such that its aerodynamic and thermodynamic behavior is equivalent to that of the original multi-segmented ventilation shaft. This "equivalent" vent shaft "segment" is then used in all further computations, resulting in a decrease in the number of calculations required and a reduction in computer cost. Velocity in the ventilation shaft is given with respect to the area of this "equivalent" shaft.

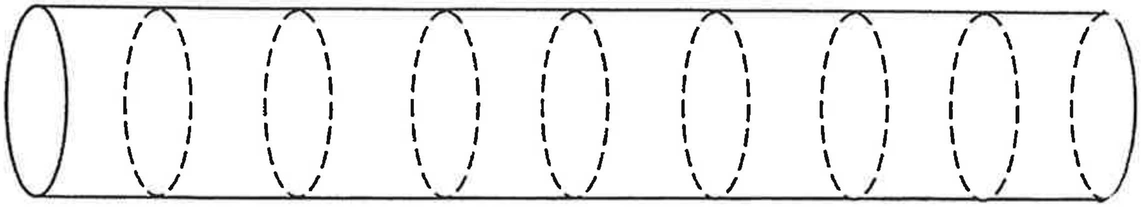
<u>Subsegments</u>. As previously noted, the geometrical partitioning of a system includes dividing the subway stations, tunnels and ventilation shafts into a number of segments, each of which has "uniform" cross-sectional area, perimeter, wall thermal properties, etc. However, temperature and humidity values may fluctuate over the length of a subway segment for which the geometrical and physical properties are uniform. Therefore, it is necessary to divide segments into smaller geometrical entities called subsegments, each of which can have an independently computed temperature and humidity, thereby making it possible to reflect small-scale variations in subway air sensible and latent heat. This geometrical subdivision increases the accuracy of the temperature and humidity calculations, as shown in Figure 3.4.

Each line segment in a system is divided into one or more line subsegments. Rules for determining the number of subsegments to place in each segment are outlined in Chapter 5 of this manual. Each ventilation shaft section can also be divided into one or more subsegments. The total of all the subsegments in the system (this includes both line subsegments and ventilation shaft subsegments) cannot exceed the limit given in Appendix A.



SEGMENT WITH ONE SUBSEGMENT

SEGMENT WITH THREE SUBSEGMENTS



SEGMENT WITH EIGHT SUBSEGMENTS

Figure 3.4 Sample Subdivision of Three Similar Segments Into Subsegments Presented in Order of Increasing Accuracy

REFERENCES

1. Developmental Sciences, Inc., "Double Track Porosity Testing", November 1975, Technical Report No. UMTA-DC-06-0010-75-4, Transit Development Corporation, Washington, DC.

4. AERODYNAMIC PHENOMENA

The airflow at any point in an underground rapid transit system is influenced by many different factors. The main influences on the airflow within a subway system are system geometry, forced ventilation, and the direction and frequency of train movement. The airflow within a subway system is also affected by buoyancy, the geometrical configuration of the trains, the roughness of the walls in the system, and outside ambient conditions.

The geometrical partitioning required for the computation of the system aerodynamics is accomplished by dividing the entire system into segments, each of which has a statistically uniform cross-sectional area, perimeter, and wall thermal properties. The user must determine the head losses between each of the segments, treating each segment as though it were a piece of a continuous air duct system. The user must also determine the degree of roughness of the walls in each segment. The roughness of the walls determines the friction factor of the walls.

The user must supply the program with various data on the geometry and performance of the trains in the system. Each train traveling through the tunnels in a system pushes on the air in front of it in a manner similar to a piston in an open-ended tube full of air. The amount of air pushed through the system depends upon the ratio of the cross-sectional area of the trains to the cross-sectional area of the tunnel (blockage ratio). The amount of air that trains force through a system also depends largely upon the speed of the trains and the number of trains operating in the system. A system may contain fans to provide forced ventilation in specific areas of the system. The magnitude of the airflow from fans is often equal to or greater than the airflow generated by the piston action of the trains. The user must supply the program with the fan performance characteristics for each type of fan in the system.

The computations of the airflow in each segment are carried out automatically using the system geometry, fan, and train data entered by the user. The program may be run with fans and no trains, trains and fans, or trains without fans, depending on the program option being used. These options are very useful and can, in certain instances, reduce the amount of computer time necessary for a run.

The aerodynamic subprogram continually calculates the rate of airflow within each section in a system. The airflow within the system always satisfies the law of continuity at each node in the system. The interval between each new aerodynamic calculation is specified by the user, and the accuracy of the results of the SES simulation are inversely proportional to the length of time between each successive aerodynamic calculation. The airflow in a portion of a subway system can change rapidly. These rapid changes can occur when a train passes beneath a vent shaft, when two trains pass each other in opposite directions, when a fan is switched on, and when a train enters a system at a high speed. If the user-specified time interval between successive aerodynamic calculations is too large, the results of the SES will not accurately reflect these rapid changes (see Chapter 10). The aerodynamic and thermodynamic subprograms have stability criteria that must be adhered to at all times. Each segment in the system is partitioned into smaller geometrical entities called subsegments. Each subsegment has an independently computed temperature and humidity, making it possible to reflect small variations in the system air sensible and latent heat. Similarly, each section within a system has an independently computed rate of airflow. The sensible and latent heat in each subsegment is greatly affected by the movement of air through the subsegment. The thermodynamic velocity-time stability criterion states that the velocity of the air moving through a subsegment cannot be greater than the ratio of the length of the subsegment to the user-specified time interval between each thermodynamic calculation. This velocity-time stability criterion should always be taken into account when choosing the length of the subsegments within each segment.

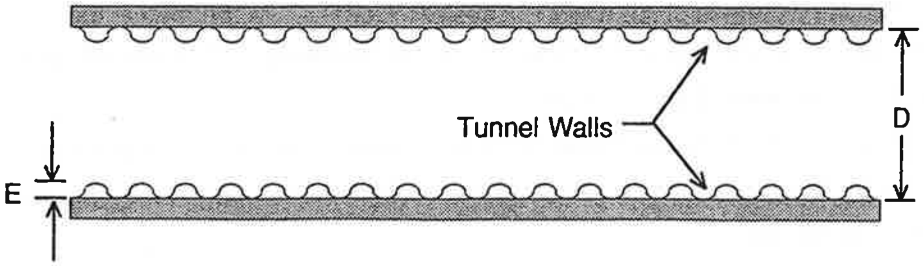
The input parameters required for the aerodynamic portion of the SES are described on the following pages. These input parameters include the tunnel roughness lengths, segment head loss coefficients, fan performance data, and system geometry within the vicinity of the nodes.

4.1 Roughness Length (Input Form 3B)

The roughness length (E) of a tunnel is the average height of the uniform protuberances from the tunnel wall. The roughness length is a function of the type of construction and finishing techniques used within the tunnels of the system. Table 4.1 gives typical ranges of values for common types of materials used in subways. Roughness lengths are measured in feet. The roughness lengths are entered in Form 3B. The SES program distinguishes between tunnels with uniform roughness and tunnels with ribs. A sketch of a tunnel with uniform roughness is given in Figure 4.1 and a sketch of a tunnel with ribs is given in Figure 4.2. These two types of tunnels are discussed below.

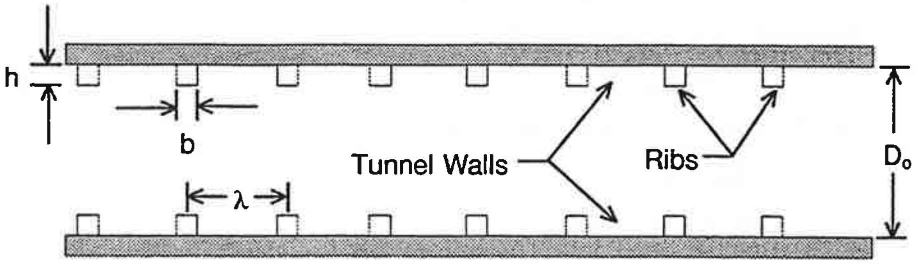
Table 4.1 Ranges of Values for Common Types of Materials Used in Subways

Material	Roughness Length E, ft.
Concrete Rough Forms	0.0055 - 0.01
Concrete Smooth Forms	0.001 - 0.0055
Track Bed with 2" Ballast	See Text
Tile Walls	0.0008
Ribbed Tunnel	See Text



E = Average Roughness Length
D = Diameter of the Tunnel

Figure 4.1 Schematic Diagram of Tunnel with Uniform Roughness Lengths



h = height of ribs
b = width of ribs
λ = center to center spacing between ribs
D_o = diameter of tunnel

Figure 4.2 Schematic Diagram of Ribbed Tunnel

<u>Tunnels With Uniform Roughness</u>

The Reynolds Number is defined as follows for a given flow throughout the system:

$$N_{RE} = \frac{\rho VD}{\mu} = \frac{4Q}{p\nu}$$

where N_{RE} = Reynolds Number
ρ = mass density of air, slugs/ft^3
V = velocity of the air, ft/sec
D = hydraulic diameter of the tunnel, ft
μ = absolute viscosity of air, slugs/ft-sec
Q = volumetric rate of airflow in the tunnel, ft^3/sec
p = perimeter of the tunnel, ft
ν = kinematic viscosity of air, ft^2/sec

The relative roughness of the walls in a system is defined as the ratio of the roughness length and the hydraulic diameter of the tunnel. This is expressed symbolically as E/D where E is the roughness length and D is the hydraulic diameter of the tunnel.

The Darcy-Weisbach friction factor of the walls within a system depends on the relative roughness of the walls and the Reynolds number for the airflow through the system. This Darcy-Weisbach friction factor is defined as follows:

$$\Delta P = \frac{\rho f L V^2}{2D}$$

where ΔP = pressure drop over the given length, lb/ft^2

ρ = mass density of the air, slugs/ft^3

L = length of the tunnel, ft

V = velocity of the air in the tunnel, ft/sec

D = hydraulic diameter of the tunnel, ft

f = Darcy-Weisbach friction factor

The user must enter the roughness length for each line segment in a system. The program utilizes the user-entered roughness lengths to calculate the friction factor for the walls within each line segment. The SES calculates and prints the hydraulic diameter, relative roughness, and fully turbulent friction factor in the input verification for each line segment in a system.

The roughness length of a wall is obtainable from many different sources. Figure 4.3 is a Moody diagram showing the relationships between the friction factor, Reynolds number, and relative roughness for various types of tunnels with uniform roughness. Since the airflow in subway tunnels is almost always fully developed turbulent flow, the SES assumes fully turbulent flow if the Reynolds Number is greater than 2000. Therefore, the user may determine the relative roughness, and thereby the roughness length, for a tunnel where the only known parameter for the walls is the friction factor due to the fact that the friction factor is no longer Reynolds Number-dependent for fully turbulent flow.

Table A in Appendix B provides the Darcy-Weisbach friction factor as a function of relative roughness for fully developed turbulent flow. The user may use this table to determine the relative roughness, and thereby the roughness length, for a tunnel instead of using a Moody diagram.

Table B in Appendix B provides the Darcy-Weisbach friction factor as a function of Reynolds Number and relative roughness. This table is simply a Moody diagram in tabular form.

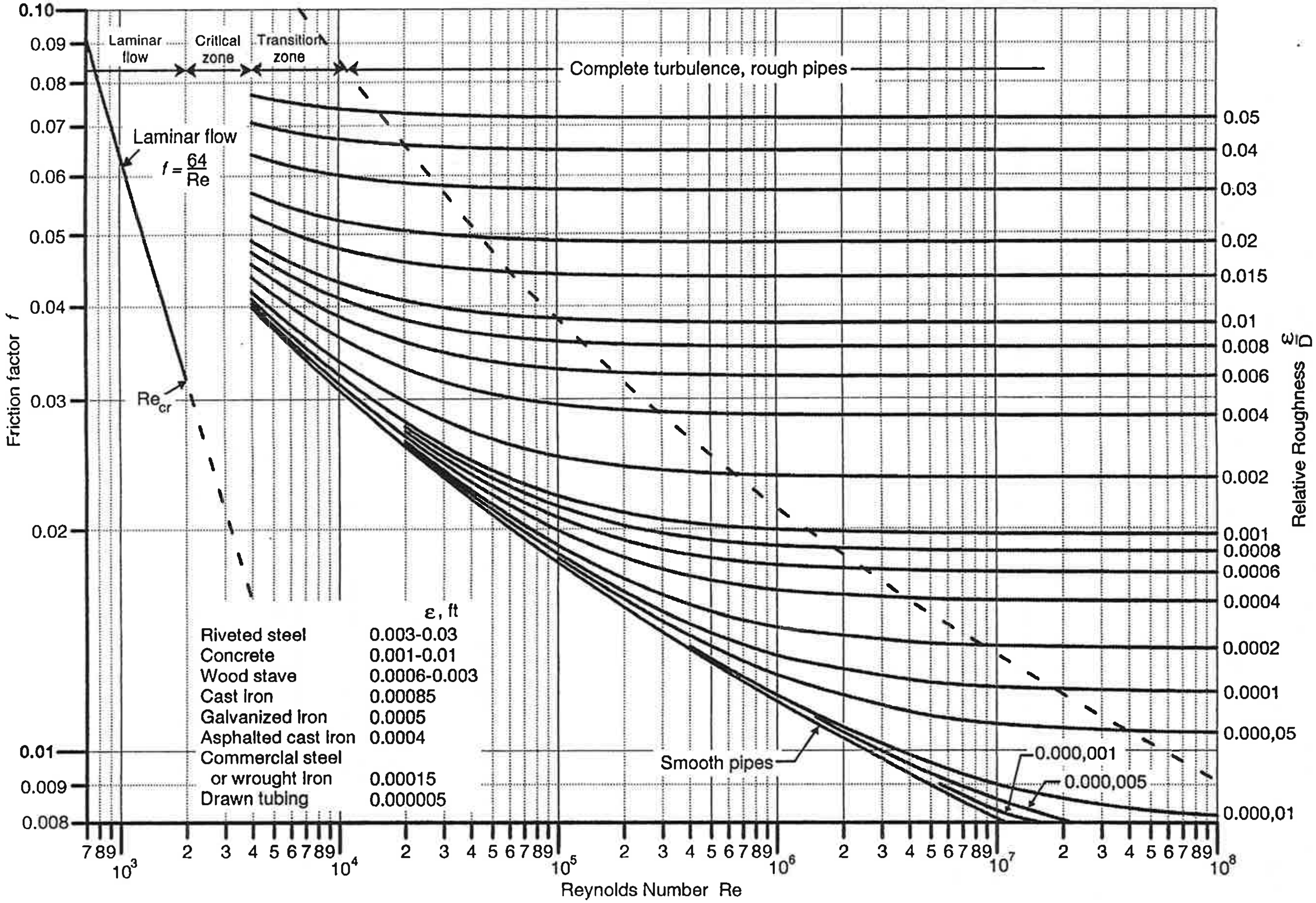


Figure 4.3 Moody Diagram

Table C in Appendix B provides the relative roughness as a function of the Darcy-Weisbach friction factor for fully developed turbulent flow. The user may also use this table to determine the relative roughness, and thereby the roughness length, for a tunnel instead of using a Moody diagram.

Ribbed Tunnels

If the protuberances in a tunnel are spaced widely enough so that the roughness of the tunnel can no longer be considered uniform, the tunnel is considered a ribbed tunnel. A sketch of a ribbed tunnel is given in Figure 4.2. The fully turbulent friction factor for a ribbed tunnel can be determined from Figures 4.4 and 4.5. Once the friction factor for a ribbed tunnel has been determined from Figure 4.4, the user must use Tables A through C in Appendix B to determine the appropriate equivalent roughness length for the tunnel. The user cannot enter the height of the ribs as the roughness length — the user must first determine the friction factor and then work backwards from Tables A through C in Appendix B as previously explained to obtain the roughness length.

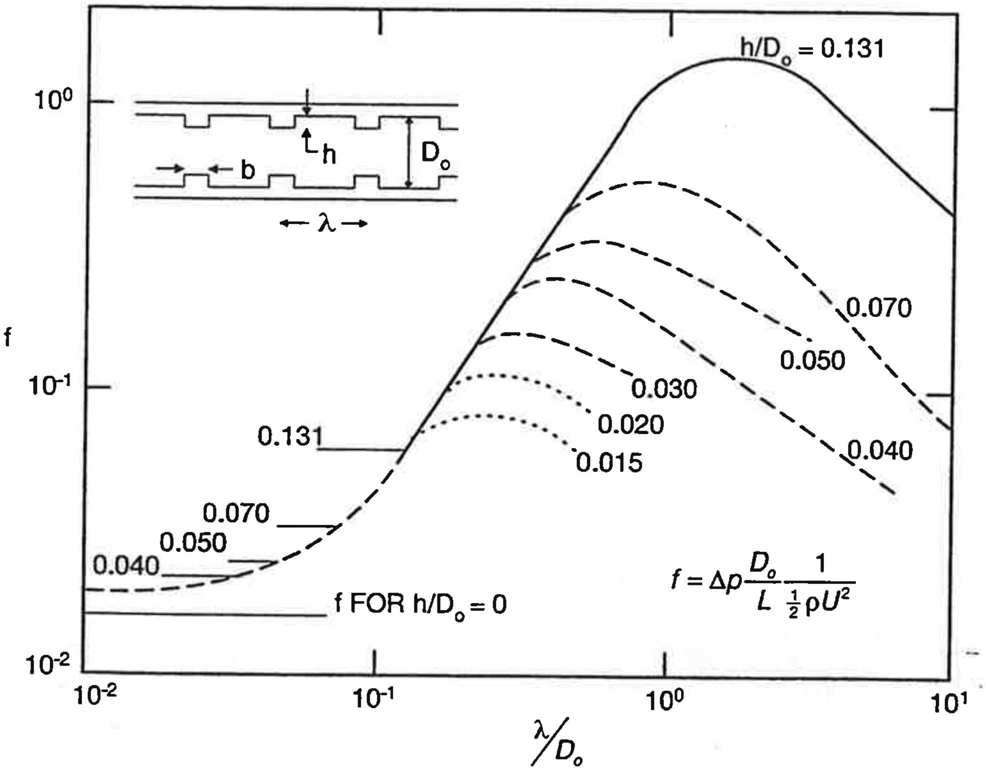


Figure 4.4 Effect of Ribbing on Pipe Flow Friction Factor (Ref.6)

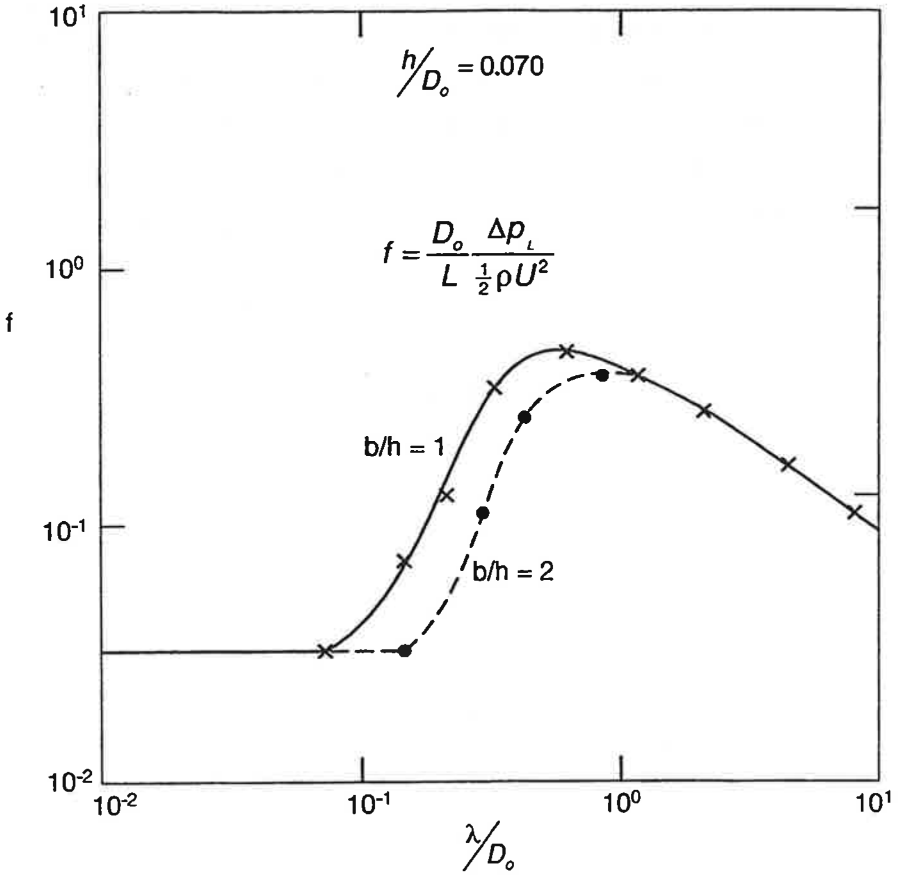
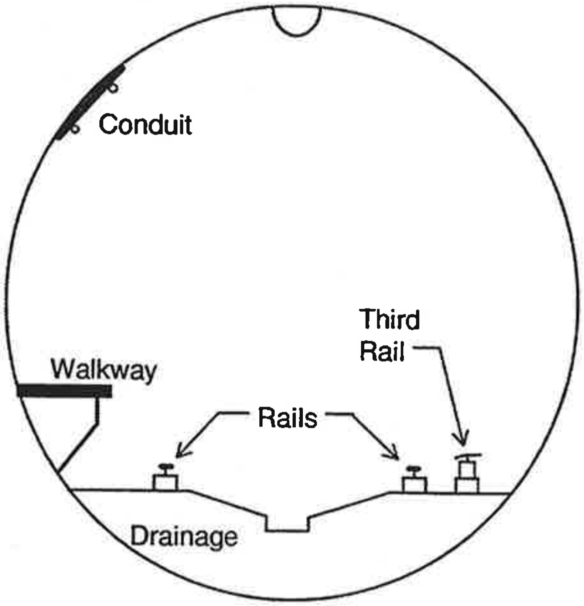


Figure 4.5 Effect of Shape of Internal Ribbing on Pipe Flow Friction Factor (f based on D_o) (Ref.6)

Varying Roughness Length Along the Tunnel Perimeter

The walls of a subway system will generally have varying roughness lengths along the different portions of the tunnel boundaries. For instance, the trackbed will have a different roughness length than the ceiling and the walls. The perimeter of a line segment can be entered in separate lengths to account for the various surfaces comprising the total inner surface of the tunnel segment. A roughness length must be entered for each of the separate fragmented perimeters. Up to eight perimeter "segments" and corresponding roughness lengths may be entered for each line segment in the system. An example of how segmented perimeters and corresponding roughness lengths may be used is given in the following example. The SES calculates a weighted average roughness length when more than one segmented perimeter and corresponding roughness length are entered for a line segment. The weighted average roughness length is printed in the input verification for each line segment (See Example 4.1).

Example 4.1 Consider the tunnel line segment cross-section given in Figure 4.6. The walls of this tunnel line segment have various items attached to them such as pipes and walkways. The entire perimeter of this tunnel line segment can be broken into the segments outlined in Table 4.2. Table 4.2 provides the approximate theoretical roughness lengths and resulting friction factors for each of the segmented perimeters. The weighted average friction factor is also provided.



Section not to scale

Figure 4.6 Example of Segmented Perimeters

Table 4.2 Theoretical Tunnel Friction Factors for Segmented Perimeters Described in Example 4.1

		(3) Roughness Characteristics				
(1) Subperimeter Identification	(2) Percentage of Perimeter	Relative* Roughness	λ^{**}/D	h^{**}/D	(4) f_t	(5) Weighted Contribution to Total f_t (2 x 4)
Pipe supports	11%	—	0.61	0.01	0.051	0.0056
Rail and pads	4%	—	0.09	0.015	0.037	0.0015
Catwalk and supports	4%	—	0.24	0.15	0.135	0.0054
Third rail and supports	2%	—	0.3	0.04	0.22	0.0044
Concrete wall surface	79%	0.0002	—	—	0.014	0.0111
			Weighted tunnel friction factor:			0.028

* For use with Moody diagram to evaluate f_t

** Roughness characteristic of ribbed tunnels (h = height, λ = spacing); f_t evaluated using Figure 4.4

The user does not have to perform all the calculations shown in Table 4.2. The SES computes the friction factors, the user only has to enter the roughness lengths for each perimeter segment.

The user may use a particular friction factor for a line segment by entering the total perimeter of the line segment and the corresponding weighted average roughness length required for the tunnel friction factor using the tables in Appendix B.

4.2 Head Loss Coefficients (Input Forms 3C, 5D)

The energy lost by a fluid when work is done by the fluid against friction between two given points of flow is referred to as the head loss for the fluid between the two points. There are two types of head losses: head loss due to viscous friction, and head loss due to abrupt changes in area or turns within a tunnel. The head loss due to friction between two given points of flow is defined as follows:

$$h_f = \frac{P_1 - P_2}{W} + \frac{V_1^2 - V_2^2}{2g} + Z_1 - Z_2$$

where h_f = head loss between points 1 and 2 due to friction
P_1 = static pressure at point 1
P_2 = static pressure at point 2
W = specific weight of the fluid
V_1 = velocity of the fluid at point 1
V_2 = velocity of the fluid at point 2
Z_1 = vertical height of point 1
Z_2 = vertical height of point 2
(Any consistent set of units may be used with these equations.)

Expressions have been developed to determine the head loss due to friction. The most convenient expression to use is the Darcy-Weisbach equation:

$$h_f = f\frac{L}{d}\frac{V^2}{2g}$$

where f = Darcy-Weisbach friction factor
L = length of tunnel between points 1 and 2
d = hydraulic diameter of the tunnel
V = velocity of the fluid

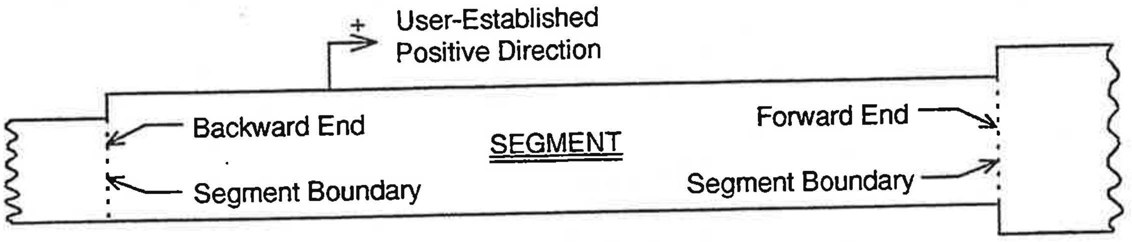
The losses that occur when sudden enlargements, contractions, or turns occur in a tunnel can be expressed in terms of the velocity head of the fluid just before the sudden change in area or the turn occurs. This loss is often referred to as the minor head loss. A minor head loss is an irreversible head loss in the total (static plus dynamic) head in the segment. The term "minor" does not imply that these losses are small, but it is a name which has been historically applied to this type of head loss. The minor head loss can also be expressed as a friction loss by calculating the equivalent length of tunnel through which the fluid would have to flow in order to lose an amount of energy equivalent to the energy lost during the rapid change in area or the turn. The minor head loss is expressed as follows:

$$(h_f)_m = f\frac{L}{d}\frac{V^2}{2g} = \frac{KV^2}{2g}$$

where $(h_f)_m$ = minor head loss
K = minor head loss coefficient
V = velocity of the fluid

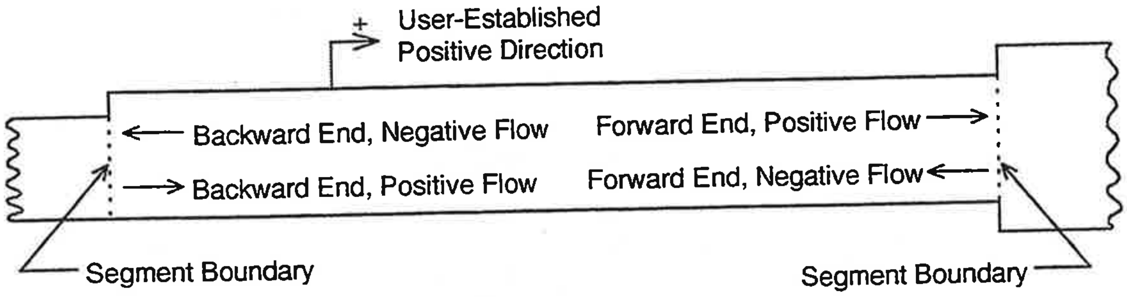
Various tables which supply minor head losses for certain types of system geometry provide these head losses in the form of equivalent lengths of tunnel. The above relationship must be used to convert head losses in equivalent lengths to an equivalent head loss coefficient (K) for each abrupt area change or turn.

The SES program internally calculates the head loss due to friction for each line segment in the system. Therefore, the user need only enter the minor head loss coefficients for each line and vent shaft segment in a system. The SES program requires the user to determine the minor head loss coefficients based on changes in total pressure only (static pressure plus velocity pressure). Head loss coefficients are sometimes calculated using the change in static pressure and the user should make certain that only the total pressure changes are considered. These minor head loss coefficients must be entered for both the forward and backward ends of each segment. The forward end of a segment is the end where positive flow leaves the segment. The backward end of a segment is the end where negative flow leaves the segment. A sketch describing the forward and backward ends of a segment is given below:



The minor head loss coefficients may be obtained from various sources. Table 4.3 provides loss coefficients based on total pressure loss for many types of sudden changes in area. Table 4.4 provides the loss coefficients based on total pressure loss for many different types of turns.

The user must enter the head loss coefficients for both positive and negative flow at each end of each segment in the system. The positive and negative flow directions at the forward and backward ends of a segment are shown in the diagram below:



Minor Head Loss Coefficients Between Two Segments

The user must only enter the minor head loss coefficients once at each segment boundary. In other words, if the user enters the forward end positive and negative flow loss coefficients at a segment boundary, zeros must be entered for the head loss coefficients for the subsequent adjoining segment at the adjoining segment's backward end, and vice versa. It is extremely important that the user fully understand the methods for entering minor head losses outlined below. A common error often made by new users is that they enter head losses at a segment boundary twice. It cannot be emphasized strongly enough that the head losses at a segment boundary are entered only once for a given flow direction. Example 4.2 on page 4-14 shows the four different ways minor head losses at a segment boundary may be entered.

Table 4.3 Loss Coefficients Based on Total Pressure Loss for Area Changes

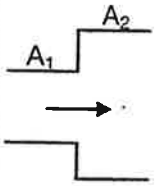
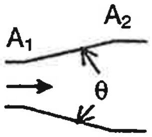
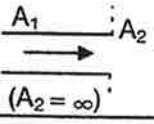
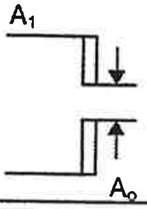
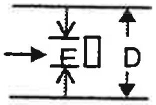
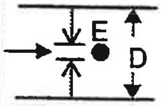
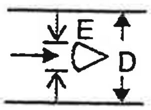
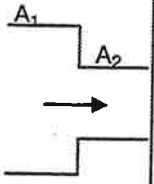
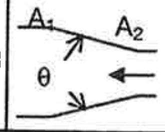
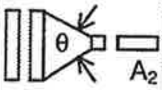
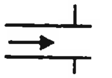
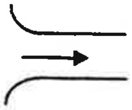
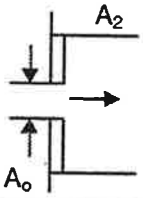
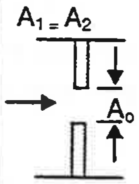
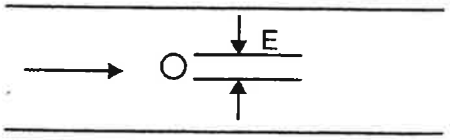
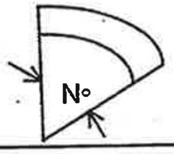
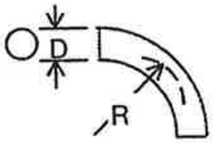
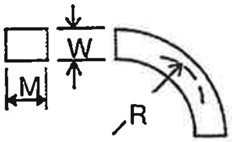
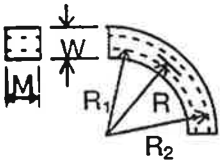
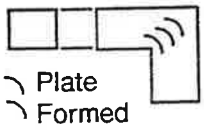
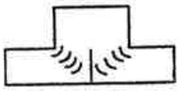
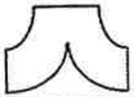
TYPE	ILLUSTRATION	CONDITIONS	LOSS COEFFICIENT	
ABRUPT EXPANSION		A_1 / A_2 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9	C_1 0.81 0.64 0.49 0.36 0.25 0.16 0.09 0.04 0.01	C_2 81 16 5 2.25 1.00 0.45 0.18 0.06 0.01
GRADUAL EXPANSION		θ 5° 7° 10° 20° 30° 40°	C 0.17 0.22 0.28 0.45 0.59 0.73	
ABRUPT EXIT		$A_1/A_2 = 0.0$	1.0	
SQUARE EDGE ORIFICE EXIT		A_o / A_1 0.0 0.2 0.4 0.6 0.8 1.0	C_o 2.50 2.44 2.26 1.96 1.54 1.00	
BAR ACROSS DUCT		E / D 0.10 0.25 0.50	C 0.7 1.4 2.0	
PIPE ACROSS DUCT		E / D 0.10 0.25 0.50	C 0.20 0.55 2.0	
STREAM-LINED STRUT ACROSS DUCT		E / D 0.10 0.25 0.50	C 0.07 0.23 0.90	
ABRUPT CONTRACTION SQUARE EDGE		A_2 / A_1 0.0 0.2 0.4 0.6 0.8	C_2 0.34 0.32 0.25 0.16 0.06	
GRADUAL CONTRACTION		θ 30° 45° 60°	0.02 0.04 0.07	
EQUAL AREA TRANS-FORMATION		$A_1 = A_2$ $\theta \leq 14°$	C 0.15	
FLANGED ENTRANCE		A = ∞	C 0.34	
DUCT ENTRANCE		A = ∞	C 0.85	
FORMED ENTRANCE		A = ∞	C 0.03	
SQUARE EDGE ORIFICE ENTRANCE		A_o / A_2 0.0 0.2 0.4 0.6 0.8 1.0	C_o 2.50 1.90 1.39 0.96 0.61 0.34	
SQUARE EDGE ORIFICE IN DUCT		A_o / A_2 0.0 0.2 0.4 0.6 0.8 1.0	C_o 2.50 1.86 1.21 0.64 0.20 0.0	
INTERNAL TIE ROD		E 1/8 IN. 1/4 IN. 5/16 IN.	C 0.0104 0.0255 0.040	

Table 4.4 Total Pressure Losses Due to Elbows

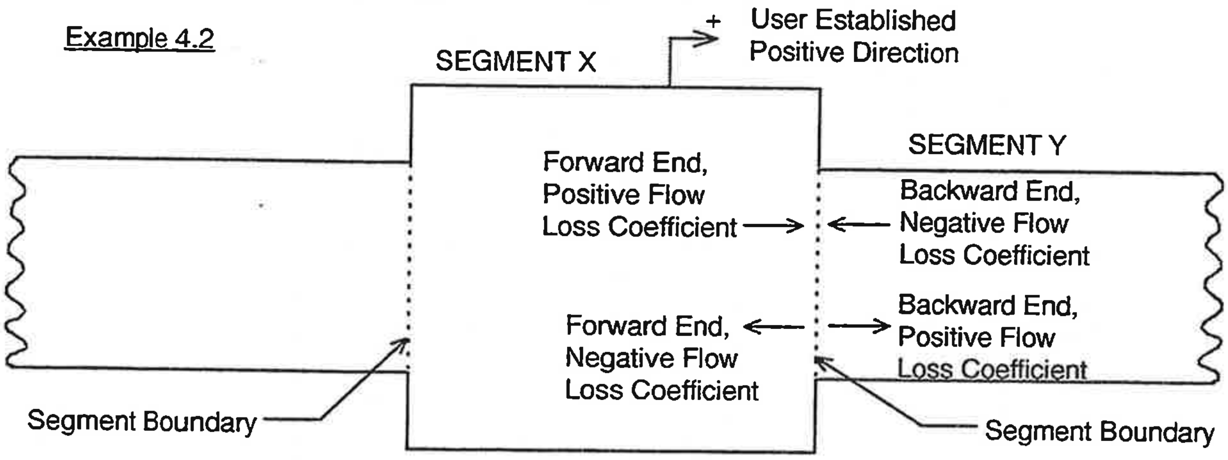
(Additional Equivalent Losses in Excess Friction to Intersection of Center Lines)

TYPE	ILLUSTRATION	CONDITIONS	PRESSURE LOSS		
			Ca	L / D	L / W
N - DEGREES		RECTANGULAR OR ROUND ; WITH OR WITHOUT VANES	$\frac{N}{90}$ TIMES VALUE FOR SIMILAR 90 - DEG. ELBOW		
90 DEGREE ROUND SECTION		MITER	1.30[b]	65	
			0.90		
		R/D = 0.5	0.45	23	
		0.75	0.33	17	
		1.0	0.24	12	
		2.0	0.19	10	
90 DEGREE RECTANGULAR SECTION		M / W R / W			
		0.25 { MITER 0.5 0.75 1.0 1.5	1.25[b] 1.25 0.60 0.37 0.19		25 25 12 7 4
		0.5 { MITER 0.5 0.75 1.0 1.5	1.47 1.10 0.50 0.28 0.13		49 40 16 9 4
		1.0 { MITER 0.5 0.75 1.0 1.5	1.50 1.00 0.41 0.22 0.09		75 50 21 11 4.3
		4.0 { MITER 0.5 0.75 1.0 1.5	1.38 0.98 0.37 0.19 0.07		110 65 43 17 6
90 DEGREE SQUARE SECTION WITH SPLITTER VANES		R/W R/W R_2/W MITER 0.5 0.5 0.4 0.7 0.8 1..0 1.0 1.5 MITER 0.3 0.5 0.5 0.2 0.4 0.75 0.4 0.7 1.0 0.7 1.0 1.5 1.3 1.0	0.70 0.13 0.12 0.45 0.12 0.10 0.15		28 19 12 7.2 22 16
MITER WITH TURNING VANES		C = 0.10 TO 0.35 DEPENDING ON MANUFACTURE			
MITER TEE WITH VANES		CONSIDER EQUAL TO A SIMILAR ELBOW. BASE LOSS ON ENTERING VELOCITY.			
RADIUS TEE					

[a] Values based on *f* values of approximately 0.02.

[b] Values calculated from *L/D* and *L/W* values for *f* =0.02.

Example 4.2



Case I

Area of Segment X = 300 ft^2

Area of Segment Y = 150 ft^2

Loss Coefficients Obtained As Follows From Table 4.3:

For the forward end, positive flow loss coefficient for SEGMENT X, use square edge abrupt contraction:

A_2/A_1 = Area SEGMENT Y/Area SEGMENT X = 0.50

$C_2 = K_2 = 0.205$ (this coefficient is referenced to the area of A_2)

The loss coefficient must be referenced to area A_1 (SEGMENT X)

$$K_2 = \frac{K_1^2 A_2^2}{A_1^2}$$

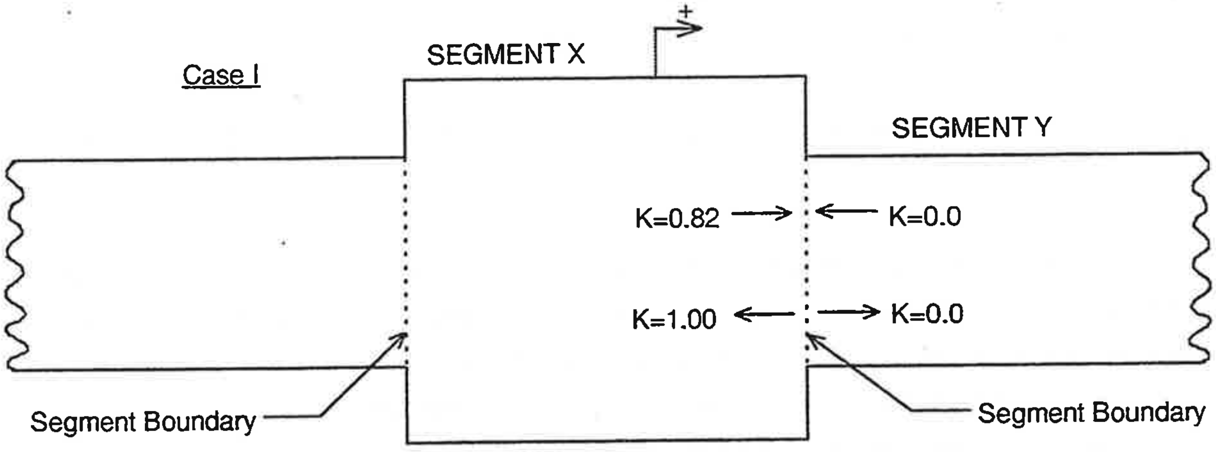
$$K_2 = 0.205 = C_1\ (0.50)^2$$

$$K_1 = C_1 = 0.205/0.25 = 0.82$$

For the forward end, negative flow loss coefficient for SEGMENT X, use abrupt expansion:

A_1/A_2 = Area SEGMENT Y / Area SEGMENT X = 0.50

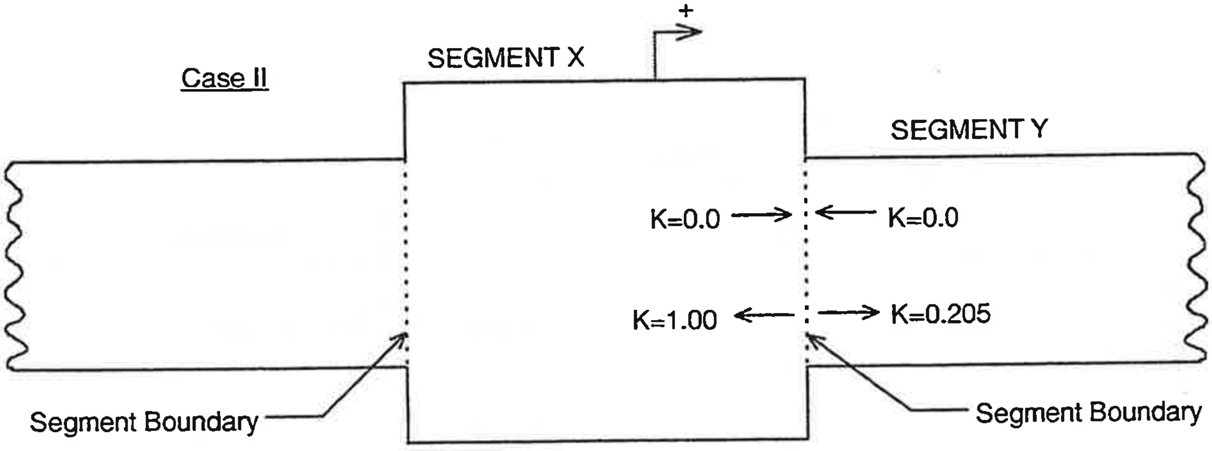
$C_2 = 1.00$ (obtained directly from Table 4.3)



The minor head loss coefficients for both positive and negative flow at the boundary between SEGMENT X and SEGMENT Y have now been described. Therefore, the loss coefficients at the backward end of SEGMENT Y must be set equal to 0.0 as the loss coefficients at a segment boundary must only be described once.

Case II

Alternatively, the user may enter the minor head loss coefficients at the boundary between SEGMENT X and SEGMENT Y as follows:



The loss coefficients are obtained as follows from Table 4.3:

For the backward end, positive flow loss coefficient for SEGMENT Y use square edge abrupt contraction:

A_2/A_1 = Area SEGMENT Y/Area SEGMENT X = 0.50

C_2 = 0.205 (obtained directly from Table 4.3)

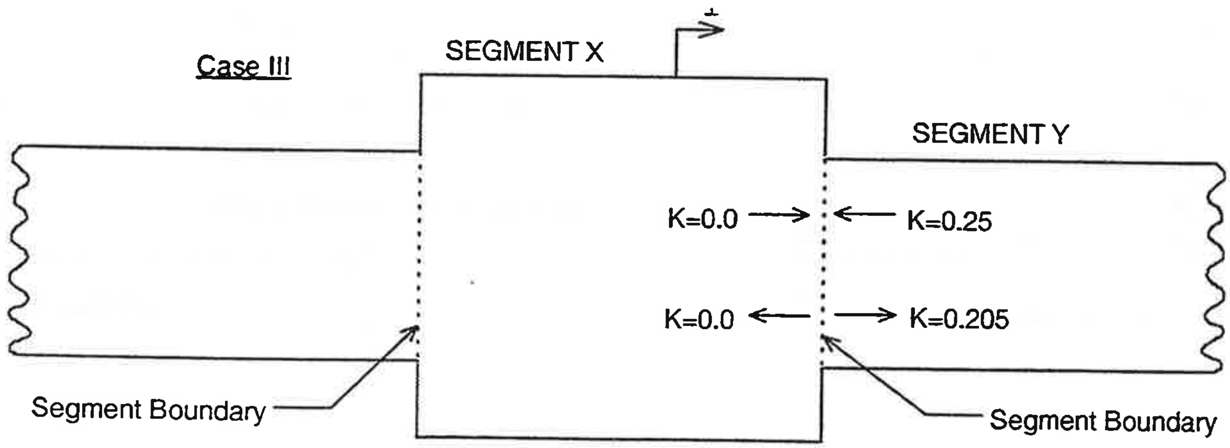
The minor head loss coefficient at the forward end, negative flow for SEGMENT X is the same as in Case I.

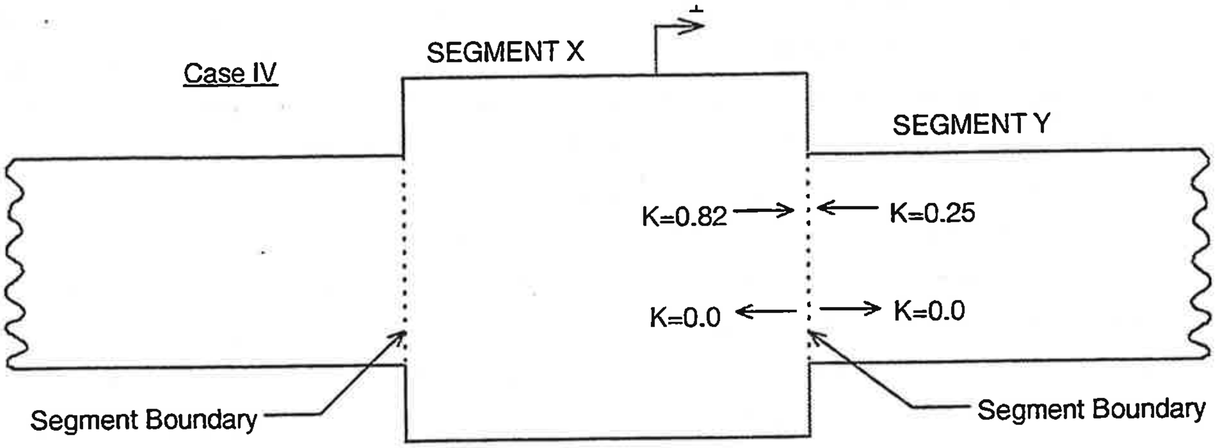
The minor head loss coefficients for both positive and negative flow at the boundary between SEGMENT X and SEGMENT Y have now been described. The loss coefficient for the forward end, positive flow for SEGMENT X, and the backward end, negative flow for SEGMENT Y must be set equal to 0.0 as the loss coefficients at a segment boundary must only be described once.

Both of the above methods used to describe the minor head loss coefficients at the boundary between SEGMENT X and SEGMENT Y will provide the same results in the SES. The only difference between Case 1 and Case II is that the minor head loss coefficients in the positive direction between SEGMENT X and SEGMENT Y was referenced to the area of SEGMENT X in Case I, whereas it was referenced to the area of SEGMENT Y in Case II. As shown in Case II, when the minor head loss coefficient in the positive direction between SEGMENT X and SEGMENT Y is referenced to SEGMENT Y, the loss coefficient must be placed at the backward end positive flow position of SEGMENT Y, and the loss coefficient at the forward end positive flow position of SEGMENT X must be set to zero.

Case III and IV

The user could also have established the minor head loss coefficients between SEGMENT X and SEGMENT Y as shown in the following two cases:

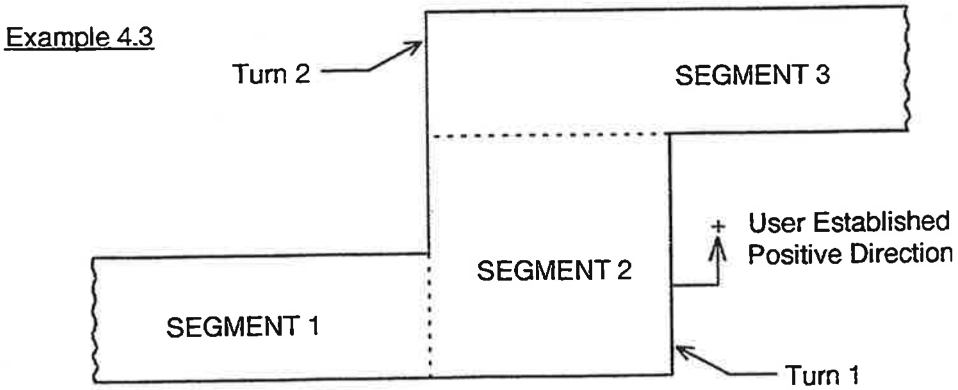




All four cases are equivalent to one another — the only differences between them are the segments and corresponding areas to which the loss coefficients were referenced. All four cases will provide the same results in the SES.

Abrupt Turns Within A Segment

When a segment has a sudden turn, the minor head losses that result from this turn must be added to the loss coefficients entered for the forward and backward ends of the segment. Abrupt turns occur very often in ventilation shafts. An example of the head losses from abrupt turns within a vent shaft segment is given below:



Area of Segment 2 = 300 ft^2
Area of Segments 1 and 3 = 150 ft^2

The minor head loss coefficients at the boundary between SEGMENT 1 and SEGMENT 2 can be treated as an abrupt expansion at the forward end positive flow of SEGMENT 1 and as a square edge abrupt contraction at the backward end negative flow of SEGMENT 2. This corresponds exactly with Case IV of the previous example as the areas of SEGMENT 1 and SEGMENT 2 correspond exactly to the areas of SEGMENT Y and SEGMENT X respectively.

The minor head loss coefficients at the boundary between SEGMENT 2 and SEGMENT 3 are treated as a square edge abrupt contraction at the forward end positive flow of SEGMENT 2 and as an abrupt expansion at the backward end negative flow of SEGMENT 3. This corresponds exactly with Case IV of the previous example as the areas of SEGMENT 2 and SEGMENT 3 correspond exactly to the areas of SEGMENT X and SEGMENT Y respectively. In addition to the abrupt changes in area between SEGMENT 2 and SEGMENT 3, there is an abrupt 90 degree miter turn in SEGMENT 2. The minor head loss that occurs when flow passes through this turn (Turn 1) must be added to the minor head losses that occur due to the abrupt changes in area. A more detailed drawing of the sample vent shaft under discussion is given in Figure 4.7. From Figure 4.7 and Table 4.2 it can be seen that the minor head loss coefficients for the turning losses in Turn 1 are equal to 1.42 for flow in both the positive and negative directions. Therefore, a minor head loss coefficient of 1.42 must be added to the minor head loss coefficients attributable to the abrupt changes in area at the forward end positive flow and backward end, negative flow of SEGMENT 2.

The turning loss at Turn 2 is slightly different due to a different ratio of the height of the segment to the width of the segment. Again, from Table 4.4 and Figure 4.7, it can be seen that the minor head loss coefficients for the turning losses in Turn 2 are equal to 1.48 for flow in both the positive and negative directions. Therefore, a minor head loss coefficient of 1.48 must be added to the minor head loss coefficients attributable to the abrupt changes in area at the forward end positive flow and backward end, negative flow of SEGMENT 3.

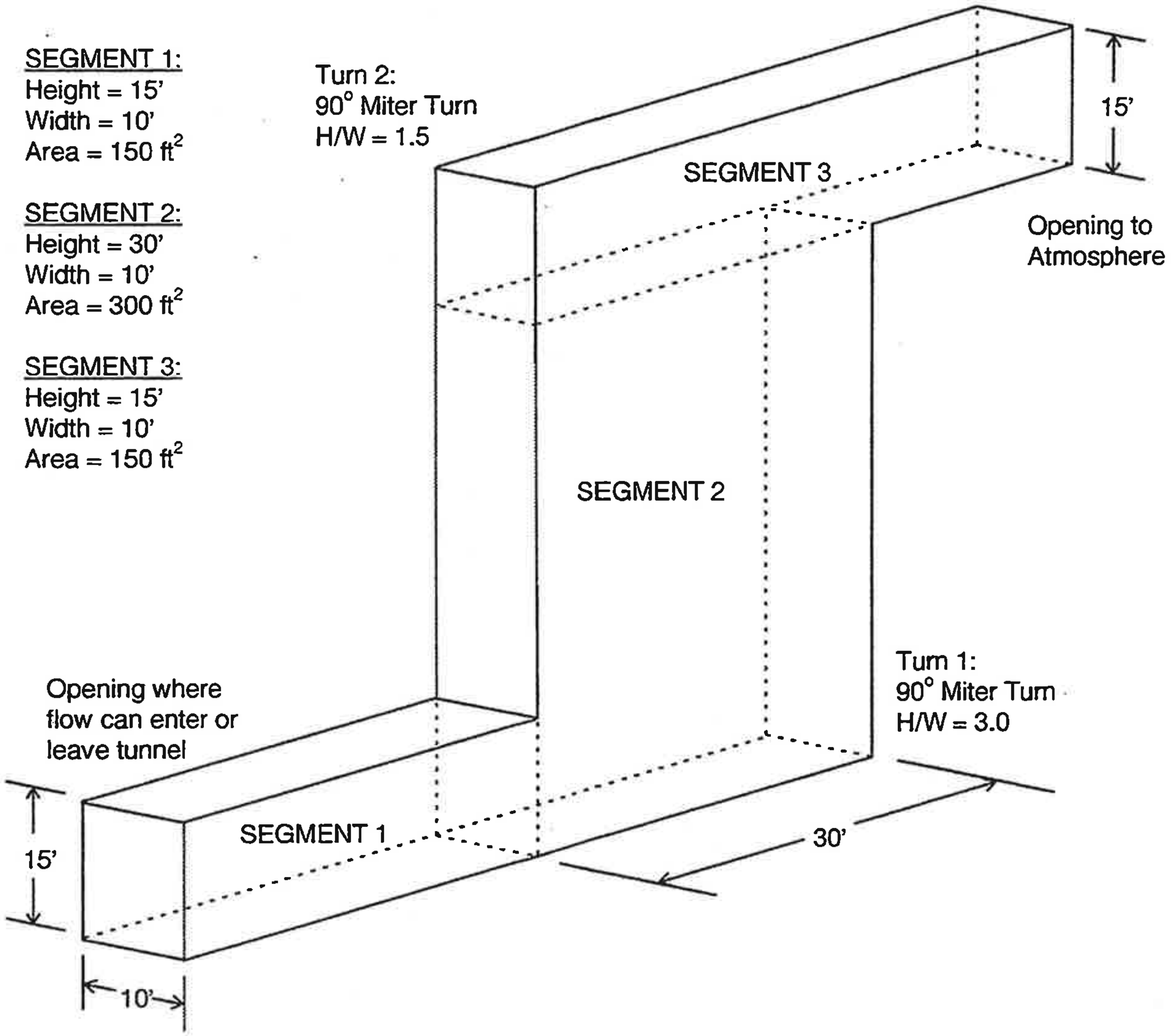
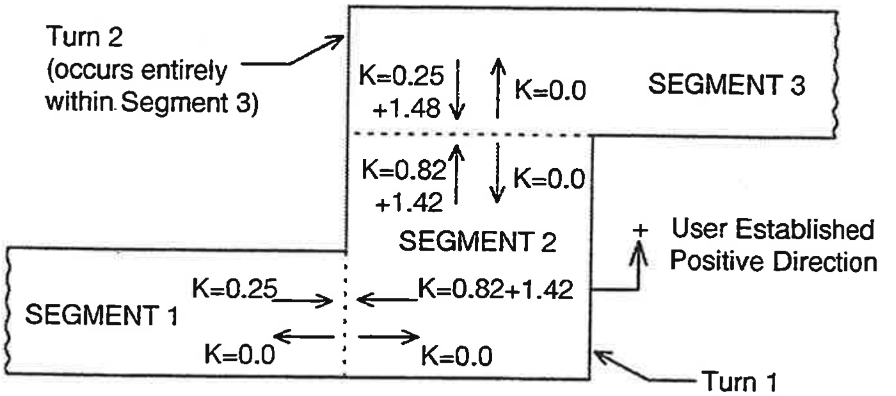


Figure 4.7 Sample Vent Shaft - Calculation of Minor Head Losses Through Turns

The minor head loss coefficients at the boundary between SEGMENT 1 and SEGMENT 2 and at the boundary between SEGMENT 2 and SEGMENT 3 are depicted in the drawing on the next page:

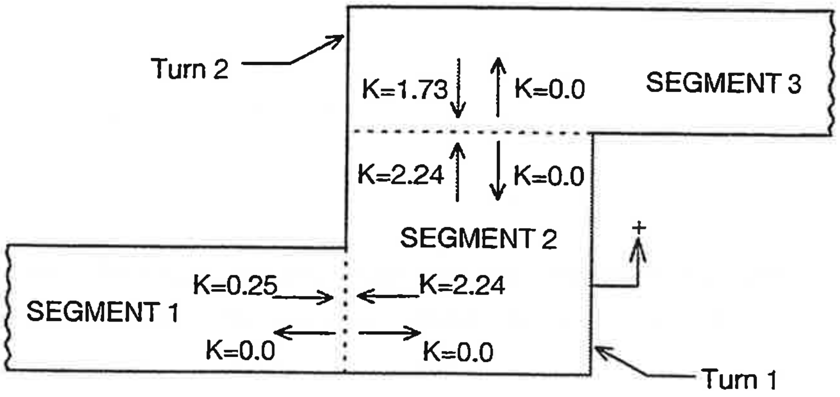


Area of Segment 1 = 150 ft^2

Area of Segment 2 = 300 ft^2

Area of Segment 3 = 150 ft^2

The loss coefficients attributable to the turns in the vent shaft are shown above for the purpose of clarity as separate additions to the loss coefficients attributable to the sudden changes in area. The user must enter the <u>sum</u> of the appropriate loss coefficients for a particular end and flow direction of a segment when entering data in the program. Therefore, the final values of the minor head loss coefficients calculated for the above vent shaft would be entered in the SES as follows:



Minor Head Losses Due to Entrances and Exits

The minor head losses that occur when flow enters or exits a tunnel or vent shaft to or from the atmosphere must also be taken into account when entering the minor head loss coefficients for a segment.

Entrance Losses. There is an entrance loss at every opening to the atmosphere where air can enter a system. This entrance loss depends on the configuration of the entrance. Table 4.3 provides head loss coefficients for various types of entrances.

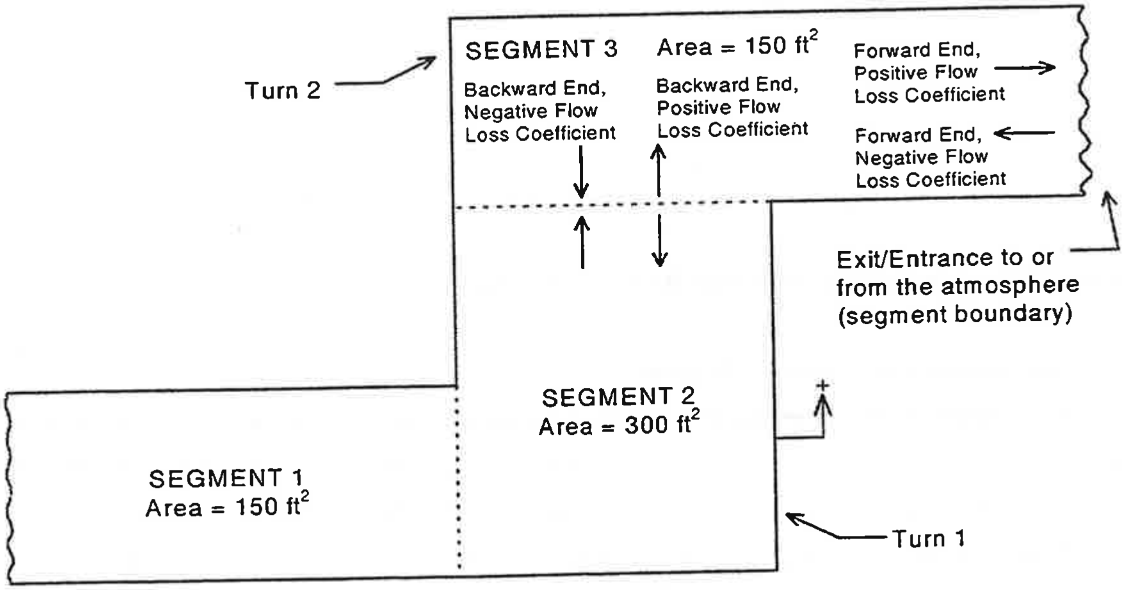
There will be an entrance loss at each portal in a system and at the top of each vent shaft where flow enters the vent shaft.

Exit Losses. There is also an exit loss at every opening to the atmosphere where air can leave a system. This exit loss depends on the configuration of the exit.

Almost every vent shaft has a grating over the top of the vent shaft to prevent people and/or objects from falling into the shaft. Obstructions such as gratings will affect the losses in a vent shaft during both inflow and outflow.

An example of the entrance and exit losses at the top of a vent shaft is given below.

Example 4.4 Using the vent shaft described in the previous example (Example 4.3) and shown in Figure 4.7, the entrance and exit losses are the minor head losses at the forward end positive, and forward end negative flow for SEGMENT 3. These entrance and exit losses are depicted as follows:



ENTRANCE LOSS = SEGMENT 3 Forward End, Negative flow loss coefficient

EXIT LOSS = SEGMENT 3 Forward End, Positive flow loss coefficient

The vent shaft has a grating at the outlet to the atmosphere. This grating has a specified total pressure drop of 0.2 inches of water at a flow rate of 1,000 feet per minute (fpm).

The entrance loss is calculated as follows:

From Table 4.3 it is seen that K = 0.34 for a square edged orifice entrance. This is a very good approximation of the minor head loss for flow entering the vent shaft as the inlet configuration for this vent shaft is very similar to a square edged duct outlet.

In addition, the head loss due to the grating at the top of the vent shaft must be taken into account. The relationship between total pressure drop in inches of water and the head loss coefficient for a given flow velocity is as follows: (At standard pressure)

$$\Delta P = \frac{KV^2}{(4005)^2}$$

where K = minor head loss coefficient, dimensionless

V = velocity of the fluid, fpm

ΔP = change in total pressure, inches water gauge

If we assume the velocity of the air leaving the shaft is 1,000 fpm, the loss coefficient for the grating is as follows (1,000 feet per minute is generally considered to be the maximum permissible outflow velocity for a vent shaft at the grating, and is therefore a good design point):

$$\Delta P = 0.2 = \frac{K(1000)^2}{(4005)^2} = K(0.06234)$$

$$K = 3.21$$

The total entrance loss coefficient is then 0.34 + 3.21 = 3.55.

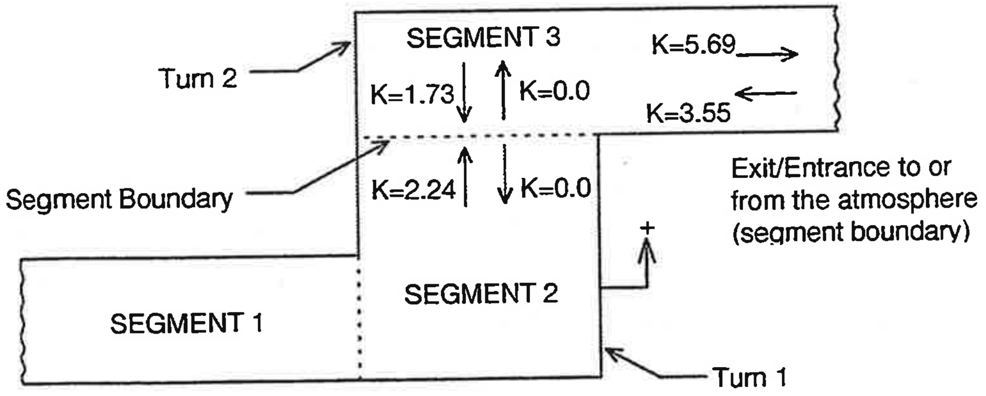
The exit loss is calculated as follows:

As explained in the previous example, the loss coefficient for Turn 2 was 1.48 for flow in both the positive and negative directions. The loss of 1.48 velocity heads attributable to positive flow through Turn 2 must be added to the forward end positive flow loss coefficient for SEGMENT 3. The 1.48 velocity head loss coefficient attributable to negative flow through Turn 2 must be added to the backward end negative flow loss coefficient for SEGMENT 3 (this has been previously explained and shown in the earlier example utilizing this same ventilation shaft).

The loss through the grating at the top of the vent shaft has already been determined to be 3.21 velocity heads. In addition, it can be seen from Table 4.3 that the loss coefficient for an abrupt exit is equal to 1.00. This loss of 1.00 velocity head must also be taken into account.

Therefore, the total exit loss coefficient is then 1.00 + 1.48 + 3.21 = 5.69.

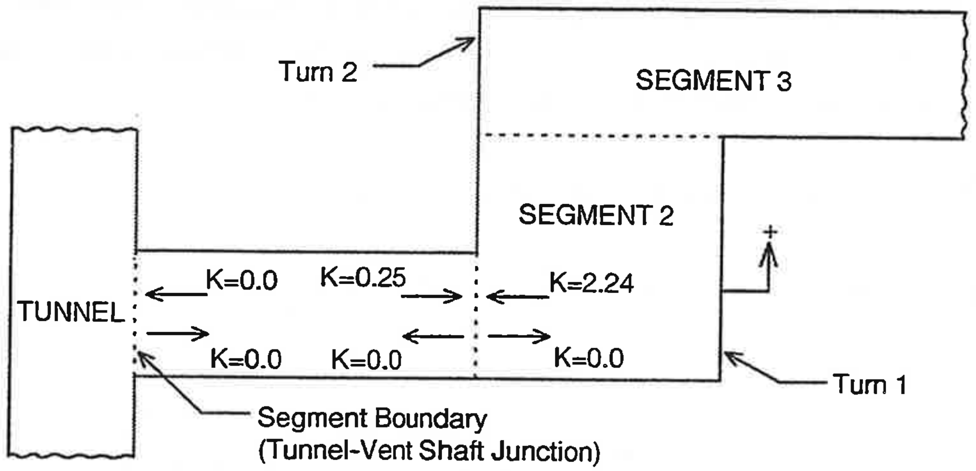
The results of the above calculations are depicted in the drawing below:



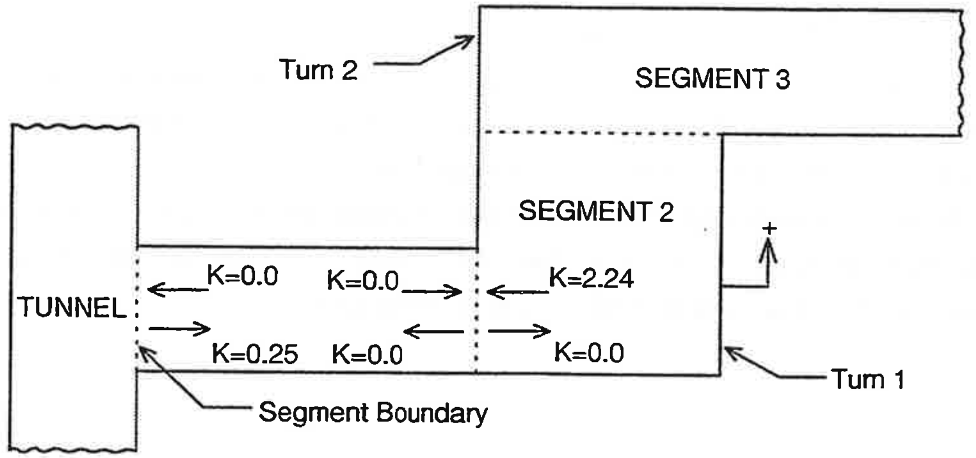
Head Loss At The Tunnel-Vent Shaft Junction

The losses at a junction between a vent shaft and a tunnel are internally calculated by the SES. The user simply has to provide the program with the appropriate geometry configuration of the junction between the tunnel and the vent shaft in Forms 6A through 6H.

The head losses for SEGMENT 1 in the previous example would be 0.25 for the forward end positive flow, 0.0 for the forward end negative flow, and 0.0 for the backward end positive and backward end negative flow. The losses in SEGMENT 1 are depicted as follows:



The head loss coefficients within a given segment may be assigned to either end of the segment due to the fact that the program sums the loss coefficients for a given direction within each segment. Therefore, it does not matter if a loss coefficient is assigned to the forward end positive flow or the backward end positive flow of a segment. To illustrate this concept, the losses in SEGMENT 1 (above) can be described at the user's option as follows:



The user should establish a convention when calculating head loss coefficients within the system. The establishment of a convention will greatly reduce the chance of error when calculating head losses.

The minor head loss coefficients (in accordance with the convention established in the above examples) for the entire vent shaft shown in Figure 4.7 are given in Figure 4.8. These loss coefficients are the coefficients that would be entered in the SES for this ventilation shaft.

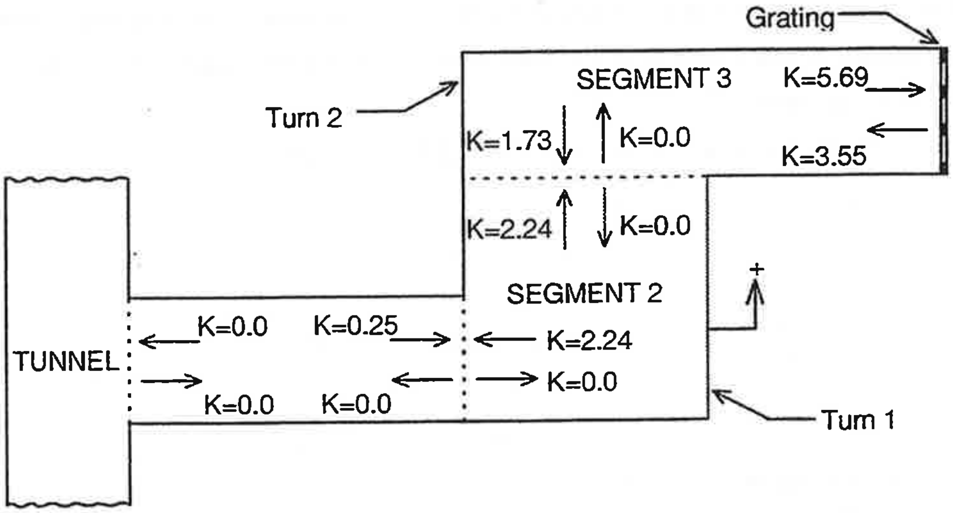
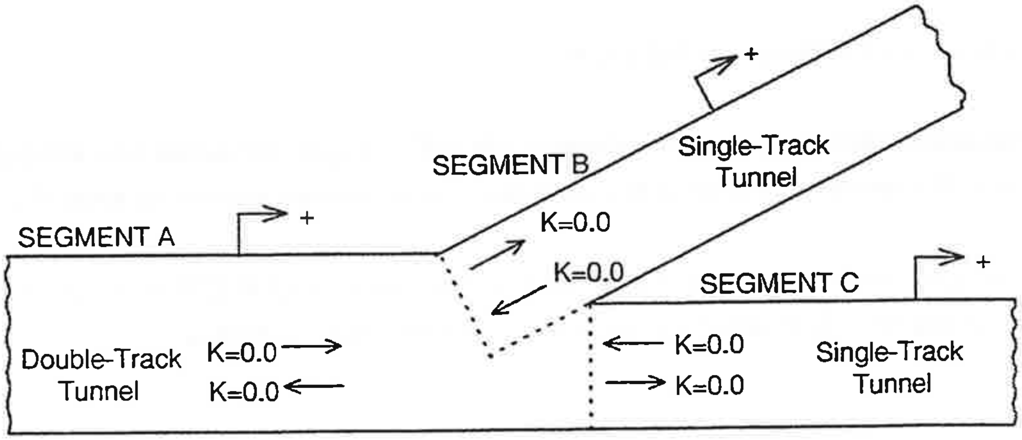


Figure 4.8 Sample Vent Shaft - Head Loss Coefficients for Entire Vent Shaft

Head Losses at Junctions. A junction is defined as the intersection of two or more sections, or the point where a section exits to the atmosphere (such as at portals and the tops of vent shafts). A node is located at each junction in a system. The losses at a junction are internally calculated by the program. The user simply has to provide the program with the appropriate geometrical configuration of the junction. Head losses due to obstructions may be entered at a junction, but the user must not take into account any head losses due to turns or changes in area at a junction. To further explain the losses at junctions, the following example is provided:

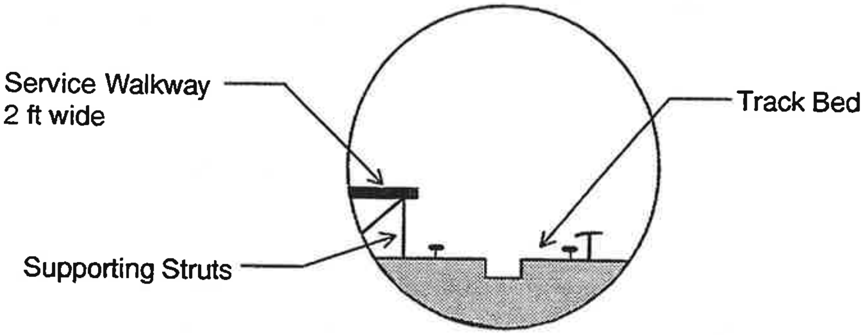
Example 4.5 Suppose a double-track tunnel branches into two single-track tunnels as shown in the drawing below:



If there are no obstructions in any of the three tunnel segments, the loss coefficients at the segment boundaries surrounding the junction will all be equal to 0.0 for both positive and negative flow as shown in the drawing above.

Suppose there is a service walkway in SEGMENT C as shown in the cross-sectional drawing of SEGMENT C below:

Cross-section of SEGMENT C



The walkway is basically 1/4 inch thick metal plate supported by struts as shown. The area is free between the walkway and the struts. The hydraulic diameter of SEGMENT C is 20 feet.

Assuming the walkway is a bar across the tunnel, Table 4.3 can be used to determine the loss coefficient due to the walkway. This loss is calculated as follows:

E = 2 ft

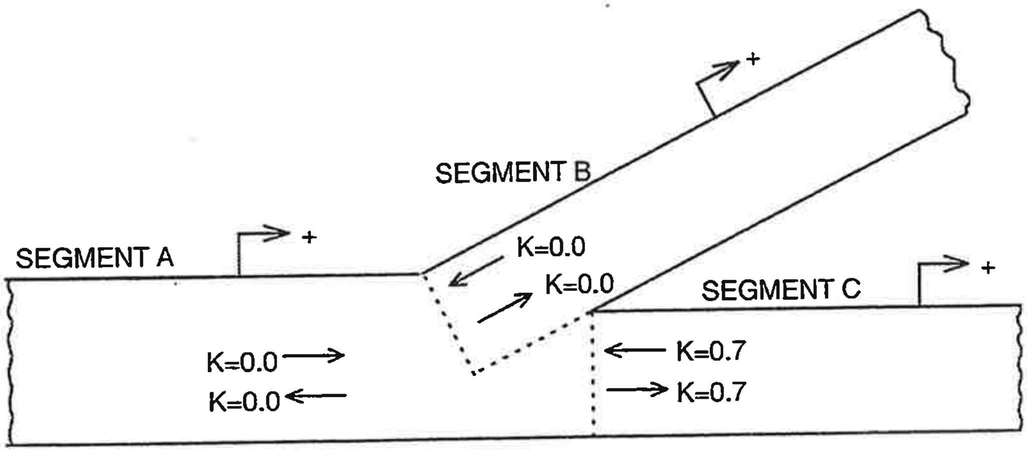
D = 20 ft

E/D = 0.10

Therefore, C = K = 0.7 (directly from Table 4.3)

This loss coefficient must now be placed in SEGMENT C <u>once</u> for positive flow and <u>once</u> for negative flow. The losses for positive and negative flow may be entered at either the forward or backward end.

If the user chooses to enter these losses at the backward end of SEGMENT C, the head losses at the junction of segments A, B, and C will be as depicted in the following drawing:



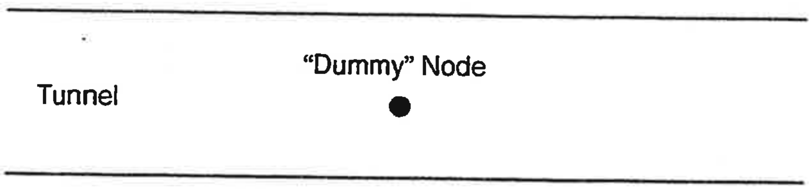
Losses at junctions are only permitted to be entered for factors other than changes in area or turns between the segments at the junction. The user could just as easily enter the losses in both the positive and negative directions due to the walkway in the above example at the forward end of SEGMENT C, or the positive loss at the forward end, positive flow position and the negative loss at the backward end, negative flow position. Similarly, the user could have entered the positive loss at the backward end, positive flow position, and the negative loss at the forward end, negative flow position of SEGMENT C. The orientation of the losses and the convention established when entering losses is entirely up to the user.

4.3 Aerodynamic Nodes and Junctions (Input Forms 6A Through 6H)

As previously stated, a junction is defined as the intersection of two or more sections, or the point where a section exits to the atmosphere (such as at portals and the tops of vent shafts). A node is located at each junction in a system. As explained in the Geometry Section, nodes may be placed in a continuous tunnel section to enable future modifications to the system to be done without large changes in the input data. These nodes are referred to as "dummy" nodes as they serve no purpose but to allow for future modifications to the program. When a "dummy" node is placed in a continuous tunnel section, the continuous tunnel section is divided into two continuous tunnel sections. In addition, a junction is created at the "dummy" node as the two newly created sections intersect at the "dummy" node. Obviously, when a node is added to a system, a junction is created, and vice versa. There are eight different types of junctions. The junction type depends on the geometry of the system in the vicinity of the node. All possible junction configurations can be described by at least one of these eight junction types. The user must determine which type of junction best applies for each node location in the system. The user enters the junction data in Forms 6A through 6H. A drawing of the various types of system geometry that determines the type of junction is given in Figure 4.9. A description of each junction type is given as follows:

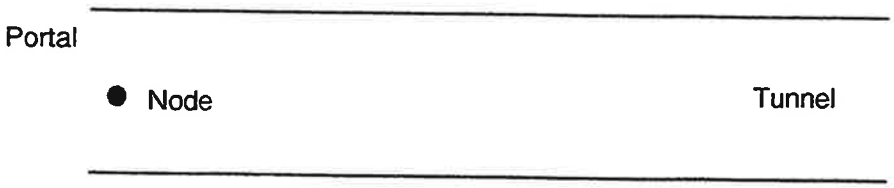
Examples of Three Aerodynamic Type 0 Nodes

I.



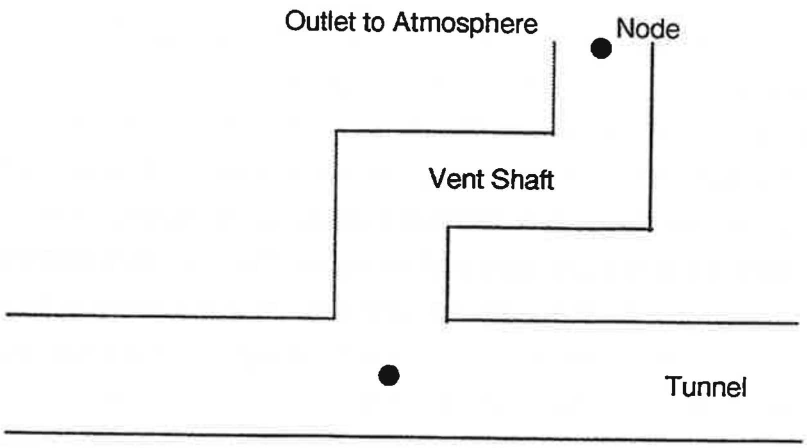
Straight-Through Junction

II.



Portal (Tunnel Outlet to Atmosphere)

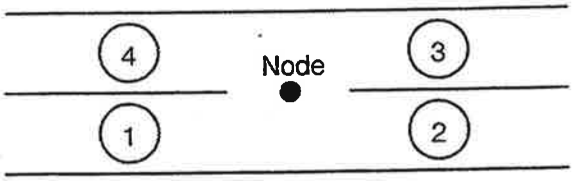
III.



Portal (Vent Shaft Outlet to Atmosphere)

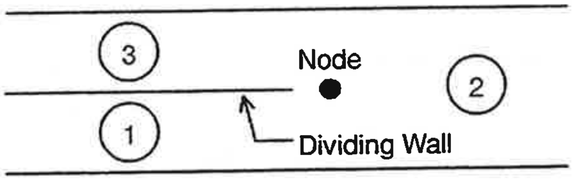
Figure 4.9 Junction Configurations

Aerodynamic Node Type 1



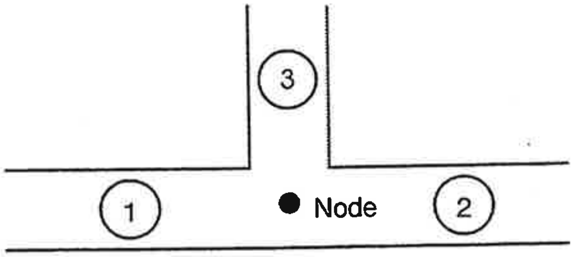
Tunnel to Tunnel Crossover Junction

Aerodynamic Node Type 2



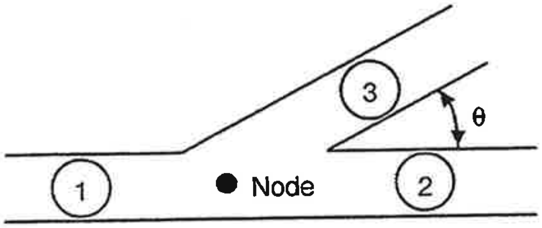
Dividing Wall Termination Junction

Aerodynamic Node Type 3



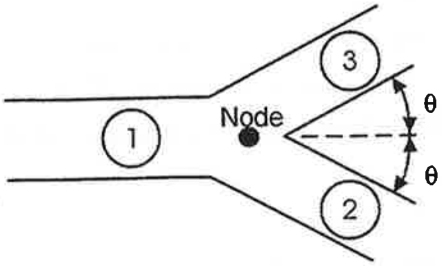
"T" Junction

Aerodynamic Node Type 4



Angled Junction

Aerodynamic Node Type 5



"Y" Junction

NOTE: Refer to page 4-33 for a description of Node Type 7.

Figure 4.9 (Continued)

Aerodynamic Type 0 Node: Straight-Through Junction or Portal

The straight-through junction is at the point where a "dummy" node has been placed in a uniform length of tunnel. The dummy node divides the uniform length of tunnel into two different sections with the same physical characteristics. The dummy node creates a "two-branch" junction which is formally referred to as a "straight-through" junction.

There is a node at every opening to the atmosphere in a system. These openings include portals and vent shaft outlets where flow exits to the atmosphere. The portal junction is a "single-branch" junction and includes both portals and vent shaft outlets to the atmosphere. Portal junctions are also aerodynamic type 0 nodes (see Figure 4.9).

The user does not have to provide the geometry of the junction for aerodynamic Type 0 nodes. The user only has to enter a zero for the aerodynamic node type in Form 6A.

Aerodynamic Type 1 Node: Tunnel to Tunnel Crossover Junction

The tunnel-to-tunnel crossover junction occurs where a large opening in a dividing wall between two adjacent tunnels exists (see Figure 4.9). The data on the geometry of a tunnel-to-tunnel crossover junction is entered in Form 6C.

The tunnel-to-tunnel junction is a "multiple-branched" junction comprising four separate branches. The user must enter in Form 6C the section identification numbers of the sections that constitute the four branches of the tunnel-to-tunnel crossover junction. In addition, the user must enter the aspect ratio for the junction. The aspect ratio for a tunnel-to-tunnel crossover junction is defined as the ratio of the length of the crossover opening to twice the height of the tunnel (L/2H).

Aerodynamic Type 2 Node: Dividing Wall Termination Junction

The dividing wall termination junction is where a dividing wall between two adjacent tunnels ends and the two tunnels merge into one (see Figure 4.9). The data on the geometry of a dividing wall termination junction is entered in Form 6D.

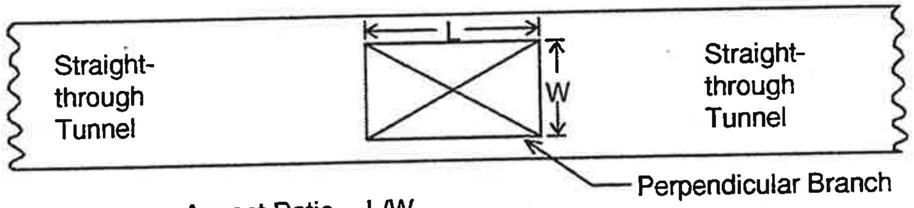
The dividing wall termination junction is a multiple-branched junction comprising three separate branches. The user must enter in Form 6D the section identification numbers of the sections that constitute the three branches of the dividing wall termination junction.

Aerodynamic Type 3 Node: "T" Junction

The "T" junction occurs where either a tunnel or a vent shaft branches off at a 90-degree angle from a separate continuous tunnel. The area of the continuous tunnel before the junction must be greater than or equal to the area of the continuous tunnel after the junction (see Figure 4.9). The data on the geometry of a "T" junction is entered in Form 6E.

The "T" junction is a multiple branched junction comprising three separate branches. The user must enter in Form 6E the section identification numbers of the sections that constitute the three branches of the junction. In addition, the user must enter the aspect ratio for the junction. The aspect ratio for a "T" junction is defined as the ratio of the axial length of the vent shaft or tunnel that runs perpendicular to the straight-through tunnel (Branch 3) to the width of this perpendicular branch at the junction (L/W). The aspect ratio for a "T" junction is depicted as follows:

TOP VIEW OF "T" JUNCTION

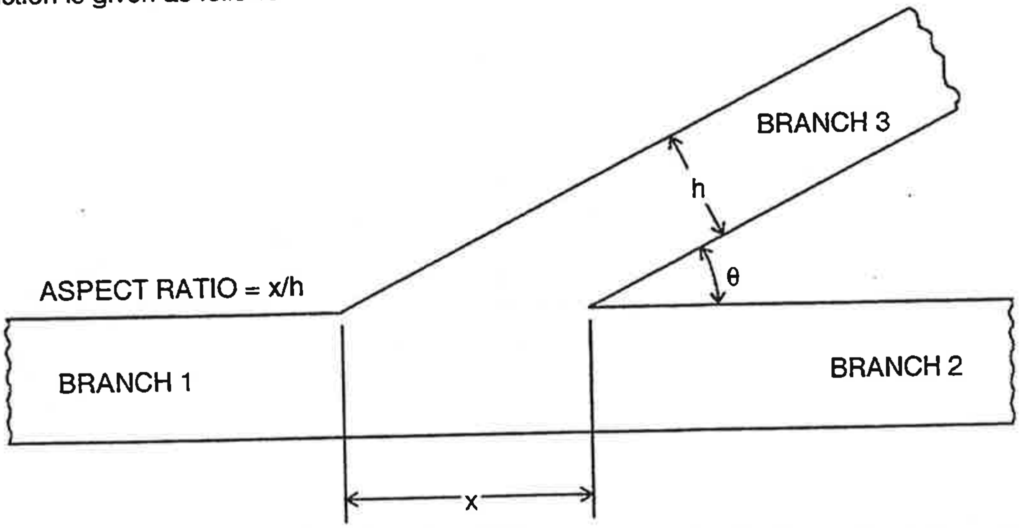


Aspect Ratio = L/W

Aerodynamic Type 4 Node: Angled Junction

The angled junction occurs where either a tunnel or a vent shaft branches off at an acute angle (θ) from a separate continuous tunnel (see Figure 4.9). The data on the geometry of an angled junction is entered in Form 6F.

The angled junction is a multiple branched junction comprising three separate branches. The user must enter in Form 6F the section identification numbers of the sections that constitute the three branches of the junction. In addition, the user must enter the aspect ratio and the acute junction angle between Branch 2 and Branch 3. The aspect ratio for an angled junction is defined as the ratio of the axial length of the angled tunnel (Branch 3) opening to its height. A graphical explanation of the aspect ratio for an angled junction is given as follows:

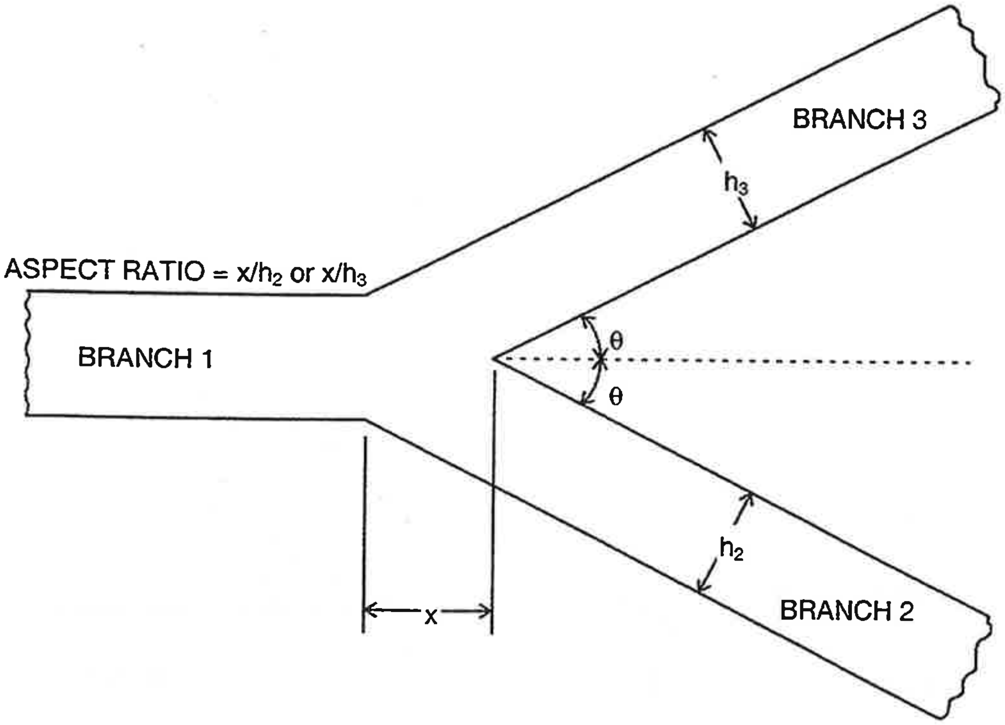


The junction angle (θ) may only be entered as either 10, 20, or 30 degrees. Therefore, if a vent shaft is at a 26-degree angle with the tunnel, the user must enter this angle as 30 degrees, as a 30-degree angled junction more closely approximates a 26-degree angled junction than does a 20-degree angled junction. If the angle θ is greater than 30 degrees, the user must determine whether the junction is closer to a 30-degree angled junction or a 90-degree "T" junction.

Aerodynamic Type 5 Node: "Y" Junction

The "Y" Junction occurs where a single tunnel branches into two tunnels which diverge from the single tunnel at equal acute angles with respect to the center line of the single tunnel (see Figure 4.9). The data on the geometry of a "Y" junction is entered in Form 6G.

The "Y" junction is a multiple branched junction comprising three separate branches. The user must enter in Form 6G the section identification numbers of the sections that constitute the three branches of the junction. The aspect ratio for the "Y" junction must also be entered. The aspect ratio for a "Y" junction is defined as the ratio of the axial length of one of the two angled branches (Branches 2 and 3) to the height of the chosen branch. The axial length of Branch 2 will always equal the axial length of Branch 3, but the height of Branch 2 may differ from the height of Branch 3. A graphical explanation of the aspect ratio for a "Y" junction is given as follows:



Note: The "Y with Vent" four-branched junction, which was included in some preliminary versions of the SES program and documentation, is not contained in the final version of the SES program.

In addition, the user must enter the acute junction angle (θ) with respect to the center line of the single tunnel at which each of the two diverging branches separate from the single tunnel. The junction angle (θ) is equal to one-half the total angle between Branch 2 and Branch 3. The user may only enter a junction angle of either 10, 20, or 30 degrees. Therefore, if the total angle between Branch 2 and Branch 3 is 52 degrees, the user should enter a junction angle of 30 degrees, as a 30-degree "Y" junction more closely approximates one-half the total angle between Branch 2 and Branch 3 (26 degrees) than does a 20-degree "Y" junction. If one-half of the junction angle is greater than 30 degrees, the user must determine whether the junction is closer to a 30-degree "Y" junction or a 90-degree "T" junction.

Aerodynamic Type 7 Node: Zero Total Pressure Change Junction

The zero total pressure change junction serves two purposes. First, there may be certain junctions within a system that do not have any total pressure changes across their boundaries. An example of such a junction is at a stairway between a platform area and a mezzanine area. Both the mezzanine and platform area can be considered plenums with very little total pressure changes between the two areas. Therefore the junction at a stairway between a mezzanine and a platform may be entered as an aerodynamic type 7 node. As always, the geometry of the system at the node dictates the type of node. The junction between a mezzanine and a platform area could also be a tunnel-to-tunnel crossover junction, depending on the geometry of the station.

The zero total pressure change junction also serves as a "catch-all" type junction. When a junction cannot be described as one of the six other types of junctions outlined in this section, it should be entered as an aerodynamic type 7 node. As an example, suppose a system has a "Y" junction with a ventilation shaft at the junction. The SES program does not have the specific capability to handle a "Y" type junction with a vent shaft. Therefore the user must enter the junction as a type 7 node. The user should always check to see whether or not a junction that does not conform to the geometrical constraints of at least one of the six other junction types can be closely approximated by any of these six junction types. It is always better to use a junction type that closely approximates a non-conforming junction than to use junction type 7 to describe it.

4.4 Fans

Subway environmental control systems make extensive use of fans for both normal and emergency ventilation. Fans are used to create a pressure difference in an air distribution system so as to cause air to flow. This pressure difference is usually less than about 30 inches water gage (in. w.g.) or 1 pound per square inch. Devices that generate higher pressures are known as blowers or compressors. Fans are classified either as centrifugal or axial fans, depending on the direction of airflow through the impeller or wheel. In centrifugal fans, the air generally enters the impeller near and parallel to the axis of rotation, flows radially through the impeller, and discharges at the outside edge. In axial fans, the air generally flows through the impeller parallel to its axis of rotation. Centrifugal fans are classified by the shape of the impeller: airfoil, backward inclined (or curved), forward inclined, or radial. Axial fans are classified according to the configuration of the fan housing relative to the wheel as propeller or tubeaxial, or vaneaxial.

The SES has the ability to simulate two types of fan arrangements: conventional supply/exhaust fan systems and impulse fan systems. In a conventional supply/exhaust system, the supply air is exhausted or discharged at a relatively low velocity (usually less than 2000 fpm). The function of the fan system is to move air either into the subway system (outside air supply), out of the subway system (exhaust) or to circulate air within the subway system (e.g. air conditioning supply and return systems and air circulation fans moving air from one tunnel to another). In a conventional system the full air stream to be moved passes through the fan. Figure 4.10 shows a simplified conventional supply/exhaust fan arrangement. The entire air stream, Q_D, passes through the fan. The tunnel airflows are related to the fan airflow by the following equation:

$$Q_D = Q_1 + Q_2$$

where: Q_1 is the tunnel airflow on one side of the ventilation shaft

Q_2 is the tunnel airflow on the other side of the ventilation shaft

Q_D is the airflow processed through the ventilation shaft and fan

An impulse fan system (also known as induction fan system) operates on the principle that a high-velocity air jet injected along a plane nearly parallel to the longitudinal axis of a tunnel can induce a high volume, lower velocity airflow in that tunnel. They operate by drawing air into a fan (this air may be either tunnel air or outside air, depending on the design), accelerating it to a high velocity, and then injecting it into the tunnel.

The momentum exchange between the high-velocity air jet and slower-moving tunnel air results in a static pressure rise in the desired flow direction to create a net flow of air in the tunnel. The magnitude of this tunnel airflow is governed principally by the tunnel flow resistance and the quantity and velocity of the high velocity jet of air from the impulse fan.

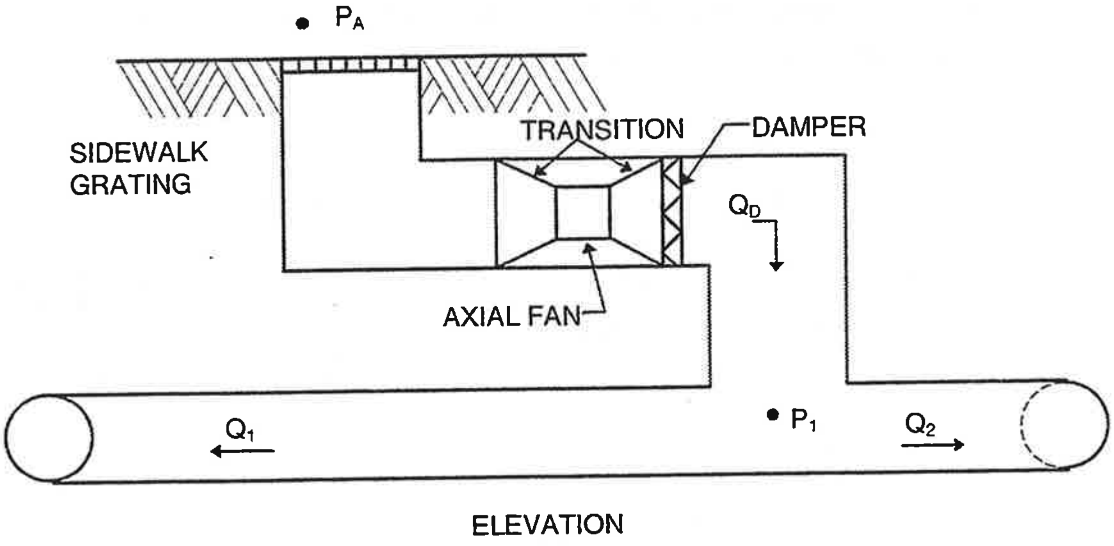


Figure 4.10 Conventional Supply/Exhaust Fan

Impulse fans have an advantage over conventional methods of ventilation by their ability to produce longitudinal airflows without the necessity of building ventilation shafts to the surface. In addition, better control of tunnel airflows can sometimes be achieved with impulse fans than with conventional supply/exhaust fans, particularly in locations where track crossovers and parallel tunnels reduce the amount of ventilation air flowing in the desired tunnel. A conventional low-velocity supply fan can only pressurize the tunnels, and the resulting quantity of airflow is inversely proportional to the square root of the flow resistance of the many flow paths available to the air. Frequently, the desired flow path has the added resistance of a stalled train and much air is lost by "short circuiting" through parallel flow paths of lower resistance. This problem is reduced by using impulse fans.

The disadvantages of impulse fans are that they usually require more power for the quantity of air moved, are noisy, are not effective when the system's resistance is greater than 1 in. wg, and often cause structural problems where the tunnel is made bigger for them.

Figure 4.11 shows a simplified arrangement of an impulse fan system. In this arrangement the tunnel is enlarged to house the impulse fan system, and a shaft to the surface is not provided. The air processed through the fan is shown as Q_D. The tunnel airflow upstream and downstream from the impulse fan are shown as Q_1 and Q_2, respectively, and for this arrangement $Q_1 = Q_2$. The net pressure rise in the tunnel resulting from the impulse fan operation is measured as $(P_2 - P_1)$. The magnitude of this pressure rise is a function of the design of the impulse fan system, including the velocity and CFM of the air jet, the angle of the jet with respect to the longitudinal axis of the tunnel, the aerodynamic design of the nozzle, the tunnel area, and the tunnel air velocity. Unlike a conventional fan, the tunnel pressure rise, $P_2 - P_1$, is not directly related to the performance characteristics of the fan which powers the impulse fan system assembly.

In the SES, conventional supply/exhaust fans may be located only in Type 1 ventilation shafts; impulse fan systems may be located only in line segments Types 9 through 14.

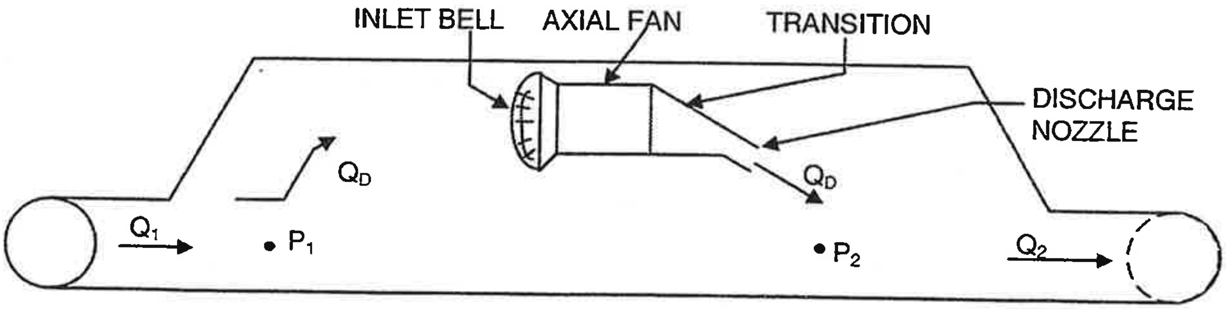


Figure 4.11 Impulse Fan System

4.4.1 Conventional Supply/Exhaust Fans

The ability of a fan to move air is its performance. Fan performance may be stated in terms of fan total pressure, fan static pressure, volume flow rate, efficiencies and rotational speed at a given inlet density. The most common statement of fan performance is its characteristic or performance curves which are plots of pressures, efficiencies, and horsepower as a function of volume flow rates at a given inlet density.

The range of volume flow rates where the pressures are always decreasing is often referred to as the fan operating (or design) range - e.g. for the fan shown in Figure 4.12 between about 11,000 and 18,000 cfm. Fan manufacturers customarily supply performance data over the fan operating range for a given inlet air density (usually 0.075 lbs/ft^3). The SES program requires fan total pressure (gain in total pressure from fan inlet to outlet) versus volume rate information for cfm's ranging between zero (known as shutoff) and the value where fan total pressure of near zero is achieved (known as free delivery). Referring to Figure 4.12 as an example, these points would be zero cfm (6 in. wg fan total pressure) and about 19,000 cfm (0.75 in. wg fan total pressure).

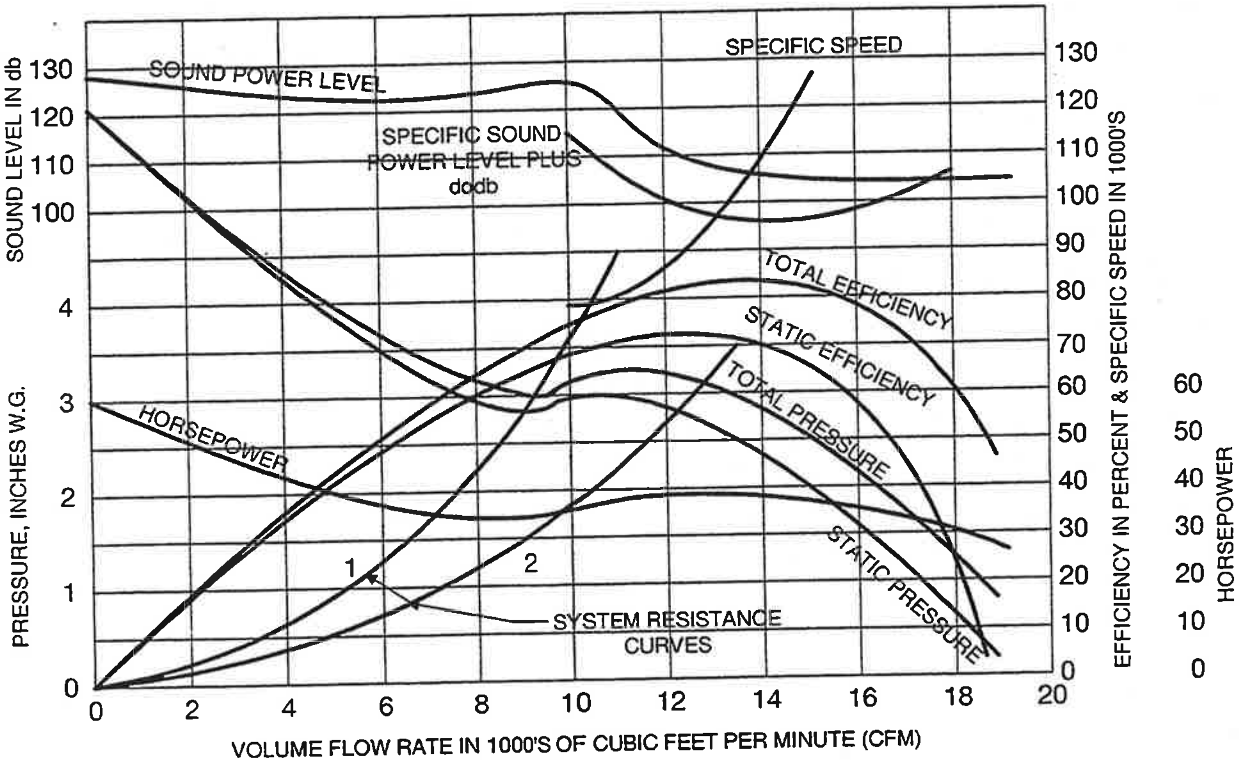


Figure 4.12 Typical Constant Speed Performance Curves for a Vaneaxial Fan (Centrifugal Fans Similar Except for Horsepower)

Fans may be operated as a unit in either parallel or series, depending on whether the objective is to provide a greater volume flow rate for a given fan total pressure or to provide a greater fan total pressure for a given volume flow rate. A fan total pressure performance curve for two identical fans in parallel may be constructed by doubling the volume flow rate for a given fan total pressure. For example, from Figure 4.12, the cfm at which the parallel fan total pressure of 2.5 in. w.g. would be achieved would be 15,000 + 15,000 = 30,000 cfm. Operating two non-identical fans in parallel would involve the addition of two different cfms at the same fan total pressure. This procedure may be extended to N fans operating in parallel by adding together the N cfms at a given fan total pressure. The operation of non-identical fans in parallel is not common. A fan total pressure performance curve for two fans in series may be constructed by adding the fan total pressures for a given volume flow rate. For example, from Figure 4.12, the fan total pressure generated by two of these fans operating in series at 15,000 cfm would be 5.0 in. w.g. This procedure may be extended to N fans operating in series by adding together the N fan total pressures at a given cfm. The operation of fans in series is not common in subways.

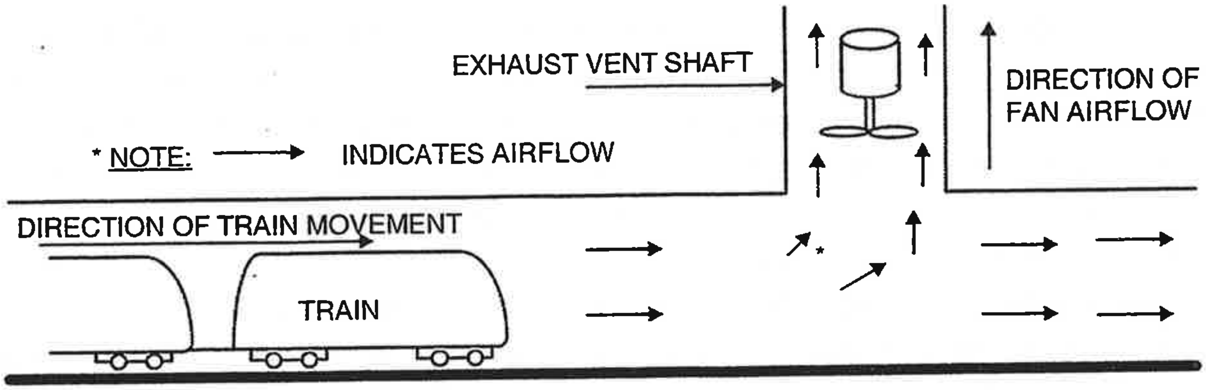
Reversible fans have been used in subways in order to optimize their application. The ability to have a fan operate in either the exhaust or supply direction is used to provide the desired tunnel airflow direction for emergency ventilation regardless of train location with respect to the ventilation shaft. The volume flow rate for a fan running in a reversed direction is usually 60-100% of that of the normal operating direction. For the case where it is 100%, the fan is known as a bi-directional or fully reversible fan.

Airflows in building air distribution systems usually do not vary with time (i.e., they are steady-state). Under this circumstance, it is useful to consider the concept of the system resistance curve as typified in Figure 4.12. This curve is usually of the type $P=KQ^2$ where P is the pressure drop or resistance, Q is the airflow through the fan (and thus through the entire air distribution system) and K is a constant determined by the air distribution system geometry and the adjustment of airflow control devices such as dampers. The intersection of the system resistance curve with the fan total pressure curve gives the operating point of the system (i.e. the resulting airflows and pressure losses).

Subway airflows vary with time (i.e. they are transient or unsteady) with the exceptions being emergency ventilation and sometimes nighttime ventilation. This airflow variance with time is different from the usual fan application mentioned above and is caused by a constantly changing system resistance curve due to train motion and the inertia of the system air. Since this implies the airflow through the fans is of a transient nature, consideration must be given to transient fan performance. A special terminology is used to describe the phenomenological aspects of transient fan performance. Terms included in this terminology are: fan run-up time, windmilling, stall, hunting or instability, and stopping.

Fan run-up time is the time required for the fan to reach full operating speed (rpm) from start-up. The fan run-up time is generally between 0 and 30 seconds with an average of about 10 seconds. A value of eight seconds has been specified. Fan run-up time is primarily determined by the inertia of the fan impeller and motor assembly, and the motor torque available for a given rpm. Fan run-up time has very little effect on the subway environment. Lower fan run-up times generate higher acceleration stresses in the fan impeller and motor assembly and require higher starting motor currents.

Windmilling is the rotation of the fan impeller by the airflow passing through the fan. There are two types of windmilling. The first (and often unimportant) type occurs when air passes through a shutdown fan that is free to turn. The fan acts as a windmill, providing a small resistance to the airflow. Since it is common practice to isolate a shutdown fan from high volume flow rates by dampers, the usual source of air in this case is leakage through the dampers. The second and more important type of fan windmilling is encountered during fan operation. It is the circumstance of the fan being forced by external pressures to operate at high volume flow rates such that the pressure rise through the fan is negative. For example, consider the following:



While the train is approaching the ventilation shaft, it "helps" the air to flow out to the ventilation shaft. This "help" (which is the pressure generated by the moving train) can overtake the fan impeller to the point where the fan acts as a brake on the ventilation shaft airflow. Windmilling at volume flow rates exceeding the free delivery rate by amounts up to 20% does not normally cause any fan mechanical problems, however, the accompanying noise levels are often beyond the allowable noise criteria. In Figure 4.12 windmilling occurs at about 21,000 cfm. This windmilling level is often referred to as the fan upper operating limit.

Stall When the air cannot follow the surfaces of a fan blade, separation of flow occurs. The aeronautical term "stall" is sometimes used to describe such a phenomenon in fans. Stall may originate at only one portion of a blade when the angle of the blade to the flow exceeds a certain value. Rotating stall passes from one blade to the next and produces the same net effect in fan performance as if it occurred continuously on only one blade. Rotating stall is often caused by an asymmetrical air velocity profile at the fan inlet. In this case, rotating stall can lead to fan destruction by rapid loading and unloading of a fan blade at frequencies at or near the natural frequency of the blade. Pronounced separation is accompanied by appreciable circulatory flow or swirl in the fan itself. Stall appears on the fan performance curves as the region where the fan total pressure increases with increasing volume flow rates. In Figure 4.12 this is from about 9,000 to 11,000 cfm. Fans that do not stall have been constructed, i.e. their pressures rise continuously from free delivery to shutoff.

Hunting or instability is a phenomenon associated with stall. When the system resistance curve is approximately parallel to the fan total pressure performance curve, small changes in it can cause large fluctuations in the volume flow rate. (As approximately shown by system resistance curve 1 in Figure 4.12, at the point where it intersects the total pressure performance curve.) An example of a small change of this nature is acoustic pulses or waves traveling or echoing through the air distribution system. These volume flow rate fluctuations are described by the terms hunting and instability since the fan is constantly trying to adjust to a new system curve and the volume flow rate is not constant (i.e. stable) with respect to time.

Stopping is a phenomenon associated with very low or even negative volume flow rates through an operating fan. Stopping is the reduction in fan rotational speed (rpm) from the normal rate to a full stop, to the point where drives such as belts or clutches slip, or to the point where the fan motor protective devices (such as circuit breakers) shut down the fan. The latter circumstance is the most probable. The sequence of stopping for fans having circuit breakers is as follows. An increasing system resistance curve (i.e. K increases with time) causes a reduction in fan cfm below the stalling range. The torque required to maintain rpm increases to a level where the motor can no longer provide it. The fan motor rpm decreases to the level where adequate torque is available; however, motor current increases. The increased motor current eventually heats the circuit breakers to the point where they trip out and shut down the fan. Fans can operate in and out of a stopping condition if the circuit breakers do not heat up enough to trip out. Fan stopping can impose structural loads on a fan greater than those encountered during acceleration. The quantitative aspects of stopping are not well known from either a theoretical or experimental viewpoint. An alternative to working with available information from fan manufacturers is to obtain from them (if possible) a "complete characteristics diagram" (Ref. 1) for the fan. The complete characteristics diagram provides for a given fan the relationship among fan total pressure, motor torque, and volume flow rates over the range of both positive and negative volume flow rates. From the complete characteristics diagram and the motor curves of torque, rpm, and current, it is possible to quantify stopping for the fan. A complete characteristics diagram must be generated experimentally.

Further information on fans may be obtained from References 2, 3 and 4, in addition to Volume I of the Subway Environmental Design Handbook.

Fan Input

Fan Performance Curve. The SES program requires the user to enter in Form 7B the fan total pressure versus volume flow rate for each different fan type used in a simulation. The SES only operates with fan total pressures — the user must make certain the fan total pressure versus volume flow rate is entered for each fan type. The fan total pressure is entered in inches of water and the volume flow rate is entered in cubic feet per minute. This fan performance curve is described by the cubic polynomial curve fitting of four data points. The data is usually taken from manufacturer-supplied fan curves. The data points entered should cover the range of fan volume flow rates from zero cfm to the point where the fan total pressure is zero inches of water. In addition, the points entered should be about the same distance apart on the CFM scale. The SES program assumes all fans are bi-directional, operating on identical fan curves for both directions. In other words, the SES program assumes all fans are 100 percent reversible unless informed otherwise. If a fan operates in the outflow (exhaust) direction only, either blanks or all zeros should be entered for the curve data points specified for the inflow (supply) direction. Similarly, if a fan operates in the inflow (supply) direction only, either blanks or all zeros should be entered for the curve data points specified for the outflow (exhaust) direction.

Fan Upper and Lower Limits. As previously explained, variations in the air pressure within a system can cause a fan to either stop or windmill, depending on the direction of the fan and the operation of trains within the system. A fan may stop or windmill during a simulation and then return to its normal operating range. The summary output provides the average flow rate through the fan, as well as the maximum and minimum flows through the fan during the time period over which the summary was taken. It may not be readily apparent from these maximum and minimum flow rates whether or not the fan stopped or began windmilling and then recovered. Therefore, the user may be totally unaware of a temporary stopping or windmilling condition. The SES has a warning system in the form of an error message to notify the user when a stopping or windmilling condition occurs, as a stopping or windmilling fan may greatly affect the results of a simulation. When a stopping or windmilling situation occurs the user has two options: 1) the simulation will be stopped immediately, or 2) the fan that is in a stopping or windmilling condition will be turned off, but the simulation will continue. The user enters this option in Form 1E in the Fan Stopping/Windmilling Option.

The point along the fan operating curve where the fan begins to stall and the point along the fan operating curve where the fan begins to windmill are supplied by the user for each different fan type in Form 7A in the Fan Lower and Upper Operating Flow Limits, respectively. The error message occurs if the fan either exceeds the user specified upper flow limit or attempts to fall below the user-specified lower flow limit.

As mentioned previously, the point at which the fan stops is the point of motor breakdown torque or stopping. The point of stopping must be less than zero cfm and greater than, or equal to, -100,000 cfm. The point of windmilling for a fan varies depending on the design and use of the fan. If a fan is designed to operate at an approximately constant volume flow rate, the user should set the point of windmilling equal to a value just slightly above the design flow rate of the fan. If a fan is designed to operate over a given range, the user should set the point of windmilling equal to a value approximately 20% above the upper design flow rate of the fan. As explained above, when trains pass beneath a vent shaft they are going to affect the pressure within the shaft. These fluctuations in pressure in a vent shaft generally result in fluctuations in the volume flow rate from the fan. The user accounts for these fluctuations when setting the upper operating flow limit for a fan. If large fluctuations in the pressure within the vent shaft are expected, the upper operating flow limit should be set to a number large enough to allow for all of these fluctuations.

User Suggestions. The user should enter approximately -5,000 cfm for the fan lower operating flow limit for any non-emergency fan which is started up at the beginning of a simulation. If the fan is an emergency fan, or a fan that is started-up after the beginning of a simulation, the lower operating flow limit should be set equal to -50,000 cfm.

The point of windmilling for a fan will generally be between 20 and 100 percent of the fan upper design flow limit. For example, if a mid-tunnel exhaust fan is designed to operate between 120,000 and 160,000 cfm and the designer is not extremely concerned if the volume flow rate from the fan slightly exceeds its upper design flow limit (160,000 cfm), the upper operating flow limit (point of windmilling) for the fan should be set equal to approximately 200,000 cfm. The user may allow a fan to windmill within the program to a volume flow rate of 2,000,000 cfm, but the results of allowing for too much windmilling can be disastrous. The fan may theoretically be able to handle 200,000 cfm more than its design delivery rate, however, in real life the actual fan would most likely have destroyed itself in the process. Therefore, the results of the SES may be inaccurate due to a fan that is allowed to deliver a higher volume flow rate than it is physically capable of delivering. The user must be fairly conservative when entering the upper operating flow limit for a fan to make certain the fan does not exceed its actual real life physical capabilities.

Input Verification for Fan Curve. The input verification calculates the complete fan curve between the lower operating flow limit and the upper operating flow limit for each fan entered in the program. The fan performance curve is obtained from the cubic polynomial curve-fitting of the four fan curve data points entered by the user for each different fan in the system. The SES prints the complete fan performance curve data by supplying evenly-spaced points along the curve calculated by the SES during the input verification. The printing interval between the points is 5,000 cfm if the range in volume flow rate for the fan is less than or equal to 250,000 cfm. The range of a fan is the difference between the upper and lower operating flow limits for the fan. The printing interval between the points is 10,000 cfm if the range of the fan is greater than 250,000 cfm and less than or equal to 1,000,000 cfm. The printing interval is 50,000 cfm if the range of the fan is greater than 1,000,000 cfm. The first of the fan performance curve points printed is the point that coincides with the printing interval that is equal to or below the fan lower operating flow limit. For example, if the fan lower operating flow limit is -8,000 cfm and the printing interval is 5,000 cfm, the first point on the fan performance curve to be printed will be at -10,000 cfm. If the fan lower operating flow limit is -5,000 cfm and the printing interval is 5,000 cfm, the first point on the fan performance curve to be printed will be at -5,000 cfm.

The fan characteristic curve is computed and printed for seven points at a time. These seven points occupy one line of printing in the input verification. The printing of the curve stops when the last static pressure rise computed is negative and the corresponding volume flow rate is greater than, or equal to, the fan upper operating flow limit. Printing of the fan performance curve is also halted if more than 500 points have been printed, as any fan that requires more than 500 printing intervals is considered a "run-away" fan. A run-away fan is any fan whose curve has been defined by the input data in such a manner that its maximum fan total pressure rise for positive volume flow rates is unbounded. This may be explained graphically as follows:

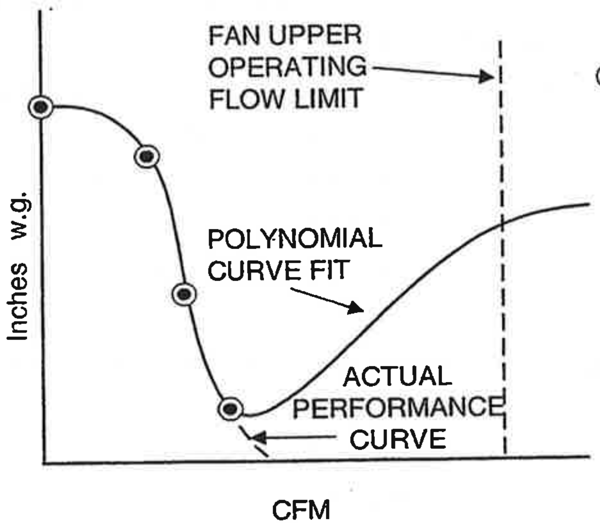


Figure 4.13 Run-Away Fan Curve

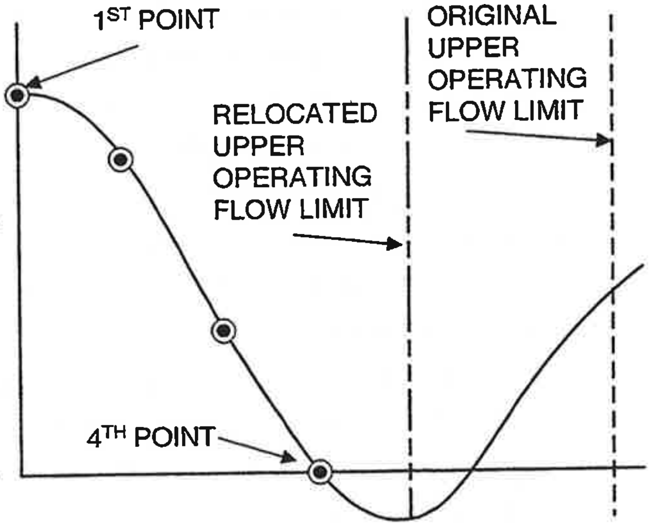


Figure 4.14 Correction Procedure for Run-Away Fan Curves

The run-away fan curve is shown in Figure 4.13. This situation may be avoided by entering evenly spaced data points such that the first data point is at zero cfm and the last (fourth) data point is approximately at a point of zero fan total pressure. The corrections that must be made to prevent the occurrence of the run-away fan are shown in Figure 4.14. The fan upper operating flow limit must be relocated to coincide with a point along the fan curve where the fan total pressure across the fan is negative and the volume flow rate is greater than the volume flow rate associated with the fourth and last data point.

Fan Run-Up. The SES program can simulate (at the user's option) the run-up of a fan that occurs when a fan is started-up (turned on). The program simulates this run-up by attenuating the fan total pressure across the fan over the user specified run-up period. This attenuating function is the greatest at the instant the fan is turned on. The attenuation of the fan total pressure across the fan decreases at a rate that depends on the time required for the fan to reach the full operating speed entered by the user. The attenuating function ceases to have any effect upon the fan total pressure rise across the fan when the simulation time is greater than or equal to the user entered fan run-up time. A plot of this run-up attenuating function is given in Figure 4.15. An illustrative example on how this fan run-up attenuating function works is shown.

It can be seen from Figure 4.15 that when a fan has started-up and has been operating for 30 percent of its run-up time, fan total pressure across the fan will be 0.563 times the pressure that would normally be associated with the volume flow rate generated by the fan at that particular point in time. Therefore, if a fan has the fan characteristic curve shown in Figure 4.16 and has a run-up time of 10 seconds, the fan might be delivering (depending on the system) 100,000 cfm at 1.126 inches of water three seconds after the fan is started-up. If the same fan has been running for 10 or more seconds and is delivering 120,000 cfm, the fan total pressure across the fan will be 1.000 inches of water.

The fan run-up time is generally between 0 and 30 seconds. If the user enters 0 for the fan run-up time, there will be no attenuation of the total pressure rise across the fan at any time during the simulation.

Fan Run-Down. A similar, but opposite function is used to gradually reduce the fan pressure when a fan is shut-off. This function starts at zero attenuation at the time of shut-off and gradually increases to 1.0 attenuation when the time after shut-off is equal to the run-up period. The function used is equal to (1-Y) where Y is shown on Figure 4.15.

Air Density at which Fan Curve was Measured. The user must enter in Form 7A the Air Density at Which the Fan Performance Curve was Measured. The manufacturer of a fan most often supplies the air density conditions that existed at the time the performance curve was obtained for the fan. If the air density in the first subsegment of the ventilation shaft differs from a standard density at which the fan performance curve was depicted, the program will internally adjust the fan performance curve to account for the difference between the two densities. This standard density is usually 0.075 lbs/ft^3. During a fire, the temperature in the first subsegment of the ventilation shaft will be quite high, causing the fan to derate and not provide the pressure it would at its standard density.

Fan Type. Two fans are the same type only if they possess identical fan curves, run-up times, upper and lower operating flow limits, and air densities at which the fan performance curves were measured. Data describing each different Fan type must be entered in Forms 7A and 7B. The fan type identification numbers are assigned to each fan type according to the order in which the fans are entered in the data. The first fan type entered is Fan Type 1, the second fan type is Fan Type 2, and so on, until all the fan types have been entered in the data.

User Suggestion. A user may locate a fan in a ventilation shaft but not operate the fan during a particular simulation by entering a number greater than the Maximum Simulation Time for the Simulation Time After Which Fan Switches On and Off or by entering zero for the Direction of Fan Operation.

As mentioned above, the fan run-up curve is applied to both fan run-up (after switching "on") and run-down (after switching "off"). This means that the fan remains active past the Simulation time After Which Fan Switches Off (on Input Form 5C) for a time equal to the Time Required For Fan To Reach Full Operating Speed (on Input Form 7A).

Even if the user chooses to locate a fan in a ventilation shaft and not operate it, as per the above user suggestion, the Simulation Time After Which Fan Switches On and Off must be set to a time greater than the Maximum Simulation Time (Form 13). Setting both times equal will not simulate fan operation, but will simulate fan run-down starting at the time entered.

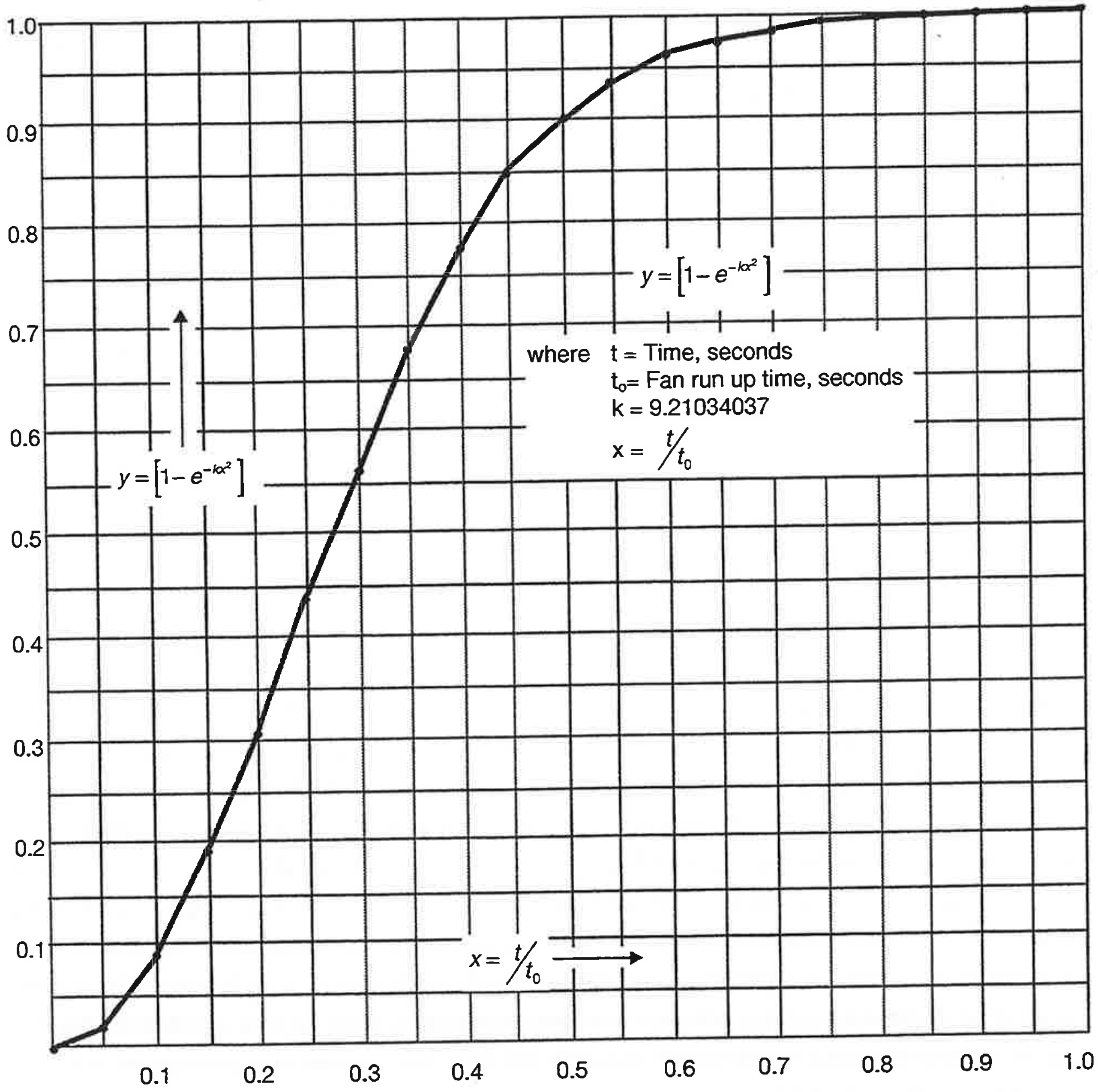


Figure 4.15 Fan Run-up Attenuating Function

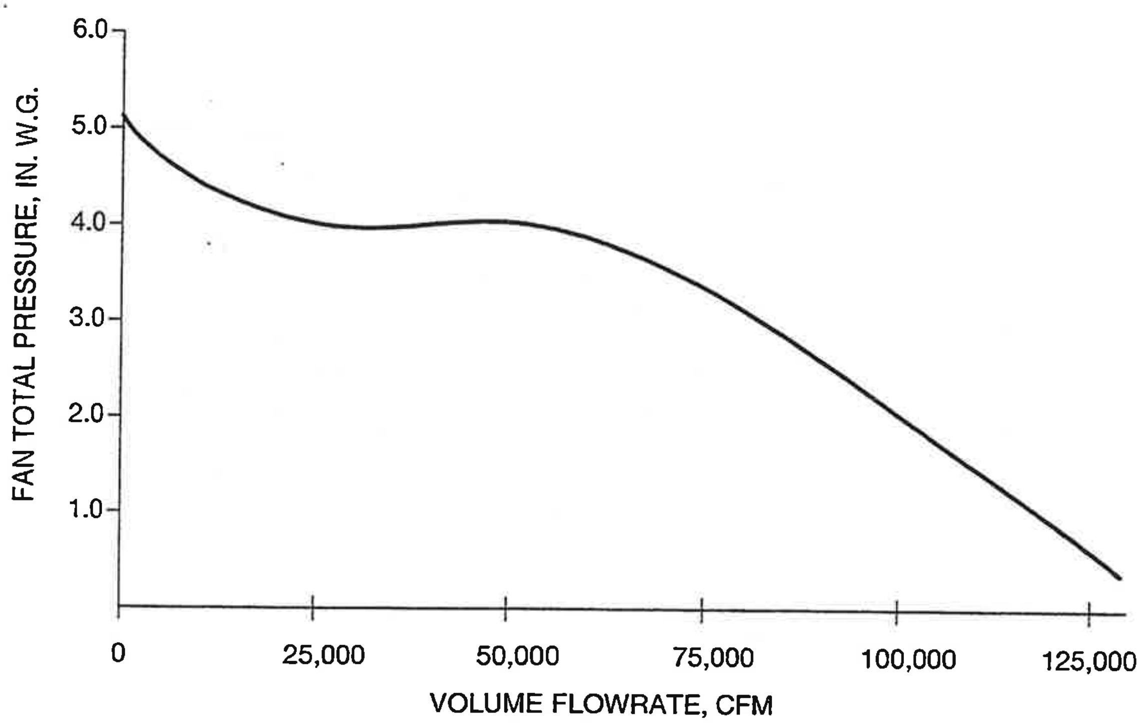


Figure 4.16 Sample Vaneaxial Fan Performance Curve

4.4.2 Impulse Fan Systems

An impulse fan system (IFS) is a device for moving air by directing a high-velocity jet of air in the direction that air movement is desired. It is suitable for producing longitudinal air movements in tunnels since it allows free movement of trains past the fan system. (A conventional low-velocity fan would require the tunnel to be blocked at the point of the fan, for example by a door, to prevent the air discharged by the fan from recirculating into its intake. For this reason the SES restricts the location of impulse fan systems to line segments, while conventional supply/exhaust fans can only be located in ventilation shafts.)

In modeling an impulse fan "system" the SES considers only characteristics of the high-velocity air jet and its effect on air pressure and flow in the tunnel in which it is located. While an axial or centrifugal fan is usually incorporated within an impulse fan assembly, the SES does not model the pressure vs. flow characteristics of the fan itself, nor the transient pressures created by passing trains blocking the IFS intake or discharge.

Impulse Fan System Input

The Number of Impulse Fan Types is entered on Form 1E. Each Impulse Fan Type is described by completing one copy of Form 7C. (IFS information should not be confused with the Number of Fan Types on Form 1D and their description on Forms 7A and 7B.) Impulse fans are located in line segments, and the "Line Segment Type" indicates which "Impulse Fan Type" is located in it according to the following table:

Line Segment Type	Impulse Fan Type
9	IFS Type 1
10	IFS Type 2
11	IFS Type 3
12	IFS Type 4
13	IFS Type 5
14	IFS Type 6

Input Form 7C is used to describe each Impulse Fan Type. The first Form 7C entered describes IFS Type No. 1, the second Form 7C describes IFS Type No. 2, etc.

The Impulse Fan Flow Rate is the rate of air discharged from the IFS nozzle in cubic feet per minute. The Impulse Fan Nozzle Discharge Velocity is the velocity of the air discharged from the IFS nozzle, and is measured at the face of the nozzle. The Impulse Fan Pressure Efficiency is a dimensionless number which accounts for energy losses due to turbulence and other effects associated with the IFS discharge jet. This number may range from 0.0 (all energy lost) to 1.0 (no energy losses). See Section 7E of Appendix B of the Programmer's Manual for the equation used to describe an IFS in the SES. Experimental tests have shown that a pressure efficiency of 0.90 can be obtained with a discharge velocity of 5900 fpm in a single-track tunnel with an aerodynamically well-designed nozzle and discharge arrangement, using a discharge angle of 30° from the longitudinal axis of the tunnel. For small changes in the discharge angle, the Impulse Fan Pressure Efficiency can be adjusted by the ratio of the cosine of the new angle to the cosine of 30°.

The impulse fan begins operation when the simulation time is greater than the Time at Which the Impulse Fan is Switched On. The impulse fan stops operation when the simulation time is greater than or equal to the Time at Which the Impulse Fan is Switched Off. A "Run-up" and "Run-down" attenuation curve is not used for impulse fans. An impulse fan will remain inactive for the entire simulation if 0.0 is entered for both the time it is "switched on" and "switched off".

REFERENCES

1. Donsky, Benjamin, "Complete Pump Characteristics and the Effects of Specific Speeds on Hydraulic Transients," Journal of Basic Engineering, Dec., 1961.

2. "Fan Engineering," Buffalo Forge Company, 8th Edition, 1983.

3. ASHRAE Handbook and Product Directory, 1977 Fundamentals.

4. "Mark's Standard Handbook for Mechanical Engineers," McGraw-Hill, 8th Edition et al.

5. I.E. Idel'chik, "Handbook of Hydraulic Resistance," 3rd Edition 1994.

6. Associated Engineers Report No. UMTA-DC-MTD-7-71-7. "Preliminary Steady-State Subway Aerodynamic Analysis (Incompressible)". Prepared by Graduate Aeronautical Laboratories/California Institute of Technology for United States Department of Transportation.

5. THERMODYNAMIC PHENOMENA

The temperature and humidity at any point in an underground rapid transit system are influenced by the movement of air carrying sensible and latent heat through the system and by the sources and sinks which add and remove heat at various locations in the system. The temperature and humidity of subway system air is also affected by the temperature conditions above ground and by the temperature of the system walls and surrounding deep heat sink. The predominant source of sensible heat in an operating subway system results from the acceleration and braking cycles of the train. Sensible and latent heat is also rejected from vehicle air conditioners, passengers, and ancillary sources. Heat is removed from the system through the expulsion of heated air from ventilation shafts and by heat conduction across the tunnel walls into the surrounding underground heat sink. Heat may also be added or removed by mechanical means such as heating or cooling equipment.

As noted in the previous section, the geometrical partitioning required for the computation of aerodynamic parameters is accomplished by dividing the subway station, tunnels, and ventilation shafts into a number of segments each of which has statistically uniform cross-sectional area, perimeter, and wall thermal properties. This basic geometrical partitioning is also the basis for the calculation of the system temperature and humidity. However, since temperature and humidity values may vary along the length of subway segments for which the aerodynamic values are statistically uniform, these segments are partitioned into smaller geometrical entities called "subsegments," as indicated in Figure 5.1. Each subsegment of a segment has an independently computed temperature and humidity, making it possible to reflect small-scale variations in subway air sensible and latent heat.

The computations of temperature and humidity are carried out automatically in the program using airflow information computed in the aerodynamic portion of the program and train heat release information computed in the train performance portion of the program. The user must specify other sources of heat addition (or removal) which are not computed automatically from the train performance simulation. The user must also specify certain thermodynamic starting conditions within the subway in order for the simulation to begin. These include subsegment air temperatures and wall surface temperatures, and temperature at the system boundaries (e.g. outside air at portals or temperature at interfaces with contiguous portions of the underground system not included in the simulation).

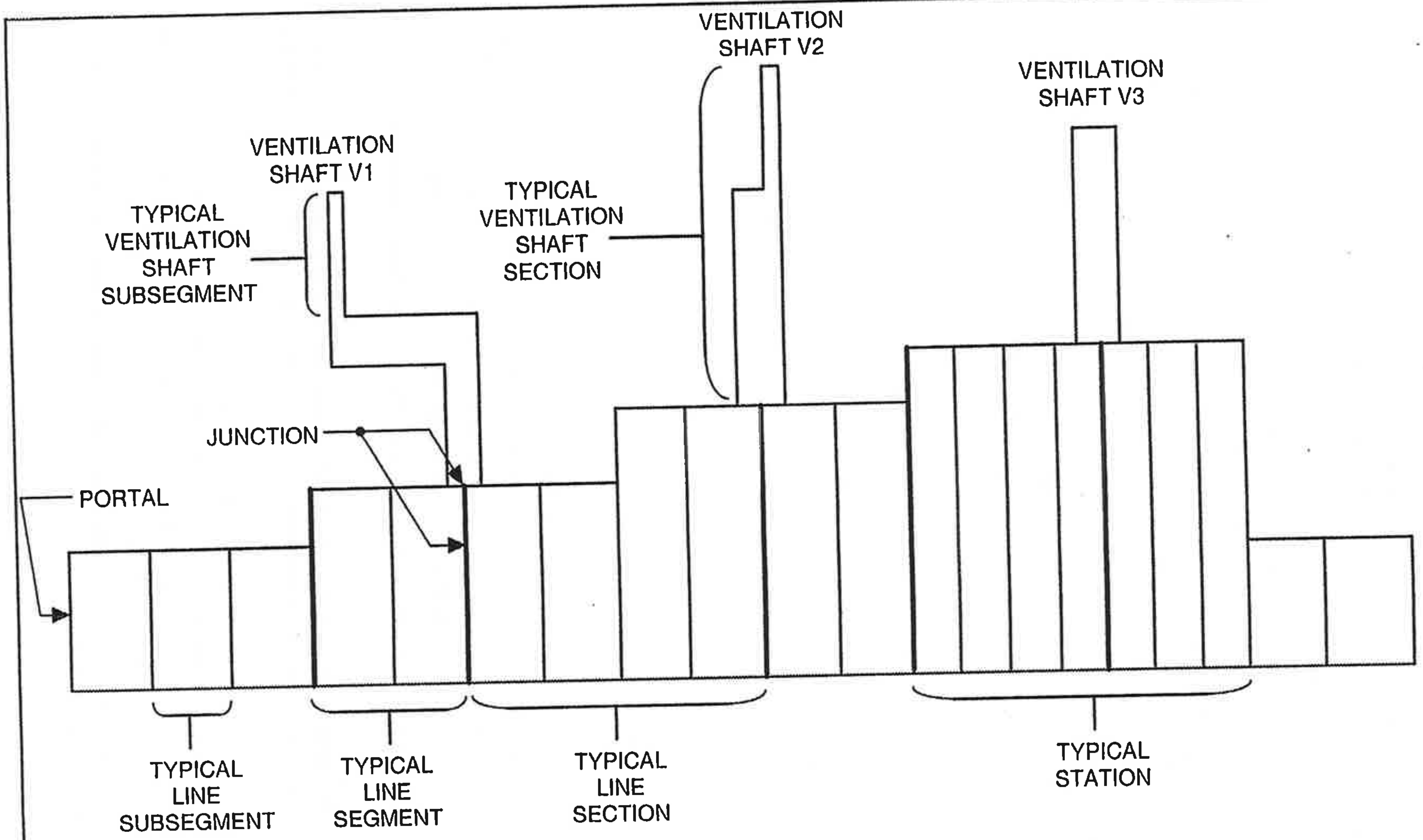
In addition to the mandatory requirement that the user supply values for the initial conditions and boundary conditions, the program also allows the user the option of specifying heat rates for any steady-state and/or unsteady-state heat and humidity sources and sinks. Station lighting would be an example of a steady-state heat source. The program also includes the optional capability to evaluate the effects of evaporation on the latent and sensible heat content of the system air. Finally, as part of the computational sequence, the program includes the added optional capability of a procedure for determining the impact of a trackway exhaust system on the station temperature.

As part of the designer-oriented features of the program, the user has the option of allowing the program to provide air-conditioning or heating load estimates. These estimates provide information regarding the rate of heat removal or addition necessary to maintain user-specified average temperature and humidity design conditions for specified areas of the system.

The program also accounts for buoyant effects of airflows in tunnel, station and ventilation shaft segments caused by differences in air density due to varying elevations and temperatures throughout the system. This feature of the program operates during a fire simulation as explained in detail in Chapter 9.

Another feature of the program, designed to permit a more accurate thermodynamic simulation of the mixing of airflows at the junctions of system sections (i.e., at the nodes), allows the user the option of specifying the degree of mixing which can occur among airflows in the system which are allowed to communicate at the system intersections. This feature permits the user to specify whether complete thermodynamic mixing is expected to occur at a node or whether the mixing is expected to be only partial. The airflows and temperature/humidity information computed by the program for each of the sections which can communicate at a given node are used by the program to compute automatically the degree of temperature/humidity exchange which can occur at the node.

Finally, the program provides the user with the option of evaluating the effects of long-term changes in tunnel wall temperature upon the environmental conditions in an operating system. This capability is made possible through a special procedure which allows the user to implement an ancillary analytical program for estimating future values of tunnel wall temperature together with the short-term computations of system air temperatures provided by the main program.



(DIVISION FOR TEMPERATURE AND HUMIDITY SUBPROGRAM COMPUTATIONS)

Figure 5.1 Schematic Elevation of a Sample Underground Transit System

5.1 Subsegment Length (Input Form 3C)

The temperature and humidity calculations require that every line segment or ventilation shaft segment in the system be divided into one or more subsegments. The program user must provide a value for the <u>number of subsegments</u> as part of the individual segment descriptive information required for Input Form 3C. Using this value for the <u>number of subsegments</u> the program automatically creates an equivalent number of subsegments of equal length in each segment. Since these subsegments are merely mathematical subdivisions of the aerodynamic segments, each subsegment will have the system geometry and air velocity which characterizes the segment, in addition to its own unique air temperature and humidity. For each subsegment the SES performs a lengthy calculation in order to evaluate the instantaneous temperature and humidity within the subsegment. As the number of subsegments increases, the amount of computer time (and therefore the cost) required to evaluate the temperature and humidity within the system also increases; thus, the choice of the number of subsegments for each individual system segment must be made carefully. Shorter subsegments should be used where large temperature gradients may be expected or where greater detail on local temperature conditions is desired. A good "rule of thumb" is 200 to 400 foot long subsegments in tunnel areas and 50 to 100 foot long subsegments in stations. Ventilation shafts usually contain only one subsegment[1]. This rule of thumb cannot be applied in all cases, and the system user must always consider the peculiarities of the system being simulated.

Among the several factors which must be considered in choosing how many subsegments should be defined for each line segment and ventilation shaft are the following:

Factors favoring short subsegments:

Since each subsegment is represented by one value of temperature and humidity, a change in either temperature or humidity of the inflowing air at one end of a subsegment is immediately distributed mathematically throughout the entire subsegment. Thus a temperature gradient within the segment is represented by a number of discrete temperatures, each uniform over the length of a subsegment. The use of shorter subsegments provides a more accurate representation of the temperature continuum with

---

[1] Since the length of the ventilation shafts may be small and high velocities may be created in them from the piston action of trains moving past at high speeds, the combination of short lengths and high velocities would cause the velocity-time stability criteria (See Footnote 2) to be exceeded.

Under such conditions, the stability criteria of the finite difference technique could cause incorrect values for the temperature or humidity to be computed. One solution to the problem would have been to force the entire Temperature and Humidity Program to operate using time intervals sufficiently small to satisfy the specialized stability criteria of the ventilation shafts. Instead, a technique was developed whereby the ventilation shaft is shrunk mathematically to zero length whenever extremely high velocities occur. This technique is fully accurate in such instances, since at high velocities the chances of stagnant air in the ventilation shaft being recycled back into the subway system is unlikely.

the limiting case being the use of subsegments of infinitesimal length, thereby allowing a true representation of a gradient over the segment length.

Factors favoring long subsegments:

Although it would appear that, ideally, the user would always strive to have small subsegment lengths, there are several practical constraints that impose limits on subsegment size. First, there is a velocity-time stability criterion associated with the mathematics of the temperature computation scheme[2]. If this criterion is violated, the SES program will state that it has and terminate the simulation when the number of allowable simulation errors is exceeded. Stated simply, this criterion requires that the subsegment length must always be greater than the velocity of air moving through the subsegment multiplied by the aerodynamic calculation-time interval. This criterion can be satisfied in either of two ways: 1) by choosing long subsegments such that the entire volume of air in the subsegment would not be replaced within a calculation-time interval, or 2) by choosing a small calculation-time interval. The choice of longer subsegments is preferable since shortening the calculation-time interval increases the number of calculations required for the simulation (and hence the costs). In addition, the user must be sure that the program storage capacity is not exceeded. There is a limit to the number of line subsegments and the total number of line and ventilation shaft subsegments that the program can simulate at one time. These limits are given in Appendix A of this manual.

---

[2] Mathematically, this velocity-time stability criterion for each subsegment is satisfied if

$$\left(\frac{V_i}{L_i}+K_i\right)\frac{\Delta t}{2}<1$$

where

$$K_i=\frac{2h_iS_{t_i}}{C_p\rho A_{t_i}}$$

h_i = Convective heat transfer coefficient (Btu/sec-°F-ft^2)

S_{t_i} = Tunnel perimeter, (ft)

C_p = Specific heat of air at constant pressure, (Btu/°F-slug)

ρ = Air density (slugs/ft^3)

A_{t_i} = Tunnel cross-sectional area corrected for presence of train (ft^2)

V_i = Air velocity (ft/sec)

L_i = Subsegment length (ft)

Δt = Specified time interval for integration of thermodynamic equations

5.2 Outside Ambient Conditions (Input Forms 1F, 6B)

The outside ambient conditions are boundary conditions for the simulation and consist of the following: 1) ambient air dry-bulb temperature, 2) ambient air wet-bulb temperature, and 3) ambient barometric pressure.

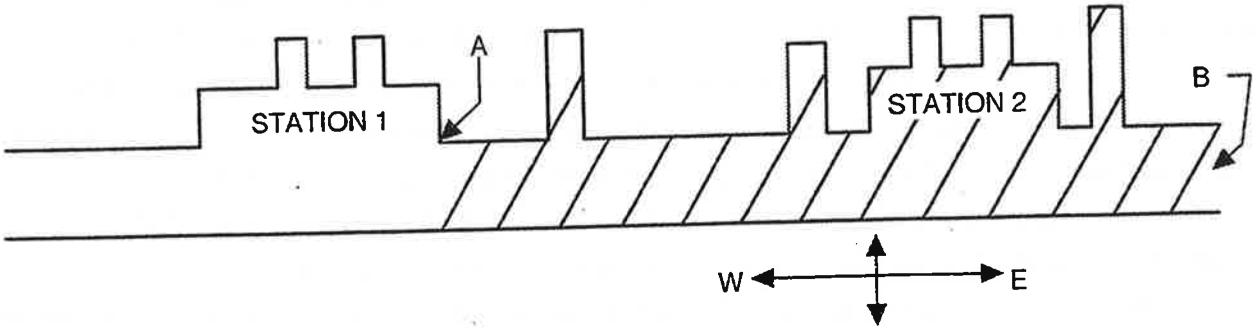
A value for each of these parameters must be entered on Input Form 1F. The outside ambient conditions directly affect the heat content of the air within a system, since outside air enters a system through portals, ventilation shafts, station entrances, and other openings to the atmosphere. Consequently, the program user must obtain pertinent data on the weather conditions surrounding the site of the system. This weather data can be obtained from the National Climatic Center, Asheville, North Carolina, the Department of the Army Technical Manual TM5-785, "Engineering Weather Data", or from local weather services near the site of the system. The user may also employ data given in the Carrier Corporation System Catalogue, Part 1, Chap. 2, ("Design Conditions") provided as Tables 1 through 3 in Appendix C. The Weather Data and Design Conditions Tables in the ASHRAE Handbook of Fundamentals should not be used because the temperatures in these tables are not referenced to a specific time of the design day.

The user should note that the time of day when the peak air temperatures within a subway system occur is often different from the time of day the peak outside ambient temperatures occur. Due to the nature of subway system operation, the peak system temperatures in July will usually occur around the time of the evening rush hour even though the outside ambient temperatures peak at approximately 3:00 P.M. Therefore, in order to simulate a subway system for the peak summer design conditions, the user should simulate the system for 5:00 P.M. in July, and use the peak summer 3:00 P.M. July ambient temperatures corrected to July at 5:00 P.M. The methods used to obtain approximate corrections to design conditions are described on Pages C-1 to C-2 of Appendix C, which include an example.

The user should also note that when inputting values for Morning and Evening or Off-hour Ambient Air Dry and Wet Bulb Temperatures, as described in Section 5.10, that for a morning rush hour simulation the design hour and morning rush hour temperatures are the same. Similarly, for an evening or off-hour simulation the design hour and the evening or off-hour temperatures are the same.

If the boundary conditions at any given portal or ventilation shaft exit are expected to differ from the overall outside ambient conditions specified on Input form 1F, the user must define these special boundary conditions on Input Form 6B. These boundary conditions are of particular use when the user wishes to simulate only a portion of a continuous system. When a portion of a continuous system is being simulated, the user may find it necessary to have the conditions at the "portal" of the system differ from the outside ambient conditions entered in Form 1F.

Example 5.1 Suppose the user wishes to simulate only the portion between the east end of Station 1 and the portal at the east end of the system as shown cross-hatched in the sketch below:



Station 1 is an air conditioned station with a design air temperature of 80°F dry-bulb and 70°F wet-bulb. The outside ambient air temperature is 95°F dry-bulb and 85°F wet-bulb.

When the user enters the outside ambient conditions for this system the tunnel-station intersection at point A will be one of the two "portals" in the system. The actual portal at point B is the second portal in the given system.

The air temperature in Station 1 is held constant at the design temperature for the station. Therefore, it is safe to assume that all the air leaving Station 1 is, on the average, at the station design temperature. The user should therefore enter the boundary conditions at portal A as 80°F dry-bulb and 70°F wet-bulb. The boundary conditions at portal B and at the top of all the vent shafts where flow exits to the atmosphere are equivalent to the outside ambient conditions of 95°F dry-bulb and 85°F wet-bulb.

To eliminate unnecessary duplication in these cases, the user need only enter a zero for the first entry on Input Form 6B and leave the rest blank. The program will then assume that boundary conditions are equivalent to those entered on Input Form 1F.

The user must decide between designing the system for the most severe outside weather conditions and the normal weather conditions, at the time of year for which the system is being designed. This decision often involves the selection of a design temperature that will be exceeded by a worst condition a certain percentage of the time such as 2 1/2 or 5 percent.

5.3 Initial Temperature and Humidity Conditions (Input Forms 3E, 5B)

The initial conditions within a system are the conditions that exist at the beginning of a simulation. The user must specify the following initial conditions on Input Form 3E for subsegments in the line segments in the system: (1) Initial wall surface temperature, (2) Initial dry-bulb air temperature, and (3) Initial wet-bulb air temperature. If there are N subsegments within a segment, the initial conditions are entered for each of the N line subsegments. Although initial dry-bulb and wet-bulb air temperatures are required to begin a SES simulation, these values are replaced by SES-computed values during a simulation and have no effect on the end results of a properly executed simulation attaining thermodynamic equilibrium. Thus, if the user is not certain of the initial dry-bulb and wet-bulb air temperature in a line segment, it would be sufficient to enter values equivalent to the outside ambient dry-bulb and wet-bulb air temperatures, respectively. Similarly, in a simulation which includes the optional heat sink evaluation (section 5.10), the SES recomputes wall surface temperatures in tunnels and unairconditioned stations. As a first approximation of the wall surface temperature in these parts of a system, it is suggested that the user enter a value equal to the outside ambient dry-bulb temperature.

The user must specify the following initial conditions on Input Form 5B for each ventilation shaft in the system: (1) Initial wall surface temperature, (2) Initial dry-bulb air temperature, (3) Initial wet-bulb air temperature. The initial conditions are uniform throughout the entire ventilation shaft. If the user is not certain of the initial conditions in a ventilation shaft, values equivalent to the outside ambient dry-bulb and wet-bulb air temperatures should be entered for the initial dry-bulb and wet-bulb air temperatures, respectively. Similarly, if the user is uncertain of the wall surface temperature of a ventilation shaft, a value equal to the outside ambient dry-bulb air temperature should be entered.

User Suggestions. The initial wall surface temperatures in parts of a system with a controlled environment, such as mechanically cooled stations, assume greater importance since these values are not re-computed during any SES simulation. Experience with the SES heat sink computations has shown that in these instances the heat transfer between the air and the station structure is a small percentage (generally less than 5 percent) of the total load required to cool the station. The following approximations are recommended for initial wall surface temperatures in mechanically-cooled stations.

The wall surface temperature in a mechanically-cooled station where the air temperature is held practically constant over an entire 24-hour period will in general be approximately 1 to 2°F below the station air design temperature. This is because the average station air temperature is controlled by the mechanical cooling system and the walls and the air are in equilibrium with no benefit being derived from daily fluctuations in outside ambient temperature. In addition, any short-term temperature fluctuations in the station attributable to train operations have very little impact upon the wall surface temperatures. Therefore, the user should enter the wall surface temperature as either one or two degrees F below the design air temperature for segments in air-conditioned areas where the temperature is held approximately constant over a 24-hour period. The former wall surface temperature estimate (1°F difference) is more conservative than the latter (2°F difference) from a design point of view.

When the average air temperature in an air-conditioned station is permitted to fluctuate over a 24-hour period, the user should enter as the wall surface temperature a value equal to the maximum design air temperature for the 24-hour period minus one-half the total temperature fluctuation of the station air. If the mechanical cooling equipment in an air-conditioned station can maintain an average air temperature of 75°F during the morning rush hour and 85°F during the evening rush hour, then the total air temperature fluctuation for the station is 10°F. Therefore, the user should enter 85°F - (10/2)°F = 80°F for the wall surface temperature in the station.

5.4 Steady-State Heat Sources (Input Form 3D)

A steady-state heat source is any positive or negative heat source that is constant over the entire simulation. Examples of possible steady-state heat sources include the following:

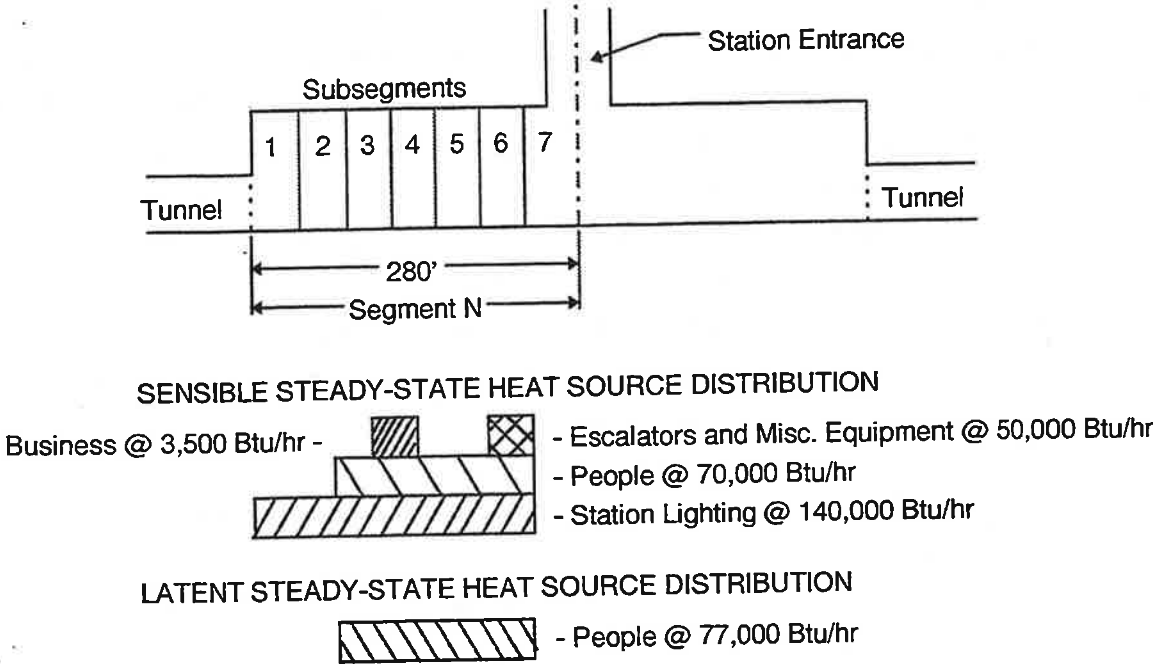
1. Tunnel lighting
2. Third rail losses
3. Station lighting
4. Passenger heat
5. Display lighting
6. Escalators
7. Fare collection equipment
8. Train indicators
9. Station mezzanine concessions
10. Heat removed by mechanical cooling equipment, etc.

The user must determine the amount of heat gain or loss from each individual steady-state heat source within each line segment and then distribute these heat sources in the appropriate subsegments (depending on the location of the source) within each line segment. The methods by which various steady-state heat sources may be calculated are presented in Appendix D .

The user may either enter both the heat gains and heat losses within a single subsegment or determine the net gain or loss from all the sources in the subsegment and enter only this net gain or loss (see Example 5.2). The heat sources within each line segment are assigned a range within the line segment over which the sources are evenly distributed. In other words, each source is assigned by the user a starting subsegment number and an ending subsegment number. The ending subsegment number of a steady-state heat source must be greater than or equal to its starting subsegment number. In addition, if a line segment has N subsegments, the starting and ending subsegment numbers must be between 1 and N. The user may enter the steady-state heat gains or losses in any order desired as long as their starting and ending subsegment numbers meet the constraints mentioned above. Two or more different heat gains or losses may be entered as overlapping one another, the user may simplify the input data and lump all the heat gains and losses in the overlapping subsegments together and enter only the net steady-state heat gain or loss within each subsegment.

The user must supply both a sensible heat rate and a latent heat rate for each steady-state heat source entered. These heat rates are simply the rates of heat addition and/or removal of sensible and latent heat within the line segment being described. Heat removal is signified by a negative rate and heat addition is signified by a positive rate. All steady-state heat rates must be entered in Btu/hr.

Example 5.2 Figure 5.2 shows a station line segment with some typical steady-state heat sources. The distribution of these sources within the station segment and the amount of sensible and latent heat gain or loss from each steady-state heat source is also shown. In this example, each steady-state heat source is shown to be evenly distributed solely for the sake of simplicity - the user may distribute the steady-state heat loads in any manner desired.



Input Data

Steady-State Heat Source	Starting Subseg. No.	Ending Subseg. No.	Source Type	Sensible Heat Rate (Btu/hr)	Latent Heat Rate (Btu/hr)	Identification
Escalators and Misc. Equip.	7	7	1	50,000	0	Escal. & Misc. Equip.
People	3	7	1	70,000	77,000	Evenly Dist. People
Station Lighting	1	7	1	140,000	0	Station Lights
Business	4	4	1	3,500	0	Hot Dog Stand

INPUT DATA METHOD 1 - LISTING EACH STEADY-STATE HEAT SOURCE INDIVIDUALLY

Input Data

Steady-State Heat Source	Starting Subseg. No.	Ending Subseg. No.	Source Type	Sensible Heat Rate (Btu/hr)	Latent Heat Rate (Btu/hr)	Identification
Escalators, Misc. Equip., Station Lights and People	7	7	1	84,000	15,400	People, Lights & Escalators
People and Station Lights	5	6	1	68,000	30,800	People and Station Lights
Business, People, & Station Lighting	4	4	1	37,500	15,400	Business, People, Lights
People & Station Lighting	3	3	1	34,000	15,400	People & Station Lights
Station Ligthing	1	2	1	40,000	0	Station Lights

INPUT DATA METHOD 2 - LUMPING STEADY-STATE HEAT SOURCES TOGETHER

Figure 5.2 Entering Steady-State Heat Sources

In addition to the source rate, the user must enter the source type. There are two types of steady-state heat sources. The first type is the "miscellaneous heat source" which is entered as Type 1, and the second type is the "heating or cooling source" which is entered as Type 2. Type 1 sources are all steady-state heat losses or gains that are not specifically used to control the environment within the segment being described. Although people and display lighting would provide heat to a system that required a positive heat source in order to maintain its design temperature, the people and display lighting are not an intentional or specific means of controlling the system's environment. Any heating or cooling equipment within the segment that is specifically used to control the environment within the segment must be entered as a Type 2 steady-state heat source. Type 2 steady-state heat sources may also be used to supply initial estimates of the heating or cooling load required within the segment being described.

> Example 5.3 An example of the use of a Type 2 steady-state heating or cooling source as an initial heating or cooling estimate is as follows: Suppose a user has estimated prior to an initial simulation through hand computations that the cooling load in a station would be approximately 100 tons of sensible cooling (1 ton = 12,000 Btu/hr). The user may then enter a -1,200,000 Btu/hr Type 2 steady-state sensible heat source evenly distributed over all the subsegments in the station.

Entering initial heating or cooling estimates is not mandatory - a simulation may be performed with or without these initial estimates. However, if the user is performing an Environmental Control Load Evaluation, the initial heating or cooling estimate may decrease the total number of environmental control load evaluations that have to be performed to obtain the required cooling load for the station segment under evaluation. The reason an initial heating or cooling estimate may reduce the number of environmental control load evaluations required is that these evaluations are done by an iterative process, with the initial estimate generally serving as the first iteration. Reducing the number of environmental control load evaluation iterations diminishes the amount of computer time required for a simulation and therefore reduces the cost of the simulation.

5.5 Unsteady Heat Sources (Input Form 4)

Input procedures for an unsteady heat source are basically the same as those for a steady-state heat source, with the single difference that the steady-state heat source is any positive or negative heat source constant over the entire simulation whereas the unsteady heat source is any positive or negative heat source that is constant for only a given portion of the simulation period. In addition, since the unsteady heat sources are entered independently of any system geometry data, the user must supply (on Input Form 4) both the line segment and corresponding subsegment number for each unsteady heat source described. The user must also supply the time after which the source becomes active and the time after which the source becomes inactive. These times simply define the operating period for the unsteady heat source. Finally, during the simulation, the user must enter the total number of unsteady heat sources within the system on Input Form 1D, which must equal the <u>number of unsteady</u> heat sources described on Input Form 4.

The unsteady heat source option is also used for simulating a fire within a system. In brief, the user simulates a fire by:

- Setting the Fire Simulation Option on Form 1G to 1.0.
- Entering a 1.0 for Fire Segment for the appropriate segments on Form 3A.
- Entering an unsteady heat source equivalent to a fire.
- Halting all trains.
- Turning the system fans to their emergency mode.

For more information and details on how to simulate a fire, refer to Chapter 9 of this manual.

5.6 Wall Surface Evaporation (Input Forms 1C, 3C)

Studies have indicated that evaporation from subway walls can, under certain conditions, act to reduce the air temperature in an operating system since evaporation represents the conversion of sensible heat to latent heat. The SES program has the capability of evaluating on a continuous basis the evaporation rate from wetted tunnel wall surfaces and the resulting depression of tunnel air dry-bulb temperature and increase in specific humidity. This optional capability is implemented by setting the <u>Temperature/ Humidity Simulation Option</u> (Form 1C) to 2.0 and by specifying for each line segment of the system (Form 3C) the percentage of the wall surface area to be considered wet. In the analysis of this phenomenon it is assumed that water is always replenished to the evaporating surface at a rate sufficient to maintain wetness.

<u>User Suggestions.</u> Through a review of the literature concerned with the permeability of concrete by water it was found that, for concrete of conventional mixes and properly cured, the permeability by water, a mass diffusion phenomenon, is sufficiently small to be unmeasurable. Based on these findings and field observations and discussions with experienced tunnel engineers, it has been concluded that the moisture which sometimes exists on subway walls and in the trackways occurs primarily when there is seepage through joints and cracks in the tunnel supporting material.

In general, the designer of a new system would not be likely to take credit for this source of cooling since tunnel structures are designed to prevent seepage. However, in the analysis of an existing system geared toward improving environmental conditions, observations of the existing structure may indicate sufficient moisture on the tunnel wall surfaces to warrant inclusion of the evaporation analysis.

5.7 Trackway Exhaust (Input Form 1G)

A trackway exhaust system is designed to prevent the heat rejected by the train from entering the station environment. This is intended to reduce the temperature in stations that are cooled by means of fans and train-produced piston ventilation or to reduce the cooling load requirement of mechanical cooling systems.

The major sources of heat on a train are the acceleration and deceleration resistor grids, traction motors and, if the train is equipped with an air conditioning system, the air conditioning condenser. Depending on vehicle design, this heat is usually discharged into the surrounding air either beneath or above the car, or both. The trackway exhaust system attempts to capture this heated air, preventing it from mixing with the air in the station. An exhaust system operates by sweeping the air from beneath or above the train and discharging it outside of the station. The system may comprise either exhaust or a combination of supply and exhaust at the trackway.

The SES program provides the user the option to simulate the heat removal brought about by the trackway exhaust system. A user-specified fraction of the instantaneous heat rejection of the train is captured by the trackway exhaust system, and this heat is removed from the system. The simulation of a trackway exhaust system does not affect the airflows within the system. If a balanced supply and exhaust system is used, there is no net change in airflow within the system, and only heat is removed. If an exhaust-only system is used, there is a net removal of air from the station in addition to the removal of heat. The removal of heat is simulated by using the trackway exhaust feature of the SES program and the removal of air from the station must be simulated by the addition of one or more ventilation shafts containing fans serving the station. The fans which are located in these shafts should be chosen with operating characteristics such that the average airflow rate being removed from the station through these additional ventilation shafts is equal to the rate of air removal at which the trackway exhaust system is designed to operate.

The trackway exhaust system only captures train heat when it is released within station segments. Trackway exhaust systems are usually designed to serve only the platform area of stations, and while approaches to the station may be physically located within the station structure, they should not be designated station segments unless they are equipped with a trackway exhaust system. The trackway exhaust system does not operate if a train passes through the station in constant speed mode (see Chapter 8 - Train Performance) as would usually be the case if there is no scheduled stop in the station for the route on which the train is operating.

The amount of heat captured by the trackway exhaust system when it is operating[3] is expressed as a percentage of the heat rejected from the train. This is referred to hereafter as the percent of heat

---

[3] Trackway exhaust system "operation" as used herein refers strictly to heat extraction by the system. "Operation" does not connote the aerodynamic behavior of the trackway exhaust mechanical system (e.g. On-off operation of the fans).

captured. The percent of heat captured varies with train speed. The program is set up so that a different value of percent of heat captured can be used for three different stages of train activity:

A. Train is stopped. The value of percent of heat captured is applied to the train heat released in "station" (Type 2) line segments.
B. Train is moving at a speed less than or equal to the "maximum train speed at which the trackway exhaust system operates." This value of percent of heat captured is applied to the portion of the train that is within "station" line segments as the train coasts or brakes into the station, or accelerates out of the station.
C. Train is moving at a speed greater than the "maximum train speed at which the trackway exhaust system operates."

The values of percent of heat captured for activities A and B are input on form 1G. The program automatically uses zero as the value for activity C.

The percent of heat captured also varies with the type and location of the vehicle heat source. The program allows for flexibility in this area by using a different percent of heat captured for the two following types of vehicle heat sources:

A. Train propulsion/braking system heat. This heat results from acceleration losses from either acceleration resistor grids or chopper losses, plus electrical heating of the traction motors, heat from work done against friction from mechanical rolling resistance and curve resistance, and braking heat (both deceleration resistor grid heat from dynamic braking and heat from friction brakes). These sources produce sensible heat only.
B. Train auxiliaries and passenger heat. This is the heat load from on-board auxiliary equipment (lights, air compressor, miscellaneous electrical equipment and, if present, vehicle air conditioning) and metabolic heat from passengers if the vehicle is not air-conditioned. These heat loads from the vehicle are entered on form 9C and vary with the number of passengers on-board the train. NOTE: The trackway exhaust system captures a percentage of only the <u>sensible</u> portion of this heat; the trackway exhaust system has no effect on the latent portion of this heat load.

The division of the vehicle heat sources into two categories better accomodates vehicle designs in which one category of heat is discharged beneath the vehicle, and the other category is discharged above the vehicle. In such a situation, two different trackway exhaust systems may be provided (underplatform exhaust and overtrack exhaust). Further flexibility is provided by the ability to simulate three different trackway exhaust system configurations: 1) a trackway exhaust system that captures only train propulsion/braking system heat, 2) a trackway exhaust system that captures only train auxiliaries and passenger heat, and 3) a trackway exhaust system that captures both types of heat. This is explained in further detail in section 3.3 of this manual.

The percent of heat captured for each of the two vehicle heat sources discussed above must be entered for both train activities A and B. Thus a total of four entries of percent of heat captured are entered on Form 1G.

A summary of the trackway exhaust percent of heat captured is shown in Table 5.1.

Table 5.1 Trackway Exhaust Percent of Heat Captured

TRAIN		HEAT SOURCE	
Activity	Speed	Propulsion/Braking	Auxiliaries/Passengers
A	$U_v=0$	P_1	P_3
B	$0<U_v\leq U_{max}$	P_2	P_4
C	$U_v>U_{max}$	0.0	0.0

where: U_v is the vehicle (train) speed

U_{max} is the maximum train speed at which the trackway exhaust system operates

P_1, P_2, P_3, P_4 are heat capture percentages

The trackway exhaust system simulation operates in the following manner: the train will usually approach the station and begin braking at a speed which is above the Maximum Train Speed at which the Trackway Exhaust System Operates. As the train slows to a speed which is below this maximum speed, the trackway exhaust system applies the activity B percent of heat captured for the propulsion/braking heat and sensible auxiliaries/passenger heat for the portion of the train which is inside the station. When the train comes to a stop, the activity A percent of heat captured is applied for the propulsion/braking heat and sensible auxiliaries/passenger heat for the portion of the train which is inside the station. The activity B percent of heat captured is again used to reduce both types of vehicle heat rejection for the portion of the train which is inside the station while the train is accelerating out of the station. This continues until the train speed becomes greater than the Maximum Train Speed at which the Trackway Exhaust System Operates, above which the train heat rejection assumes its normal value.

5.8 Thermodynamic Node Type (Input Forms 6A, 6B, 6C)

The air temperature and specific humidity of each subsegment are recomputed at every thermodynamic computation interval during the simulation. Three fundamental processes can occur to alter the temperature and humidity in each of these subsegments: (1) sensible and latent heat can be added directly from sources within the subsegment; (2) heat can be exchanged with the tunnel walls; and (3) there can be a net difference in the heat and moisture content between air flowing into the subsegment and air flowing out. Air flowing into a node from a subsegment bears the temperature and humidity of the subsegment from which it is leaving. Air flowing into a subsegment from a node bears the temperature and humidity either computed by the program or assigned by the user (e.g. outside ambient) depending on the number of subsegments joined by the node.

On Input Form 6A the user is required to indicate a thermal characteristic for each of the nodes in the system, by specifying whether the node is to be defined as a Type 1, Type 2, or Type 3 thermodynamic node. The Thermodynamic Type assigned to a node defines the manner in which the program determines the temperature and humidity of airflow leaving a node and entering a subsegment. A Type 1 may be assigned to a node which joins two, three, four or five subsegments. A Type 2 may be assigned to a node which joins four or five subsegments. Type 1 and Type 2 differ in the method of computing the temperature and humidity of air leaving the nodes. These methods reflect the degree of thermodynamic mixing of the airflows at this confluence point. Type 3 must be assigned to nodes which are joined to only one subsegment and represent an opening to the atmosphere or any other boundary condition where the air entering the subsegment from this node is at a user-specified temperature and humidity.

Type 3 and Type 1 nodes occur in all subway systems, whereas Type 2 nodes are defined only for nodes joining four or five subsegments and then at the discretion of the user. Accordingly, these node types will be described in the order of increasing complexity.

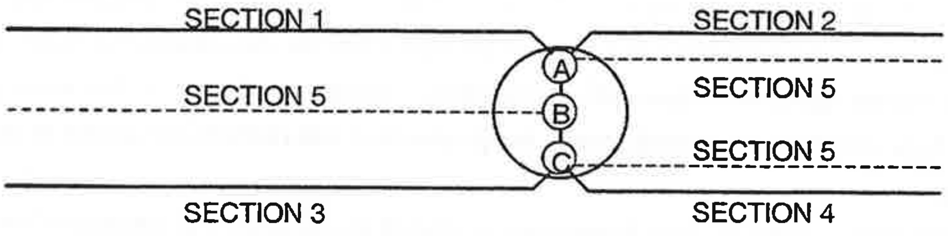
Boundary Nodes (Type 3). A node defined as Type 3 may only be connected to one subsegment, and all airflows entering the subsegment from this node have the dry-bulb and wet-bulb temperatures at this boundary defined by the user on Input Form 6B. Air entering the subsegment through this node bears user-specified temperature and humidity boundary conditions, and air leaving the system through the Type 3 node is exhausted bearing the temperature and humidity computed for the terminal subsegment.

Mixing Nodes (Type 1). Prior to recomputing the air temperature and humidity of each subsegment, the program first computes the instantaneous airflows in each section of the system. These computations insure continuity of flow about each node; i.e., the flow approaching a node equals the flow leaving. If a Type 1 is assigned to a node on Input Form 6A, the program automatically treats this node as one where complete thermodynamic mixing of the incoming airflows occurs. The temperature and humidity of the airflows leaving this node are computed simply as the energy-based average of the temperature and humidities of the airflows approaching the node. Type 1 must be assigned to nodes which join either two or three subsegments, and may be assigned to any node which joins four or more subsegments.

Partial - Mixing Nodes (Type 2). For subway geometries where either four or five sections meet at a node, flow situations may occur where inflowing air from one section does not mix completely in a thermodynamic sense with other inflows before leaving the node. Typical circumstances where this may occur are tunnel-to-tunnel crossovers (4 sections meet) and ventilation shafts which connect to two separate tunnels (5 sections meet). The SES Program enables the user to address such complexities in a straightforward manner through the use of the Type 2 thermodynamic node.

A node assigned a Type 2 on Input Form 6A is internally represented in the program thermodynamic network by a set of three thermodynamic "subnodes". Unlike the nodes designated as Type 1, which may form a confluence of two to five system sections, Type 2 may only be assigned to nodes which joins either four or five system sections. The three thermodynamic "subnodes" of a Type 2 node are treated mathematically as though a minor network existed within the node which links the sections joined by the node in a special manner reflecting preferred intra-section flows.

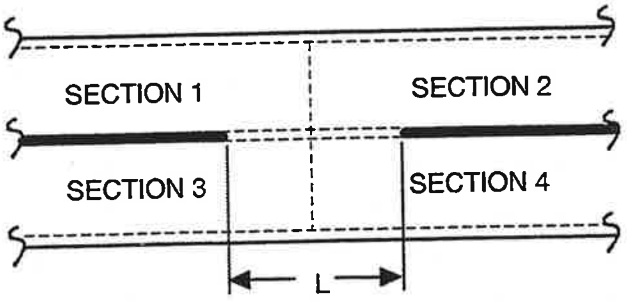
Each thermal subnode behaves individually as a mixing, or Type 1 thermodynamic node; that is, the temperature and humidity of the airflows leaving a subnode are computed simply as the energy-based average of the temperature and humidity of the airflows entering the subnode. The Aerodynamic Subprogram provides the magnitude and direction of airflow in each section. If the node is thermodynamic Type 2, the program goes one step further and applies the principle of continuity to each of the three subnodes to determine the intra-node flows. The temperatures and humidities of the flows leaving the subnodes are interdependent and are determined simultaneously by the program. Referring to the "subnodes" in the minor network as A, B and C, it is possible to describe the "subnodes" as internally linked by two branches - one extending from A to B and the other from B to C.



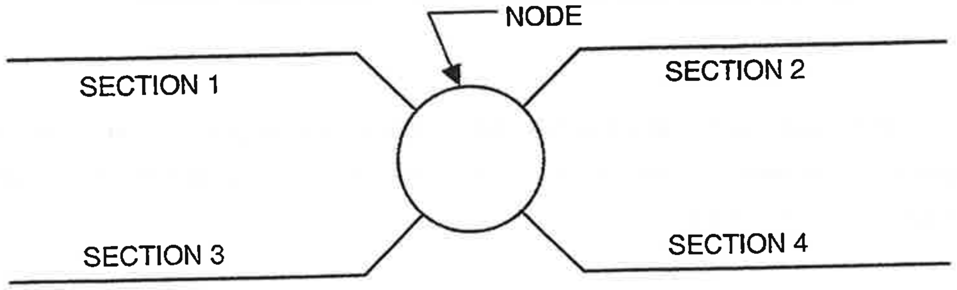
The program user must designate on Form 6C the sections connected to thermal subnode A, thermal subnode B, and thermal subnode C. Two sections must be connected to each of the two end subnodes (A and C). If five sections are connected to the node, the remaining section may be connected to any of the three subnodes. By assigning certain sections connected to a common subnode, the user is indicating to the program that in circumstances where the aerodynamic subprogram computes airflow to be approaching the subnode in one of these sections and leaving in the other, the approaching air prefers to continue to the outflowing section without mixing thermodynamically with flows in sections connected to other subnodes. Whether or not mixing actually occurs will depend on the actual flow rates in the other sections; there may be crossflows among the subnodes as a consequence of continuity.

Since the internal geometric configuration of a Type 2 node may significantly affect the thermodynamic relationship among the subsegments adjacent to the node, it is necessary that this configuration reflect the physical nature of the junction to insure a valid thermodynamic simulation. The following examples will illustrate the use of a Type 2 thermodynamic node and the user discretion required.

Example 5.4 A common geometrical configuration in subway systems is illustrated by the following schematic plan of tunnel crossover, which shows a point at which two adjacent subway tunnels provide a brief area of communication at a point where no dividing wall exists; i.e., a "tunnel-to-tunnel crossover."

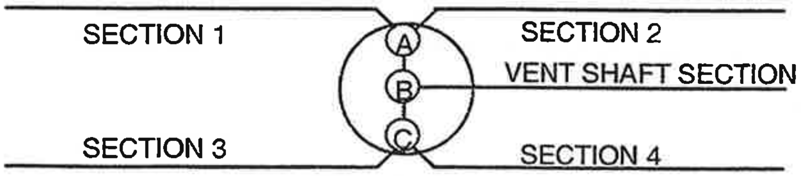


This geometrical configuration would be represented in the system network by four line sections (1,2,3, and 4) which meet at a common node.

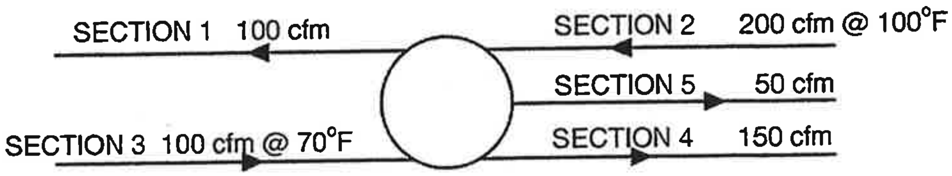


In flow situations where the flow rate approaching subnode A in section 1 is the same as the flow rate leaving via section 2, there would be no thermodynamic mixing with the flow in sections 3 and 4. When the aerodynamic subprogram computes a greater approaching flow rate in section 1 than the leaving flow in section 2, the net difference in flow passes through subnode B to subnode C, to mix thermodynamically with other flows approaching subnode C.

If the distance L is relatively long (five or six tunnel diameters), the area of the system represented by the node is large, allowing the incoming flows the opportunity to intermix by virtue of the large, turbulence promoting, interface area of the various flows. In this case the type 1 characteristic would be assigned and no thermal subnodes would be used. On the other hand, if the distance L were relatively short (one or two tunnel diameters or less), there would be little opportunity for mixing of the incoming flows. The type 2 node designation would be used and the program user would enter on Input Form 6C sections 1 and 2, connected to thermal subnode A and sections 3 and 4 connected to thermal subnode C. In flow situations where the flow rate approaching subnode A in section 1 is the same as the flow leaving subnode A via section 2, there would be no thermodynamic mixing with the flow in sections 3 and 4. When the aerodynamic subprogram computes a greater approaching flow rate in section 1 than the leaving flow in section 2, the net difference in flow passes through subnode B to subnode C to mix thermodynamically with other flows approaching subnode C. As another example, consider a configuration where a vent shaft is located directly above this break in the dividing wall. The user would connect this section to thermal subnode B; the thermodynamic network created at this node would be as follows:



For the purposes of this example, let us assume the program has just computed the airflows in the sections joined by this node at an instant during the simulation and that these airflows are as shown.



Let us also assume that at this time the temperature of the air entering the node from sections 2 and 3 are 100 and 70ºF, respectively. If this node was defined as Type 1 (Mixing Node), the program would compute the temperature of the airflows entering sections 1, 4 and 5 as 90°F - the energy-based average of the temperatures of the airflows entering the node. If this node was defined as Type 2 (Partial-Mixing Node) having sections 1 and 2 connected to subnode A, sections 3 and 4 connected to subnode C and section 5 to subnode B, the program would first compute the flow from subnode A to subnode B as 100 cfm and from subnode B to subnode C as 50 cfm. The temperatures of the airflows leaving subnodes A, B and C (to sections 1, 5,and 4) would be computed as 100, 100 and 80°F, respectively - the energy-based averages of the temperatures of the airflows entering each subnode.

User Suggestions. It is important to remember that the use of the Type 2 node only need to be considered in situations where four or five sections are joined at a node. As the tunnel-to-tunnel crossover example shows, the criterion for selecting a Type 2 node over a Type 1 is based on the expected degree of mixing of incoming flows in all flow situations. The selection is to a certain extent dependent upon the judgement of the user. It is recommended that in cases where the type of a junction is uncertain, it should be assigned as a Type 1.

5.9 Environmental Control Load Evaluation

(Input Forms 1C, 1E, 3F, 6B, 11A, 11B)

The SES program provides the user with an important optional capability: the estimation of cooling or heating loads required to achieve temperature and humidity design conditions in specified areas of the system (station mechanical cooling, for example). In order to use this option, the user must divide the entire system into separate areas or groups of areas identified as zones. There are three zone types as specified on Input Form 11A: controlled (Type 1), uncontrolled (Type 2) and non-inertial (Type 3). Table 5.2 summarizes the characteristics of these three types of zones.

Table 5.2 Summary of Zone Characteristics

Zone Type	Description	Characteristics	May Only Be Adjacent To	May Contain
1	Controlled	Wall temperature fixed at initialization values Mechanical heating/ cooling requirements to maintain design conditions computed during environmental estimate	Uncontrolled Zones Other Controlled Zones Atmosphere or boundary condition	Line Segments
2	Uncontrolled	Air and wall temperatures computed during environmental estimate	Controlled Zones Non-Inertial Zones Atmosphere or boundary condition	Line Segments Vent Shafts
3	Non-Inertial	Wall temperatures fixed at initialization values	Uncontrolled Zones* Atmosphere or boundary condition*	Vent Shafts

* Must only be connected between uncontrolled zone and atmosphere or boundary condition.

Controlled Zones (Type 1). A controlled zone is defined as a grouping of one or more contiguous line segments which are to be maintained at the same user-specified design dry-blub and wet-bulb temperatures. A controlled zone refers to an area of the system where temperature and humidity are to be regulated by mechanical cooling or heating equipment. This equipment will have the net effect of either introducing heat into or removing heat from the area at a constant rate in order to maintain the user-specified design conditions on an average basis. The program estimates the net internal heating or cooling load this equipment would have to provide. Only uncontrolled or other controlled zones may be contiguous to this zone. Wall temperatures are fixed at the initialized values.

Uncontrolled Zones (Type 2). An uncontrolled zone is defined as a group of one or more contiguous line segments and or ventilation shafts where mechanical cooling or heating equipment will not be used directly to control the environment. The SES program does not compute load estimates for these zones. Instead, the presence of uncontrolled zones is reflected in the environmental load estimates of contiguous controlled zones and the effect of maintaining these controlled zones at specified temperatures is reflected in the program's estimate of temperature and humidity conditions in uncontrolled zones. In a typical application this means that the impact of heated tunnel air on the station mechanical cooling load is accounted for, as is the effect of outflowing, cooled station air on tunnel air temperatures.

Only controlled or non-inertial zones may be contiguous to this zone. Air and wall temperatures are computed during an environmental estimate.

Non-Inertial Zones (Type 3). A non-inertial zone is defined as a group of one or more ventilation shafts which have one end of each shaft connecting to the atmosphere. Normally, ventilation shafts like these should be placed in the same uncontrolled zones that they are connected to. However, the total number of subsegments and thermal subnodes which the program internally permits in an uncontrolled zone is limited by array size (see Appendix A and Programmer's Manual). Thus, when circumstances permit, the placing of a vent shaft in a non-inertial zone allows more line subsegments to be placed in a given uncontrolled zone.

Vent shafts may be placed in non-inertial zones when the air processed through the shaft is large in comparison with the shaft volume. Physically, this means that the average temperature of inflowing air through the shaft is essentially at outside ambient conditions. This situation, which is encountered in most vent shafts, implies that the thermal inertia of the shaft in terms of recycling heated tunnel air back into the system is negligible (hence the term "non-inertial"). If in doubt as to whether a particular shaft qualifies for the non-inertial zone type, the SES summary output for the shaft should be consulted. If the average dry-bulb temperature of the inflowing air through the shaft is within 2°F of the outside ambient dry-bulb temperature, the shaft may be designated as a non-inertial zone with negligible loss of accuracy in the environmental control load calculations. The wall temperatures are fixed at the initialized values.

Input Procedures

The environmental control load evaluation can be performed for rush hour (morning or evening) or off-hour operations. These evaluations differ in the manner in which the air-wall heat transfer computations are performed for the uncontrolled zones of the system. If the Environmental Control Load Evaluation Option (Input Form 1C) is entered as 1.0 (evening or morning rush hour), the program will compute the appropriate wall surface temperature distribution for the uncontrolled zones of the system corresponding to the month of the year and the time of day for which the SES simulation is intended (using the heat sink computations described later in this section). If this option is entered as 2.0 (off-hour - e.g. any time other than morning or evening rush hour), the program will use the values entered by the user for each subsegment as the wall surface temperatures.

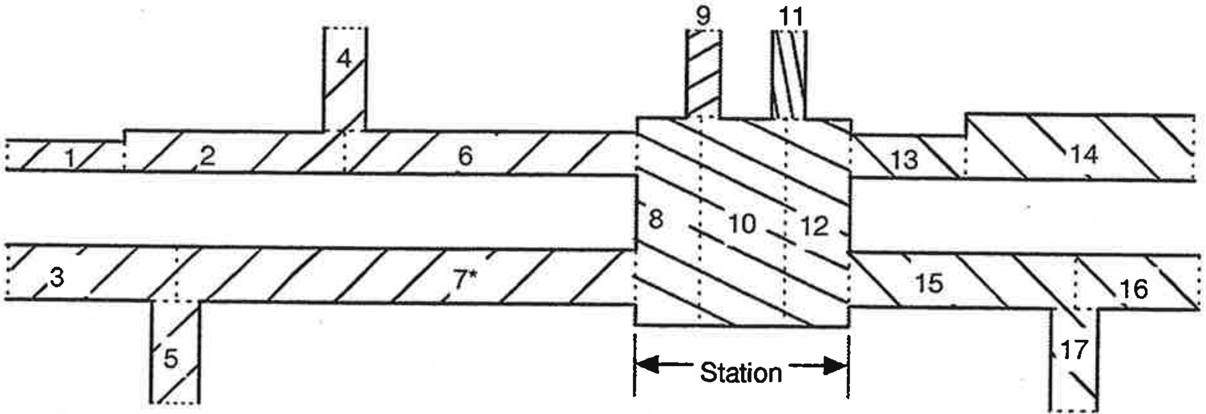
A rush hour simulation which includes the environmental control load evaluation should be performed prior to an off-hour simulation to determine the correct wall surface temperature distribution. This simulation provides as output the wall surface temperatures of the uncontrolled zones for both morning and evening rush hours. The user may estimate the wall surface temperatures for the off-hour simulation by interpolating from these temperatures. This can be accomplished by assuming that the wall surface daily temperature profile is approximated by a simple harmonic function with the evening rush hour temperature being the maximum point and the morning rush hour temperature being the daily mean.

When performing an environmental control load evaluation for rush hour or off-hour operation, the wall surface temperatures of subsegments in the controlled zones are held fixed and equal to the values which were assigned by the user as initial conditions. (See "Initial Temperature and Humidity Conditions" for guidance in the selection of appropriate wall surface temperature values in controlled zones.)

When Environmental Control Load Evaluation Option 1 or 2 is used, the Number of Environmental Control Zones must be entered on Input Form 1E. This requires that the user identify the total number of controlled, uncontrolled, and non-inertial zones which collectively comprise the complete system geometry.

Forms 11A and 11B require zone geometry information in greater detail: for each Zone Type, the total Number of Line Segments and Ventilation Shafts in the Zone must be entered on Form 11A. Form 11B requires that the Identification Numbers of Line Segments and Ventilation Shafts in the Zone, as entered on form 3A or 5A, be listed for each zone.

Example 5.5 To illustrate the division of a system into zones, consider the schematic diagram of a sample system shown in Figure 5.3.



* Line segment or ventilation shaft identification number.

Figure 5.3 Example of Environmental Zones

For the case where the user desires an evaluation of the mechanical cooling or heating required to maintain design conditions in the station, the required zone input data would be developed as follows:

Zone Type (Input Form 11A)	Identification Numbers of Line Segments and Vent Shafts in Zone (Input Form 11B)
2. (uncontrolled)	1., 2., 3., 4., 5., 6., 7.
1. (controlled)	8., 10., 12.
2. (uncontrolled)	9.
2. (uncontrolled)	11.
2. (uncontrolled)	13., 14., 15., 16., 17.

Number of Environmental Control Zones (Input Form 1E): 5.

For each controlled zone (Type 1), the user must specify on Input Form 11A the Dry-Bulb and Wet-Bulb Design Temperatures for morning rush hour and either rush or off-hour operations. These are the temperatures that the user wishes to maintain with the aid of mechanical equipment. (See SEDH Volume I Part 2.) The morning rush hour design temperatures must be entered even if the simulation is for some other time of day. Depending on the criteria selected by the user, these may or may not be the same as evening rush hour design temperatures.

In addition, there may be a need to identify temperature boundary condition data on Input Form 6B in greater detail than described earlier in this section. The user is required to specify the Dry-Bulb and Wet-Bulb Boundary Condition Temperatures corresponding to morning rush hour and either evening rush or off-hour operations. These additional data are not required if the boundary temperature conditions are the same as outside ambient conditions specified on Input Form 1F.

User Suggestions. The environmental control load evaluation is formulated on the premise that the system for which the estimate is being performed is in a state of "equilibrium", i.e., the temperature and air velocity-time profiles throughout the system are repetitive over a system period. This period is defined as the minimum length of time into which the headway (the time between trains) of all the routes are evenly divisible. For example, if a system contains four routes with headways of 90, 120, 180 and 360 seconds respectively, the system period would be 360 seconds. A summary (see print controls) over this period must be taken while the system is in equilibrium prior to performing an environmental control load evaluation.

Studies with the SES program indicate that after all the routes within the system are traversed by at least one train, two or three system periods must elapse before system equilibrium is reached. After an environmental control load evaluation is performed and the simulation is continued, the aerodynamic state of the system remains in equilibrium but the thermodynamic state does not. This occurs because of the following changes:

1. For environmental control load evaluation Option 1, the wall surface temperatures in the uncontrolled zones are replaced by the temperatures computed in the heat sink evaluation (described in section 5.10).
2. The air temperatures and specific humidities in the uncontrolled zones are initialized at the average values computed in the heat sink evaluation.
3. The air temperatures and specific humidities in the controlled zones are initialized at the design conditions for the respective zones.
4. The heating or cooling loads attributable to environmental control equipment in the controlled zones (which were specified originally in Input Form 3D) are replaced by the loads computed in the environmental control load evaluation.

SES studies have shown that two or three system periods must elapse after an environmental evaluation is performed before system thermodynamic equilibrium is re-established.

Since certain key parameters (environmental heating and cooling loads and wall surface temperatures) which influence the thermodynamic state of the system at equilibrium are altered after an environmental control load evaluation is performed and because this evaluation is based on the thermodynamic state of the system at equilibrium prior to these changes, SES studies have shown that two or three environmental control load evaluations are necessary before the design conditions are established on an average basis in the controlled zones of the system. If there are no controlled zones in the system, then in most cases only one environmental control load evaluation is necessary to predict the appropriate wall surface temperature throughout the one uncontrolled zone of the system.

Based on studies with the SES program, a suggested procedure for using the environmental control load evaluation option for a system containing one or more controlled zones is presented here. Although certain systems may require more or less time to reach a state of equilibrium than this procedure provides, this rule of thumb procedure should be closely followed until information concerning system equilibrium for a specific application is available.

1. Initialize system summaries (see Chapter 10 - "SES Program Options") when two system periods have elapsed after each train route within the system has been completely traversed by at least one train.
2. Perform an environmental control load evaluation one system period later.
3. Initialize system summaries two system periods later.
4. Perform an environmental control load evaluation one system period later.
5. Initialize system summaries two system periods later.

6. Perform an environmental control load evaluation one system period later.

To check the previous environmental load requirement estimated for the controlled zones of the system, the user may:

7. Initialize system summaries two system periods later.
8. Print summary one system period later.

During these intervals, the user may print any additional information required.

This process may be considerably shortened when a series of runs is being made, by using the Initialized File Option as explained in Chapter 10.

The SES program does not simulate detailed local airflow patterns in stations, and thus is not geared to calculate the air distribution along the platform length as induced by mechanical systems. To approximate the effect of station mechanical systems on global station aerodynamics, two or three fan shafts should be spaced along the station length. The total capacity of these fans should equal the net addition or extraction of air from the station by all mechanical systems. This air should be introduced at station design conditions by entering the appropriate temperatures for the boundary nodes of these shafts. In designs where there is an equalization of air supplied and exhausted within the station there is no effect on global station aerodynamic behavior, and therefore no fan shafts are required.

The SES-computed mechanical cooling or heating load estimates are reflected in a continuing simulation as subsegment heat sources or sinks. No correction is made for the effect that a revised load estimate may have on mechanical system airflow requirements. If the revised load estimate should require a significant adjustment to net station mechanical system airflow, it is suggested that this adjustment be made and a subsequent simulation performed. In determining the significance of the required mechanical system airflow adjustment, it is suggested that the total station ventilation rate (sum of all average inflows from tunnels, stairways, and shafts) be used for comparative purposes. If the required adjustment is less than 10 percent of this total ventilation rate, little would be gained in the way of load computation accuracy by another SES simulation.

5.10 Heat Sink Evaluation (Input Forms 1B, 1F, 3F, 6B)

During the short term SES simulation the wall surface temperature distribution along the length of the system is held fixed. This procedure is followed as a result of investigations which have shown that the wall surface temperature, although it may change along the length of the system, remains essentially invariant with time during the SES simulation period. However, there is an important thermal inertia effect caused by the daily variations in outside ambient temperature and system utilization as well as annual variations in outside conditions. An accurate subway temperature and heat load analysis must include consideration of this phenomenon and the long-term heat transfer effect created by the temperature differential between the subway air and the soil far removed from the subway. (See Reference 1 for a detailed description of the heat sink computation scheme). In order to implement the Environmental Control Load Evaluation Option, the user must enter a 1. on Input form 1C, notifying the SES program to undertake a series of computations resulting in a detailed evaluation of the heat exchange between the air and tunnel walls in each uncontrolled zone. When called upon during the SES simulation, the heat sink computation scheme computes the thermal inertia and long-term heat transfer effects to produce results for direct use by the short term evaluation - that is, the correct wall surface temperature distribution throughout the uncontrolled zones of the system corresponding to the month of the year and time of the day (either morning or evening rush hour) for which the SES simulation is intended. These computed wall surface temperatures may then be implemented in a continuation of the SES simulation, enabling an accurate computation of the wall heat transfer as affected on a short-term transient basis by train operations and the continuously varying subway air temperatures.

In order to perform this analysis, the heat sink computation scheme requires data from the short-term simulation such as subway airflow and heat load averages. In addition, the user must supply data on the design conditions of controlled zones, daily and annual variations in outside conditions, thermal properties of the structure and soil surrounding the subway, and separation of distance between any parallel tunnels.

The heat sink computations are provided as an optional feature of the SES program. A user may elect to omit the heat sink analysis if interest is only in subway aerodynamics, if wall surface temperature data are available from field measurements, or if wall surface temperature data are known by virtue of a prior SES simulation which included a heat sink evaluation. The last situation applies in particular to the off-hour simulation described in the previous section. Detailed heat sink computations will not be performed if the Environmental Control Load Evaluation Option is entered as 2. (Off-Hour) on Input Form 1C.

If the user opts to include the heat sink analysis, the following information must be provided for the heat sink computations.

Outside Ambient Temperatures. The output of the heat sink computation focuses on the evening and morning rush hours of a specified design day. This day is selected by the engineer and is considered in the computations to be typical for a given month of the year. The morning or evening outside ambient dry-bulb and wet-bulb temperature value entered on Form 1F must correspond to the time of the day at which the rush hour occurs. For example, if the evening rush hour occurs between 5 and 6 P.M., the user would then specify the outside ambient conditions occurring during this period of the design day. This data may be estimated using Tables 1 through 3 in Appendix C or, at the option of the user, any of the references cited in section 5.2 of this chapter.

When entering the morning and evening outside ambient dry-bulb and wet-bulb temperatures, the user should adhere to the following rules: If the user is performing a short-term simulation for the evening rush hour, the design evening rush hour air temperature should be entered for the evening ambient air temperature, and the difference between this design evening rush hour air temperature and one-half the average daily range for the design month should be entered for the morning ambient air temperature.

When the user is simulating the morning rush hour, the morning design dry-bulb air temperature should be entered for the morning ambient air dry-bulb temperature on Form 1F. One-half the average daily temperature range for the design month should then be added to the morning ambient air design dry-bulb temperature to obtain the evening or off-hour ambient air dry-bulb temperature. The average daily temperature range is usually supplied with climatological data.

In the heat sink computation, the annual temperature fluctuation in a subway system is estimated as a function of the amplitude of the outside ambient annual temperature fluctuation (Form 1F). The computation considers this ambient fluctuation to be a simple harmonic function which approximates as closely as possible the annual fluctuation of daily average temperature. The SES user is required to provide the amplitude of this function.

Example 5.6 The following calculation is presented as a methodology for arriving at the required amplitude of the annual temperature fluctuation given suitable historical climatological data for the geographical location of interest. For clarity, this calculation for the city of Atlanta, Georgia is presented in a step-by-step format.

1. Obtain the normal average monthly temperature for the city of Atlanta.*

MONTH	NORMAL AVERAGE TEMPERATURE (°F)
January	44.7
February	46.1
March	51.4
April	60.2
May	69.1
June	76.6
July	78.9
August	78.2
September	73.1
October	62.4
November	51.2
December	44.8

*Source: National Climatic Center, Asheville, N.C.

2. Plot these temperatures. (See Figure 5.4.)
3. Compute the arithmetic annual average temperature by simply taking the average of the twelve temperatures

$$T_{average} = 61.4$$

4. Integrate the area between the monthly average temperature curve and the annual average (using a planimeter):

$$\text{Area} = 137.9\ (°\text{F-Month})$$

5. Equate this area to the absolute area (as a function of the annual amplitude) between a cosine curve having the same period (12 months) as its abscissa and solve for the annual amplitude.

$$137.9 = \frac{4 \times 12}{2\pi} \times \text{annual amplitude}$$

$$\text{Annual amplitude} = 18.0\ °\text{F}$$

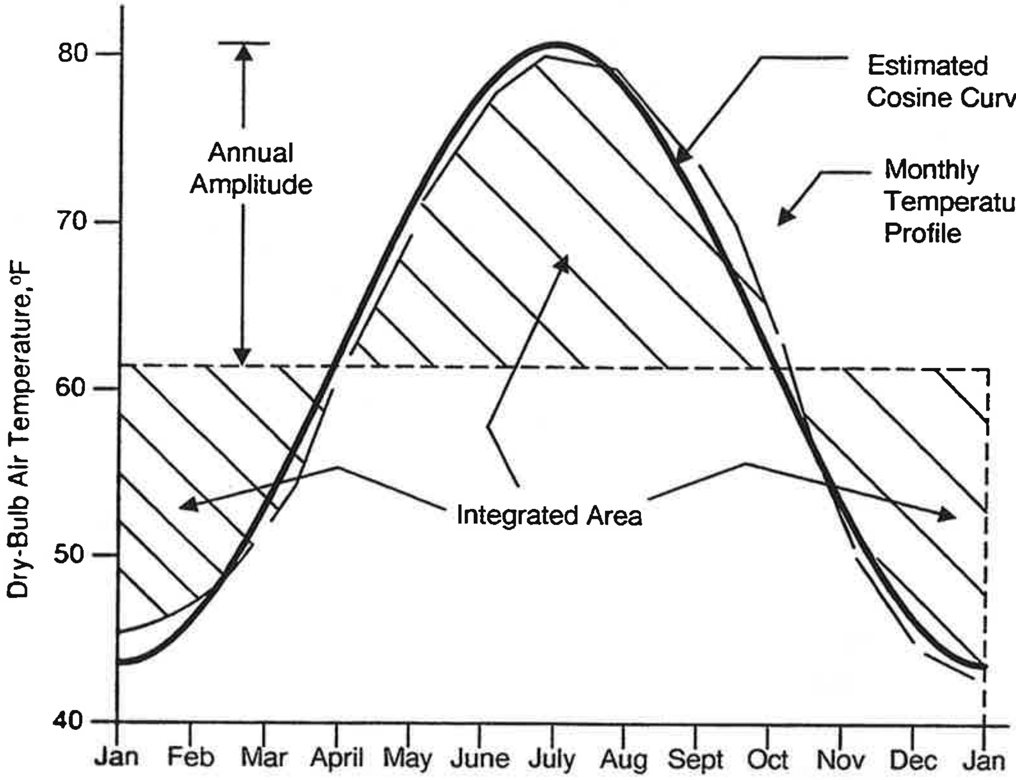


Figure 5.4 Plot of the Normal Average Monthly Temperatures for the City of Atlanta, Georgia

A check of the computation may be performed by plotting the cosine curve together with the monthly temperature profile.

In this particular example, the two curves are very similar to each other. However, certain geographical locations may have annual temperature fluctuations which do not correspond closely to simple harmonic behavior. This discrepancy should not concern the user as long as the computation is done correctly. The simple harmonic function is used to approximate the annual air temperature fluctuation and not to duplicate it.

As a further example, consider the following:

Example 5.7 Suppose the user is simulating the evening rush hour for a day in July with a two percent incidence design temperature (the maximum summer air temperatures can be expected to exceed this design temperature no more than 2 percent of the summer) of 95°F, dry-bulb. The region in which this system exists has a 28°F average daily dry-bulb temperature range during the month of July. The user should then enter 95° F for the Evening or Off-Hour Ambient Dry-Bulb Temperature, and 95 - 28/2 = 81 degrees Fahrenheit for the Morning Ambient Air Dry-Bulb Temperature on Form 1F.

5.11 Thermal Properties

In order to account for the possibility of marked differences in thermal properties between tunnel construction materials and the surrounding earth, the mathematical model employed to simulate heat conduction in these materials surrounding a subway tunnel considers two material regions. Region I extends from the inner wall surface to the earth-wall interface, whereas Region II extends outward from this earth-wall interface. Each region is considered to consist of a homogeneous material whose thermal conductivity and diffusivity are constant. The effective thermal properties of Region I must be input on Form 3F as the tunnel wall thermal conductivity and tunnel wall thermal diffusivity, for each line segment of the system. Similarly, the properties for Region II are entered as the surrounding soil conductivity and surrounding soil diffusivity. Data for various types of soil, rock, and concrete are provided in Appendix G.

Studies with the heat sink subprogram indicate a low sensitivity to soil thermal property variations within the normally encountered range of values. This is fortuitous, since nonhomogeneity and anisotropy of local composition renders a precise determination of soil thermal properties impossible.

In the process of selecting the appropriate thermal properties, the program user should consider other phenomena in the vicinity of the tunnel which may influence the thermodynamics in the region. An example of such a situation would be the presence of underground water migration. Since the mathematical model does not include the analysis of water migration in the conducting medium, it is suggested that Figure 5.5 be applied to quantify migrating groundwater effects in terms of an enhancement of the surrounding soil thermal conductivity.

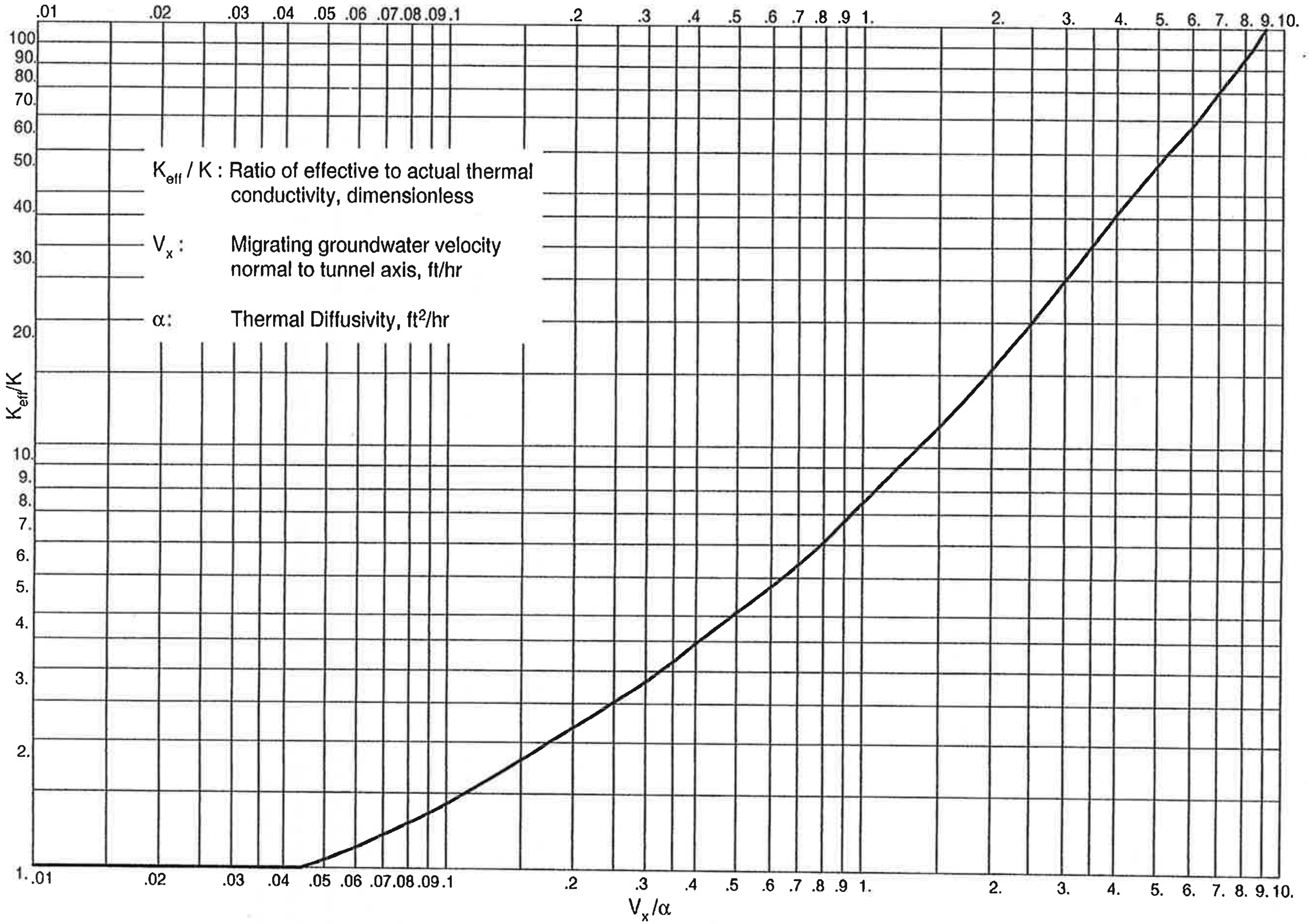


Figure 5.5 Effective Soil Thermal Conductivity as Influenced by Migrating Groundwater (Ref. 2)

Example 5.8 To illustrate the use of Figure 5.5, consider the situation where migrating groundwater with a velocity component normal to a subway tunnel of 0.04 ft/hr (350 ft/year) is encountered in soil with a diffusivity of 0.025 ft^2/hr and an actual thermal conductivity of 0.75 Btu/hr-°F-ft. In this case,

$$\frac{V_x}{\alpha} = \frac{0.04 \text{ ft / hr}}{0.025 \text{ ft}^2 \text{ / hr}} = 1.6 \text{ ft}$$

From Figure 5.5

$$\frac{K_{eff}}{K} = 12$$

Thus the effective surrounding soil thermal conductivity to be entered on Form 3F for this segment is 9.0 Btu/hr-°F-ft.

Tunnel Separation. The soil heat conduction computations are applied independently to each of the tunnels comprising the subway. In the instances where there are two separate tunnels running side by side, the heat transfer between the air and the surrounding structure of one tunnel is affected by the heat transfer between the air and the surrounding structure of the other tunnel. The heat conduction computations are corrected to account for this situation. The basis for this correction is the distance between the inside wall surfaces of adjacent tunnels (Input Form 3F).

The program user is required to provide this distance when there are parallel tunnels. When there is only one tunnel, this distance must be entered as zero.

Deep Sink Temperature. One of the assumptions upon which the heat conduction computations are based is that the earth surrounding the tunnel is initially at the deep sink temperature (Input Form 3F); i.e., the tunnel is at a sufficient depth below the earth's surface such that annual and diurnal fluctuations in ground temperature caused by surface variations have little effect on the heat conduction.

This temperature is usually approximated as the annual average temperature of the area or the groundwater temperature as typified by Figure 5.6. However, in the presence of underground geothermal activity this temperature can be considerably higher than the annual average temperature. The deep sink temperature is usually presented in the geophysical and/or geothermal data for the area, and such sources should be consulted for a more accurate determination.

Tunnel Wall Thickness. The mathematical model employed to simulate heat conduction in the materials surrounding a tunnel is considered a two material region, each consisting of a homogeneous material. Region I extends from the inner wall surface through the structure to the earth-wall interface. The tunnel wall thickness (Input Form 3F) is entered as the average structure thickness.

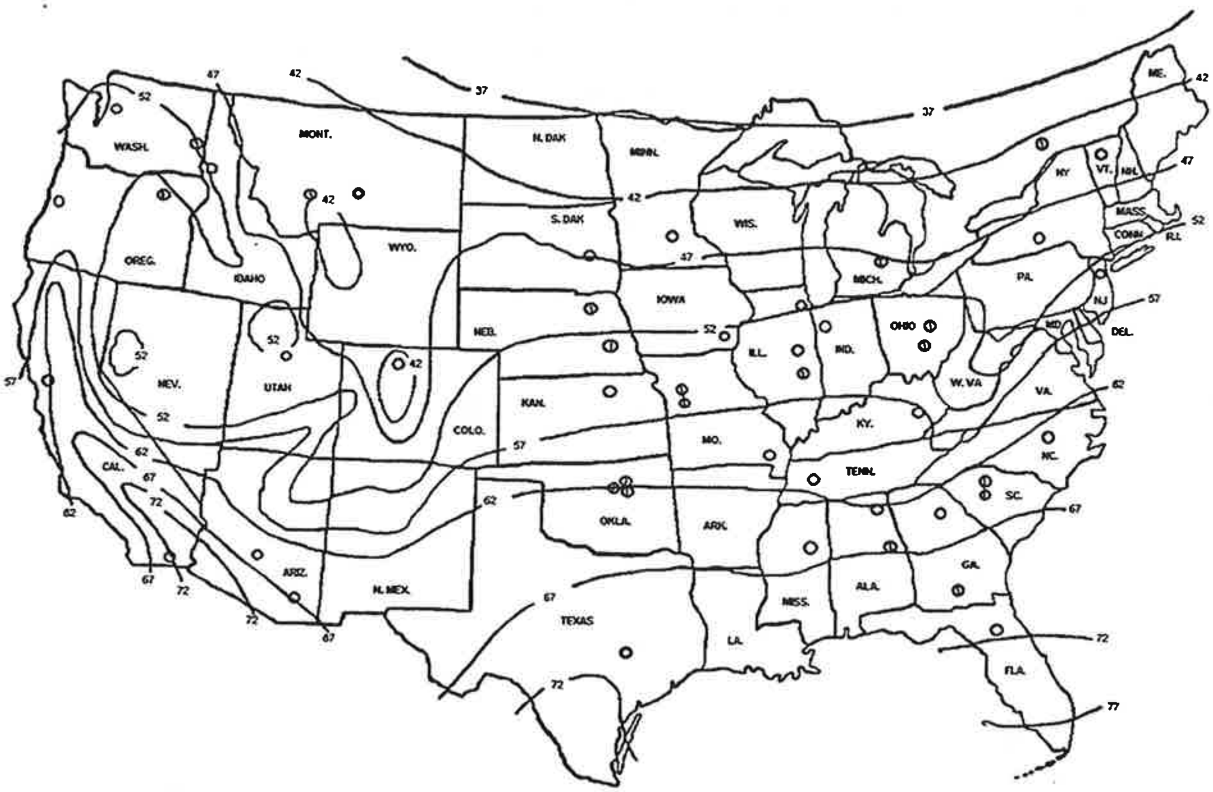


Figure 5.6 Ground Water Temperature Isotherms (Ref. 3)

User Suggestions. For cases where the user wishes to implement a heat sink evaluation for a system with no controlled zones (i.e., no mechanical cooling or heating equipment is planned), the entire system should be entered as one uncontrolled zone. However, this may not always be possible since there is an internal limit to the array size of the matrix of equations which the program generates for heat sink computations in each uncontrolled zone. This array size is equal to the sum of the number of subsegments and thermal subnodes in the uncontrolled zone. If a line segment or ventilation shaft in an uncontrolled zone is linked to a node, all the corresponding thermal subnodes are internally placed in the same uncontrolled zone. The array size limit (LMEQRM) is given in Appendix A. When the number of subsegments and thermal subnodes in an uncontrolled zone exceeds the array size limit. The user has the following options:

1. Enter the ventilation shafts of this uncontrolled zone connected to the atmosphere as Type 3 (non-inertial) zones in accordance with the guidelines in section 5.9.
2. Decrease the number of subsegments in the uncontrolled zone.
3. Increase the array size limit (see Programmer's Manual).

REFERENCES

1. Associated Engineers Report No. UMTA-DC-MTD-7-72-22. "A Model for the Prediction of Long Term Heat Sink Effects on Subway Thermal Environment". Prepared by Parsons, Brinckerhoff, Quade & Douglas, Inc., New York for United States Department of Transportation and Transit Development Corporation, Washington, DC.

2. Vienna City Council, Vienna Office of Public Works - Council Dept. 32, Transport Construction - Special Buildings. "Part 2 - Investigation of the Thermodynamic Problems of the Underground Railway," Vienna, May 1970.

3. ASHRAE Transactions 0.71, pt 1, pp 61-75, 1965.

6. TRAIN SIMULATION OPTIONS

The SES program provides the user with four options regarding the extent and manner in which train operation is to be simulated. The program allows the user to simulate the operation of trains in open air, within a tunnel system, or both. In addition, the program provides options regarding the manner in which the location, speed, acceleration, and rate of heat release of each train is computed, enabling the user to compute or to pre-specify any or all of this information. In new systems for which no train operating information is available, the user may wish all this information to be computed. In other instances, when the program is being applied using existing train operating data, the user may specify either the train operating data and the heat release or only the train operating data.

The selected option is specified by the user by indicating a Train Performance Option of 0, 1, 2, or 3 on Input Form 1C. For each option, only the input forms needed for that option need to be filled out; remaining input forms should be skipped. The four train simulation options available to the user are as follows:

Option 0 - Bypass Train Simulation. This option allows the user to simulate tunnel system without simulating trains. Input Forms 8A through 8F (Train Route Description), Forms 9A to 9L (Train Data), and Form 10 (Train Initialization Data) should be skipped when using this option.

Option 1 - Implicit. The implicit train performance option directs the train performance subprogram to make use of a modified version of the classical train performance calculation method to compute the train location, speed, acceleration and energy consumption. This calculation makes use of the motor characteristic curves, track grades, speed limits, etc. The placing of trains into operation, their movement through the system, the rate of heat rejection, and their removal from operation is controlled by the train performance subprogram based upon the data supplied for the Train Route Description (Input Form series 8) and the Train Data (Input Form series 9). In addition, the system may be initialized with trains in operation (Input Form 10).

Option 2 - Explicit (Train Heat Rejection Computed). Explicit train performance is used when the movement of the trains through the system is known prior to the simulation. This information may be obtained from another train performance computer program, or if the system is operational, from measurements taken onboard operating trains.

The schedule of train movement through the system must be supplied by the user on Input Form 8E in the form of a time-dependent table of train speeds. By using the train performance characteristics and route data, the program will approximate the rate of heat generation created by accelerating and decelerating the train. Some of the data requested for Input Form series 8 and Input Form series 9 is not required, and the items which may be skipped are identified in Tables 6.1 and 6.2. This option also allows the system to be initialized with trains in operation.

Option 3 - Explicit (User-Specified Train Heat Rejection). This option is similar to Option 2 in that the user specifies a time-dependent table of speeds that each train is to follow as it moves through the system. However, in this case the user also specifies the corresponding rates of heat generation by the train. This option requires the minimum amount of data in the Train Route Description and Train Data (Input Form series 8 and 9) but does require a prior knowledge of train movements and heat generation (Input Form 8E). In addition, the system may be initialized with trains in operation.

It should be noted that for Train Performance Options 0 and 3, the Train Energy Summary described in Section 10.9 is not printed. The following two sections of this manual discuss the Train Routing (Input Form Series 8), and Train Performance (Input Form Series 9) input requirements for the SES program. Depending upon the Train Performance Option indicated on Input Form 1C, certain forms required in the Input Form series 8 and Input Form series 9 may be skipped. The specific forms which may be skipped are identified in Tables 6.1 and 6.2.

Table 6.1 Train Route Description Requirements

	Train Performance Option			
Input Form	0	1	2	3
8A - General Data and Dispatching	-	X	X	X
8B - Dispatching	-	X	X	X
8C - Track Section Data	-	X	X	-
8D - Scheduled Stops	-	X	-	-
8E - Speed-Time Profile	-	-	X	X
8F - Section Sequencing	-	X	X	X

Table 6.2 Train Data Requirements

Input Form	Train Performance Option			
	0	1	2	3
9A - General Data	-	X	X	X
9B - General Data	-	X	X	X
9C - Steady-State Heat & Auxiliary Power Consumption	-	X	X(1)	X(1)
9D - Resistor Grid Characteristics	-	X	X	X
9E - General Data	-	X	X	X
9F - Motor Data	-	X	X	-
9G - Motor Data	-	X	X	-
9H - Chopper Control Characteristics	-	X(2)	X(2)	-
9I - Motor Data	-	X	X	-
9J - Acceleration and Deceleration Limits	-	X	-	-
9K - Flywheel Data	-	X(3)	-	-
9L - Flywheel Data	-	X(3)	X	-

X = Data must be entered on input form
- = Input form must be skipped
(1) = Passenger-dependent variable rates do not apply
(2) = Omit this form if Train Controller Option 1.0 is indicated on Form 9G
(3) = Omit this form if Onboard Flywheel Simulation Option 1.0 is indicated on Form 9H

7. TRAIN ROUTING

A train route is a path taken by a subway train as it moves through the system. The train route information includes data describing the train scheduling, track profile, coasting information, location of stops and dwell time at each stop, the route the train follows through the tunnel system and, if Train Performance Option 2 or 3 is being used, the speed-time profile or speed-time-power dissipation profile that the train follows as it travels along the route. The train scheduling data specifies the headway (the time between trains) and the physical type of trains which are to operate on the route. The track profile consists of a description of the grade, curvature, speed limits, and energy sector numbers along the route. The coasting information consists of the coasting parameter which indicates whether or not coasting is permitted, and the coasting option which indicates which type of coasting will be used. A stopping point is defined by the location along the route where the front of the train is located when it comes to a stop, and the dwell time is the length of time that the train remains stopped in the station. The route the train follows through the system consists of a list of the identification numbers of the line sections through which the train passes. The speed-time profile specifies the speed and location of the train as a function of simulation time, and the speed-time-power dissipation profile specifies the rate of power dissipation caused by train acceleration and deceleration, as well as the speed and location of the train as it travels along its route. All of the above items compromise the specification of a route.

All trains operating on a route are subject to the specifications of that particular route, and one route is required for each different set of specifications. The maximum number of train routes that can be defined for a simulation is controlled by the array size limit to the number of train routes. (Appendix A lists the numerical value of this limit.)

Trains are categorized into different types based on their physical or operational characteristics. The trains operating on any route may consist of any of the types which have been defined for the simulation.

Train routes are referenced internally in the program by a route number which is implicitly assigned to each route according to the sequential order in which it is defined to the program. Each route is self-contained and independent of other routes in the system. A line segment may have none, one, or more than one route passing through it. If there is more than one route, these routes may operate in the same direction, or in opposite directions.

Depending on the physical arrangement, a trackway may be simulated by one or more routes. If each train which travels upon the track passes through the same line segments and stops in the same locations for the same dwell time, then only one route is required to simulate that track. If, on the other hand, the track has a switch allowing some trains to pass through some line segments and others to turn off and pass through other line segments, or if some trains have different dwell times or stop at different locations, then more than one route is required to simulate that track. In the case of different stopping locations on the two routes, the track profile and path through the system would be the same on each route, but the location of the stopping points, dwell time, and possibly the speed limits would differ.

Each line section through which the route passes must be listed in the sequential order that the route, and also the train, passes through them. Each line section is entered with either a positive or a negative section identification number. (The method by which positive and negative directions are established within the sections is described in section 3.3.) The sign of this number is used to indicate the direction in which the trains pass through the section: (+) a plus sign indicates that the direction of the trains through the section is the same as the direction of the positive airflow in the section; (-) a minus sign indicates that the trains pass through the section in the direction which is opposite to that of positive airflow in the section.

When entering the list of positive or negative section numbers, several factors must be considered. Since train routes may only pass through line sections, ventilation shaft sections must not be entered. The list of positive and negative section numbers must form a consistent path; that is, two sequential sections in the list must be connected at a common node in the proper sense, such that it is possible for trains to move through the sections in the directions which were specified.

7.1 Section Sequencing for Route (Input Form 8F)

This portion of the input data specifies the path the route takes through the tunnel network. This path is described by a sequential list of positive or negative section numbers through which the routes and the trains pass.

The user must first specify the number of sections through which the route passes. If the route remains in the open air throughout its entire length, this number should be entered as zero. In this case, where no tunnel system has been defined, the remainder of the form may be skipped.

Each train route has a coordinate system that begins at a point which is called the route origin and increases in the direction of train movement on the route. Figure 7.1 is a sketch which illustrates route terminology.

All distances along the route are measured in feet, and locations are given in feet with respect to the route origin, which is located at zero feet. A route may enter or leave the tunnel system through a portal, which is a place where a line segment terminates in an opening to the atmosphere. The user must specify the distance from the route origin to the portal or first node on route on Input Form 8F. This distance is used to fix the location on the route of the first tunnel section, with each subsequent tunnel section following in the order in which the route passes through them. If the route originates within the tunnel system, the route origin must be located at a node. This is accomplished by entering zero for the distance from the route origin to the portal or first node on route.

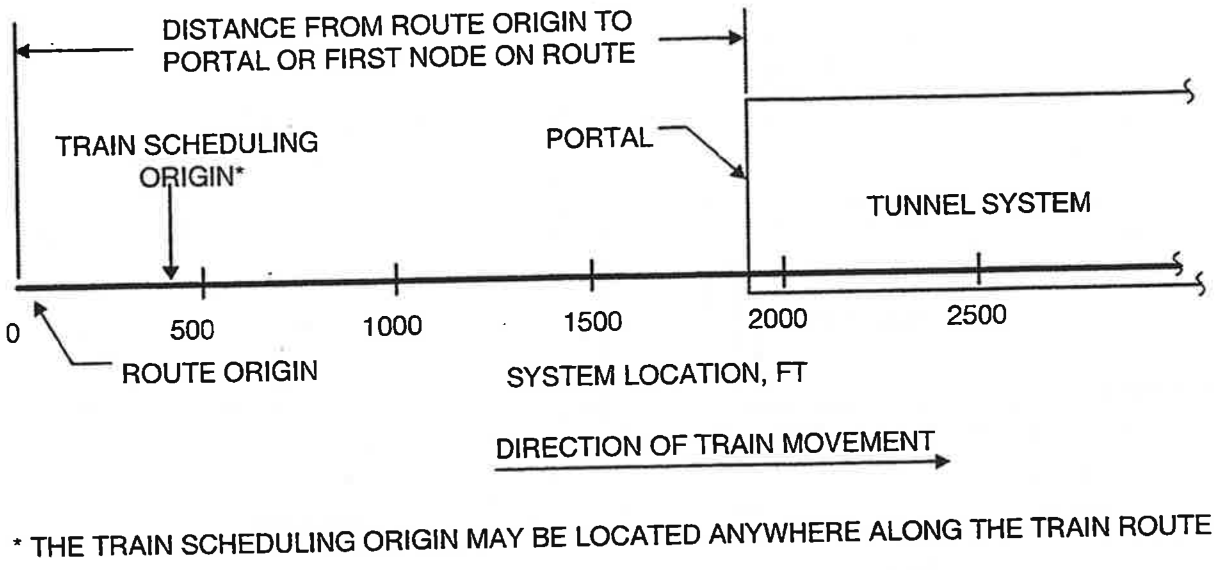
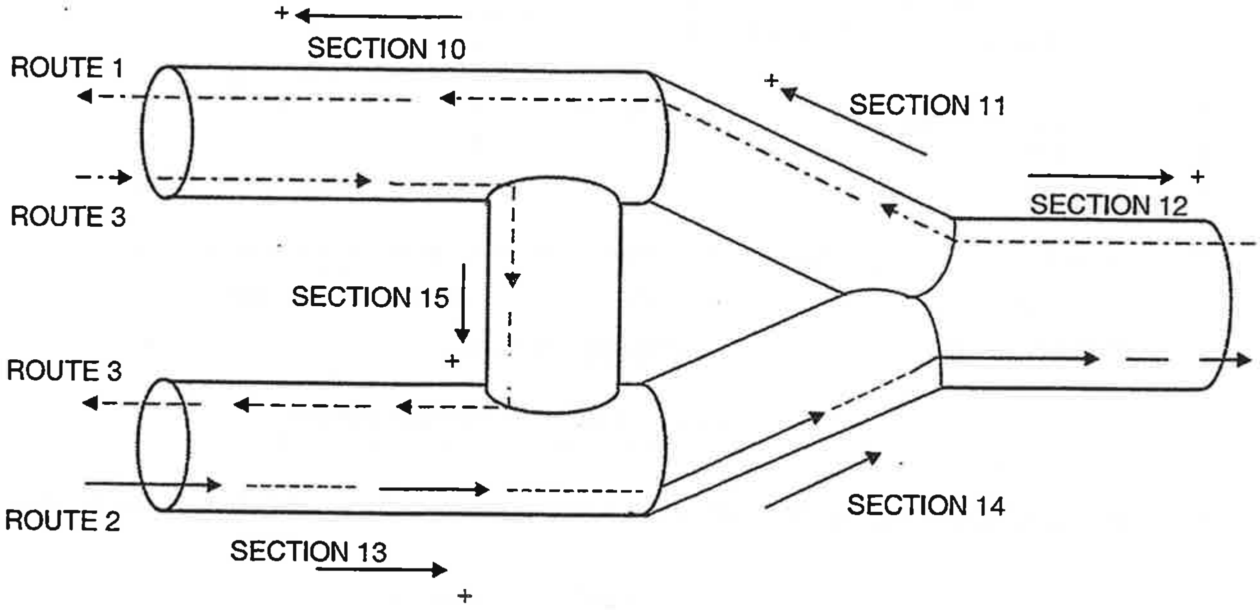


Figure 7.1 Train Route Terminology

The user is reminded that the SES program will not simulate dead end tunnels. However, a line segment may terminate at a node which has only one other section, usually a ventilation shaft, connected to it. Or, if only the line section is connected to the node, the node becomes a portal and the line section terminates at an opening to the atmosphere.

A sample of train routing through a small system is shown in Figure 7.2. The tunnel system consists of 6 sections, and 3 train routes pass through it. Each section identification number is shown on the figure, with the direction of positive airflow in each section indicated by an arrow. The section sequencing is shown for each of the three routes. An additional example of section sequencing for train routes is provided in Figure 7.3.

User Suggestions. Two types of track switching can be found in subway systems. The first is a switch where one track diverges into two tracks. This would be simulated by two routes, which would run parallel through the same segments until the switchpoint where they would branch into different directions. The second type consists of two tracks which converge into one track at a switch. This would also be simulated by two routes. However, in this case the routes would originate at two different points and pass through different segments until they both reach the switchpoint. From that point on, they would run parallel through the same segments.



KEY:

→+ AN ARROW AS SHOWN SIGNIFIES THE USER-DEFINED POSITIVE DIRECTION FOR A SECTION

ROUTE 1

NUMBER OF SECTIONS THROUGH WHICH ROUTE PASSES = 3.
SECTION SEQUENCING FOR ROUTE IN THE ORDER IN WHICH THE TRAINS PASS THROUGH THE SECTIONS

-12.
+11.
+10.

ROUTE 2

NUMBER OF SECTIONS THROUGH WHICH ROUTE PASSES = 3.
SECTION SEQUENCING FOR ROUTE IN THE ORDER IN WHICH THE TRAINS PASS THROUGH THE SECTIONS

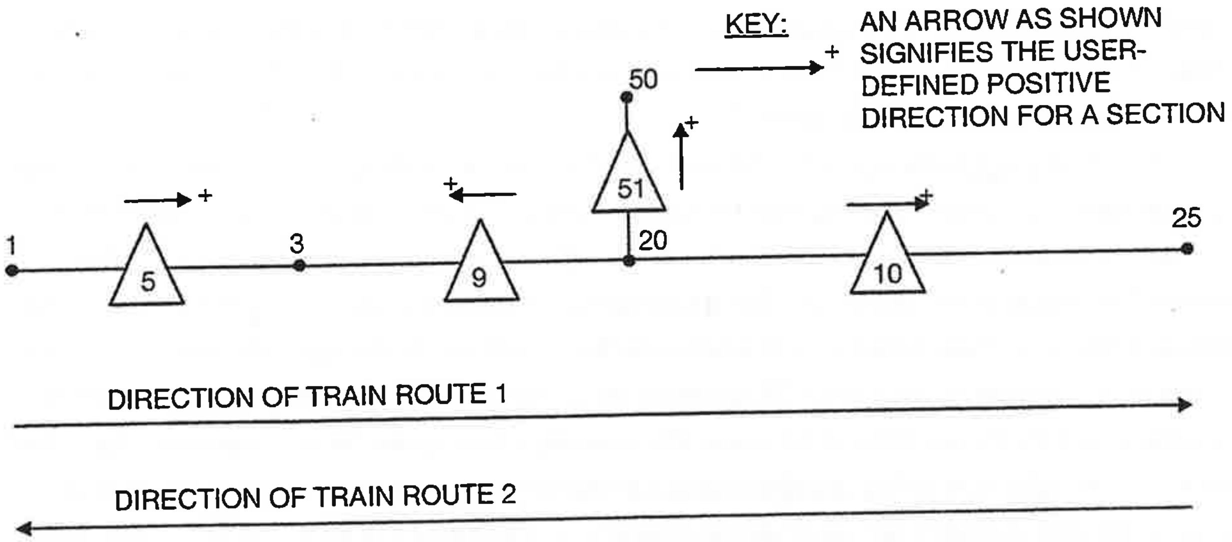
+13.
+14.
+12.

ROUTE 3

NUMBER OF SECTIONS THROUGH WHICH ROUTE PASSES = 3.
SECTION SEQUENCING FOR ROUTE IN THE ORDER IN WHICH THE TRAINS PASS THROUGH THE SECTIONS

-10.
+15
-13.

Figure 7.2 Sample of Train Routing



<u>SCHEMATIC DIAGRAM OF SYSTEM INCLUDING DIRECTION OF TRAIN ROUTES WITHIN THE SYSTEM</u>

<u>SECTION SEQUENCING FOR TRAIN ROUTE 1</u>

THE NUMBER OF SECTIONS THROUGH WHICH ROUTE PASSES = 3.

SECTION I.D. NUMBERS IN THE ORDER IN WHICH THE TRAINS PASS THROUGH THE SECTIONS } +5. -9. +10.

<u>SECTION SEQUENCING FOR TRAIN ROUTE 2</u>

THE NUMBER OF SECTIONS THROUGH WHICH ROUTE PASSES = 3.

SECTION I.D. NUMBERS IN THE ORDER IN WHICH THE TRAINS PASS THROUGH THE SECTIONS } -10. +9. -5.

Figure 7.3 Examples of Section Sequencing for Train Routes

1. <u>Diverging Tracks</u>: The program user will be able to control train spacing by adjusting the relative time of dispatching trains on the different routes. The train headway and the time lag between the trains on the different routes can be adjusted. The case of one track branching into two tracks could be handled easily. The two routes would run on the same track through the same segments up to the branch point, and then diverge. To simulate alternate operation on two routes, A and B, with a 90-second headway in the common section, the user would specify a 180-second interval between trains and no time delay on Route A and a 180-second interval between trains on Route B with a 90-second time delay. A time delay is a means of delaying the dispatch of the first and subsequent trains on a route. The amount

of the time delay is entered as the delay time before dispatching the first train on Input Form 8A. This scheduling scheme would result in a 90-second headway in the common section of track, and a 180-second headway on each leg of the branch.

2. Converging Tracks: A situation wherein two separate tracks merge into one track poses a more difficult problem since proper spacing must be maintained between the converging trains. However, the time it takes the trains on each route to travel from their scheduling origin to the switchpoint is initially an unknown. This problem is solved by simulating train operation until a train on each route has reached the switchpoint. The time it takes each train to travel from the respective scheduling origin to the switchpoint can then be determined for each route. These times are compared and from them the time lag necessary to properly space the trains can be determined. This time lag is then applied to the proper route by placing the value as the delay time before dispatching the first train on Input Form 8A. In this way the user can coordinate the train operation on both routes to ensure a smooth merging of the trains at the switchpoint.

7.2 Entering Trains Upon Routes (Input Forms 8A, 8B)

Trains are placed into operation on the route at the train scheduling origin (Input Form 8A). The location of a train is defined to be the distance along the route coordinate system where the front of the train is located. The remainder of the train extends in the negative direction along the route coordinate system. The train scheduling origin (see Figure 7.1) may lie anywhere along the route — from the route origin to the forward end of the last track section which defines the end of the route. In the case of a route that originates outside of the tunnel system and enters the tunnel system through a portal, the train scheduling origin may be located in either the open air portion of the route or within the tunnel system.

Trains are placed in operation at the train scheduling origin according to the time schedule defined for the route in the dispatcher information. If implicit train performance (train performance Option 1 on Input Form 1C) is being used, the trains are placed in operation at zero speed and immediately begin to accelerate and travel along the route. If explicit train performance (train performance option 2 or 3 on Input Form 1C) is being used, the trains are placed into operation at the speed which is specified for time zero on the speed-time profile. Trains are removed from operation when the front of the train goes beyond the forward end of the last track section, or, in the case of explicit train performance only, when the front of the train goes beyond the last point of the speed-time profile.

A train is considered to be operational from the time that it is dispatched onto its route until it is removed from operation. Each train is assigned a train number by the program which is used to identify a particular train throughout its period of operation. Train numbers are assigned to trains in the sequential order in which they are created — the trains which are in operation at system initialization first, and then in the order in which they are dispatched onto their respective routes. There is a limit to the number of trains that can be operational at a given instant. This number is controlled by the limit to simultaneous operating trains, the value of which is listed as LMTRAN in Appendix A of this manual.

An attempt to exceed the maximum number of simultaneous operating trains during a simulation will result in a simulation error message. When this occurs, a new train will not be placed into operation until after a train has been removed from operation in order that the new train will not cause the limit of simultaneous operational trains to be exceeded. It should be noted, however, that by not placing this train into operation the normal train scheduling is disrupted. If the user is analyzing the events in the system at stabilization, the disruption of the train schedule, which is a major forcing function of the system, will prevent the system from reaching stabilization and, in many cases, invalidate the results of the simulation.

A maximum of eight trains may be located in a line segment at one time, and these trains may be on the same route or on different routes. If the program limit of eight trains simultaneously located in a line segment is exceeded during a simulation, only eight of the trains will be considered to be in the segment for aerodynamic and thermodynamic calculations. The remaining trains will temporarily be considered to be outside of the tunnel system, and a simulation error message will be printed. When the number of trains in the line segment becomes eight or less, the error condition would no longer exist and the simulation would continue.

Minimum Coasting Velocity. For each route on which coasting is permitted, the user must specify the minimum speed that can be attained by the train. In addition, the user must indicate the coasting option, the trains mode of operation, should the minimum speed be reached. The user has the option of allowing the train to operate in a constant speed mode at the minimum speed, or to switch to an accelerating mode.

Train Dispatching and Scheduling. For each route which is being simulated, the user must provide the schedule by which trains are to be dispatched onto that route. When a train is dispatched a new train is created with the characteristics of the train type which is indicated, it is assigned a train number by the program which can be used to identify the particular train, and the train is placed into operation at the train scheduling origin of its route. The train then proceeds to travel along its route in the positive direction.

A train group consists of one or more consecutive trains which are dispatched on the same route that are of the same type and the same headway. The train headway is defined as the time interval between trains on the same route. The headway for a given train is the elapsed time between the dispatching of the previous train on the given train's route and the time the given train was dispatched. Since a train group consists only of trains with the same characteristics, if either the train type or headway changes, a new group is formed for that route.

The user must define the number of groups of trains that could enter the route. The first train group contains only one train, but the second and subsequent train groups can be composed of one or more trains of the same type and operating at the same headway. The first group, which is a special case, does not have a headway, rather it has a delay time before dispatching the first train. This is the time that the program is to wait after the beginning of the simulation before the first train is dispatched onto this route. After all the trains in a group have been dispatched, the program begins to dispatch trains from the next group.

Example 7.1 Figure 7.4 shows sample input for train scheduling data. The number of groups of trains that could be entered is 4, and the delay time before dispatching first train is 70 seconds. The first train type was entered as 3, and therefore the first train group consists of one train of Type 3 which is dispatched 70 seconds after the start of the simulation. In the case of the first train group, the number of trains is understood to be 1. The second train group contains three trains of Type 1 which are operating at 100-second headway. They are dispatched at 170 seconds (70 plus 100), 270 seconds (170 plus 100), and 370 seconds (270 plus 100). The third group contains only one train of Type 3 which is operating at 150-second headway. It is dispatched at 520 seconds (370 plus 150).

Number of groups of trains that could enter route = 4.
Delay time before dispatching first train = 70 seconds.

Group Number	Number of Subway Trains	Train Type	Headway (Seconds)	Time Last Train in Group becomes Operational (Seconds)
1	1	3	70	70
2	3	1	100	370
3	1	3	150	520
4	5	1	100	1020

Figure 7.4 Example of Train Dispatching Data

The fourth train group contains five trains of Type 1 which are operating at 100-second headway. The first is dispatched at 620 seconds (520 plus 100), and the last is dispatched at 1020 seconds (520 plus 5 x 100).

In the above example only trains of Type 1 and 3 are being dispatched, and no trains of Type 2 are being dispatched onto this route. Type 2 trains may be dispatched on other routes, or they may not be dispatched at all. It is not incorrect to define additional train types that are not being used in a particular simulation providing the program array size limit for the number of train types, given as LMTRTP in Appendix A, is not exceeded. The additional train type might have been originally defined for another simulation, and the user did not wish to remove it from the data set since it was planned to be used in future simulations. However, it is incorrect to attempt to dispatch a train type that has not been defined. Whereas in example 7.1, the trains are dispatched into the system at irregular intervals, generally a system would be simulated with trains dispatched at regular intervals. Since the trains are a major forcing function upon the airflows and temperatures in the system, a regular train schedule is necessary for the system to become stabilized. A stabilized system is one in which all calculated values of parameters — airflow rate, temperature, and humidity — repeat at regular intervals. The interval over which this repetition occurs is usually the same interval over which the train dispatching repeats for all of the routes.

The user should define enough trains to be dispatched into the system such that the time at which the last train is to be dispatched is at least equal to, and preferably greater than, the maximum simulation time for the simulation. The maximum simulation time indicated on Input Form 13, which is used to control the program operation, defines the point at which the simulation is to be terminated. If the simulation is terminated before all the trains are dispatched into the system the remaining trains will neither be dispatched nor simulated. If, on the other hand, the maximum run time was more than one headway greater than the time at which the last train on each route is to be dispatched, then the results of the simulation might not be meaningful. If this is the case, when there are no new trains entering the system, it will go into an aerodynamic "die-down" mode in which the airflows will decrease due to damping, and the temperatures within the system will approach the wall surface temperature. If the user is taking summaries of the results, the results of the stabilized system and not of the system in "die-down" will usually be used.

It frequently occurs during a series of runs simulating a system that the length of the simulation must be increased. Users are cautioned that it is a common error to increase the "maximum simulation time" and to adjust the print controls accordingly, but to fail to adjust the train dispatcher data to reflect the longer simulation. This causes the system to die-down near the end of the simulation and possibly invalidate the results. Other items which must be checked when a longer simulation is performed are fans and unsteady heat loads. Each ventilation shaft which contains a fan has associated with it a time at which the fan switches on, and a time at which the fan switches off. If the fan is to remain operational throughout the entire simulation, the time when the fan switches off must be greater than the maximum simulation time. Unsteady heat loads also have associated with them a time after which the load becomes active and a time after which the load becomes inactive. If the load is to remain active throughout the remainder of the simulation, the time after which the load becomes inactive must be greater than the maximum simulation time.

7.3 Track Section Description (Input Form 8C)

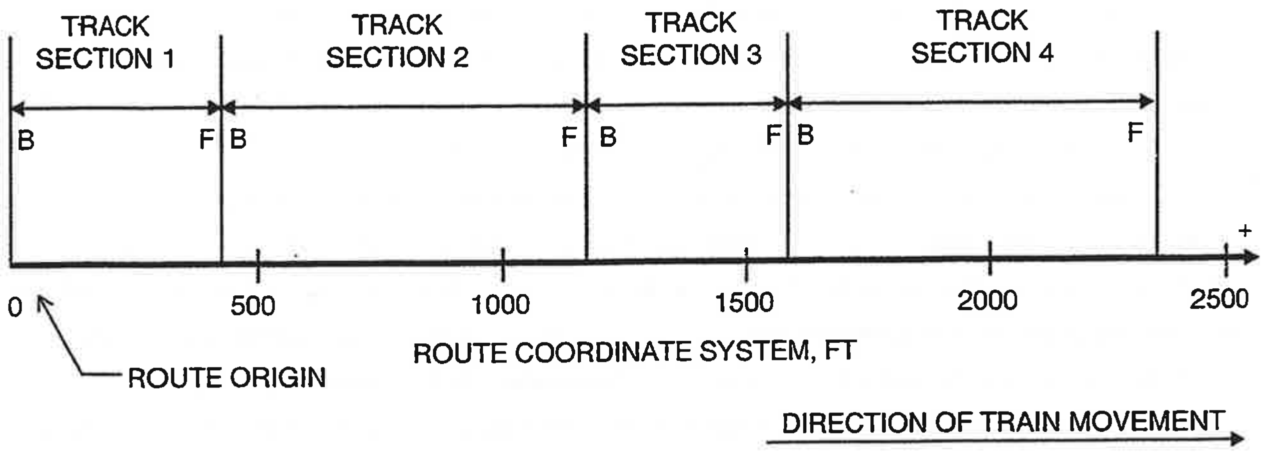
When train performance Option 1 or 2 is being used, each route must have associated with it a description of the track curvature, grade, maximum allowable train velocity that occurs along the route, energy sector number and coasting parameter. The train route is divided into lengths, called track sections, over which these parameters remain constant. These track sections are not to be confused with the line sections required for the aerodynamic simulation. A change in any of the five parameters - track curvature, grade, maximum allowable train speed, energy sector number, or coasting parameter - necessitates the formation of another track section.

A forward end and a backward end must be defined for each track section. These ends are defined with respect to the route coordinate system which starts at the route origin and increases in the direction of train movement on that route. The backward end of the track section is the end which is located closest to the route origin, and the forward end of the track section is the end which is located furthest from the route origin and has the higher coordinate upon the route coordinate system.

Figure 7.5 shows a route which consists of four track sections. The track sections are numbered in increasing order in the positive direction with respect to the route coordinate system. The first track section is situated with its backward end at the route origin (location 0.0) and its forward end further along the route. The backward end of the second track section is coincident with the forward end of the first track section. The route is defined from the route origin to the forward end of the last track section. Track sections are defined by giving the location of the forward end of the track section. This location is the coordinate, in feet, along the route coordinate system. The length of the Nth track section is equal to the location of the forward end of track section N minus the location of the forward end of track section N-1. However, the first track section begins at the route origin and extends to the location of its forward end. The location of the track section boundaries must be given in feet measured along the track. This is the actual distance that a train operating on that route would travel, and this distance would differ from the horizontal distance if the route contains grades or curves.

The user must determine the number of track sections that are required to describe a route and then proceed to describe each of the track sections. The track sections are described in increasing order, beginning at the route origin and continuing in the positive direction along the route. Trains operating on a route are removed from operation on the first complete train evaluation (defined in Section 10.11; in most cases 1 second) after the front of the train has gone beyond the location of the forward end of the last track section. With this in mind, a route which exits a tunnel system through a portal should be extended at least one train length beyond the portal. This will allow the train to completely exit the portal before it is removed from operation. If the route is not continued far enough past the portal, the train will be removed from operation while it is exiting the tunnel, and the airflow will be affected by a sudden drop in the train forcing function.

Routes which terminate within the tunnel system should have the forward end of the last track section located at the place where the train is to be removed from operation. This might be a short distance, for example 20 feet, from the physical end of the tunnel. (The user is reminded that dead end tunnels cannot be simulated by the SES program.) The allowable speed in the last track section should be low, so that the train approaches the terminal point slowly. To prevent a violation of airflow continuity within the system, a new train should be placed in operation for each train that is removed from operation within the system. This train should be placed in operation at exactly the same physical location in the system that the corresponding train is removed from operation. (This alignment problem is reduced if the process of removing trains from operation and placing new trains in operation is done entirely within the same line subsegment which is longer than one train length - in this way for every train that enters the subsegment one train will leave, thus preserving continuity of air mass entering and leaving the subsegment.) Train reversals can be accomplished in this manner - i.e. a train traveling in one direction is removed from operation and a train is placed into operation at the same location but traveling in the opposite direction on a different route.



KEY:

F = THE FORWARD END OF THE TRACK SECTION

B = THE BACKWARD END OF THE TRACK SECTION

Figure 7.5 Track Section Relationship to Route Coordinate System

Radius of Curvature. Horizontal curves are usually constructed as portions of a circle. The amount of curvature is measured by the radius of this circle. That is, a sharp curve would have a small radius and gentle curve would have a long radius. Track curvature is a parameter winch is used by the train performance subprogram since an additional amount of train resistance is experienced by trains as they round curves. This additional train resistance is caused by increased friction of the wheels on the rails. For properly banked curves, it is inversely proportional to the radius of curvature. The additional train resistance which is caused by the train rounding a curve is small compared to the rolling resistance and other resistances that act upon a train. Often a spiral will be used as a transition between the straight section of track and the curved portion. For defining the track sections the spiral may be ignored with the boundary between the straight and curved portions of track at the midpoint of the spiral. A straight section of track, sometimes referred to as tangent track, is a curve of infinite radius. To represent this a convention has been established by which a curve radius of zero feet (0.0) is interpreted to mean that the track is straight. All other curve radii are entered by giving the radius length in feet.

Grade or Elevation of Forward End. For each track section the track grade may be entered. This grade may be positive (uphill) or negative (downhill). The grade for each section may be entered as a percentage or as an elevation of the forward end of the track section. If the percentage grade is available from the plans, the grade would be preferred rather than elevations.

. The elevation of the forward end of the track section is given in feet and may be measured with respect to an arbitrary datum. The grade of a track section is the difference in elevation between the forward end and backward end of the track section divided by the horizontal distance (the length of the track section is actually the sloping distance or the hypotenuse of the triangle).

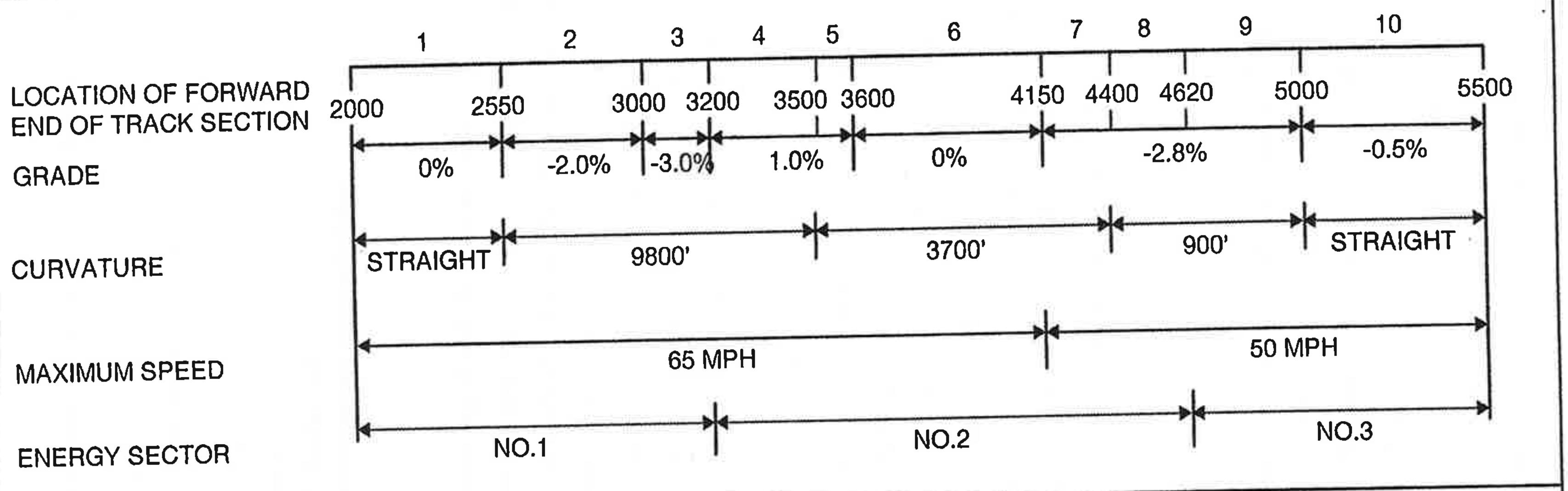
Elevations may be either positive or negative indicating that they are, respectively, either above or below the datum. It is usually best to set the datum below the lowest point and use only positive elevations. This eliminates sources of user error which can occur from manipulating numbers of different sign. All elevations must be either greater than +0.1 feet or less than -0.1 feet. When an elevation is entered as zero or close to zero, the program uses the number which is entered as the grade. Consequently, an elevation of zero cannot be entered. When the elevation of the forward end of the first track section is entered, this same elevation is taken as that of the backward end of the first track section and the grade is equal to zero. The second and subsequent track sections use their elevation with the elevation given for the previous track section to compute the grade.

Maximum Allowable Train Velocity. For each track section the user must enter the maximum train speed at which the train may operate in the track section. This speed will not be exceeded by the train, but the train will attempt to speed up to this limit with one exception. The exceptional case occurs when coasting has been specified for a track section and, if the train reaches the minimum speed restriction within that track section, the option to remain at the minimum speed has been designated.

Energy Sector Number. A tabulation of the energy consumed by train propulsion and auxiliary systems is made for each energy sector. One or more track sections can be located in an energy sector, and the track sections within the same energy sector need not be contiguous. The energy sector numbers may range from one (1) to LMSTR, which is given in Appendix A. An entry of zero for energy sector number indicates that an energy tabulation is not required for that track section. See Section 10.9 for further details on the Train Energy Summary Output.

Coasting Parameter. If train performance option 1 is being used, coasting can be designated within a track section. For each track section permitting coasting the user must enter a 1.0 for the coasting parameter; otherwise, a 0.0 must be entered.

Example 7.2. The route must be divided into track sections, each of which is a length of track over which the grade, curvature, maximum allowable train speed, coasting parameter and energy sector number are constant. Figure 7.6 shows an example of how track section data would be prepared for a route on which coasting is not permitted. The portion of the route which is shown is divided into ten track sections. If coasting were permitted, for example, on track sections 2 and 3 the total number of track sections would remain at ten. However, if coasting were permitted only for a portion of track section two, the user would have to enter each portion as a separate track section raising the total to eleven. The maximum number of user-defined track sections



SAMPLE PROGRAM INPUT CORRESPONDING TO THE ABOVE TRACK SECTIONS

TRACK SECTION NUMBER	1	2	3	4	5	6	7	8	9	10
LOCATION OF FORWARD END OF TRACK SECTION	2550	3000	3200	3500	3600	4150	4400	4620	5000	5500
GRADE, PERCENT	0.0	-2.0	-3.0	1.0	1.0	0.0	-2.8	-2.8	-2.8	-0.5
CURVE RADIUS, FT	0.0	9800	9800	9800	3700	3700	3700	900	900	0.0
MAXIMUM ALLOWABLE TRAIN SPEED, MPH	65	65	65	65	65	65	50	50	50	50
ENERGY SECTOR NUMBER	1	1	1	2	2	2	2	2	3	3

Figure 7.6 Sample Data Describing Track Sections

is controlled by the array size limit to the number of track sections for a route, and this value is given as LMTSRT in Appendix A of this manual. The user defines a number of track sections for each route, and to the user-defined track sections is added an additional number of track sections which are internally created by the SES Program. The total of the user-defined and internally-created track sections must not exceed the array size limit for the number of track sections for a route.* If this limit is exceeded, the user may either reduce the number of track sections that has been defined by combining adjacent track sections, or expand the program array size by the procedure outlined in the SES Programmer's Manual.

7.4 Scheduled Stops (Input Form 8D)

A scheduled stop is a location on a route where the trains operating on that route come to a stop. They remain stopped for a period of time which is known as the dwell time. During this time the number of persons aboard the train is changed by the number of persons entering or leaving the train. After the dwell time has elapsed, the train begins to accelerate and travel along its route.

The user must specify the number of scheduled stops for each route which is being simulated. For each stop, the user must specify the location of the front of the train when it comes to a stop, the dwell time, and the number of persons entering the train at the stop. The location of the stop does not necessarily have to be at a station, although it probably will be located at stations in the system. Stops may also be located in portions of the route that are outside the tunnel system.

The SES train performance subprogram also keeps track of the number of passengers onboard the train. Changes in the number of passengers aboard the train affect the train mass which changes the acceleration profile and other performance characteristics of the vehicle. The user must specify the number of persons aboard the train at the scheduling origin, and for each stop the number of persons entering the train must be specified. The number of persons entering the train at a stop is the net change in passengers at the stop. A positive number indicates more passengers are entering than leaving the train, and a negative number indicates more passengers are exiting than entering the train.

---

* The total number of user-defined and program-created track sections is given by the following equation:

$$TNITS = NTS + NLSB + 2 \times NSTOPS$$

where: TNITS = Total Number of Internal Track Sections for a Route
NTS = Number of Track Sections which are defined by user
NLSB = Number of Line Segment Boundaries
- Equal to the number of line segments that the route passes through plus one.
- Equal to zero for routes which remain completely in open air.

NSTOPS = Number of Scheduled Stops on the Route

The Total Number of Internal Track Sections for a Route must be less than or equal to the array size limit to the number of track sections for a route.

The train weight consists of two parts: the empty car weight (Input Form 9E) and the weight of the passengers (average patron weight on Input Form 1G).

The train may be simulated in two different ways. First, the user may enter the average empty car weight, the number of persons aboard train at scheduling origin and the number of persons entering the train at each stop. Second, if the number of persons entering the train is not available, then the average number of persons aboard train at scheduling origin may be entered. This number can be kept constant for the remainder of the simulation by entering a zero for the number of persons entering the train at each stop.

User Suggestions. Should the user desire to simulate stalled trains within the tunnel system, this may be done in either of two ways; the first may be used to examine the steady-state flow conditions produced by ventilation fans, and the second method would more accurately examine the transition from normal operation to the steady-state condition.

Steady-state ventilation may be examined by using a stop of long dwell time to position a stalled train in the proper location. The user would enter the train data and the train routes in a manner similar to that for the simulation of normal train operation. If train performance Option 1 (implicit train performance) is used, the user would initialize the system with one train in operation. This train should be located in the position of the stalled train, with a speed of zero, and a long remaining dwell time. The user is required to specify to the program the number of trains in operation at initialization. For each train which is in operation at initialization the user must specify the train location along its route, train speed, route number, train type, acceleration grid temperature, and deceleration grid temperature and, if the train is stopped, the remaining dwell time. All of the above information can be taken directly from a print (either detailed or abbreviated) of the instantaneous status of the system, except the remaining dwell time, which can be estimated by determining when the train came to a stop from prints of the system status at times prior to the time for which the trains are being initialized. The train would then be placed into operation at that location, and remain there for the duration of the dwell time, which should be longer than the maximum simulation time. The user should also enter a large value for the delay time before dispatching the first train on all the routes to prevent interference from other trains which would normally be dispatched into the system on their respective routes. Fans can be switched on at the beginning of the simulation and after an initial run-up period, the resulting steady-state airflow rates and air velocities can be observed throughout the system.

A more detailed study of a train breakdown can be performed by observing the transition from normal train operation to fan ventilated operation. This can be done by defining a system with the train data and train route information as would be done for normal operation. In addition, another route would be defined which is similar to the existing route except that it has only one train dispatched on it and has a scheduled stop of long dwell time at the point where the stalled train is to be located.

The system would be simulated in the normal mode of train operation until it had reached stabilization. Then train operation on the normal route would be suspended and, after one headway had elapsed, the train would be dispatched onto the route that contains the extra stop which is being used to simulate the train breakdown point. After this train has come to a halt, the user can switch on the emergency ventilation fan . The results of such a simulation would show the die-down of the stabilized airflow rates, and the length of time after the fans are switched on that they become effective and establish the minimum required airflows (see SEDH Vol. I, Part 3). The designer must not only specify that sufficient airflow is produced in the area of a stalled train, but this airflow must be established in a reasonable time after the fans are switched on. The designer might also wish to investigate the effects of train operation on opposing routes or the effects of other stalled trains within the system upon the emergency ventilation airflow rates.

8. TRAIN PERFORMANCE

The operation of subway trains may account for as much as 90 percent of the heat released in a subway transit system. Therefore, the simulation of train operations and the airflows that result from these train operations are a vital part of the SES computer model. The SES train performance subprogram computes the location, velocity, and acceleration of each train as it moves through the system using the instantaneous value of the unsteady air drag on the train computed by the aerodynamic subprogram. The air drag on the train is a function of the blockage ratio (the ratio of the frontal area of the train to the cross sectional area of the tunnel), the air velocity with respect to the train, and other factors. In addition, the train performance subprogram has been specifically designed to accurately compute the total heat release by trains, passengers, and ancillary equipment such as car air conditioning and lighting.

The calculation of the train location, velocity, and acceleration is performed by the train performance subprogram on a time-dependent basis. At any instant, a train may be in any of five operational <u>modes</u>: accelerating at full power, maintaining a constant speed, braking, coasting or stopped. The train performance subprogram monitors the operation of each train and switches modes when appropriate. It also dispatches new trains onto each route when directed and removes from operation those trains which have gone past the ends of the route.

Different trains which are operating in the system at a given time may have different physical characteristics. A <u>train type</u> is assigned to each train, with trains having similar characteristics being given the same <u>type</u>. Different train <u>types</u> would be required to identify trains with differing numbers of cars, empty car weights, motor characteristics, or any other parameters which are used to describe the train in the train data.

The train <u>route</u> is the path the train takes as it travels through the system. Coding for the route includes information describing the track geometry and the path the train takes through the tunnel network. Track geometry information includes grades, curvature, speed limits and stopping points with their respective dwell time. The path through the tunnel network consists of a list of section identification numbers which describe which sections the train passes through as it moves through the system. The train route also contains the data prescribing the times at which new trains are to be dispatched onto the route.

The user may define one or more train <u>types</u> and one or more train <u>routes</u> for a simulation. Train <u>types</u> are referenced within the program by type number which is determined by the sequential order in which the different train types are defined to the program. That is, the first train type is Type Number 1, the second is Type Number 2, etc. Similarly, the first train route is Route Number 1, the second is Route Number 2, etc.

The SES train performance subprogram monitors the operation of each train as it travels through the system. It generally attempts to move the trains along their respective routes as quickly as possible without exceeding the limits of speed, acceleration, and deceleration specified by the user. The travel time is minimized by accelerating as quickly as possible until either a limiting speed is attained, or the train must begin braking. When braking is required, the train brakes at a rate which is close to, but does not exceed, the maximum braking rate specified by the user.

8.1 Train Operating Modes

Accelerating Mode. When a train is accelerating the train's propulsion system is providing the maximum tractive effort which is available from the train motors at the speed at which it is operating. The net tractive effort is that which is available from the train motors minus the resistance to movement which the train encounters from track grade, track curvature, rolling friction, and air drag. The train acceleration is calculated using the net tractive effort, but never exceeds the upper limit of train acceleration specified by the user even if the tractive effort available would enable the train to accelerate faster than the user-supplied acceleration upper limit. The train acceleration rate varies with the speed-dependent motor curves and train resistance. The train continues accelerating until its speed reaches the maximum speed allowed in the track section on which the train is operating, or until it is forced to begin braking for an upcoming lower speed limit or a stopping point.

Constant Speed Mode. The constant speed mode of operation is used when the train speed has reached the maximum speed which is allowed in the track section. In this mode the tractive effort produced by the propulsion motors is set equal to that required to overcome the total resistance to train movement. The train continues in this mode until any of four situations is encountered: (1) the train enters a track section which has a higher speed limit, in which case the train switches to the acceleration mode to try to speed up to this new limit; (2) the train is forced to begin braking for either an upcoming lower speed limit, or a stop; (3) the train enters a track section where coasting is permitted; or (4) the train's propulsion system does not have enough tractive effort available at that speed to overcome the train resistance. In this last case the train would begin to decelerate slowly. This situation would typically occur when the train encounters an upgrade while running at a relatively high speed and cannot maintain this speed while negotiating the grade.

Braking Mode. The braking mode of train operation is used when the train is slowing for either an upcoming speed restriction which is lower than the train's current speed, or when the train is slowing for a stop. The train braking rate consists of two portions: a constant deceleration rate (used at low speeds), and a deceleration rate which increases linearly with decreasing train speed (used at higher speeds). These braking rates are defined by the user and are explained in more detail in the train data description. Once the train enters the braking mode it continues braking until it has either come to a stop or the train speed is equal to the speed limit for which it is braking. In the latter case the train would either switch to the constant speed mode and continue at the prescribed speed, or switch to the coasting mode if coasting is permitted in the new track section.

Coasting Mode. The coasting mode of operation is used when a train enters a track section on which coasting is permitted. Coasting is initiated only when the train reaches the maximum speed restriction specified by the user for the track section. The train's motors are turned off in the coasting mode. Depending on the grade of the track section, the train can begin to accelerate or decelerate while coasting. When operating on a level track or on an upgrade, the train will begin to decelerate slowly as its kinetic energy is expended overcoming the resistance forces. The resistance forces acting on the train include the air drag, the rolling resistance, the grade resistance and the curve resistance. On a downgrade, the train will accelerate up to the maximum speed permitted on the track section and maintain that speed by applying the brakes until one of the following events occur: a higher speed limit is encountered; a non-coasting track section is entered; a coasting track section with a less severe grade is entered; or it becomes necessary to brake for a lower speed restriction or a stop.

The minimum speed permitted during coasting for each route must be specified by the user. When a coasting train reaches the maximum speed two options are available: the train can maintain the minimum speed until a lower speed restriction is encountered, a non-coasting section is entered or a downgrade is encountered; or the train can revert to an accelerating mode. The decision to maintain speed or accelerate must be specified by the user for each route which permits coasting.

Stopped Mode. The stopped mode is used when the train has come to a stop. The train waits until the prescribed dwell time has elapsed, and then switches to the acceleration mode and resumes travel along the route.

8.2 Train Physical Data (Input Forms 9A, 9B, 9C, 9E)

The train type identifies a class of trains with a particular set of identical physical or mechanical properties which are defined by the user. Trains with different physical or mechanical properties would be classified into a different type. The user must determine the Number of Train Types (Input Form 1E) to be simulated, and then provide a complete set of train data for each type. The maximum number of train types that the program can simulate is controlled by the limit to the number of train types which is defined in Appendix A.

A subway train is composed of one or more cars which are connected to operate as a single unit. The Total Number of Cars Per Train is the combined total of all cars, both powered and unpowered. Some cars contain motors which are used to propel the train, while other cars do not, either by design or due to a malfunction of the propulsion system. Motor characteristics are given for each motor. By using the Number of Motors per Powered Car and the Number of Powered Cars in the train, the performance characteristics of the entire train can be evaluated.

The Total Length of the Train is the distance from the front of the first car in the train to the rear of the last car. The Frontal Area of the Train is the sum of the area of the car body and the area of the tracks and undercar equipment as seen in a frontal projection of the vehicle. (The subway car trucks usually consist of four load bearing wheels, a spring suspension system to which they are attached, and the traction motors which are used to power those wheels. The truck is attached to the car body with a pivot, which allows the truck to rotate as the car rounds a turn. The undercar equipment comprises an electrical motor control system which controls the operation of the traction motors, a resistor grid if it is required by the motor control system, an air compressor which supplies air for the braking system, electrical fuse boxes, emergency lighting batteries, and miscellaneous equipment.) This frontal area is used as an effective area in the aerodynamic calculations, hence it should be the average area along the length of the car. The Perimeter of the Car is the perimeter corresponding to the train frontal area. This number is the length of the sides and top of the car body plus the length of the sides and bottom of a rectangle whose width is equal to the width of the train and whose area is equal to that which was used for the average area of the truck and undercar equipment. The Total Length of Train and Perimeter of Car are measured in feet; the frontal area is measured in square feet.

The aerodynamic drag on the train comprises three parts: the drag on the front or nose of the vehicle, the drag on the sides, top, and bottom of the vehicle and the drag on the back or tail of the vehicle. The Front of Train Drag Coefficient is used in the computation of the aerodynamic drag on the front of the train, and Table 8.1 gives typical coefficients which should be entered for various train shapes. The Skin Friction Coefficient is used in the calculation of the Darcy-Weisbach friction factor for the sides and roof of the train. This number is difficult to obtain, but in a few cases it has been measured experimentally. Values usually range from .009 to .015 with the median of .012 suggested for modern transit vehicles. Field observations in the Berkeley Hills Tunnels (Ref. 4) substantiated the use of this suggested value.

The Drag Coefficient Weighted Total Truck Area* is used to compute the additional form air drag on the train which is caused by air flowing around the vehicle trucks. The additional frontal area of the trucks is the frontal area of the trucks minus the average area of undercar equipment. For most modern transit vehicles the truck drag coefficient is approximately 1.0. In these cases, the Drag Coefficient Weighted Total Truck Area is equal to the number of trucks in the entire train multiplied by the additional area of the truck.

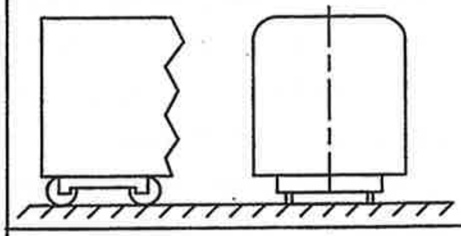
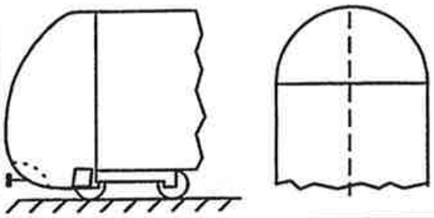
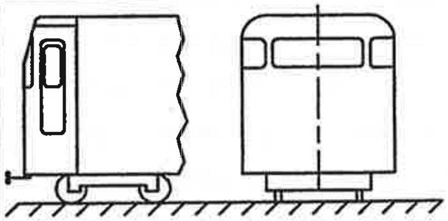
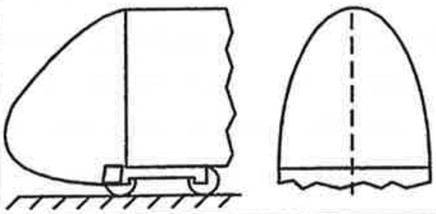
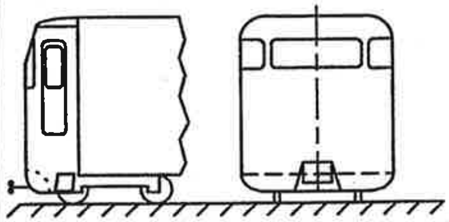
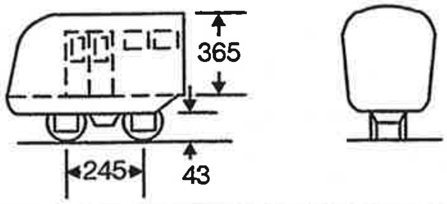
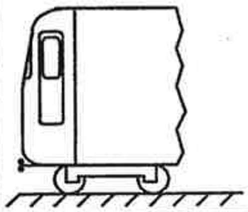
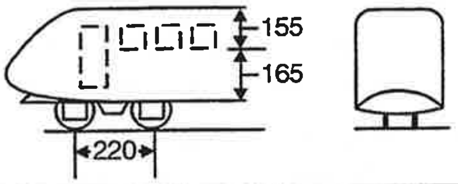
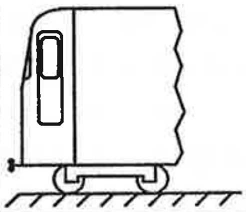
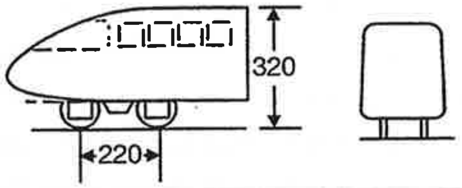
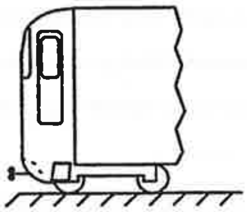
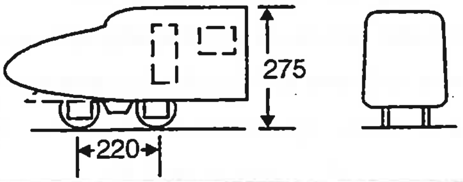
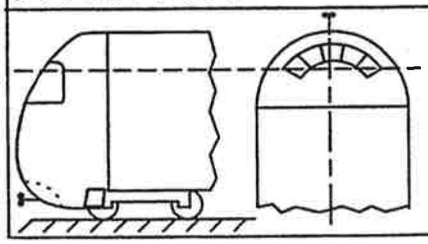
---

[*] The value of the truck drag coefficient is dependent on the truck's location within the train, the proximity to other undercar equipment, and the direction of airflow. The truck drag coefficient can be evaluated either experimentally or mathematically by using the method outlined in Reference 2. If this is done, the Drag Coefficient Weighted Total Truck Area can be evaluated using the following formula:

$$C_A = \sum_{T=1}^{n} C_T A_T$$

where: C_A = Drag Coefficient Weighted Total Truck Area
C_T = Truck drag coefficient
A_T = Additional frontal area of truck
n = Number of trucks in entire train

Table 8.1 Front of Train Drag Coefficient

 0.99	 0.48
 0.64	 0.45
 0.62	 0.45
 0.56	 0.25
 0.55	 0.24
 0.52	 0.21
 0.48	

. The Average Empty Car Weight (Input Form 9E) is the average weight, in tons, of an unloaded car. If flywheels are being simulated for a transit vehicle not ordinarily equipped with flywheel units, the Average Empty Car Weight should be increased. If specific information on the weight of the additional equipment is not available, a value of 5.5 tons is suggested since this was the additional weight in a trial conducted (See Ref. 5). The weight of the passengers aboard the train is added to this to compute the total weight of the train. The weight of the passengers aboard the train is computed from the number of passengers aboard the train (which may vary after each scheduled stop) and the Average Patron Weight. The Acceleration Resistance of Rotating Parts is a factor which is used to increase the effective mass of the train to allow for the rotational inertia of the wheels, motors, axles, etc. The train effective mass consists of two parts: the empty car mass which is increased by a factor to account for the acceleration resistance of rotating parts and the mass of the passengers. The train weight is used in the calculation of the grade resistance and rolling resistance, and the train effective mass is used to calculate the inertial effects of accelerating and decelerating the vehicle. The value for the acceleration resistance of rotating parts may be entered on the input form, or this entry may be left blank and a commonly used value of 8.8 lbs per ton/(mph/sec) will be supplied by the program.

The Train Rolling Resistance Coefficients are used to compute the mechanical friction created by train movement, and suggested values for rubber-tired and steel wheels are provided on the instructions for Input Form 9E.

A quantity of sensible heat and latent heat can be released from a train as a result of the on-board auxiliary systems and passengers. The auxiliary systems which are a source of sensible heat include vehicle lighting, heating, air compressors, fans and miscellaneous car equipment (excluding traction motors and other propulsion-related equipment). The vehicle air conditioning system, which is also an item of auxiliary equipment, is a source of sensible heat and may also be a source of latent heat. This latent heat results from the condensation on the cooling coils of moisture from the passengers and outside air which enters the subway car. Depending on vehicle design, it may be re-evaporated by the air conditioning system (resulting in a latent heat load from the vehicle) or be released as liquid water onto the trackbed. (This water would either flow into the trackway drainage system or evaporate from the trackbed, resulting in a latent heating and sensible cooling load in the line segment.) The rate of sensible and latent heat rejection from the vehicle air conditioning system is usually dependent on the system design and number of passengers on-board the vehicle. For non-air-conditioned vehicles the sensible and latent heat from the passengers is usually rejected directly from the vehicle through its ventilation system.

Input Form 9C is used to describe the sensible and latent heat rejection from the subway vehicle. Data is entered on a "per car" basis, with one or more cars in the train.

The following data items are entered:

1. Sensible Heat Rejection from Auxiliary Systems for an Empty Car Excluding Propulsion System.
2. Latent Heat Rejection from Auxiliary Systems for an Empty Car Excluding Propulsion System.
3. Sensible Heat Rejection from Passengers and Auxiliary Systems per Patron in Car.
4. Latent Heat Rejection from Passengers and Auxiliary Systems per Patron in Car.

The rate of steady-state train heat rejection is then computed using the following function:

$$Q = a + b\,P$$

where: Q = Rate of steady-state train heat rejection per car (either sensible or latent).

P = Number of passengers on-board each car. (The number of passengers on-board the train is updated by the Number of Persons Entering Train at Stop (Input Form 8D) at the beginning of the dwell period.)

a = Constant portion of the steady-state train heat (input item 1 for sensible, input item 2 for latent).

b = Variable portion of the steady-state train heat (input item 3 for sensible, input item 4 for latent).

The rate of power consumption by the vehicle auxiliary systems is also entered on Input Form 9C. Since the heat load on the vehicle air conditioning system varies with the number of passengers on-board the car, the power consumed by the auxiliary systems (which includes the vehicle air conditioning system) also varies with the number of passengers on-board the car. The following data items are entered:

1. Power Consumption by Auxiliary Systems for an Empty Car.
2. Power Consumption by Auxiliary Systems per Patron in Car.

The rate of power consumption is computed during the simulation by using the number of passengers on-board the train in a manner similar to that used for steady-state heat loads. Examples of the calculations used to obtain train steady-state heat rejection and power consumption are given in Appendix E.

8.3 Train Motor Operations

Background

The basic motor used for subway propulsion systems is the d.c. motor because of its inherent stability and the high torque available for accelerating from a standstill. Figure 8.1 shows the performance curves for a typical propulsion system. It can be seen from Figure 8.1 that the speed range requiring the highest torque is below the base speed of the motor. Base speed is the speed attained by the motor when operating at rated armature motoring voltage and full-rated field flux. The typical ratio of top to base speed for urban service is approximately 3 to 1.

Two types of d.c. motors currently in use are the series-wound motor and the separately-excited motor. These motor types differ in the way which the motor armature and motor field are electrically connected. As the name implies, the series-wound motor has the motor armature and field connected in series; hence, the same current passes through both components. The separately-excited motor has the motor armature and motor field connected in parallel; therefore, the field current can be modulated independently of the armature current.

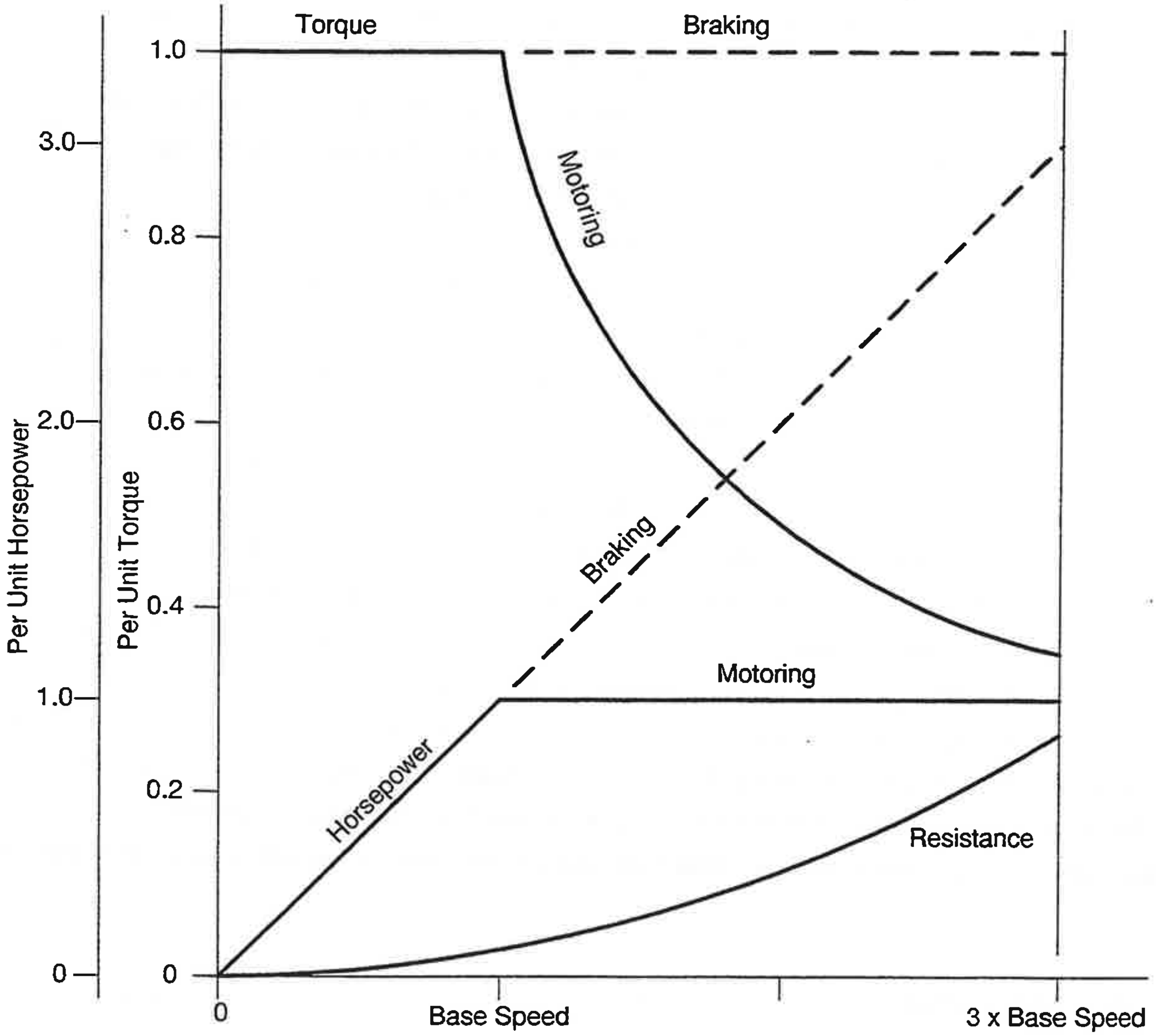


Figure 8.1 Typical Torque, Power and Speed Curves

When starting a d.c. motor, the full line voltage cannot be initially imposed across the motor without overloading it. It is necessary to control the voltage across the motor until it comes up to the base speed. In conventional trains with d.c. series motors the motor voltage is controlled by inserting external resistances in the circuit. The resistances are then notched out of the circuit by a device such as a cam controller as the motor-generated back voltage (or back EMF) increases with speed. More recently, the advent of solid-state thyristors with large power capabilities is providing a practical alternative to the cam controller equipment which had been almost universally used in rapid-transit cars. The thyristor chopper is a semi-conductor device which can be described as a switch which opens and closes very rapidly. By varying the switch "on" to "off" time ratio, the average motor voltage can be regulated. The speed with which the thyristor chopper can regulate and control the line voltage with all its fluctuations also allows the use of separately-excited traction motors.

During braking, the motor is reconnected to act as a generator whose armature is driven by the train. The generated power is dissipated at a controlled rate producing a uniform rate of deceleration, a process known as dynamic braking. Two methods for dissipating this current are in use: rheostatic braking and regenerative braking.

Rheostatic braking is the more established method and consists of dissipating the generated electricity in the form of heat by passing it through a bank of resistors (known as "resistor grids"). Regenerative braking, unlike rheostatic braking, tries to recover as much of the generated energy as possible and put it to useful work. Part of the generated current is used to power on-board auxiliary equipment and the remainder is available to the current distribution (or third rail) system for use by other trains operating in the vicinity of the regenerating train. The ability of the direct current distribution system to accept power from a regenerating train, known as the "receptivity," is a function of the distribution network circuitry and the positioning of current-drawing trains relative to the regenerating train. In the event that the line is not receptive, the excess energy is dissipated by on-board resistor grids. Other schemes have been contemplated which utilize wayside resistor banks to expel the heat outside the subway system as well as methods of energy storage such as a flywheel.

In general, a conventional train utilizing a cam controller will be equipped for rheostatic braking. Though not impossible, there are serious technical difficulties in trying to regenerate with d.c. motors having resistance control. The difficulties arise because the mechanical contactors performing the switching between the resistance and regeneration circuits cannot respond quickly enough to variations in line voltage (which is a measure of the receptivity of the line), leading to unstable operation.

The SES program has the capability of simulating both methods of speed control (i.e., cam control and chopper control) as well as rheostatic braking and regenerative braking. The program is structured to simulate either a train with cam controller and rheostatic braking or a train with chopper control and either regenerative or rheostatic braking. Also, since the SES program does not consider the details of the traction motor but uses the overall motor characteristics (i.e., tractive effort vs. speed, armature current vs. speed, etc.), both series-wound and separately-excited motors can be simulated.

Train Speed Control

Cam Controller - the electrical switching which takes place as a rapid transit vehicle accelerates from a standstill is complex and may vary with the particular control system used. The following sequence is for a cam controller. In a typical 600 volt traction system, where each car employs four 300 volt series-wound d.c. motors, all four traction motors are initially connected in series for acceleration in order to limit current and to reduce the size and weight of resistances (refer to Figure 8.2). As the train accelerates, the current limit control sequentially removes (or notches) all the resistors out of the circuit until each motor is running at 150 terminal volts. The function of the current limit control is to permit notching advance of the control system to the next increment of voltage across the motors. This occurs only after the current has decreased to a predetermined value. In this way an approximately constant average amperage is maintained through the traction motors resulting in a constant average tractive effort. This results in a constant rate of acceleration. At this point, the voltage to each motor must be increased if the train is to continue acceleration. The control system then reconnects the motors from four in series to two parallel groups of two motors in series — a switching sequence known as "transition" (refer to Figure 8.3). Resistance is again introduced into the system, this time with an imposed voltage of 600 volts per parallel circuit. The resistance is gradually notched out under current limit control until each motor is running at 300 terminal volts.

Transition ordinarily occurs at a train speed in the neighborhood of one-half of base speed. The series-parallel connection is used throughout the remainder of the cycle. The motors which have operated at full field strength throughout the series connection, continue to do so until all external resistance has been notched out. By definition, this would occur at base speed. At this point, the control system reduces the field strength of the motors as dictated by the current limit control. The base speed varies among motor designs, but a representative value would be 25 mph. When the field strength has been reduced to the minimum value, the train continues to accelerate according to the available tractive effort as indicated on the motor characteristic curves.

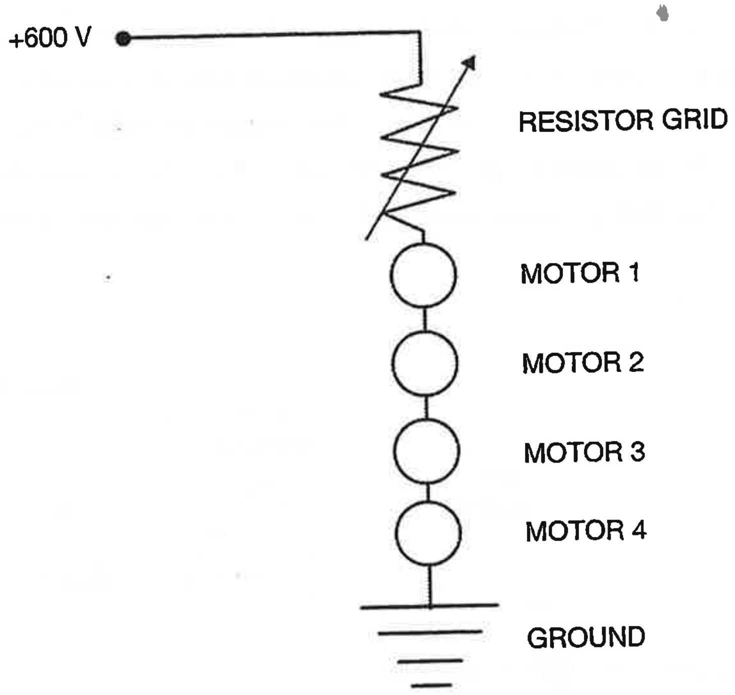


Figure 8.2 Traction Motors in Series

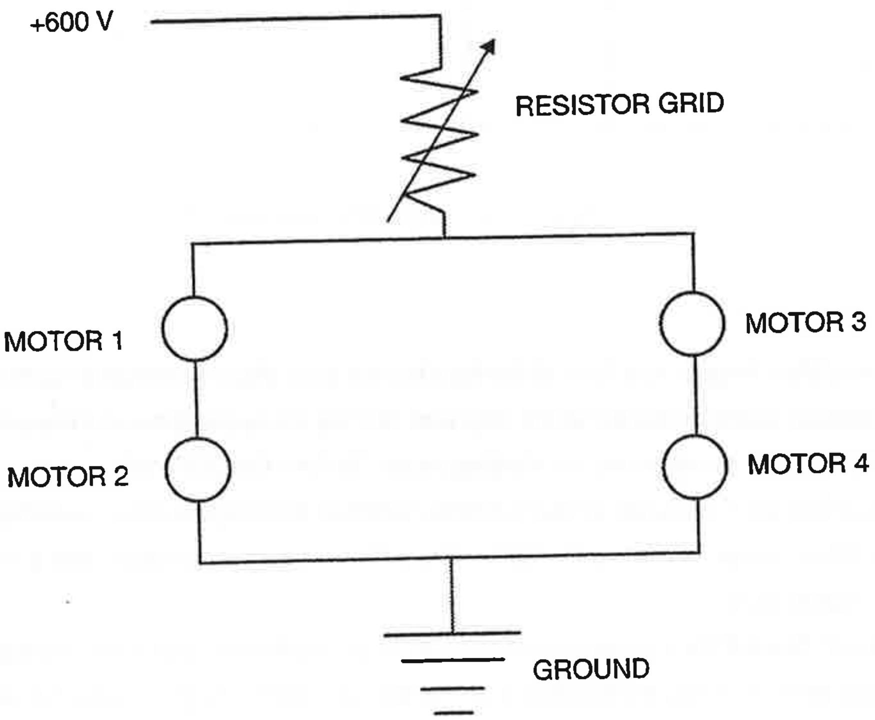


Figure 8.3 Traction Motors in Series/Parallel Connection

Chopper Controller - A typical chopper control arrangement containing the major components is shown in Figure 8.4. The system shown has four series-wound motors per car operating from a 600 volt line. Unlike the cam controller which reconnects the motors, the chopper controller is assumed to retain the motors in series-parallel. The additional components required by the chopper controller are the main thyristor and logic circuit, the line filter (capacitor and inductor), the main motor reactor (inductance), and the free-wheeling diode.

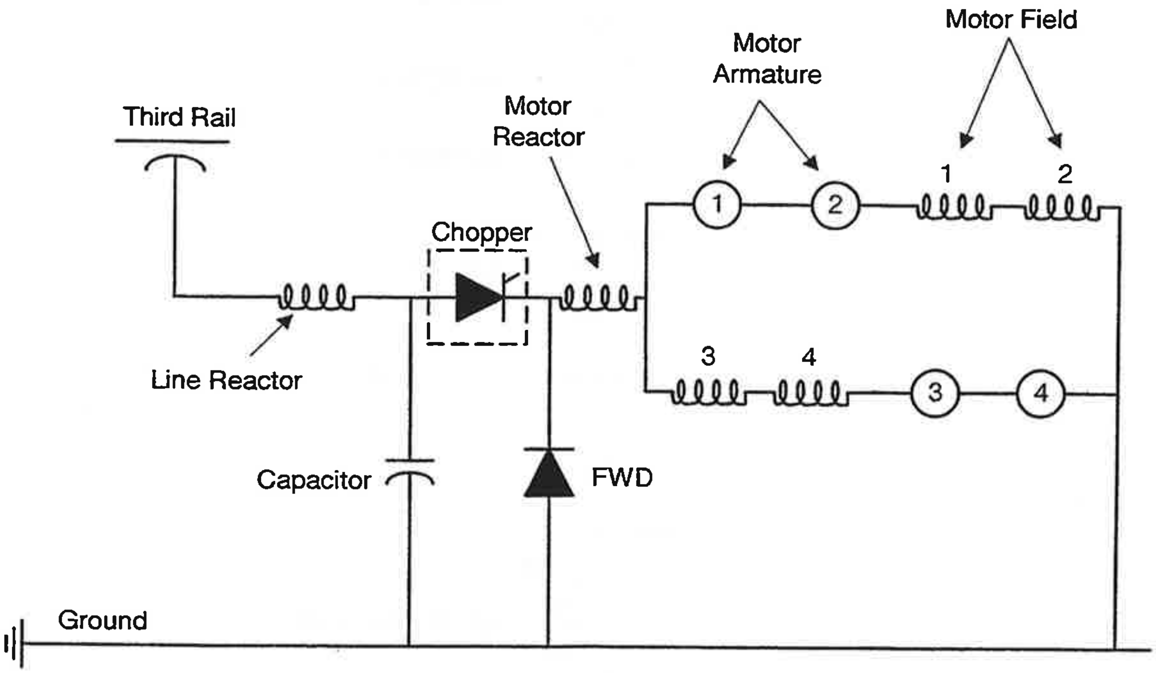


Figure 8.4 Typical Chopper Control

The heart of the chopper is a form of thyristor known as a silicon-controlled rectifier (SCR). The SCR is a uni-directional semi-conductor which may turn "on" by the application of a low-power signal to its "gate". Once "on", the SCR remains in a conducting mode. To turn the SCR "off" it is necessary to interrupt the power flow for a specified amount of time, which is accomplished by reversing the voltage across the SCR. This process of turning the SCR off is called force commutation, and it must be used when the power source is d.c.

It is sufficient to treat the chopper inner working as a "black box" operation. Hence, reference to the chopper should be interpreted as meaning both the thyristor and its logic circuits and will be treated essentially as a switch (e.g. as in Figure 8.4).

In the motoring mode, the chopper regulates the current in the motor circuits. Turning the chopper "on" builds up current in the motors by completing the circuit from the third rail through the motors to ground. When the chopper is turned "off", the energy stored in the motor reactor as well as in the collapsing motor field continues to drive current through the motor circuits by way of the loop formed by the free wheeling diode (FWD).

The average voltage applied to the motors is controlled by adjusting the ratio of the chopper "on" to "off" time. This adjustment is made by the chopper control logic to maintain the desired average motor current and hence, motor torque. The input to the control logic is from the train operator or from automatic control equipment.

A train accelerating from a standstill uses chopper control of the armature voltage (and thus torque) up to base speed. For the cam controller this operation was accomplished by progressively notching the external resistance out of the motor circuit. By eliminating the need for external resistance, the chopper demonstrates a savings in heat input to the tunnel air. The high-power portion of the accelerating cycle is extended beyond base speed by motor field weakening, as in the case of the cam-controlled train.

Braking Methods

Rheostatic Braking - Rheostatic braking refers to the method of slowing down a train by dissipating its kinetic energy in a controlled manner. The kinetic energy is converted to electrical energy which is dissipated in the form of heat by resistor losses. This is accomplished by reconnecting the traction motors as generators in series with resistor grids. The generators are driven by the motion of the train. Some of the kinetic energy is directly converted to heat due to irreversible losses from air friction and turbulence, mechanical friction of bearings and gears, electrical windage and chopper losses, etc. The remainder is released by the deceleration resistor grids.

Regenerative Braking - A suitably equipped chopper-controlled train has the potential for feeding energy back into the "line" during braking. This regenerated energy could be used to power on-board equipment as well as satisfy the power needs of a train operating in the vicinity of the regenerating train. Regeneration into the third rail is sometimes not possible because of a third rail gap or the absence of a load on the third rail. In that event, the chopper control logic provides an almost instantaneous shift to rheostatic braking (use of on-board resistances in conjunction with regeneration is termed "natural" regenerative braking). The control logic continually tests the receptivity of the line and if at a later time it determines the line to be receptive, regenerative braking will be resumed.

Other methods have been proposed for handling the regenerated energy. One feasible design consists of providing "wayside resistors" at electrical substations to dissipate the excess electrical energy which could not be absorbed by other trains. The heat generated is then released outside the subway system. Another scheme proposes recycling the regenerated energy via d.c. to ac inverters to be fed-back to the utility feeders, and yet another proposes storing the energy in a flywheel device making the energy available for future use.

The amount of energy regenerated varies from one subway system to another. Among the variables affecting regeneration are: track profile, train headway, the type of traction motor used, electrical distribution network circuitry, and the type of regeneration scheme. Because of the complex dependence on various system parameters, the results obtained for a particular system cannot be universally applied. In addition, the sparse measured data available is not always presented in a usable way. For example, measurements were taken on eight Class C7 cars on the Stockholm Subway System during off peak periods. The cars were equipped with chopper-controlled, separately-excited d.c. traction motors and natural regenerative braking. Regeneration was found to be around 25 percent, the lowest value being 20 percent and the highest more than 30 percent. The percentage of regeneration was defined as:

$$R = \frac{W_r}{W_{Total}} \times 100 \text{ percent}$$

where W_r was the energy regenerated to the line during braking, and W_{Total} is the total energy supplied from the line during the whole run without regeneration. Unfortunately, these results cannot be directly applied to the SES, and sufficient information is not available for transforming this data to a usable form.

The following convention will be established for determining the percentage of regeneration during braking:

$$\text{The Regenerative Effectiveness} = \frac{\text{Total Energy Regenerated}}{\text{Total Energy Available for Regeneration}}$$

where the total energy available for regeneration equals the total mechanical energy stored in the train (kinetic plus potential energy relative to the stopping point) minus all the losses. Note that this regenerative effectiveness pertains to a particular train during a braking cycle and does not reflect the total system efficiency. An average value for all the stations in the portion of the system being simulated is more representative of the overall benefit of regeneration. Therefore, the average regeneration effectiveness is the input required by the SES.

When running an SES simulation for an existing subway system with regenerative capabilities, the value of the regenerative effectiveness can be determined through a field testing program. On the other hand, when evaluating a system which is still in the preliminary design stage, the only resource available is to gain access to a computer program which simulates the current flow from a chopper- controlled train with regenerative capabilities or to use very rough estimates.

A computer study was made for a typical modern subway system (similar to the Atlanta Subway MARTA in design) by General Electric and Westinghouse. The study compared two regenerating schemes, Natural Regeneration and Assured Regeneration (wayside resistors), for a baseline system consisting of three subway stations and their connecting tunnels. Each of the stations was identical and the distances between stations were approximately 3800 ft and 6300 ft. The maximum train speed attained was 50 mph and the maximum rates of acceleration and deceleration were 3.0 mph/sec. The train comprised eight cars with each car weighing 50 tons. The results are given in Table 8.2.

Table 8.2 Regeneration Effectiveness

Headway (sec)	Natural Regeneration	Assured Regeneration
90	46%	73%
150	47%	75%

The values given in Table 8.2 reflect the average of six values (two per station - one value for each direction). The use of an average effectiveness in SES applications is justified by an examination of the overall thermal behavior of the train/tunnel system. In real systems with natural regenerative braking, the energy regenerated by successive trains following the same route will vary because of unavoidable changes in the relative positioning of decelerating and accelerating trains. In terms of vehicle heat release, this variation in regenerated energy is reflected first in an altered electrical input to the on-board rheostatic brakes and subsequently as heat release to the subway air. The thermal time lag of both the rheostatic braking system and the subway air temperature acts to smooth the effects of train-to-train variations in regeneration effectiveness. Hence, an average value for effectiveness will reflect the actual benefit of regeneration with reasonable accuracy.

In general, the regeneration effectiveness for a real system should increase with shorter headways since the probability of having a favorable situation for regeneration (finding an accelerating train in the vicinity of a regenerating train) is increased. The effectiveness data in Table 8.2 violates this generalization, showing a slight increase in effectiveness with increased headway. This discrepancy is explained by the limited number of relative train situations examined by the study and serves to emphasize the statistical nature of average regeneration effectiveness.

Motor Operating Characteristics

The rate of acceleration depends on the net tractive effort (i.e., the propulsive force applied at the rim of the wheel). The net tractive effort is defined as the tractive effort available from the train's traction motors minus the total drag on the vehicle. The total drag on the vehicle is a function of track grade and curvature, train speed, air velocity relative to the train, and blockage ratio. The tractive effort which is available from the motors is a function of the performance characteristics of the motors. The performance characteristics of the motor system can be obtained from the manufacturer in a graphic form as shown in Figure 8.5.

Series-Wound DC Motor - The relationship among the train speed, the tractive effort, and the current drawn may be taken from the motor characteristic curves similar to those shown in Figure 8.5. This set of curves, which is typical of series-wound motors, shows two basic relationships: train speed versus motor current at a given motor terminal voltage and tractive effort versus motor current. The curves marked "Train Speed" show the maximum current drawn by the motor as a function of the train speed. Six mph curves are shown, labeled FS1 through FS6, and these correspond to six field strength settings for this motor. FS1 shows the relationship at the maximum field strength which is used at low speeds and FS6 shows the relationship at the minimum field strength which is used at higher speeds. The curves marked "Tractive Effort" show the tractive effort produced by the motor as a function of motor current. The six curves, marked FS1 to FS6, correspond to the six train speed curves respectively.

The curves are interpreted by first choosing a train speed, entering the graph at that speed, and continuing horizontally to the "Tractive Effort" curve for the proper field strength. From this point, a corresponding motor current can be read from the scale at the bottom of the graph. This is the maximum current that would pass through the motor at the chosen train speed and field strength. This motor current is what would be observed if the motor was connected directly to a power source of the rated voltage. However, this current could be reduced if an external resistance is placed in series with the motor.

For a given motor current, the graph is entered at the bottom moving vertically until the tractive effort curve with the proper field strength is intersected. From this point, the corresponding tractive effort can be read from the scale on the right. This is the tractive effort that would be produced at the given motor current. If a smaller motor current were used, a smaller tractive effort would be produced according to the relationship shown on the graph. In summary, if no external current limiting resistances are used, the graph is entered at the left for a given train speed. The intersection with the mph curve of the proper field strength allows the motor current to be read from the scale at the bottom of the graph. If the mph line does not intersect a field strength curve, then it should terminate at the maximum amperage allowed as shown in Figure 8.7. This current is then used with the tractive effort curve corresponding to the proper field strength to determine the tractive effort from the scale on the right side of the graph. In a similar manner, the graph may be entered with a motor current or a tractive effort, and the corresponding values of the other parameters can be evaluated.

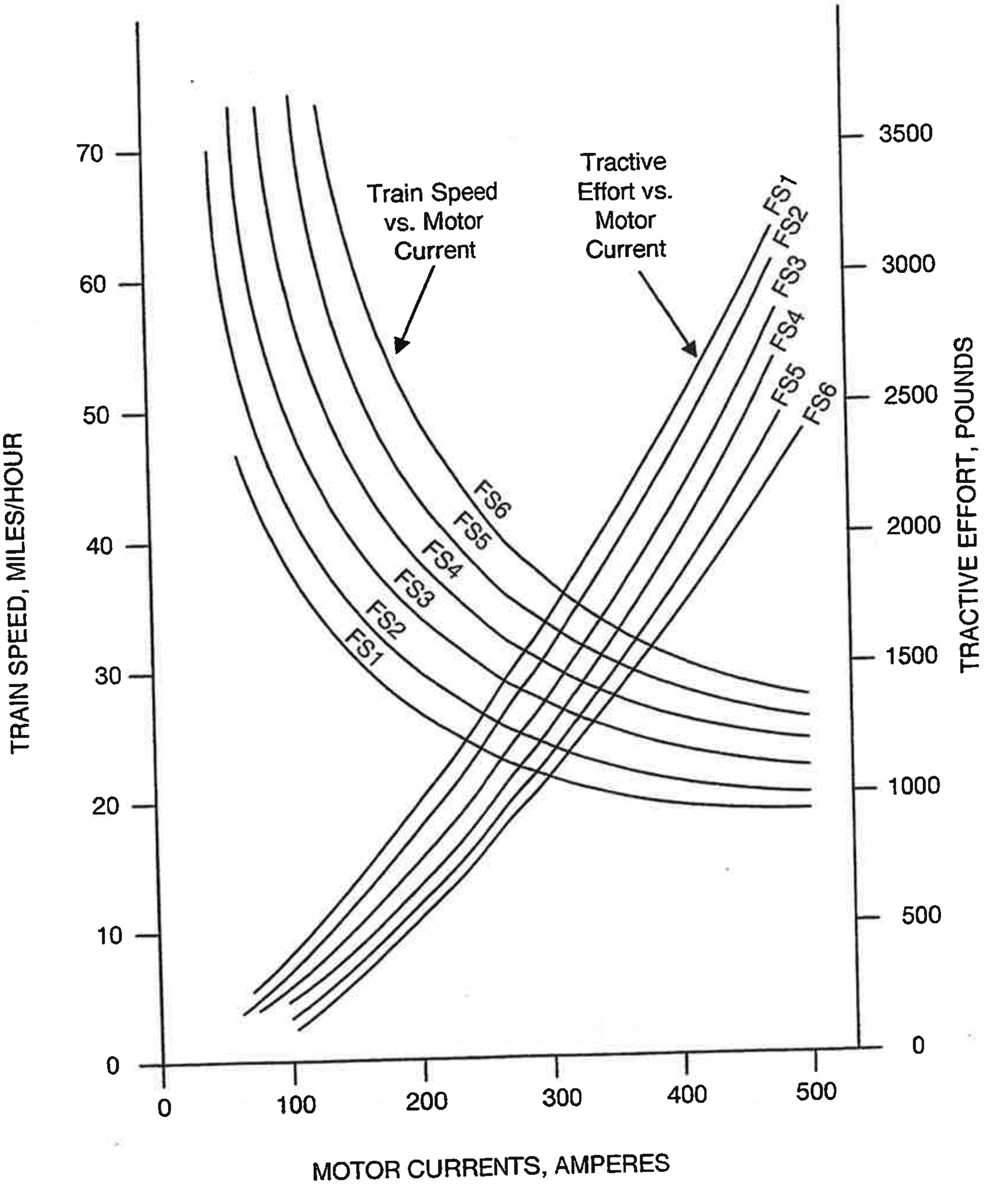


Figure 8.5 Typical Train Propulsion Characteristic Curves

. Separately-Excited D.C. Motor - The typical operating characteristics of this motor configuration are shown in Figure 8.6. This set of curves presents the following relationships: motor torque vs. motor RPM for a constant armature current and varying field current; and, motor torque vs. motor RPM for a constant field current and varying armature current. By appropriately accounting for the train wheel diameter, gear ratio, and gear train efficiency, these curves can be converted to tractive effort (pounds force) vs. train speed (miles per hour) - the units required by the SES program. For a given train speed and motor armature current, the tractive effort can be read directly from the graph.

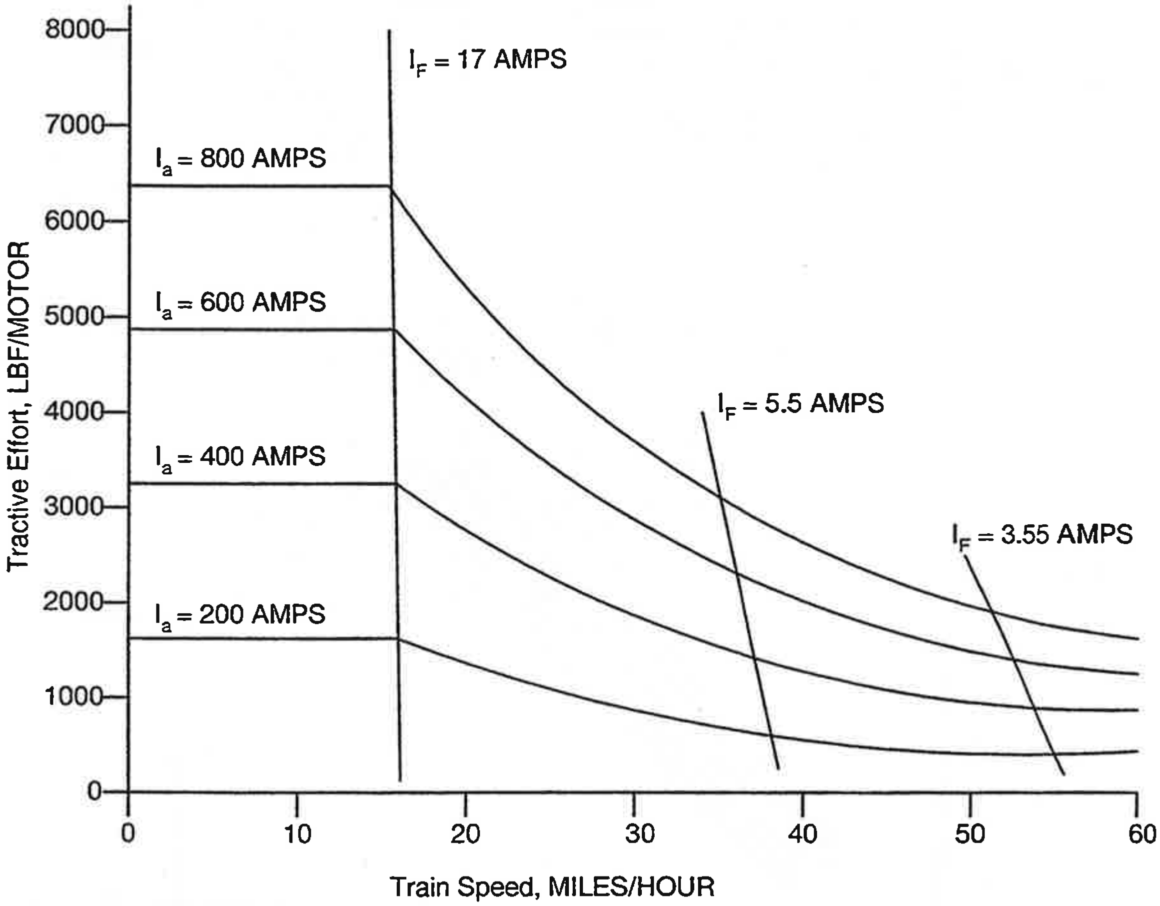


Figure 8.6 Typical Performance Curves for a Separately-Excited D.C. Motor

In comparison to a series-wound motor, the following differences in the motor operating characteristics are noted:

1. To achieve the maximum tractive effort (torque) over a given speed range, the armature current is kept constant while the field current is continuously varied. In a series-wound motor, the field current is self-adjusting, since the motor armature and motor field are connected in series.
2. For a constant field current, the tractive effort vs. train speed characteristic is very "steep"; that is, a small change in train speed causes a proportionately larger change in motor torque. This characteristic would be advantageous for Automatic Train Control (ATC) applications.

8.4 Developing Motor Input Data

The SES can simulate the various configurations of d.c. traction motors. The format of the input is sufficiently flexible to allow a wide range of variance in the motor performance characteristics. The performance data required consists of the tractive effort, the motor armature current, the line current, and the external resistance (if any) as a function of train speed. Examples of the method for adapting manufacturers data to a "usable" form are given in the following sections for a series-wound and a separately-excited d.c. motor.

Series-Wound D.C. Motor with Cam Controller - Figure 8.7 shows the propulsion motor characteristic curves of Figure 8.5 with the motor operation superimposed. Figure 8.8 demonstrates how a program user would interpret Figure 8.7.

A motor armature current is chosen which will provide sufficient tractive effort to propel the train without overloading the motors (in this case 400 amperes was chosen). The four motors are initially in series connection and a resistor grid of sufficient resistance to limit the motor current to 400 amperes is inserted in the series circuit. As the train speed increases, an increasing amount of back-EMF is generated by the motors. A back-EMF which is a voltage generated in a motor opposes the "driving" voltage. As a result of this increasing back-EMF, the series resistance must be reduced to maintain a constant current through the motor. At the transition point (Point 1 on Figure 8.7 and Figure 8.8) the motor connection is switched from series (Figure 8.2) to series-parallel (Figure 8.3). An external resistance is again inserted into the circuit to limit the armature current through the motors. As the back-EMF increases with increasing train speed, the resistance is again reduced to maintain constant armature current through the motors. At point 2 on Figures 8.7 and 8.8, the external resistance has been reduced to zero and the next stage of the cycle, field strength reduction, begins.

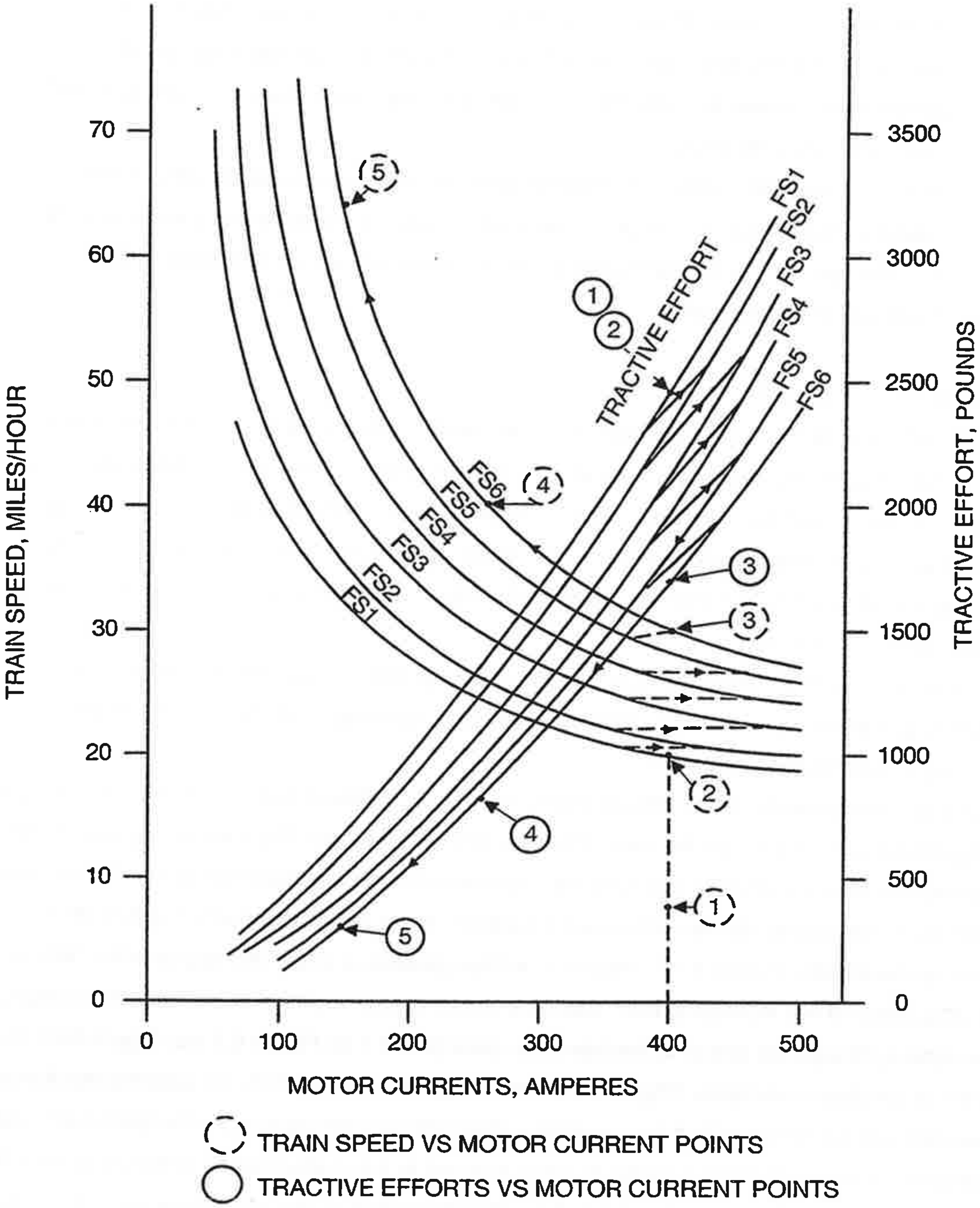


Figure 8.7 Typical Train Propulsion Characteristic Curves

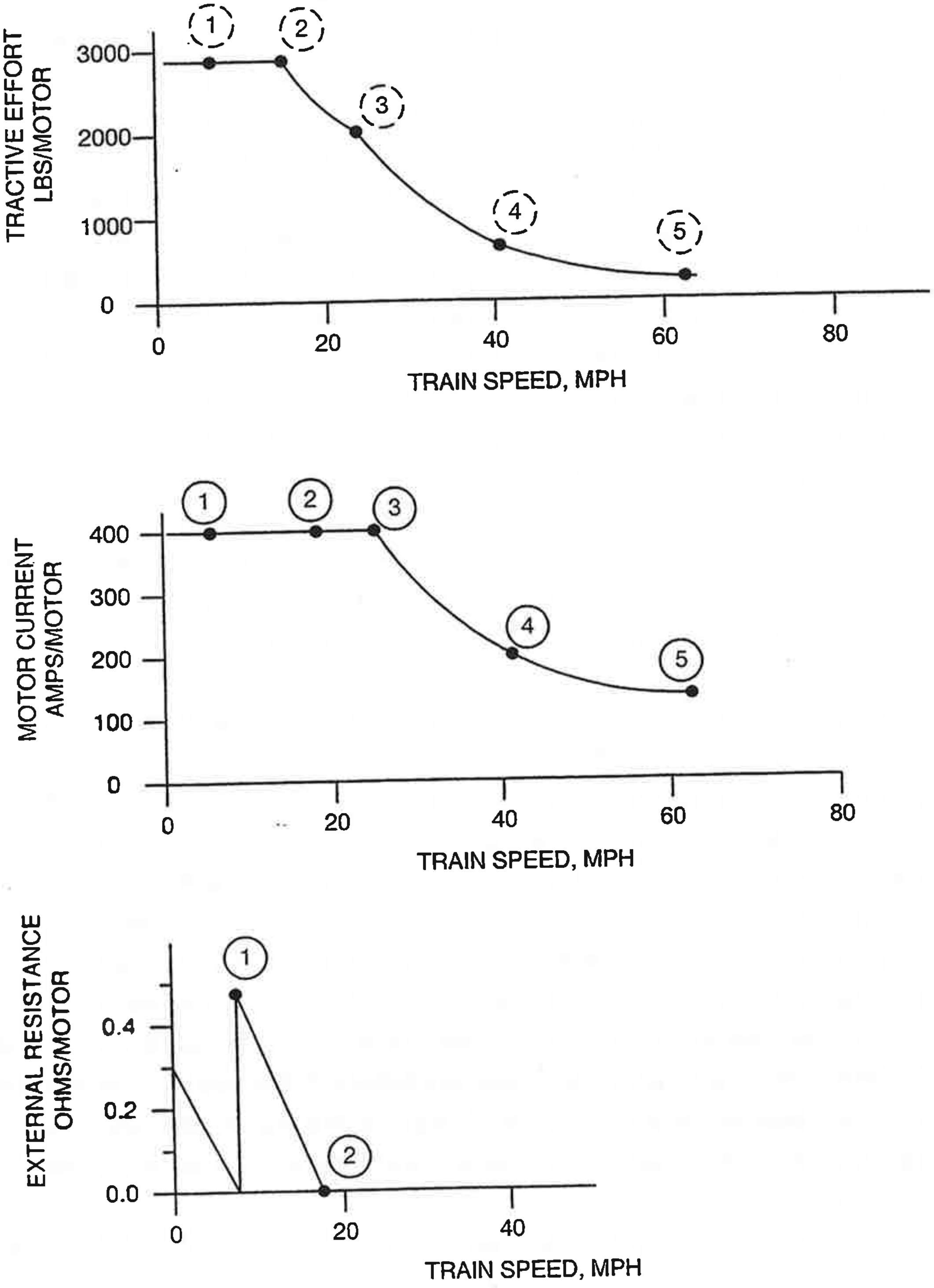


Figure 8.8 Typical Train Propulsion Motor Characteristic Curves (Series-Wound)

Field strength reduction in the motor circuit reduces the back-EMF which is generated by the motor, allowing a higher motor armature current at a given train speed. However, a reduction in field strength also causes a reduction in the torque produced by the motor for a given current. Field strength reduction is performed by a current limit control which reduces the field strength one step when the armature current falls below a pre-determined value. In a series-wound d.c. motor the motor armature and field are connected in series. The reduction in field strength is accomplished by connecting a resistance in parallel with the field, thus shunting some of the current through the resistance element and partially bypassing the field. This is accompanied by a change in the current through the motor. The control mechanism is usually adjusted such that the motor current varies equal amounts below and above the design current. The average armature current is usually equal to the design current. After field strength reduction is completed (point 3 on Figure 8.7), the motors are operating on the curves corresponding to their minimum field strength setting. Beyond this point, no further external control of the motor is performed and the motor output follows the limiting performance curve. During operation, according to the motor performance curves, as the train speed increases the motor armature current decreases. The decreasing armature current causes a reduction in the torque output of the motor. In this manner, the train would continue to accelerate at a rate governed by the opposing aerodynamic and mechanical forces until the balance speed is reached. The balance speed is the speed at which the torque available from the motor is equal to that required to overcome the train resistance; hence no further acceleration is possible.

Figure 8.8 shows the tractive effort, motor armature current, and external resistance plotted as a function of train speed. This is the form in which the motor data is used by the SES program. The five points shown on the plots correspond to those points indicated in Figure 8.7.

Series-Wound D.C. Motor with Chopper Controller - The train propulsion requirements are the same regardless of the type of controller used (chopper or cam). The function of the controller is to bring the train up to base speed without overloading the motors. This can be accomplished by inserting resistance in the motor circuit or by modulating the average motor voltage. Hence, the methods described in the previous section for obtaining the tractive effort vs. speed and motor armature current vs. speed curve from the motor performance curves also apply for a chopper controller. However, the data for the external resistances are omitted. The SES considers the chopper as a "black box" operation; therefore, to simulate the effects of the chopper control, additional data is required. This data includes the variation of line current vs. train speed and the efficiency of the chopper unit. The chopper efficiency, η , is defined as the ratio of the power output to the power input x 100%. Representative values for chopper efficiencies vary from 94% - 98%.

The line current varies linearly from zero speed up to base speed (see Figure 8.9). This is caused by the linear variation of the chopper time ratio (time ratio = $\frac{t_{on}}{t_{on} + t_{off}}$). The voltage imposed across the motors increases with increasing time ratio and the back-EMF from the motors increases linearly with speed. Therefore to maintain a constant armature current through the motors, the voltage imposed on the motors must be increased proportionally. The line current also increases because of the transformer action of the chopper.

Tractive Effort vs. Train Speed - This curve consists of three portions: a constant portion, and two hyperbolic portions. Tractive effort is constant from zero train speed through point 1 to point 2. Field strength reduction begins at point 2 and ends at point 3, and over this range the tractive effort is assumed to vary hyperbolically with respect to train speed. Points 3, 4 and 5 are on the minimum field strength motor curve which is approximated by a 2nd order hyperbola. Point 3 is the point at which the minimum field strength curve intersects the design current. Point 5 should correspond to a high train speed which the train would not normally exceed and point 4 would be an arbitrary point which is approximately equidistant from points 3 and 5.

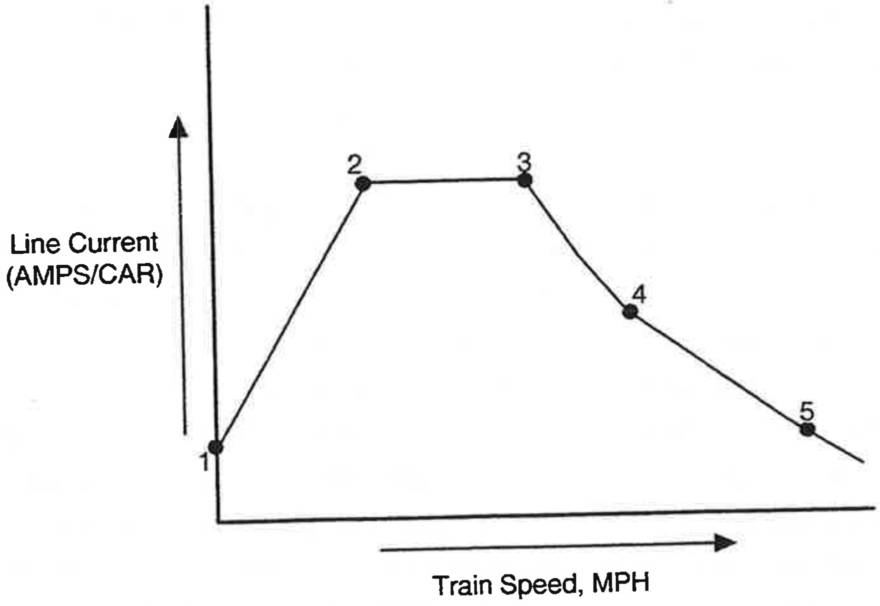


Figure 8.9 Line Current vs. Train Speed

Therefore, the chopper loss is:

$$\text{Chopper Loss} = \left(1.0 - \frac{n}{100}\right) * E_{line} * I_{line}$$

Armature Current vs. Train Speed - This curve consists of two portions: a constant portion and a hyperbolic portion. The constant portion of the curve extends from zero train speed to the speed at which field strength reduction is completed (point 3). The actual armature current through the motors is constant at the design value from zero to point 2, but may fluctuate above and below the design value during the field strength reduction, from point 2 to point 3. If present, these fluctuations are approximately equal above and below the design current so that the average armature current may be considered constant through this phase of the train operation. Once the minimum field strength is reached the motor current begins to decrease with increasing train speed. Points 4 and 5 define this portion of the curve. In this case the points on the curve are used to define the motor current versus speed relationship. These points are the same points used in defining the tractive effort versus train speed relationship.

Line Current vs. Train Speed - The line current versus train speed relationship for a chopper controlled train is approximated by a curve which consists of three portions: a linear portion, a constant portion and a hyperbolic portion. The linear portion extends from zero train speed to base speed (point 2). The current is held at a nearly constant value until field reduction is completed (point 3). Once the minimum field strength is reached, the line current begins to decrease with increasing train speed. Points 4 and 5 define this portion of the curve.

Separately-Excited D.C. Motor with Chopper Controller - Because of the rapid switching requirements previously mentioned, it is assumed that separately-excited motors are used exclusively with chopper controllers. As an example, consider the motor arrangement shown in Figure 8.4, but using separately-excited motors.

Figure 8.10 shows the motor performance curves shown in Figure 8.6 with the motor operation superimposed. Figure 8.11 shows the motor performance curves converted to an SES-usable format. The points shown are labeled 2 through 5 to keep the correspondence between Figure 8.8 and Figure 8.11.

Assuming a motor armature accelerating current of 400 amperes (as in the previous example), a train accelerating from a standstill goes through the following sequences. At zero speed, the field control maintains the field current at a constant value (17 amps from Figure 8.10) and the main chopper is operated to produce the required armature current by controlling the average motor voltage. As the train speed approaches base speed (points 2 and 3), the chopper continuously modulates the average motor voltage from zero to 300 volts per motor to compensate for the increasing back-EMF. At base speed, the chopper achieves the limiting duty cycle. Beyond point 3, the field current is continuously decreased to maintain a high tractive effort (torque) at the higher train speeds (motor RPM). This is represented by points 4 and 5.

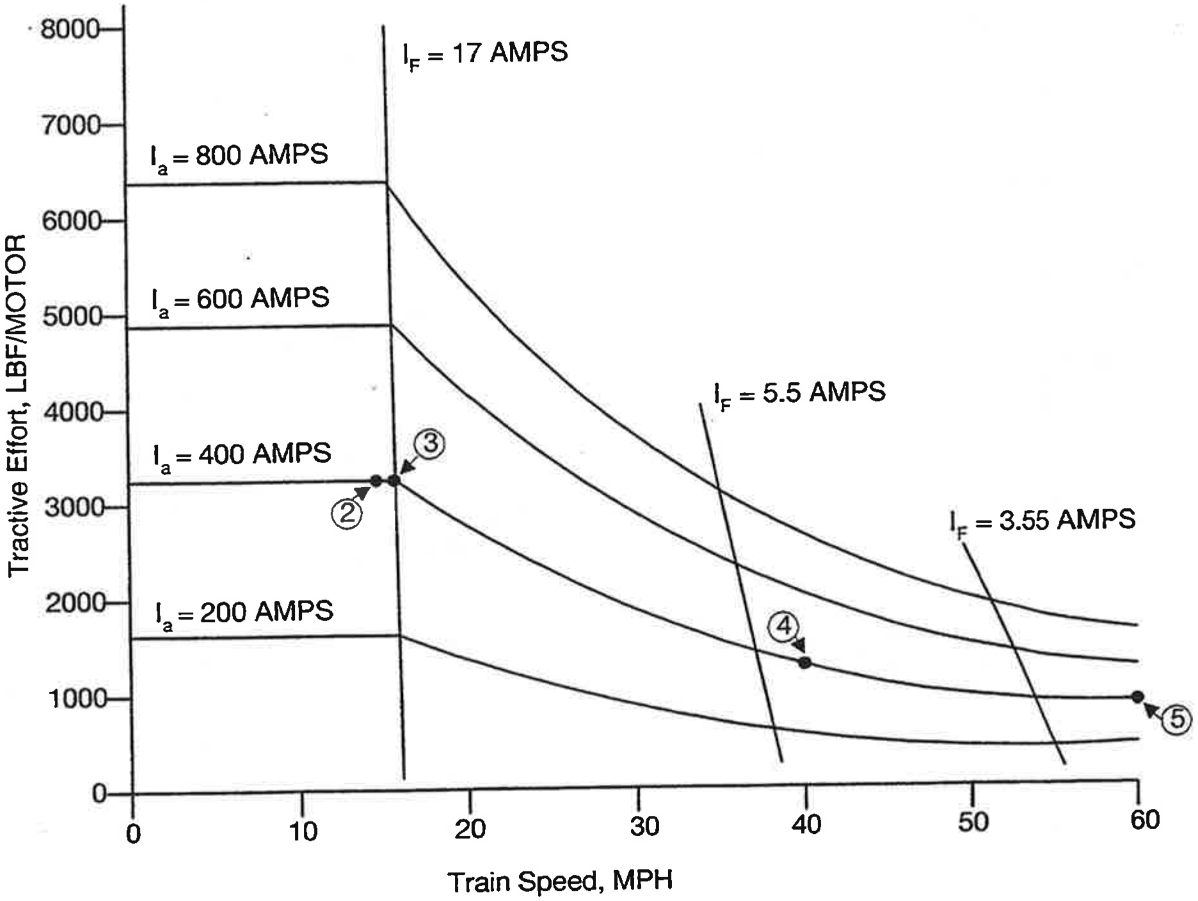


Figure 8.10 Typical Performance Curves for a Separately-Excited D.C. Motor

Tractive Effort vs. Train Speed - This curve consists of two portions — a constant portion and a hyperbolic portion. Tractive effort is constant from zero train speed through base speed (point 2). Point 3 is a fictitious item without physical significance. Actually, this point should coincide with point 2, but it is required by the way the SES program is structured. Point 3 should be entered as corresponding to a train speed slightly greater than base speed (say 0.5 mph), but with the same tractive effort. Points 3, 4 and 5 represent the maximum operating curve for the motor. Point 5 should correspond to a high train speed which the train would not normally exceed and point 4 would be an arbitrary point which is approximately equidistant from points 3 and 5.

Armature Current vs. Train Speed - The armature current remains constant from zero speed through the maximum train speed. However, to satisfy the input requirements, the armature current vs. train speed curve must be defined. Therefore, the same value of the current must be given for each train speed corresponding to points 2 through 5.

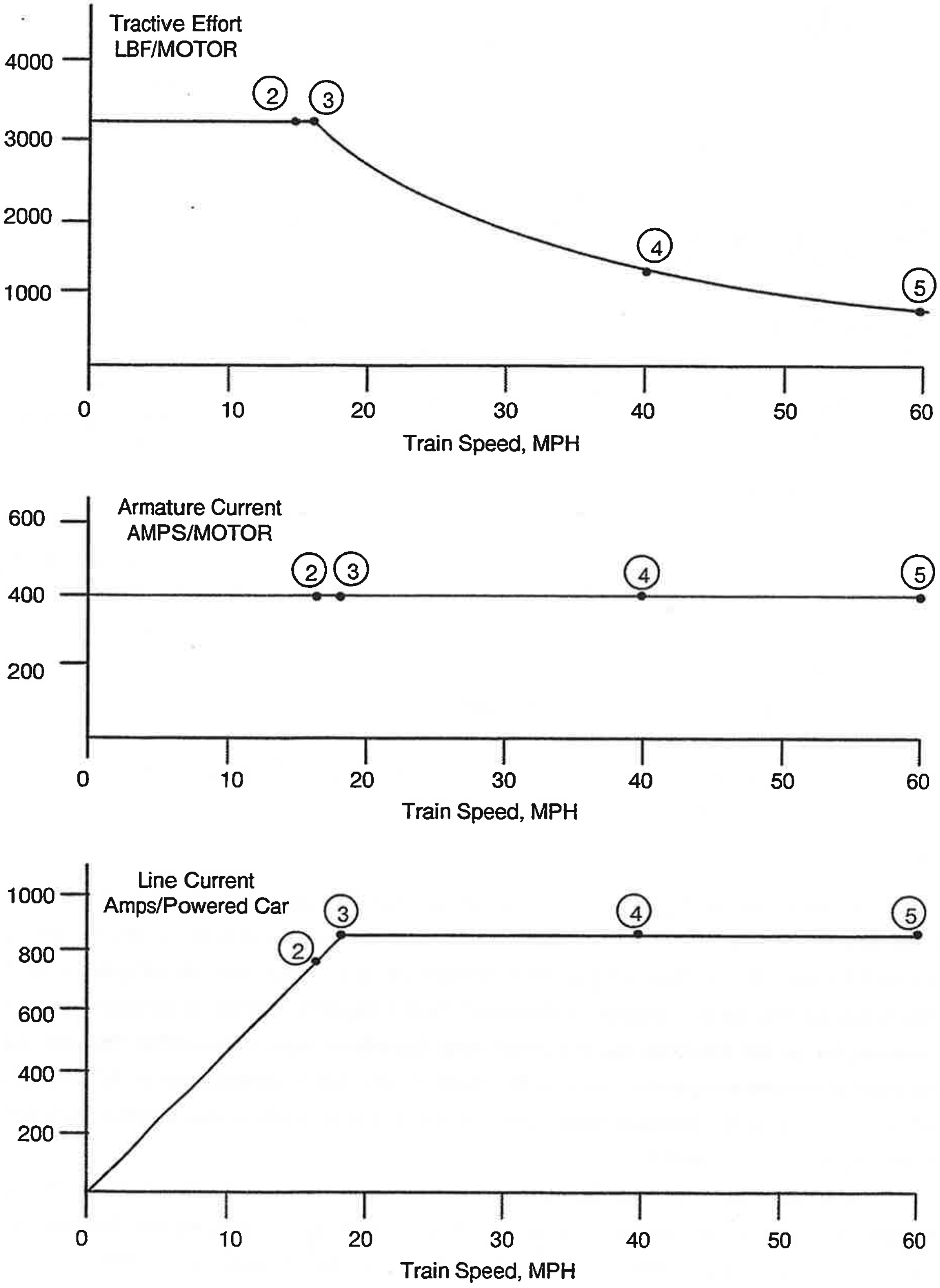


Figure 8.11 Typical Train Propulsion Motor Characteristic Curves (Separately-Excited)

<u>Line Current vs. Train Speed</u> - The line current versus train speed relationship consists of two portions — a linear portion and a constant portion. The linear portion extends from zero speed to base speed (point 2). This portion of the curve represents the period during which the main chopper is modulating the motor voltage. Beyond base speed, the line current is maintained at a constant value. Points 3, 4 and 5 define this portion of the curve. In this context, "line current" refers to the current drawn by the traction motors only (auxiliaries are considered elsewhere). Also, unlike the armature current which must be entered on a "per motor" basis, the line current must be given on a "per powered car" basis.

8.5 Entering Motor Performance Characteristics (Input Form 9G)

The motor performance characteristics are described to the SES program by specifying the <u>train speed</u>, <u>tractive effort</u> and <u>motor armature current</u> which correspond to certain critical points on the motor characteristic curves. Each point consists of a set of three corresponding readings, one from each scale on the motor curves (see Figure 8.7). Four points must be specified on Input Form 9G:

First	The speed at which field strength reduction begins (base speed) - this is the point where the starting current line intersects the maximum field strength train speed curve (point 2 on Figure 8.7).
Second	The speed at which field strength reduction is completed - this is the point where the starting current line intersects the minimum field strength train speed curve (point 3 on Figure 8.7).
Third & Fourth	Two points that can be used to define the minimum field strength curve. (This curve is actually defined by three points: points 3, 4, and 5 on Figure 8.7). The fourth point should be at a speed which the train is not expected to exceed, and it is used to fix the upper region of the curve. The third point is used to fix the midpoint of the curve and it should be approximately midway between the second and fourth points.

For each of the four points, the armature current through each motor and the tractive effort produced by that motor must be entered. For example, the armature current for a series-wound motor can be read from the bottom scale on Figure 8.7. The corresponding tractive effort is obtained from the scale on the right of Figure 8.7, by using the motor armature current and the tractive effort curve of the proper field strength to determine the tractive effort produced by the motor.

8.6 Entering Chopper Characteristics (Input Form 9H)

The simulation of a chopper-controlled train requires the line current to be specified as a function of train speed. The line current variation can be derived from the motor armature current data. In this context, "line current" refers to the current drawn from the third rail by the traction motors only; the train auxiliaries are accounted for elsewhere.

The line current vs. train speed relationship is determined by five points. The first point corresponds to zero train speed and the remaining four points correspond to the train speeds entered on Input Form 9G (see Section 8.5). The value of the line current at a given train speed is computed by substituting the motor armature current corresponding to the same train speed into the following equation:

$$I_L = \frac{nI_A^2}{E_L \eta}\left(m\sum R_i + R_{MR}\right)$$

where:

I_L = line current, amps/powered car

I_A = motor armature current, amps/motor

E_L = line voltage, volt

η = chopper efficiency

ΣR_i = sum of the internal motor resistances (i.e., motor armature, series field, etc.), ohms

R_{MR} = the resistance of the main motor reactor (inductance), ohms

m = number of parallel branches in the traction motor circuit

n = number of traction motors in series per branch of the motor circuit.

If the above equation were applied to the motor configuration shown in Figure 8.4, then m = 2 and n = 2; i.e., there are two parallel branches and each branch of the motor circuit has two motors in eries.

8.7 External Resistance versus Train Speed (Input Form 9I)

This curve consists of two portions, both of which are linear with respect to train speed but are separated by a discontinuity. The two portions may have different slopes. The initial value at zero train speed is the value of the acceleration grid resistance (this applies to cam-controlled trains only) which is in the circuit when the train starts from rest. This external resistance is decreased in steps until its value is zero at the transition speed (point 1). For the purposes of the simulation, each individual step is ignored and this decrease in resistance is considered to be linear with respect to train speed.

At the transition speed (point 1), the motor circuit is switched from a series to a series-parallel connection. The acceleration resistor grids are again inserted into the circuit and their resistance is reduced in steps until their resistance is zero at point 2 (base speed). This reduction is also approximated by a linear relationship with speed from point 1 and point 2.

All values of the resistances must be given as ohms per motor, and do not include the resistances for the entire circuit. This resistance is used with the armature current per motor in computing the electrical power which is converted to heat during the train acceleration (using the formula $P = I^2R$). The power lost per motor is then multiplied by the number of motors per car to get the power lost per car, and this is multiplied by the number of powered cars in the train to get the power lost by the entire train.

In addition to the two acceleration resistance values, one at zero train speed and the other just after transition, the value of the electrical resistance which is always in the motor circuit is required. This is the resistance of the motor armature and field, motor brushes, relay switches and wiring aboard the car. The largest contributor to this value is the motor armature and field resistance, with a typical value of 0.05 ohms. This constant resistance is added to the external resistance and remains in the circuit even after the external resistance is removed. Both the internal and the external resistances are used in computing R, the total resistance per motor which is used in the power loss computation.

For a cam-controlled train, the user must enter two resistance speeds. The first is the speed at which transition from series to series-parallel motor circuitry occurs, and the second is the speed at which the external resistance is reduced to zero (this corresponds to base speed, point 2 on Figure 8.7). Three values of resistance are also required. The first is the value of the external resistance in the motor circuit at zero train speed. The second is the value of the external resistance in the motor circuit immediately after transition to series-parallel has occurred (this corresponds to the first resistance speed above). The third resistance is the internal resistance of the motor armature and field. This resistance remains in the circuit throughout the remainder of the acceleration cycle. If a chopper-controlled train is being simulated, the user must enter zero (0.0) for the two external resistances and the two resistance speeds. However, the motor field and armature resistance must still be entered.

The user must provide motor performance data that is supplied by the manufacturer. Sometimes this data is not useful in the form in which it is presented by the manufacturer, but must be adjusted to the appropriate wheel diameter, gear ratio, or supply voltage. The data is adjusted by the ratio of the wheel diameter supplied with the manufacturer's data to the actual wheel diameter of the vehicle, the ratio of the gear ratio (to 1) supplied with the manufacturer's data to the actual gear ratio (to 1) of vehicle and the ratio of the supply voltage given with manufacturer's data to the actual supply voltage at which vehicle operates. These items are entered on Input Form 9F, and the ratios of these number are used to adjust the train speed and tractive effort which are entered on Input Form 9G and the resistance speeds which are entered on Input Form 9I. If the manufacturer's data and vehicle data are the same for an item, the same value should be entered for both the manufacturer's data and the vehicle data and the resulting adjustment ratio will be 1 to 1. In addition to the input items mentioned above, the motor terminal voltage at base speed must also be entered on Input Form 9F. This is the voltage at base speed in units of volts per motor.

8.8 Acceleration and Deceleration Characteristics (Input Form 9J)

When the train is in an acceleration mode, the motors are producing the maximum tractive effort that they are capable of producing. The train acceleration rate is proportional to the net tractive effort (the tractive effort produced by the motors minus the train resistance). The train resistance due to mechanical friction and track curvature always opposes the movement of the train, but the air drag and grade resistance may act to oppose or help the train movement. The algebraic sign of the air drag is dependent on the air velocity relative to the train and the sign of the grade resistance is dependent on whether the train is going uphill or downhill.

The maximum acceleration rate at which a train would accelerate is frequently limited by the train manufacturer in the interest of passenger comfort. This limit is built into the motor control system. The user of the SES program must specify the maximum allowable train acceleration rate, and this number will not be exceeded during the simulation.

In a similar manner, a maximum normal deceleration rate is determined by the manufacturer based upon passenger comfort considerations, and incorporated into the motor control system. This is the maximum braking rate that would not be exceeded in normal service, however, the train is usually capable of a higher braking rate for use in emergency situations. The above maximum allowable acceleration and deceleration rates do not apply when the train is coasting. Most subway trains use the propulsion motors for braking; during braking the propulsion motors are used as generators, converting the kinetic energy of the vehicle into electrical energy. This electrical energy is then dissipated in the deceleration resistor grid which is located beneath the car. The use of the propulsion motors as generators of electrical power causes a drag on the vehicle which acts as a braking force to slow the train. This method of braking is known as dynamic braking.

The dynamic braking system is usually capable of slowing the train at the normal braking rate, which is about 3.0 mph/sec in the moderate speed range, but it cannot maintain this rate at low speeds (below approximately 15 mph) or at high speeds (above approximately 50 mph, depending on the characteristics of the particular car). The voltage produced by a d.c. motor/generator is dependent on its speed of rotation and this energy output is not sufficient to maintain the normal braking rate below approximately 15 mph. When this occurs the friction braking system, which works with compressed air, is automatically activated by the train control system to maintain the desired braking rate.

At higher speeds the normal braking rate also cannot be maintained, but for the opposite reason. The rate at which kinetic energy must be removed from the vehicle to maintain a constant braking rate increases as the train speed increases. At high train speeds the propulsion system cannot convert and dissipate the energy at the rate required to maintain the normal braking rate without suffering an overload and possible damage. To prevent this, the normal braking rate is reduced at higher speeds. The amount of reduction of the deceleration rate is usually a function of the train speed.

The normal deceleration rate curve which is used by the SES program is shown in Figure 8.12. It consists of two parts: a constant portion and a portion which decreases linearly with increasing train speed. The speed above which the train can no longer maintain the desired deceleration rate is shown as V_1. The normal deceleration rate from V_1 mph to 0 is shown as D_1 and this is the desired deceleration rate which can be maintained up to speed V_1. Above this speed the deceleration rate decreases, with the normal deceleration rate at speed V_2 occurring at speed V_2. Speed V_2 must be greater than speed V_1, and the normal deceleration rate at speed V_2 must be less than the normal deceleration rate at speed V_1.

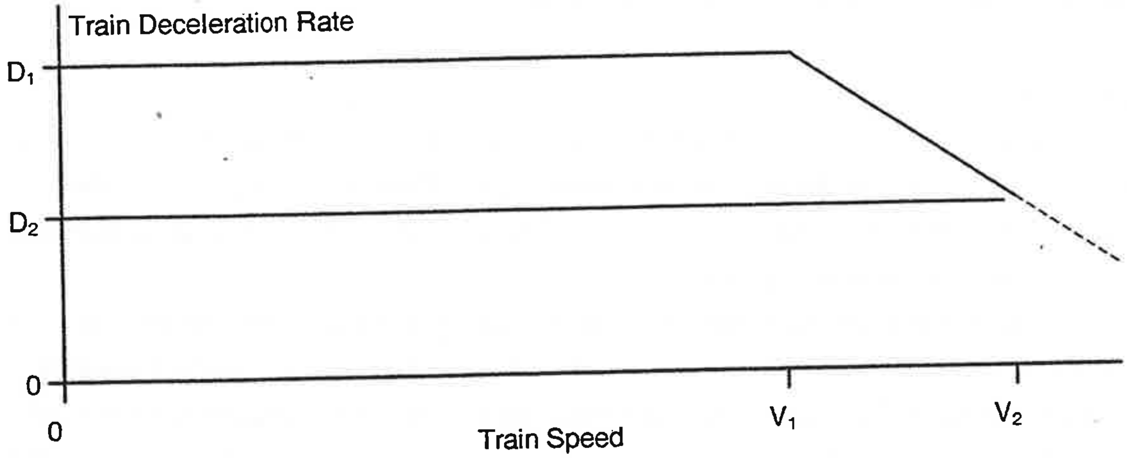


Figure 8.12 Train Normal Deceleration Rate

8.9 Resistor Grid Data (Form 9D)

The dynamic braking system of a rapid transit vehicle is used to decelerate the vehicle when it is operating at speeds greater than about 15 mph, with the change in the kinetic energy of the vehicle being converted into thermal energy in resistor grids mounted under the vehicle. This thermal energy is released in turn to the subway environment and represents the major source of heat in a subway system. The conventional resistor grid is a collection of electrical resistance elements in the form of metallic coils or tubes which are arranged in banks located beneath the vehicle. The grid elements have a high surface to mass ratio to facilitate heat dispersal. A set of grids in the propulsion system (acceleration grids) are primarily used to control the current passing through the propulsion motors during acceleration. In cam-controlled vehicles, resistor grids are an integral part of both the propulsion and dynamic braking systems, but in a thyristor (chopper) controlled vehicle they are found only in the dynamic braking system.

The SES program has the capability of computing the instantaneous magnitude and location of heat rejected by the resistor grids of subway trains operating in a given system, accounting for the thermal inertia of the grid mass. The program computations for a given train in the system are based on the following assumptions: (1) each powered car of a cam-controlled subway train has two distinct sets of resistor grids, acceleration and deceleration, (2) each powered car of a chopper-controlled train only has deceleration resistor grids and the heat released during acceleration will be instantaneous, (3) the acceleration resistor grids in all cars of a train type are alike, (4) the deceleration resistor grids in all cars of a train type are alike.

As a consequence of the above assumptions, the program computes the instantaneous grid average temperatures and heat rejection rates for one pair of acceleration (if any) and deceleration grids and uses these values for the remaining grids on the train.

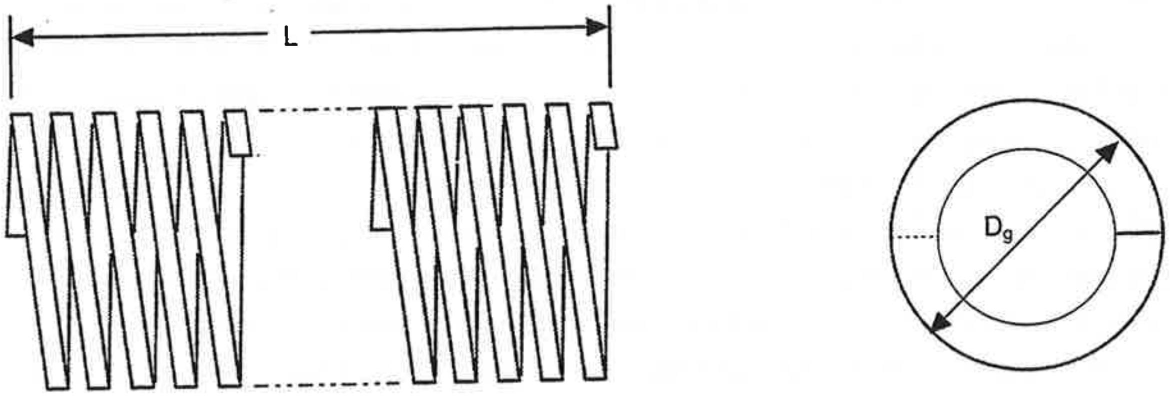
Input Requirements

The program user is required to supply the program with information which describes the physical characteristics of a train's acceleration and deceleration grids. These include the mass, specific heat, emissivity, effective diameter, effective convective surface area and effective radiative surface area of both grids for each type of train to be simulated.

The value used for the total weight of resistance elements per car represents the mass of all the resistor grid elements which actually resist current flow in the grid circuit, but excludes the weight of any of the supporting structure. The weight of the supporting frame and even the ceramic supports within each resistance element are not included in the weight entry. Typically, the weight of an individual resistance element may be on the order of 5 to 10 pounds, while the total weight of resistance elements per car for the braking resistor grid will be on the order of 300 to 400 pounds. If the grid mass is entered as zero, grid thermal inertia calculations are omitted and the energy which would normally enter the grid is instantaneously released to the tunnel air. (Note: Since a chopper-controlled train does not require acceleration grids, their mass must be entered as zero.)

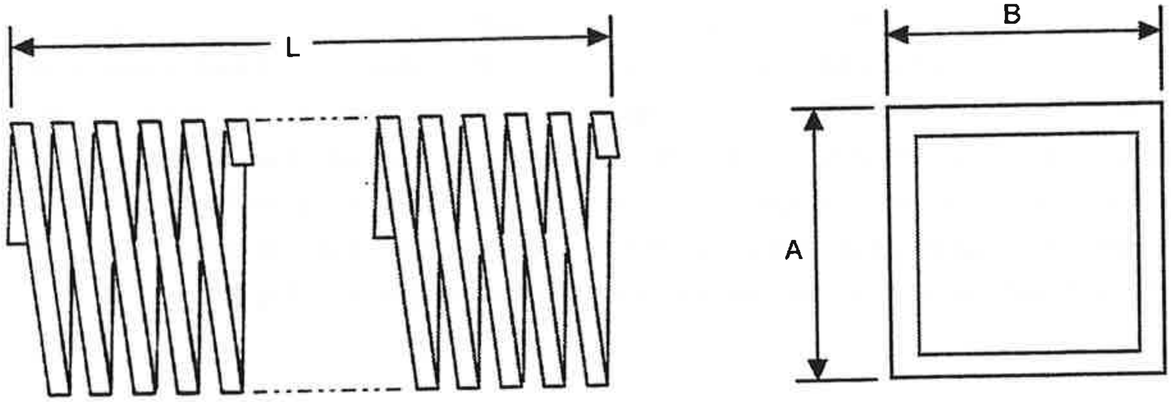
The effective diameter of an element represents the characteristic length dimension of a resistor grid element. For the circular cross-sectional type of grid element, the effective diameter is simply the diameter of the outer surface of the element (see Figure 8.13). For a grid with rectangular cross-section, the effective diameter is equal to the hydraulic diameter of the cross-section.

The effective surface area for convection of a grid is the sum of the effective surface areas of the individual grid elements. For the circular cross-sectional type of grid element, this area is defined as the cylindrical surface area at the outer surface of the element (see Figure 8.13). For a grid element with rectangular cross-section, this area is defined as the area enclosing the element at its outer surface, not including its end.



EFFECTIVE AREA = $\pi * D_g L$

EFFECTIVE DIAMETER = D_g



EFFECTIVE AREA = $2(A+B)L$

EFFECTIVE DIAMETER = $\frac{4(AB)}{2(A+B)}$

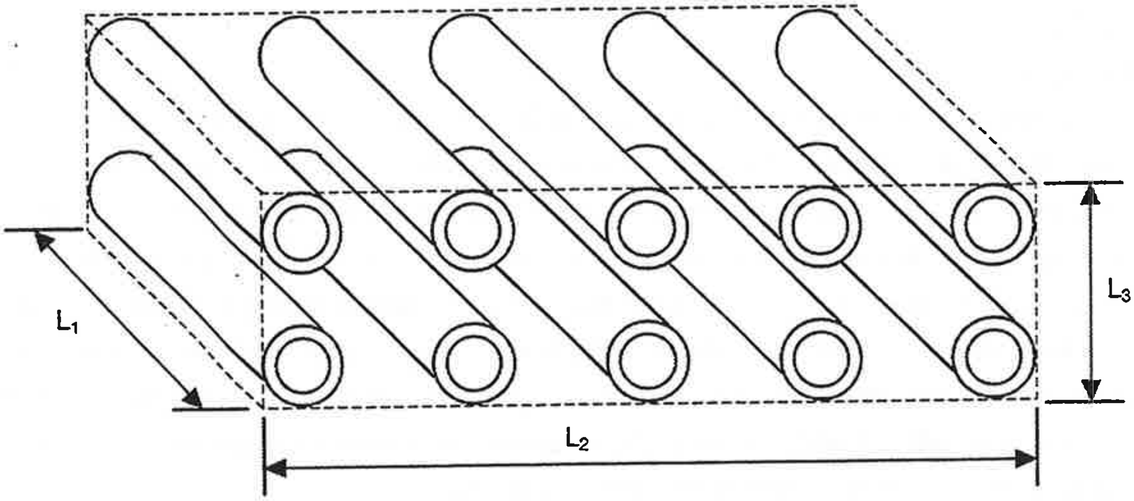
Figure 8.13 Effective Convective Area and Diameter of Resistor Grid Element

The effective surface area for radiation of a grid may be approximated by considering a resistor grid to be enclosed in an imaginary rectangular box (see Figure 8.14). Since the projected surface area of the grid is essentially equal to the projected surface area of the box as seen from any point outside the grid, the surfaces of the box can be considered as the effective radiating surfaces of the grid. The shape factor of the box with respect to its surroundings is equal to 1. Therefore, the effective radiative surface area of the grid is equal to the sum of the surface areas of the box.

The values used for the emissivity of the resistance element surface and the specific heat of the resistance element material should be evaluated at the average operating temperature of the grid. If this temperature is not known, the user should assume the deceleration grids to be operating in the temperature ranges of 500-1000°F and the acceleration grids in the range of 200-400°F.

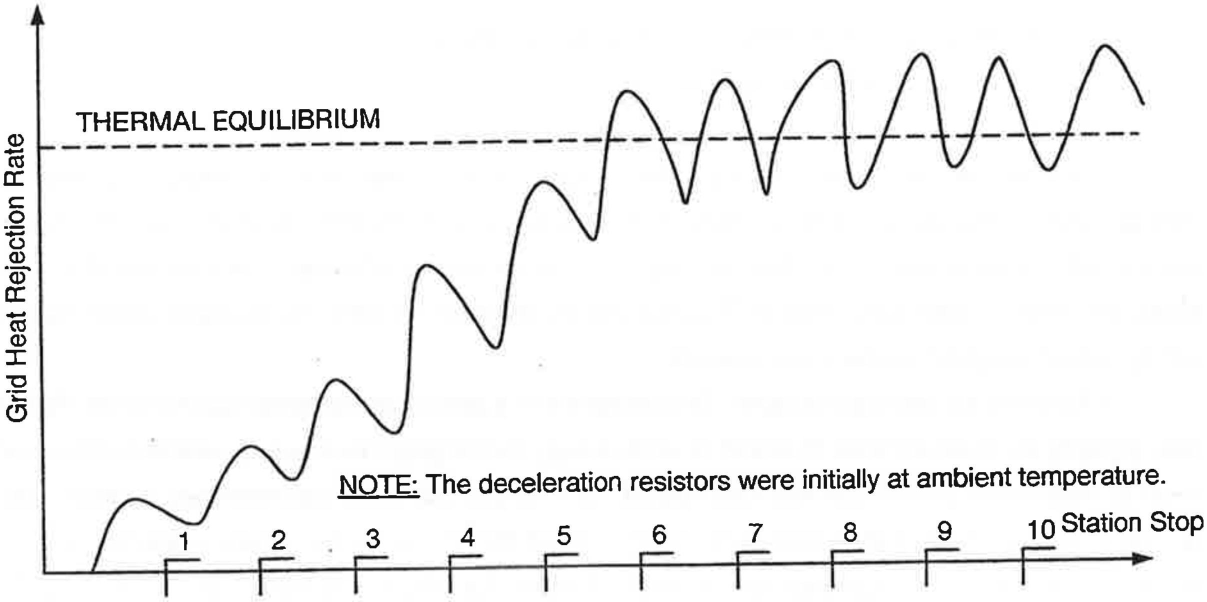
The program user must supply an initial grid temperature for each type. The grids are assigned these temperatures at the time the trains are dispatched onto their respective routes. If this initial grid temperature is entered as zero (0.), the grid is initialized at ambient temperature.

User Suggestions. Studies with the SES program indicate that heat released from train resistor grids at a given location in a subway is very much dependent on the history of train operation up to that location. The temperature history of deceleration grids (initialized at ambient temperature) as a train traverses a system shows that the resistor grid temperature builds up or cascades over several station stops, eventually leveling out to a repetitive cyclic pattern as the train continues through the system. The result is that a substantial portion of the kinetic energy dissipated during braking is retained by the resistor grid as stored thermal energy after the first station stop, but after several such stops the heat released from the grid during a train travel-dwell cycle approaches the kinetic energy dissipated during braking. When the latter occurs, the grids are said to be operating in a state of thermal equilibrium; that is, the average temperature profile of the grid becomes repetitive from station to station. The grid thermal inertia phenomenon is illustrated graphically by Figure 8.15, which shows a typical SES-computed cascading of resistor grid heat release as a train undergoes several successive travel-dwell cycles.



EFFECTIVE RADIOACTIVE SURFACE AREA =
$2(L_1 * L_2 + L_2 * L_3 + L_3 * L_1)$

Figure 8.14 Effective Radiation Surface Area for Resistor Grids



NOTE: The deceleration resistors were initially at ambient temperature.

Figure 8.15 Example of Deceleration Resistor Heat Rejection History

8.10 Flywheels

Introduction

The major source of heat within a subway system is the vehicle. The bulk of this heat is generated when the train is braking to a stop. During a typical station-to-station run, the total amount of heat generated by the train is roughly equivalent to the maximum level of kinetic energy achieved by the train, since to bring the train to a halt, all that energy must be dissipated as heat. Methods of storing this dissipated energy, for later use, were being explored. One of the more promising methods being tested during revenue service (see Ref. 5) consists of using flywheel units on board each car of a train. The flywheel receives energy from the train during braking, and returns energy to the train propulsion system when the train is motoring. A typical flywheel unit consists of a disk mounted on a shaft, a speed reduction unit, and an electric motor/generator and the necessary controls.

Basically, energy is stored in the flywheel by spinning the disk faster and faster. In other words, the translational kinetic energy of the train is converted to the rotational kinetic energy of the flywheel. The amount of energy stored in the flywheel assembly at any instant is related to the rotational speed of the disc by the following equation.

$$K.E. = 1/2\ (J\ \omega^2) \qquad (8.10.1)$$

where

K.E. = Kinetic Energy stored in flywheel

J = Polar moment of inertia of the flywheel assembly

ω = Rotational speed of the disk

The polar moment of inertia of the flywheel assembly is a measure of the flywheel's energy storage capacity. For a disk it is proportional to the size and weight of the flywheel. A typical flywheel unit would be designed to accept and store an amount of energy equivalent to the kinetic energy of a car at top speed and under "crush" passenger load (assuming one flywheel per car). The flywheel design must also satisfy system weight and space requirements.

Flywheels are normally designed to operate within a prescribed rotational speed range. Rather than allowing the flywheel to be "drained" of all its energy by bringing it to a stop, a minimum energy level is set by selection of a minimum rotational speed. For example, the prototype described in Reference 5 operates between 9,800 and 14,000 RPM. Taking 14,000 RPM to be the maximum rotational speed, this represents an operating range from 70% to 100% of maximum rotational speed. In terms of energy storage, this speed range represents energy storage between 50% to 100% of capacity.

SES Flywheel Model

The model developed for use with the SES assumes the flywheel operates within the bounds of a maximum and minimum rotational speed limit. During a braking cycle, the flywheel stores energy by spinning faster and faster until the maximum rotational speed is reached. The remaining train energy (if any) is dissipated by conventional means, i.e. through resistor grids. Similarly, during acceleration, the train draws propulsion energy from the flywheel until the flywheel slows down to its minimum rotational speed. When this point is reached, the train switches over and derives its propulsion energy from the third rail. The flywheel motor will also draw sufficient power from the third rail to overcome any internal losses (due to windage, bearings, etc.) in order to maintain its minimum rotational speed.

The model assumes that the flywheel has been properly matched with the traction motors and has been properly sized for the anticipated braking rates. These two assumptions imply that the flywheel can accept and return energy at the same rates at which the train generates and draws energy.

Flywheel Input Data

An entry of 2.0 for the Onboard Flywheel Simulation Option on Form 9H instructs the program that flywheels are to be simulated for this train. The description of the flywheel unit is done on Forms 9K and 9L.

Input on Form 9K includes the polar moment of inertia (defined as J in equation (8.10.1) above) and number of flywheels per car. The polar moment of inertia is defined differently for various geometric shapes, for a solid disk revolving around a central axis:

$$J = 1/2\ Mr^2 \qquad (8.10.2)$$

where

M = Mass of Disk in lb
r = Radius of Disk in ft

The corresponding units of J are lb-ft^2. For example, for a flywheel with a 20-inch diameter and 8- inch thickness constructed of steel:

$$\begin{aligned} M &= \pi(20/12x2)^2 \times (8/12) \times 487 \text{ lb/ft}^3 \\ &= 708.3 \text{ lb} \\ J &= 1/2\ (708.3) \times (10/12)^2 = 246 \text{ lb-ft}^2 \end{aligned}$$

assuming a density for steel of 487 lb/ft^3.

The value of J input in the program should be the sum of the J of the flywheel disk and equivalent J's of the motor alternator and other components of the unit. The other entries on Form 9K are minimum allowable, maximum allowable and initial rotational speed. These should be entered in units of revolutions per minute (RPM). The initial rotational speed of the flywheel must lie between the limits established by the minimum and maximum allowable rotational speeds.

Form 9L is used to input efficiency of power transfer from train to flywheel and from flywheel to train. Both these values are products of the efficiencies of the individual steps of power transfer. For example, suppose the efficiency of energy transfer from the train wheel to the train traction motor is 90%, and the efficiency from the traction motor to the alternator is 85%, and from the alternator to the flywheel it is 75%. Then the value that should be input for Efficiency of Power Transfer from Train to Flywheel should be: (0.90 x 0.85 x 0.75) x 100 = 57.4%. The efficiency of any particular step may be different in one direction than in the other.

The last five items of input on Form 9L describe the equation of internal losses of the flywheel. This value varies with flywheel rotational speed. The form of the equation is:

$$F(\omega) = A\omega^{d} + B\omega^{e} + C \qquad (8.10.3)$$

The variables A, B, and C must be entered in scientific notation (in Fortran Programming this is known as E-Format). That is they should be entered in two parts, the first being the mantissa which can be any number greater than zero, and the second being the power of 10 to which this number should be raised. For example, if A = 0.00006718 it should be entered as 6.7180E-05 which is equivalent to 6.718×10^{-5}. As can be seen from Input Form 9L, the letter E and the signed power of 10 to which the number is to be raised occupies the last 4 spaces of the entry. If these spaces are left blank, the program will multiply the mantissa by 1. The power of 10 to which the values of A, B, and C are raised should not be confused with the exponents d and e. The exponents d and e indicate how many times ω is to be multiplied by itself before being multiplied by A or B, respectively. If losses are directly proportional to rotational speed, the value of the exponent would be 1. If the losses are proportional to the square or square root of rotational speed, the exponent would be 2 or 0.5, respectively. Exponents may vary from 0. to 3.

Note: The internal time unit of the program is seconds. Therefore the time units of variables A and B must be in revolutions per second (RPS), and since the units of $F(\omega)$ must be in KW, the specific units for A, B and C are:

$A = KW/RPS^{d}$ $\qquad B = KW/RPS^{e}$ $\qquad C = KW$

For the case of the flywheel discussed in Reference 5, it was determined that at maximum rotational speed (14,000 RPM = 233.3 RPS) internal losses were equal to 2.94 KW. From Reference 6, it was determined that general internal losses were proportional to the 2.5 power of the speed. Solving for A gave:

$$F(\omega) = A\omega^d + B\omega^e + C \qquad (8.10.3)$$

$$2.94\ KW = A(233.3\ RPS)^{2.5}$$
$$A = 2.94\ KW/233.3\ RPS^{2.5} = 3.536 \times 10^{-6}\ KW/RPS^{2.5}$$

As can be seen these are the units specified above for A, and this would be entered as 3.5360E-06, as explained above.

It should also be noted that only one variable and one exponent were necessary to describe the internal losses of this flywheel. Depending on the flywheel being simulated and the arrangement of its components, two or all three variables may be necessary.

While the input to the model is in units associated with the flywheels, it is possible to simulate other energy storage devices by appropriate manipulation of the input. This could be done by calculating the ranges of energy storage capacity and internal losses of the particular device and relating them to fictitious values of ω by means of formula (8.10.1) and (8.10.3) above.

8.11 Initialization of System with Trains in Operation (Input Form 10)

The SES program user might wish to initialize a system with trains in operation for one of two reasons: to restart a simulation which has been partially completed, or to shorten the "run-up" time of a new simulation. The "run-up" time is the time required for a system to reach aerodynamic and thermodynamic stabilization. This occurs when all results, both aerodynamic and thermodynamic, repeat over a time interval which is known as the system period. The system period is usually equal to the train headway, or if trains are operating at different headways on different routes, it is equal to the smallest time interval into which all of the train headways are evenly divisible.

During a simulation, trains are dispatched onto the various routes according to the dispatching schedule which is defined by the user. The trains are placed into operation at the origin of operations of their designated route with a train speed of zero mph. They then begin to accelerate and travel along their route. The length of time that it takes the train to pass completely through the system and exit the other end, is dependent on the route length, speed limits, number of stops and their dwell time, as well as other factors. In large systems where the route is long, this travel time may be significant. Since most users are interested in the airflows, temperatures, and humidities in the system after it has reached aerodynamic and thermodynamic stabilization, the results during this run-up period are often of little interest.

The time required for a particular system to run up to stabilization can be shortened by initializing the system with operational trains spaced throughout the system. These trains should be in the same location and traveling at the same speed as if they were dispatched from their scheduling origin. This data on train location and speed can be taken from a detailed or abbreviated print of the status of the system at a time which is an even multiple of the headway, or if different headways are being used, an even multiple of the system period. The first simulation of a system would be performed either without initialized trains or with trains in positions which are estimated by the user. The train positions and speeds which are computed in the first simulation can then be used for initializing the trains in the second and subsequent simulations.

8.12 Explicit Train Performance Option (Input Form 8E)

The explicit train performance option allows the user to specify the travel profile which the train is to follow as it moves along its route. This travel profile is specified by means of a train speed versus time relationship. This speed versus time relationship, or table, is defined for each route, with all trains observing the speed-time profile for the route on which they are operating. There are two options available when using explicit train performance: train heat rejection computed by the SES program (Train Performance Option 2), and train heat rejection profile input to the program by the user (Train Performance Option 3).

Train Performance Option 2. When using explicit train performance with heat rejection computed by the program (Train Performance Option 2), the train follows the train speed versus time profile which is specified by the user. If the train is accelerating or running at constant speed, the tractive effort required to overcome the train resistance and produce the specified acceleration is computed and "supplied" by the motors. From this tractive effort the motor current is computed by using the motor current versus tractive effort curve which is defined in the train data. This motor current is used with the appropriate value of the external (if any) and internal motor circuit resistance to compute the rate of power loss in the acceleration grids (if any). If no acceleration grids are present, the motor current is used with the internal motor resistance to compute the equivalent amount of heat generated and the heat is released instantaneously. During periods of braking, the rate of power dissipation in the deceleration grid is equal to the net change of kinetic and potential energy of the train. When using Train Performance Option 2, the user must complete all the train data forms up to, and including the motor characteristics data. However, the form describing the maximum acceleration rate and normal deceleration rate curve should be skipped, since this data is not used by the program (refer to Tables 6.1 and 6.2).

The speed-time profile consists of a table of times and corresponding train speeds. The time, which is entered in seconds, is the simulation time which has elapsed since the train was dispatched onto its route. The time must be entered with each subsequent time greater than or equal to the previous time, and the values may be given as combinations of whole and decimal fractions of a second. The number of speed-time profile points identifies the number of points that will compose this table.

> Example 8.1 Figure 8.16 shows a typical train speed versus time profile for a station-to-station run. This figure shows a plot of train speed against the simulation time which has elapsed since the train was dispatched onto its route. Also shown is a tabular representation of the same data, which is in the form the user would use to enter the speed-time profile into the program. The area under the speed-time plot is the distance

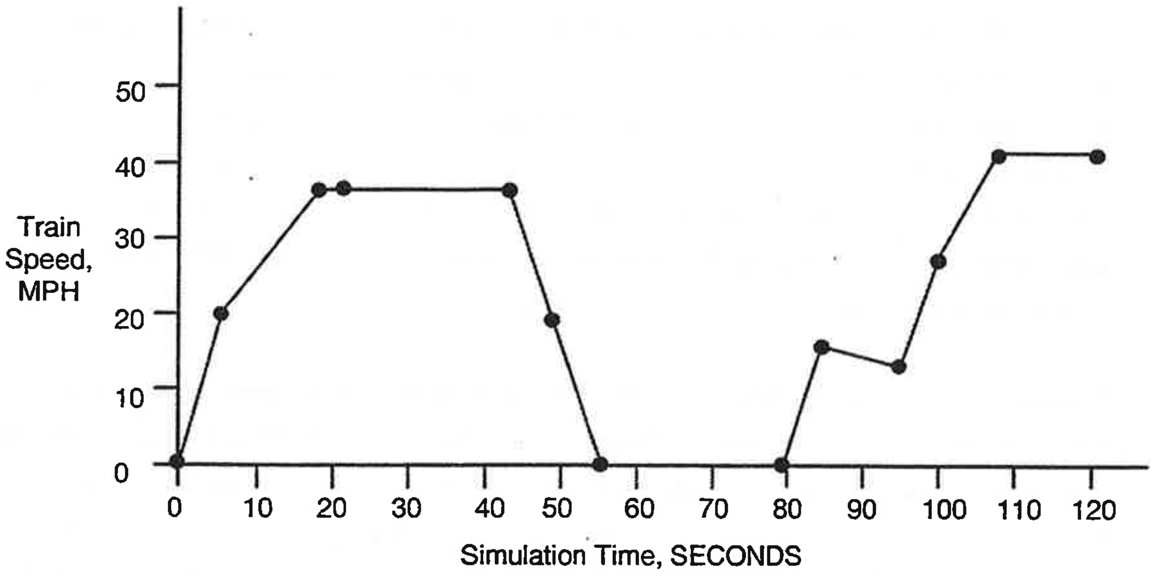
traveled by the train, and the distance between stops should correspond to the station-to-station distance.

The program performs a linear interpolation between the points of the speed-time profile which are specified by the user. The user may specify gradual changes in acceleration by specifying many points spaced close together. The user may also use fewer points to approximate the curve, but a curve with fewer points would have more abrupt changes in the train acceleration represented by the slope of the line of a speed versus time plot. The area under this curve, which is the distance traveled by the train, can be found using a trapezoidal integration method.

Trains are dispatched onto the route at the scheduling origin. The first point of the speed-time profile must be at time zero (0.0). The train is dispatched onto the route at the speed which corresponds to a time of zero on the speed-time profile. Trains are removed from operation when the front of the train goes beyond the forward end of the last track section. The location of the scheduling origin plus the distance traveled by the train during the length of the speed-time profile should be more than 50 feet, and preferably longer than the length of the track sections which have been defined for the route. To prevent a jam-up of trains at the end of the route, the speed-time profile is usually arranged so that the trains run out past the last track section at a reasonable operating speed.

Train Performance Option 3. Train performance Option 3 would be used when the speed-time profile and heat rejection-time profile are known to the user prior to the SES simulation. This information may be taken from either the manufacturer's estimates, a separate computer analysis of the train performance characteristics by using another computer program, or, if the system is operational, from measurements taken aboard operating trains.

The rates of power into the acceleration and deceleration resistor grids are specified by the user as time dependent functions. The units are kilowatts per train and this power is divided equally among the appropriate type of resistor grids which are located beneath each powered car. The rate of power dissipation into the resistor grids is given as a time-dependent function which is combined with the speed-time profile. The combined speed and power dissipation profile has for each point in time a value for train speed and rate of power into the deceleration grid. As in the speed-time table in Train Performance Option 2, the times are entered in seconds with each subsequent time equal to, or greater than the previous time. These times are the simulation time which has elapsed since an individual train has been dispatched onto its route. As with the train speed, the program performs a linear interpolation to find rates of power dissipation between the points which are specified by the user.

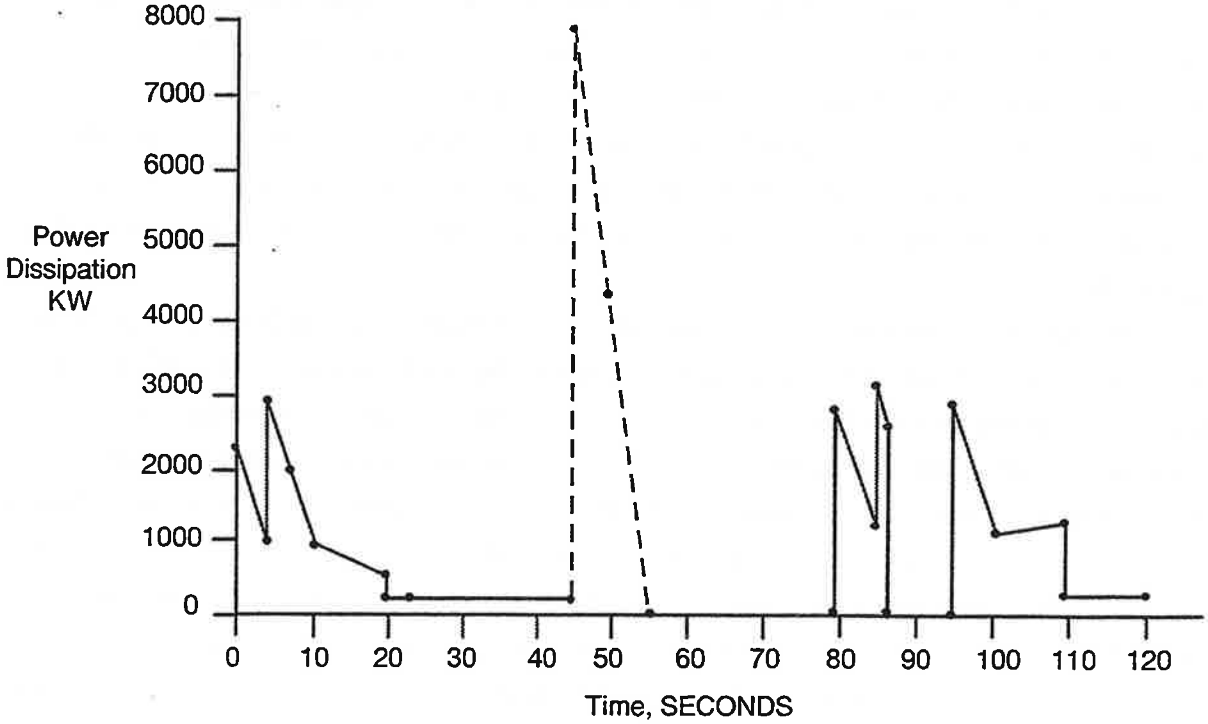


TIME	SPEED
0.00	0.0
7.00	21.0
20.00	35.0
25.00	35.0
44.80	35.0
50.00	20.0
56.67	0.0
80.00	0.0
85.00	15.0
95.00	13.0
100.00	25.0
110.00	40.0
120.00	40.0

Figure 8.16 Sample Speed-Time Plot with Tabular Data

A sample heat release profile for a cam-controlled train is shown graphically and in tabular form in Figure 8.17. This heat release profile, which provides representative values, corresponds to the speed-time profile which is shown in Figure 8.16. The characteristic peaks in the acceleration power dissipation, which occur between zero and 10 seconds, are caused by the insertion and removal of the acceleration resistor grids from the motor circuit to limit the current through the motors. The sharp peak in the deceleration power dissipation, which occurs from 44 to 57 seconds, is caused by the train braking to a stop from 35 mph.

The tabular data showing the train speed, acceleration power loss, and deceleration power loss versus time is listed in Figure 8.17. These data are in a form that would be used as input to the SES program for Train Performance Option 3. Since this data relates three dependent variables to one independent variable (time), one data point is required to show characteristic points in any of the three curves. However, for each point a correct value must be given for all three curves. The program performs a linear interpolation between the data points which are supplied by the user. A step function, which is a rapid change over a very short time interval, can be simulated by supplying two points at the same instant of time. The first point would be the value just prior to the step function and the second point would be the value just after the step. An example of this is shown in Figure 8.17 at 85 seconds. At this time the traction power is shut off, and the train coasts for 10 seconds. The first point at 85 seconds, which defines the curve from 84 to 85 seconds, has an acceleration power loss of 2500 kilowatts. The second point at 85 seconds, which defines the curve from 85 to 95 seconds, has a value of 0 kilowatts. These two points act together to produce an abrupt change in the acceleration power loss at 85 seconds. Train speed is a smooth function, and its rate of change with respect to time is the acceleration. The user must be sure that the speed-time profile supplied to the program does not contain rapid changes in train speed that would exceed the acceleration capabilities of the train. The acceleration and deceleration power loss which is specified by the user when using Train Performance Option 3, can be released to the air directly or through the resistor grid time delay mechanism. The direct release of this heat into the air is known as instantaneous heat release. This mechanism is used if the user specifies a resistor mass of zero. Both the acceleration and deceleration resistor grid may be simulated or bypassed independently. Note: When using Train Performance Option 3 (Explicit, Train Heat Rejection Input), the user may not enter a value for both acceleration power loss and deceleration power loss for the same time entry. In other words, at any point in time, power can go into either the acceleration grid or the deceleration grid, but not both.



TIME	TRAIN SPEED	ACCEL. POWER	DECEL. POWER
0.00	0.00	0.00	0.00
0.01	0.00	2400.00	0.00
4.00	12.00	1000.00	0.00
4.00	12.00	3000.00	0.00
7.00	21.00	1800.00	0.00
9.00	27.00	1000.00	0.00
20.00	35.00	500.00	0.00
20.00	35.00	300.00	0.00
25.00	35.00	300.00	0.00
44.80	35.00	300.00	0.00
44.80	35.00	0.00	7720.00
50.00	20.00	0.00	4300.00
56.67	0.00	0.00	0.00
80.00	0.00	0.00	0.00
80.00	0.00	2400.00	0.00
84.00	12.00	1000.00	0.00
84.00	12.00	3000.00	0.00
85.00	15.00	2500.00	0.00
85.00	15.00	0.00	0.00
95.00	13.00	0.00	0.00
95.00	13.00	2700.00	0.00
100.00	25.00	1000.00	0.00
110.00	40.00	1100.00	0.00
110.00	40.00	300.00	0.00
120.00	40.00	300.00	0.00

KEY: ——— Acceleration Power

– – – – - Deceleration Power

NOTE: 1. All train speeds are in M.P.H.
2. All train power is in KILOWATTS

Figure 8.17 Sample Heat Release Profile with Tabular Data

REFERENCES

1. "Aerodynamics of High-Speed Train," T. Hara, M. Kawaguti, G. Fukuchi, A. Yamamoto. 1968. ("High Speeds Symposium", Vienna 1968).

2. Hoerner, S.F., "Fluid Dynamic Drag," published by author, Bricktown, N.J., 1965.

3. "Modell Untersuchungen Uber Das Widerstandsverhalten Von Zugen In Ein- und Zweigleisigen Tunnels Der Munchnew U-Bahn" ("Model Tests of Train Air Resistance in Single and Double Track Tunnels in the Munich Subways"), R. Frimberger, E. Lukas, October 1969.

4. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., DeLeuw, Cather & Company and Kaiser Engineers, "Aerodynamic and Thermodynamic Validation Tests in Berkeley Hills Tunnel," June 1973, Technical Report No. UMTA-DC-06-0010-73-1, Transit Development Corporation, Washington, DC.

5. Raskin, Donald and Yutko, Ronald, "Energy Storage Propulsion Systems for Rapid Transit Cars," Report No. UMTA-NY-06-0006-75-1.

6. King, Charles and Kusko, Alexander, "Flywheel Propulsion Simulation", Report No. UMTA-MA-06-0044-77-1.

9. FIRE MODEL

Documented reports of tunnel fires (Appendix H) show the behavior of the fire and associated tunnel airflows to differ significantly from more familiar fire situations outside the confines of a tunnel. The most noteworthy distinction is the buoyant effect which tends to create a layer of hot smoke and gases flowing away from the fire near the crown of the tunnel, while air supporting combustion moves toward the fire beneath the smoke layer. For example, in a horizontal (0% grade) unventilated tunnel with the fire near the longitudinal mid-point, the buoyant effect will establish a symmetrical circulation pattern with the hot, smoky air leaving both ends of the tunnel and air outside the tunnel drawn in beneath it (see Figure 9.1).

A longitudinal ventilation system forcing air to flow through the tunnel will shift the balance of heated air in the direction of the forced flow. If the ventilation is of sufficient capacity, it will cause all of the heated air to flow towards the downstream direction. If the ventilation is weak, the upper layer of heated air may flow in a direction contrary to the forced ventilation (a phenomenon called "back-layering"; see Figure 9.2). Whether back layering occurs depends on a number of factors which include the intensity of the fire, the grade and geometry of the tunnel, and the velocity of the ventilating airstream.

In the event of a subway fire involving a train disabled in a tunnel, the ventilation system should be able to control the direction of smoke movement in order to both provide a clear and safe path for evacuating people and to facilitate fire fighting operations. The ability to prevent back-layering therefore should be a major objective in the design of the ventilation system and its operation during an emergency. The fire model provides the system designer with an analytical tool for evaluating the performance of the ventilation system in this regard.

The fire model that has been developed reflects a compromise between satisfying the basic needs of the ventilation system designer and utilizing the latest state-of-the-art analytical treatment of fires in enclosed spaces in a manner which is compatible with the basic structure of the SES program. In formulating the analytical treatment of the problem, it was concluded that a direct simulation of the complex three-dimensional compressible flow region of the fire was not required to be able to predict the occurrence of back-layering. Instead it was concluded that only the bulk flows and temperatures of the air moving toward and away from the fire, which are dependent on the coupled effects of the fire and the forced ventilation system, had to be simulated. Having done this, the occurrence of back-layering would then be determined by comparing the resulting velocity of the air moving toward the fire with a certain "critical velocity" above which back layering is precluded.

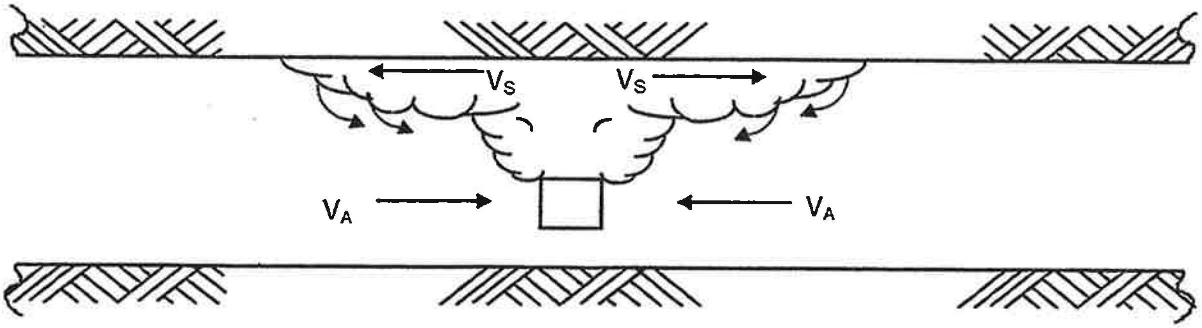
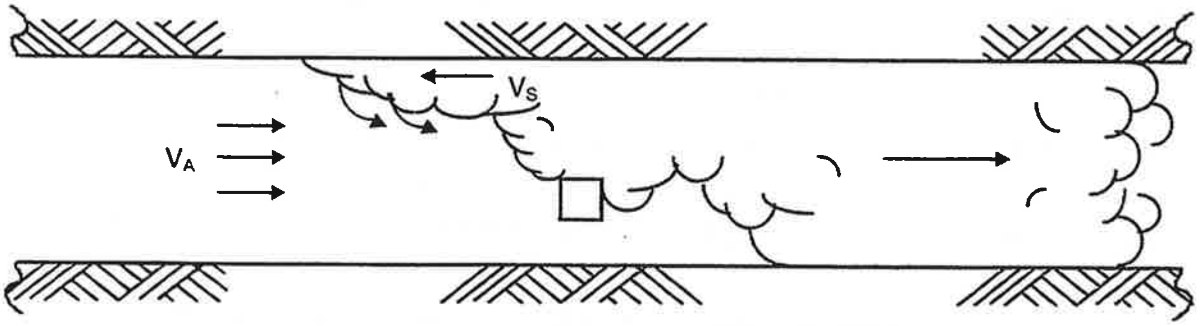
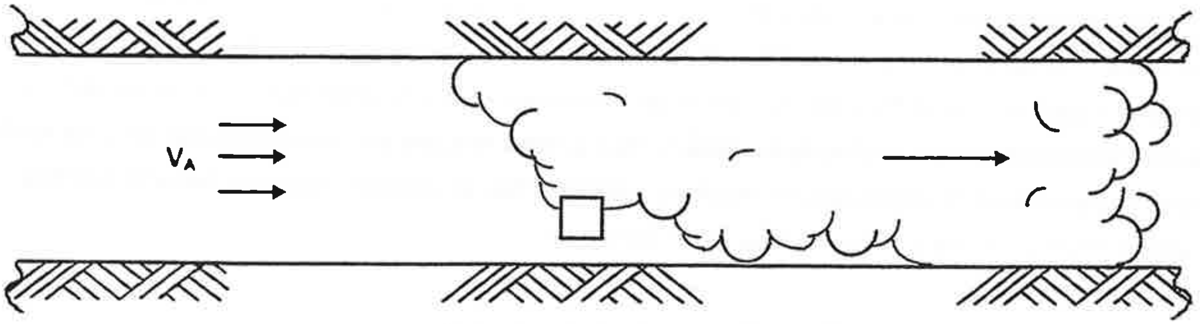


Figure 9.1 Symmetrical Airflow Patterns Typical of an Unventilated Tunnel Fire



(A). Back-Layering Occurs - Insufficient Ventilation



(B) Direction of Smoke-Flow Controlled

Figure 9.2 Tunnel Fire with Mechanical Ventilation

9.1 Critical Velocity

The method selected for treating the problem uses the results of a number of model and full-scale tests (References 1 and 2) which showed that back-layering will not occur if the velocity of the ventilating air moving toward the fire is equal to or exceeds a certain critical velocity. For a level tunnel, ($K_g = 1.0$), this critical velocity is determined from the following coupled equations:

$$V_c = K_g \left(\frac{gHQ}{Fr_c \rho_\infty C_p A T_f} \right)^{1/3} \qquad (9.1.1)$$

$$T_f = \frac{Q}{\rho_\infty C_p A V_c} + T_\infty \qquad (9.1.2)$$

where: V_c = critical velocity, ft/sec

g = acceleration of gravity, ft/s^2

H = tunnel height, ft

Q = fire heat release rate, Btu/sec

ρ_∞ = ambient air density, lbm/ft^3

C_p = specific heat of air at constant pressure, Btu/lbm-deg R

A = net cross-sectional area of tunnel, ft^2

T_f = hot gas temperature, deg R

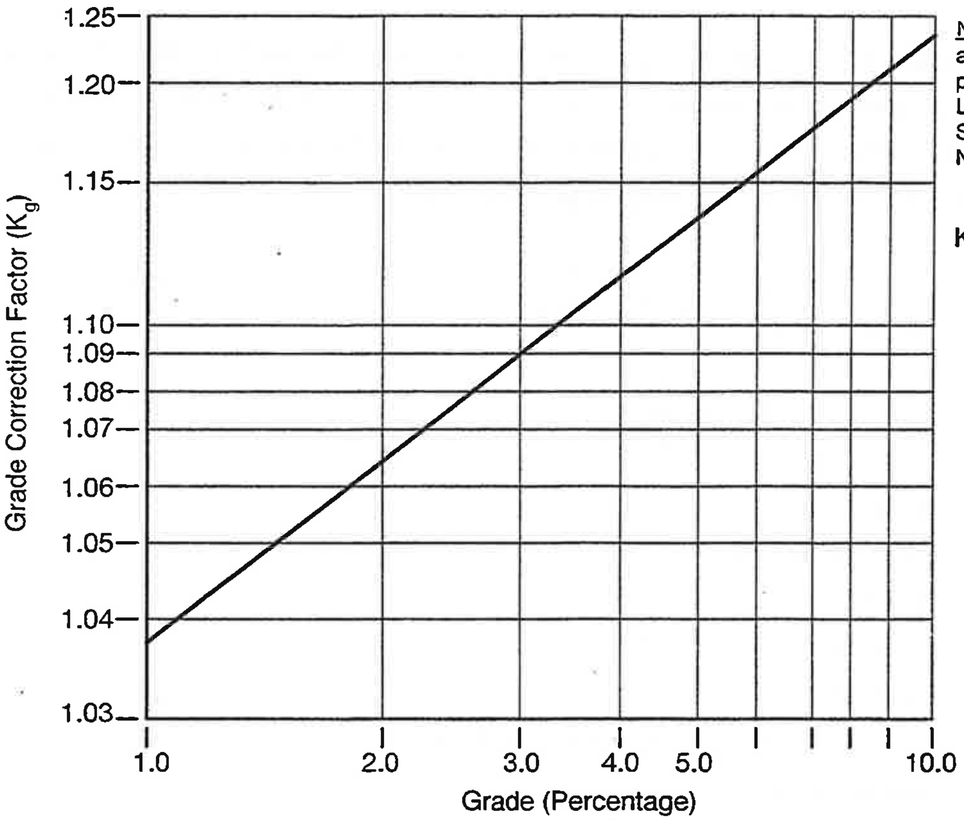
Fr_c = critical value of the Froude Number for a flow ventilating a fire = 4.5

K_g = grade correction factor (dimensionless)

T_∞ = ambient temperature, deg R

Scale model tests in ducts show the critical value of the Froude Number ranges from 4.5 to 6.7 and therefore, provides a critical velocity range of about 12 percent. Since this Froude Number is based on scale model experiments, the conservative value of 4.5 is used for calculating the critical velocity. The full-scale Memorial Tunnel Tests confirmed this value is conservative.

For a tunnel in which the direction of ventilation is downgrade, the critical velocity is greater than that for a level tunnel. Although the effect of grade on the critical velocity has not as yet been specifically studied in connection with tunnel fires, related studies on the control of methane layers in coal mines (methane, being lighter than air tends to form layers along the crown of a mine gallery) have provided some useful data. Since the physical phenomena are similar in both cases, i.e., a low density fluid flowing over a higher density fluid, the data presented for methane layers has been used to develop a grade correction factor. This factor, is tentatively determined from Figure 9.3.



NOTE: This curve has been adapted from the data presented in "Methane Roof Layers" by Bakke and Leach, S.M.R.E. Research Report No. 195, Sheffield, 1960.

$K_g = 1+0.0374(\text{grade})^{0.8}$

Figure 9.3 Grade Correction Factor

The simultaneous solution of Equations (9.1.1) and (9.1.2) determines the critical velocity. This criterion determines the minimum steady-state velocity of the ventilating air moving toward the fire that would be required to prevent back-layering. Note that this criterion determines the required air velocity during the fire and not the air velocity in the absence of the fire which can be substantially different. The velocity of the ventilating air moving toward the fire must therefore be known in order to apply this criterion. This velocity is provided by the SES fire model.

9.2 SES Fire Model

A fire in a tunnel can have a considerable effect on the airflow normally induced through the tunnel by the ventilation system. There is the buoyant effect of the hot gases which can either increase or decrease the airflow, depending on whether one is trying to ventilate upgrade or downgrade, respectively. There is a throttling effect which occurs as a result of the expansion and acceleration of gases at the fire site which retards the airflow. There is an increase in the viscous losses downstream of the fire due to the faster flowing hot gases. In addition, the operating characteristics of the downstream fans exhausting the heated air are also affected.

The above described effects are all interrelated with the thermal exchanges that occur at and downstream of the fire site. These exchanges include the direct transfer of heat from the fire to the tunnel air and the transfer of heat to the tunnel walls from the flame via radiation and from the air via both radiation and convection. The magnitude of heat transfer to the walls in the vicinity of a major fire is such that it causes the wall surface temperature to rise rapidly. This rise, in turn, reduces the cooling effect of the walls and increases the temperature of the air (for a constant heat rate fire) as the life of the fire progresses.

9.2.1 Methodology

The SES fire model is able to simulate the interaction of all these fire-related effects while still maintaining the basic structure of the SES model, i.e., one-dimensional and incompressible. This was accomplished by: 1) creating a new type of line segment referred to as a "fire segment"; 2) modifying the operating characteristics of fans processing heated air; and 3) expanding the capability of the unsteady state heat source to represent a fire. With this approach, the user only has to adjust the program printed CFM's to arrive at actual flow rates in order to account for variations in air density throughout the system.

For those segments designated by the user as fire segments, the normally performed aerodynamic and thermodynamic computations have been modified to reflect the actual density and other temperature dependent properties of air as a function of the air temperature in the respective subsegments of the segment. In addition, computations relating to buoyancy and throttling effects as well as radiant heat transfer to the walls are also performed. Furthermore, a conduction model has been included to simulate the heating-up of the tunnel wall surface.

9.2.2 Model Limitations

The SES fire model is essentially a quasi-steady-state model that has been designed with the ability to simulate the "overall" effects of a tunnel fire on the airflow induced by the ventilation system. The level of detail is considered sufficient for evaluating the adequacy of the ventilation system and is consistent with the state-of-the-art in mining ventilation programs with the capability of simulating fires. Because the SES is a one-dimensional model, the results of a fire simulation will only indicate whether or not the ventilating airflows are sufficient to prevent back-layering when compared with the critical velocity, but not the extent of back-layering, which is a two-dimensional phenomena. In addition, the early stages of a fire, before the ventilation system is activated, generally cannot be simulated, since this period is dominated by buoyant recirculating airflows.

9.3 Fire Scenario

To reduce weight, cut costs, and provide greater aesthetic appeal and comfort, most modern subway vehicles are constructed with more and more plastics and other potentially combustible materials than ever before. These materials can be found in the floor covering, wall panels, seats, light diffusers, window and door gaskets, wire insulation, and many other items. Consequently, the transit rider is being exposed to an increasing fire hazard.

A survey of fires which have occurred in subway systems has revealed three main causes:

1. An accident due to a derailment or a collision followed by an electrical short circuit
2. Electrical problems either in the vehicle interior or exterior
3. Arson (usually in the vehicle interior)

A typical fire development process for a transit vehicle is shown in Figure 9.4. The fire starts with some ignition (heat) source which may be in the interior or exterior of the vehicle. In order for a fire to develop, the ignition source must come in contact with flammable material. For an exterior fire, this will usually be beneath the floor, where electrical, equipment, wiring, and the propulsion motors and drives are located.

The floor of a typical transit vehicle is made by bonding thin metal sheets to both sides of a plywood core ("plymetal"). The metal cladding adds strength and increases the fire resistance of the flooring. The specifications for the transit vehicle will usually state the degree of "fire resistance" which is required of the floor. This will govern the selection of floor; material and the requirements for sealing all openings (penetrations). Despite these precautions, some undercar fires manage to penetrate into the interior of the car.

Soon after penetrating the floor, the fire will spread to the interior of the car but will remain relatively small in size. This fire will increase the temperature of the car interior causing the interior plastic furnishings to melt. This results in the vaporization of flammable gases. When the concentration of these gases build up and then combine with a sudden increase in air entering the car, sudden ignition can occur.

"Flashover" is an event when essentially the whole interior of the car erupts in flame. A dramatic increase in the fire heat and burning rate results from flashover.

The heat from one burning car is usually sufficient to spread the fire to adjacent cars. Several factors affect the spread of the fire, including the quantity and type of combustibles on each car and the fire resistance of the car ends.

Observations of actual subway fires have shown that the flame spread between cars occurs above the floor line. In most cases, the fire will be confined to the interior above the floor line for the second and subsequent cars. The fire resistant construction of the vehicle floor will usually prevent the fire from spreading to the undercar equipment or burning the floor itself. This has the beneficial effect of reducing the total quantity of combustible materials available to the fire, and thus reduces the heat generated from the burning of the second and subsequent cars.

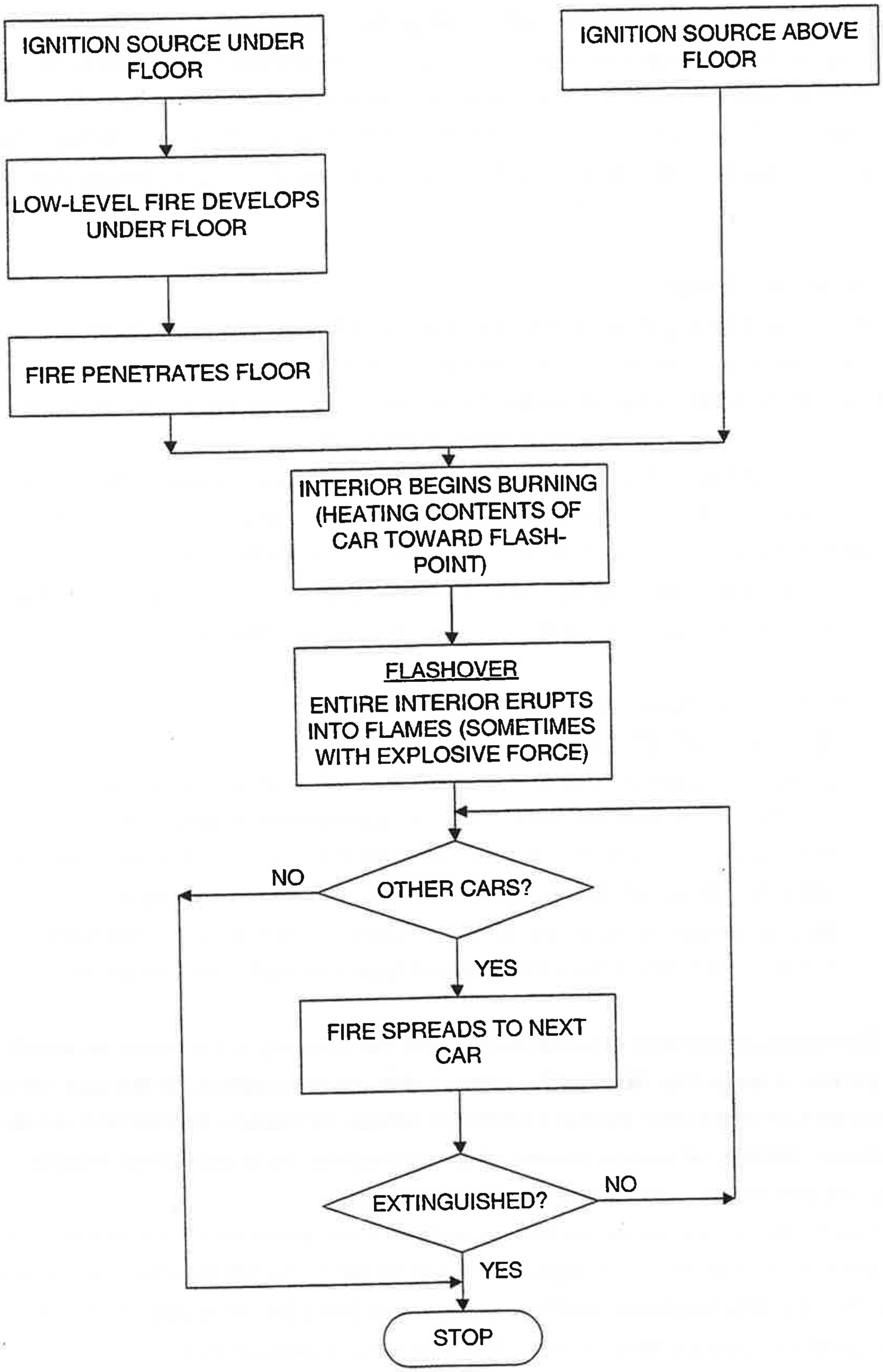


Figure 9.4 Typical Train Fire Development Flow Diagram

In summary, a transit vehicle fire can go through many stages. Many fires will be prevented from spreading by the fire resistance of the vehicle construction or be extinguished in the early stages by subway patrons, transit personnel or the fire department. Most major fires can be subdivided into two distinct stages: the "before flashover" stage where the fire is relatively small and produces a small amount of heat, and the "after flashover" stage when the fire is of major proportions, producing a large quantity of heat.

9.4 Design Fire Heat Release Rate

The key input parameter required by the fire model is the design fire heat release rate of the burning train. This value should be consistent with events observed during major subway fires involving a burning train and the overall design objectives of the subway ventilation system. One approach for estimating this value is to first develop an "inventory of combustibles."

A typical inventory of vehicle combustibles for a particular car is shown in Table 9.1. This table gives the quantity of combustible materials in the vehicle and their heat content broken down into three groups: above the floor level, the flooring material itself, and below the floor level. Having established the total amount of heat that could be liberated from the total consumption of the vehicle, an estimate of the time for this to occur is required to arrive at the average heat release rate from the fire.

The following observations have been made concerning past fire incidents:

1. San Francisco-BART (January 17, 1979) - Five vehicles were involved in varying degrees. Estimates of the quantity and type of materials burned result in an equivalent of 3 vehicles burned in 3 hours, or approximately 1 vehicle per hour.
2. Montreal (January 3, 1974) - 4½ vehicles burned in 2½ hours, for an average burning rate of 90 million Btu/hr (26.4 megawatts) or approximately 1.7 vehicles per hour.
3. Montreal (December 1971) - 24 vehicles burned in 18 hours for an average burning rate of 70 million Btu/hr (20.5 megawatts) of approximately 1.3 vehicles per hour.

On the basis of the above observations, it seems that a burning rate of one to two vehicles burning per hour is reasonable. Note that this estimate does not necessarily mean that each vehicle is completely consumed each hour, but that a number of vehicles can become involved and partially burn simultaneously, liberating an average amount of heat equivalent to one or two vehicles burning per hour. The latter case is probably the more realistic situation.

To estimate the fire heat release rate in a multiple-car fire as the life of the fire progresses, certain critical times during the fire must be estimated. These times are: 1) the time for a low-level fire to reach flashover, 2) the time for most of the vehicle to be consumed by the fire (measured starting with flashover); and 3) the time for the fire to cause flashover in succeeding vehicles.

Table 9.1 Inventory of Combustibles for Septa New Broad Street Car*

	Item	Material	lbs	Btu/lb	Btu Per Car
1.	Seats (68)	Molded FRP			5,335,000
2	Floor cover	Rubber Sheet			3,200,000
3.	Acoustic Insulation	Insulcoustic 943	200	4,000	800,000
4.	Wall & Ceiling Insulation	Woven Glass Fiber (No Binder)			—
5.	Liners	Plywood	200	7,900	1,580,000
		Melamine faced aluminum	200	11,100	2,220,000
6.	Windows	Laminated Safety Glass			—
7.	Glazing Gaskets	Rubber			825,000
8.	End Caps	FRP	152	11,100	1,687,000
		Cardboard	5.3	7,800	41,000
		Fiberglass	20 11,100	222,000	
9.	Light Diffusers	Polycarbonate			651,000
10.	Wire Insulation				201,000
	TOTAL ABOVE FLOOR				16,762,000
11.	FLOOR	Stainless steel sheet on 3/4" plywood			6,445,000
	TOTAL IN FLOOR				6,445,000
12.	Batteries	Polycarbonate	20	11,100	222,000
13.	Oil (90W)		8 gal	22,000	176,000
14.	Control Covers	FRP	150	11,100	1,665,000
15.	Wire Insulation		1000	11,100	11,100,000
	TOTAL BELOW FLOOR				13,163,000
	TOTAL FOR ENTIRE CAR				36,370,000

* Data prepared by Gage-Babcock & Associates

Figures 9.5 and 9.6 show the time-dependent fire heat release rates which result from two hypothetical fire scenarios, referred to here as case 1 and case 2. These scenarios were based on the following:

	Case 1	Case 2
Total Vehicle Combustibles - Btu	$41x10^6$	$41x10^6$
Vehicle Combustibles Above Floor Level - Btu	$20x10^6$	$20x10^6$
Vehicle Burn Rate, Undercar Fire, start to Flashover, Btu/hr	$4xl0^6$	$4x10^6$
Vehicle Burn Rate, Flashover to Burnout,		
First Vehicle - Btu/hr	$40X10^6$	$40X10^6$
Succeeding Vehicles - Btu/hr	$20x10^6$	$20x10^6$
Time Between start and Flashover First Vehicle - Minutes	15	15
Time For Flashover to spread to Succeeding Vehicles - Minutes	15	45

In each of these cases it was assumed that no intervening action was taken to prevent the fire from spreading from car to car. It was also assumed that all the combustibles in the first car were consumed (above floor, floor itself, and below floor), but that the fire was confined to the above-floor combustibles in the second and subsequent cars.

If the subway ventilation system is to be designed to always prevent back-layering, then the maximum fire heat release rate resulting from the fire scenario should be used as the design fire heat release rate. For case 1, therefore, 60 million Btu/hr would be used in the fire model, and for case 2, 100 million Btu/hr.

If the subway ventilation system is only required to prevent back-layering during the passenger evacuation process, then the maximum fire heat release rate during the time specified to complete this process should be used as the design fire heat release rate in the fire model. For a specified evacuation time of between 45 and 60 minutes, the design fire heat release rate for case 1 and case 2 would be 40 and 80 million Btu/hr, respectively.

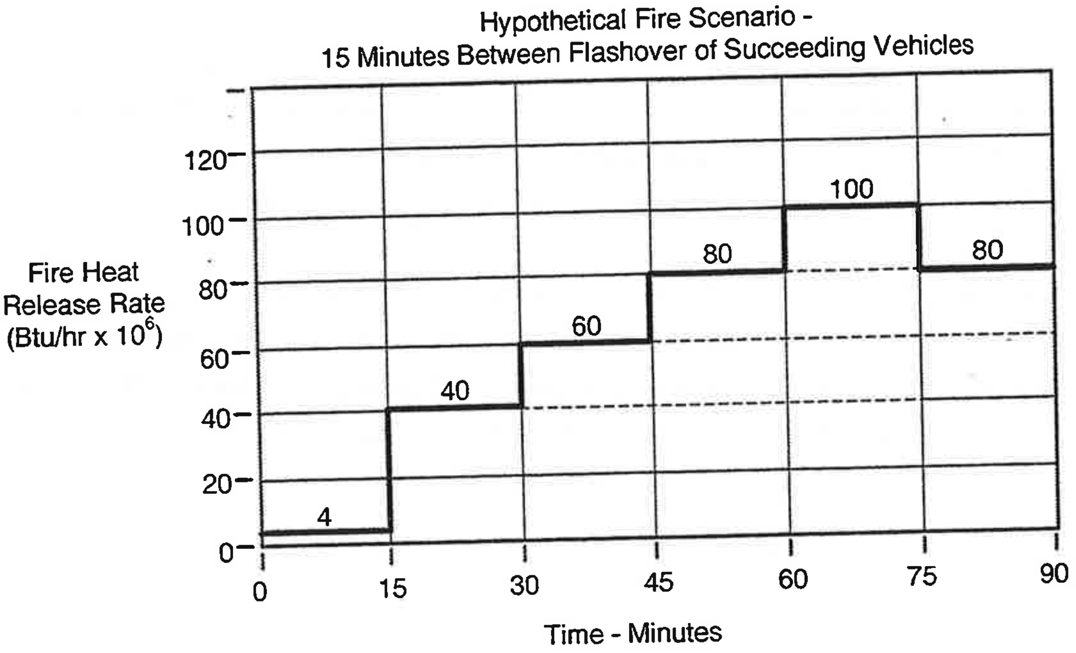


Figure 9.5 Fire Heat Release Rate for Case 1

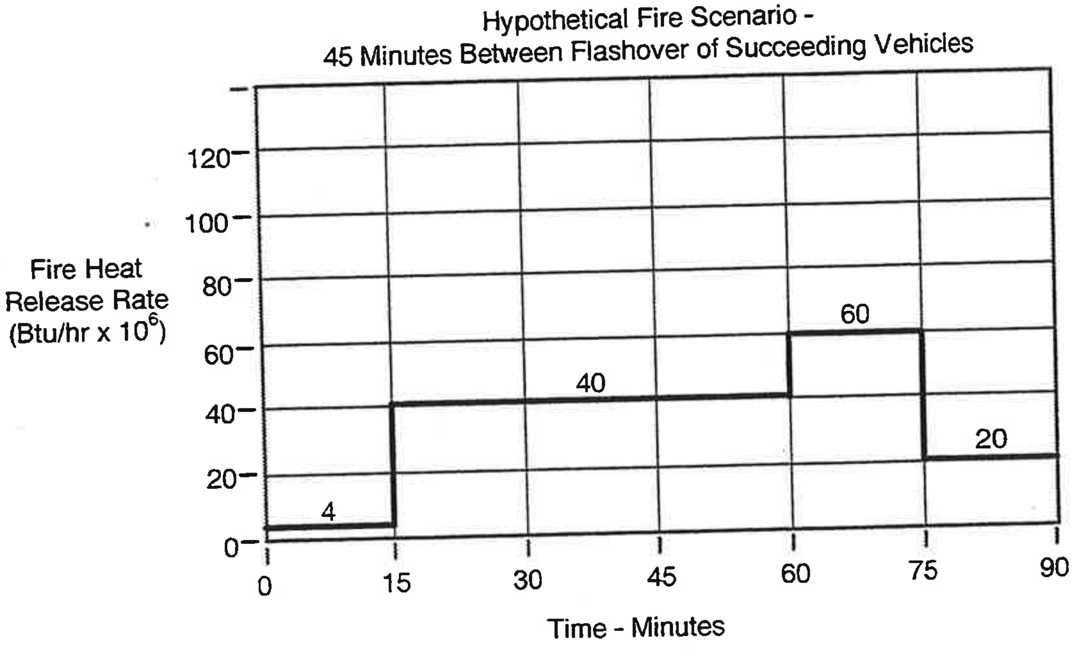


Figure 9.6 Fire Heat Release Rate for Case 2

REFERENCES

1. S.S Levy and D.P. Elpidorou, "Ventilation of the Mount Shaughnessy Tunnel," Seventh International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels, September 1991, Cranfield, England: British Hydromechanics Research Group (BHRG) Fluid Engineering 1991.

2. W.D. Kennedy, "The Influence of the Memorial Tunnel Fire Tests on Transit Tunnel Fire Emergency Ventilation Analysis," Presented at the American Public Transit Association's 1997 Rapid Transit Conference Seminar on Ventilation of Transit Tunnels and Underground Stations, Washington, 7-11 June 1997, available from Parsons Brinckerhoff, One Penn Plaza, New York City, NY 10119.

10. SES PROGRAM OPTIONS

The SES program provides the user with many options which control the extent and manner in which a system is to be simulated. Other options control the manner in which the results are presented and which results are given. Still other options concerning what is to be simulated are dependent on the data provided to the program.

10.1 Temperature and Humidity Simulation Option (Input Form 1C)

The temperature and humidity simulation option controls whether a simulation of the temperatures and humidities within the system is to be performed, and if so, the level of detail at which the calculations are to be made.

Option 0 - Bypass. This option is used when the user wishes to simulate the aerodynamic, but not the thermodynamic, phenomena within a system. When the user is not concerned with the temperatures and humidities occurring within a system, bypassing the thermodynamic portion of the simulation will produce a considerable savings in the computer cost of the simulation. This savings may be as much as 1/4 or 1/3 of the cost of the simulation.

Option 1 - Yes. This option instructs the SES program to perform the thermodynamic portion of the simulation. The thermodynamic portion of the simulation can only be performed together with the aerodynamic portion of the simulation. The reason is that the airflows carry the heat and moisture throughout the system and are vital to the thermodynamic behavior of the system.

Option 2 - Yes (with evaporation and viscous heating). When this option is specified, the thermodynamic portion of the simulation is performed as in Option 1 (above) with the addition of the evaluation of the evaporation of moisture from the wall surfaces and calculations of the amount of heat generated by the viscous friction between the air and the wall surfaces. The inclusion of these additional computations will slightly increase the computer cost of the simulation. In most systems these terms are small in magnitude and can usually be ignored.

10.2 Environmental Control Load Evaluation Option (Input Form 1C)

The environmental control load evaluation consists of a heat sink analysis for the portions of the system that are placed in "uncontrolled" zones, and a heating or cooling load estimate for the portions of the system which are in "controlled" zones. The environmental control load evaluation option requires the user to supply additional input data to the SES program. If the temperature and humidity simulation option is zero, this option is not applicable and an environmental control load evaluation may not be performed.

Option 0 - Bypass. This option may be used when an environmental control load evaluation is not to be performed for this simulation. The additional input data is not required, and the user must not specify a summary option of 4 (perform environmental control load evaluation) in the Print Control Data on Input Form 12.

. Option 1 - Yes. This option is used when the user wishes an evaluation of the environmental load within a system. If this option is used, the evaluation would be performed for either morning or evening rush hour, depending on what was entered as the design hour on Input Form 1B.

Option 2 - Off Hour. This option is used when an environmental control load evaluation is required for an off-hour (neither morning nor evening rush hour). When using this option the heat sink analysis does not compute the wall surface temperature based upon the exchange of heat with the surrounding soil. Instead, the wall surface temperatures which were input by the user remain unchanged throughout the simulation.

10.3 Heat Sink Summary Print Option (Input Form 1C)

The heat sink summary print option controls the printing of special averages which are taken during the summary interval for use by the heat sink analysis. This option is not applicable if the temperature and humidity simulation option is zero.

Option 0 - Bypass. This option indicates that the heat sink summary averages should not be printed.

Option 1 - Print Heat Sink Summary Output. This option gives further information concerning the airflows and energy flows within the system. The averages which are printed consist of airflows (cfs), temperatures (°F), specified humidities (lb of moisture per lb of dry air), and the energy flows (cfs times air temperature and cfs times specific humidity) which are leaving both ends of each subsegment and each branch of each node. These values are computed for use in the heat sink and Environmental Control Load Analysis, and this option controls whether this data is printed with the summary output. These items may be used to make a preliminary estimate of the breakdown of the convective loads for a zone.

Option 2 - Print Heat Sink Summary Output and Heat Sink Arrays. This option would normally be used by a programmer for debugging purposes. In addition to the output obtained in Option 1 above, the array elements in the Dynamic Thermal Response Matrix (DTRM), Dynamic Humidity Response Matrix (DHRM), the thermal and humidity forcing matrices, and the intermediate results of each iteration are printed.

10.4 Supplementary Output Option (Input Form 1C)

The supplementary output option controls the printing of additional output from the SES program. This output is useful when one wants other information which is not normally provided in the standard second-by-second output or summary output. Its primary application is the understanding of the internal workings of the SES Program.

Option 0 - Designer Oriented Output Only. This option would normally be selected by the program user. It provides designer-oriented output for both second-by-second and summary results. That is, the output is presented in an easily readable fashion with titles and units clearly shown.

Option 1 - Input Verification Output. This option provides additional output during the input verification only. This information is the internal representation of the user's input data and includes:

1. Geometry tables
2. Aerodynamic flow loops
3. Subsegment numbering
4. "Fitted" coefficients for fan performance curve
5. Track section tables
6. Other information

This option would not normally be used by the program user, but can be used in conjunction with Heat Sink Summary Print Option 1 to gain further insight into the SES Program. It is often used since it only adds 10-15 pages to a typical SES output.

Option 2 - Train Power and Heat Details. This option provides all of the information in Option 1 and also gives a detailed breakdown of train propulsion power, heat generation, and heat rejection.

Option 3 - Aerodynamic Information. This option provides all of the information in Option 1 and 2, and also gives the instantaneous pressure changes in each section and a table of train location with respect to line segments. These pressure changes can be used to evaluate the transient pressures caused by train piston action or fan operation.

The pressure change information is printed for each section (total pressure in units of inches of water gauge), along with the section number. The quantity printed represents the net total pressure difference between the ends of the section. For positive airflow in the section, a negative number indicates a pressure loss, and a positive number indicates a gain; for negative flow a negative number indicates a gain, and a positive number indicates a loss. This total pressure change is the summation of the losses or gains from viscous friction, segment boundary losses, train piston action, fan operation and includes the resultant pressure which is acting as an acceleration force on the air in the section. The pressure losses at junctions are not included in these section pressure changes; therefore, the summation of the pressure changes around a loop will not be exactly zero if junctions other than type 0 or 7 are used.

Option 4 - Thermodynamic Information. This option provides all of the information in Option 1 and 2, and also gives the table of train locations with respect to line segments and the instantaneous thermodynamic characteristics of each subsegment (adjusted volume, back end and front end airflow, heat transfer coefficient, sensible and latent heat load, Reynolds Number, and working value of temperature and humidity; temperature and humidity are provided for nodes).

Option 5 - Full Supplementary Output. This option provides all of the supplementary output available in options 1, 2, 3 and 4.

10.5 Humidity Display Option (Input Form 1C)

The humidity display option allows the SES program user to choose one of three methods of presentation of the quantity of moisture within the system. No matter which option is chosen, the computation of moisture content is performed using the humidity ratio (specific humidity) with units of pounds of moisture per pound of dry air (lb/lb). Depending on which option is chosen, the moisture content of the air is then converted into the appropriate units for use in displaying the instantaneous value of the results and in computing averages. No matter which method of humidity display is chosen, a psychometric chart may be used to convert the result into the other two forms of representation. This option does not apply if the temperature and humidity simulation option is zero.

Option 1 - Humidity Ratio. When this option is chosen the moisture content of the air is displayed as a humidity ratio (specific humidity) with the units of pounds of moisture per pound of dry air (lb/lb). Since this form of expressing the humidity is the same as in the internal moisture computations, no conversion is required for printing results or computing averages.

Option 2 - Wet-Bulb Temperature. This option causes the moisture content of the air within the system to be displayed in the form of wet-bulb temperature, with the units in degrees Fahrenheit. (The dry-bulb temperature is always displayed in degrees Fahrenheit no matter which humidity display option is chosen.) Since conversion of the moisture content of the air into wet-bulb temperature requires additional computations, the computer cost of the simulation is increased slightly.

Option 3 - Relative Humidity. This option causes the moisture content of the air within the system to be displayed in the form of relative humidity. As in Option 2 above, additional computations are required to compute the relative humidity and this increases the cost of the simulation slightly.

10.6 Allowable Simulation Errors (Input Form 1C)

A simulation error is an error condition which becomes apparent during the simulation. This may be caused by one or more error conditions. Each error is identified by its own "simulation error message". Often, these error conditions are transient in nature and will correct themselves. However, some simulation errors are of such serious nature that they are considered to be "irrecoverable". The user may allow a number of simulation errors to occur before terminating the simulation. This number is entered as the allowable simulation errors on Input Form 1C. The SES program will continue the simulation until either the simulation is completed, the allowable number of simulation errors has been exceeded, or an irrecoverable simulation error is found.

When making simulations which contain simulation errors, the user is cautioned that the results of the simulation should be carefully examined to determine if they were affected by the simulation error. In a similar manner, the results of all simulations must be carefully examined since many errors in input data preparation and system simulation cannot be detected by the SES program.

No Allowable Simulation Errors. If a zero is entered for the number of allowable simulation errors, the simulation will be terminated at the first occurrence of a simulation error or at the completion of the simulation, whichever comes first.

"N" Allowable Simulation Errors. If a number "N" (where N≥0) is entered as the number of allowable simulation errors, the simulation will continue until either "N" simulation errors have been exceeded, an irrecoverable simulation error is encountered, or the simulation is completed. The user is cautioned not to allow too many simulation errors, since a simulation with many errors is seldom correct. The allowable simulation errors would usually not be greater than 10.

10.7 Allowable Input Errors (Input Form 1C)

During the input verification portion of the SES program, all of the items of input data are checked against reasonable upper and lower limits. If the item exceeds the limits, an error message is printed immediately below the item in error. The wording of the error message indicates which data item exceeds the limits and what the value of these limits are.

Error messages have two levels of severity: non-fatal error messages and fatal error messages. If a fatal error message is found (see Chapter 13), the input verification is terminated. Non-fatal error messages do not cause the input verification to be terminated, but instead allows it to continue until the input verification is completed. The user may enter a value for the allowable input errors which indicates the number of non-fatal input errors. At the end of the input verification, if the number of input errors is less than or equal to the number of allowable input errors, the simulation is performed. Otherwise the simulation of the system is bypassed.

A non-fatal error message is printed when an item of data exceeds the upper or lower limit of its normal range. These limits are estimates of the probable range of the variable for most systems, and occasionally a correct value for an item will be out of the permissible range. When this occurs a non-fatal error message would be printed alerting the user that this item should be checked. If the number entered is indeed correct, the user can "allow" this error by adding one to the number of allowable input errors. If the number of input errors is greater than the allowable input errors, the simulation is not performed.

“N” Allowable Input Errors. This indicates that the simulation is to be performed if the number of non-fatal input errors is less than or equal to N (where N≥0). The simulation will not be performed if a fatal input error is found.

Zero Allowable Input Errors. This indicates the simulation is to be performed if no input errors are found. The system will not be simulated if one or more fatal or non-fatal input errors are found.

-1 Allowable Input Errors. When a negative number (-1.0) is entered for the allowable input errors, only the input verification is performed and the system is not simulated. This is useful when the data for a system is initially put together or when changes have been made, so that the user can study the input verification of the data to determine if it is correct before attempting a simulation.

10.8 Initialization File

The Initialization File Options are used to read the final conditions of a prior simulation as the starting conditions for a present simulation. When an Initialization File is not used, a system uses initialization data from the Input Forms, and runs through a number of “System Cycles” in order to stabilize. The use of an Initialization File will usually reduce the number of "System Cycles" required for the system to stabilize. This reduction in system "Run Up" time (the amount of time, or the number of

"System Cycles", required for a system to stabilize at quasi-steady state conditions) can significantly reduce the time and cost of a simulation.

General Use of the Initialization File

The Initialization File Options consist of two parts, the Initialization File Writing Option and the Initialization File Reading Option. (Referred to hereafter as the Writing and Reading Options, respectively.) The Writing Option is used to write the final conditions to a file. This file, referred to as the Restart File, has the same filename as the input file and an extension of RST. For example, if the input file is SAMPLE.INP, the restart file would be SAMPLE.RST.

The Reading Option is used to read in a previously generated restart file. The name of the restart file to be read must be entered after Form 13. For compatibility with Version 3.02 input files, the initialization data can also be appended at the end of the input file. Using this method in conjunction with the SES Input Manager, however, would result in the loss of the appended initialization data (see Chapter 11).

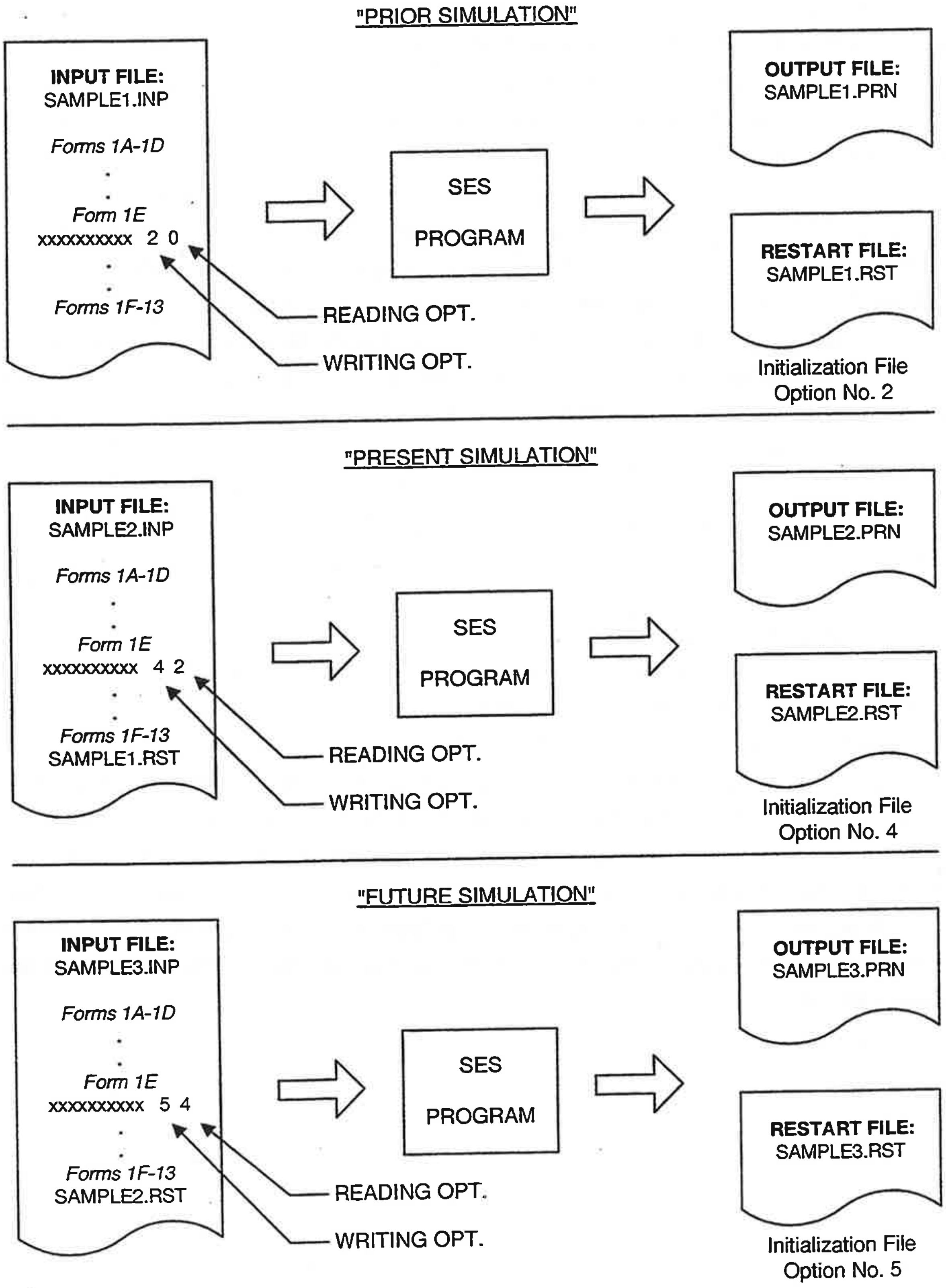


Figure 10.1 Sample Uses of the Initialization File Option

Available Options

Initialization data is classified into three types: 1) Train data, 2) Aerodynamic data, and 3) Thermodynamic data. An Initialized File may contain the initialization information for one, two, or all three of these classifications depending on the option number used to write it. A list of option numbers and their description is shown in Table 10.1.

These numbers correspond to the entries made on Form 1E for the Writing and Reading Options. For example (Refer to Figure 10.1) if the Initialized File was written in the "Prior" simulation using Writing Option number 2, it is then read in the "Present" simulation by setting the Reading Option to 2. As shown in Figure 10.1 the name of the Initialized File is inserted immediately after Form 13.

It is important to note that when using an Initialized File, the Reading Option number must be the same as the Writing Option number that was used to write it. If the Reading Option number does not correspond to the Writing Option used to write the Initialized File, the program will use the information contained in the Initialized File and ignore the value entered for the Reading Option number. In addition, an error message will be printed to show that this occurred.

Note: When an Initialization File is not being read, the Reading Option should be set to zero. Similarly, if the user chooses not to write an Initialization File, the Writing Option should be set to zero.

Restrictions on the Use of the Initialized File

The user should be aware that the Initialized File cannot be used in every situation. For example, suppose an Initialized File is written using Writing Option Number 1 (Aerodynamic initialization only). Subsequently a vent shaft is removed from the system. This Initialized File can no longer be used. The reason for this is that the Aerodynamic characteristics of the "Prior" system do not match those of the "Present" system. If, however, the Writing Option number in the "Prior" simulation was 2 (Train initialization only), and then a vent shaft was removed from the system, the Initialization File may be used because the Train-related characteristics of the system are not altered by the removal of a vent shaft.

In general, an Initialized File may be used if the characteristics related to the type or types of information contained in it do not change from "Prior" system to the "Present". The results of this rule are listed in Table 10.2.

Table 10.1 Description of Initialized File Options

Option Number	Description of Initialization	Data Contained	Initialization Data From Input Forms Which is Overridden
0.	None	—	—
1.	Aerodynamic	A,B	E
2.	Train	A,C	F,G
3.	Thermodynamic	A,D	H,J,K
4.	Aerodynamic and Trains	A,B,C	E,F,G
5.	Aerodynamic, Trains and Thermodynamic	A,B,C,D	E,F,G,H,J,K

KEY:

A. System identification and option number.

B. Number of sections, and for each, the airflow rate.

C. Number of trains in operation, and for each, location, speed, route, type, deceleration and acceleration grid temperature, operating mode, remaining dwell time, acceleration rate, track section pointer and flywheel speed (RPM).

D. Number of line subsegments, and for each, dry-bulb air temperature, humidity ratio, wall surface temperature and sensible and latent heating or cooling loads (Source Type 2). Number of vent subsegments, and for each, dry bulb air temperature, humidity ratio, and wall surface temperature.

E. Initial airflows (Forms 2A and 2B).

F. Number of trains in operation at initialization (1E).

G. Train initialization data (10).

H. Sensible and latent heat rates (3D) (for source Type 2 only).

I. Wall surface, initial dry-bulb air, and initial wet-bulb air, temperature (3E).

J. Wall surface, initial dry-bulb air, and initial wet-bulb air, temperature (5B).

Table 10.2 Changes Permitted from “Prior” to “Present” Systems by Option Number

Option Number	System Characteristics not Affected (Type of Changes Permitted)	System Characteristics Affected (Type of Changes Not Permitted)
0.	All	None
1.	Thermo., Train	Aero.
2.	Thermo., Aero.	Train
3.	Train, Aero.	Thermo.
4.	Thermo.	Aero., Train
5.	None	All

To aid the user in the selection of which option to use, the following chart shows examples of changes and which system characteristics are affected:

Type of Change (Input Form Number)		Affects
1.)	Number of Line Sections or Segments (1D)	Aero., Thermo.
2.)	Number of Vent Sections or Segments (1D)	Aero., Thermo.
3.)	Number of Nodes, Junctions or Portals (1D)	Aero., Thermo.
4.)	System Geometry (2A, 2B)	Aero., Thermo.
5.)	Number of Subsegments (3C)	Thermo.
6.) *	Status of Unsteady State Heat Sources (4)	Thermo.
7.) *	Status of Fans (5C)	Aero.
8.)	Direction of Fan Operation (5C)	Aero.
9.)	Node Thermodynamic Type (6A)	Thermo.
10.)	Track Section Characteristics (8C)	Trains
11.)	Flywheel Simulation Option (9H)	Trains

*The status (either on or off) must be the same at the end of the "Prior" simulation and the beginning of the "Present" one.

Although other input data may be changed, the user should be aware that the magnitude of the change will affect the amount of time the system will require to reach quasi-steady state conditions. While other changes may be accepted by the program, they may be physically unreasonable. For example, changing the length of a line segment will cause the location of track sections to shift, causing grades, curves, speed restrictions and other track section characteristics to be improperly positioned.

In actuality, any change made to system can be accepted by the program if the Initialized File is altered accordingly. This should be done carefully, since improper initial data can cause a simulation to fail. It is recommended that the Initialized File not be altered except by those who are familiar with the format and use of the initialization information by the program.

An example of the possible uses of the Initialization File option is shown in Figure 10.1. In the first simulation ("Prior") Writing Option 2 (Train initialization only) is used. This could be an early simulation to determine train locations and characteristics. The second simulation ("Present") would have the Reading Option set to 2 (in order to read the Initialized File of the "Prior" simulation) and the Writing Option set to 4 (Aerodynamic and Train initialization). This could be a simulation of summer operations during a non-rush hour period. The third simulation ("Future") would have the Reading Option set to 4 and the Writing Option set to 5 (Aerodynamic, Train and Thermodynamic initialization). This could be a simulation of summer operations during a rush hour period. The file written at the end of this simulation could be used to initialize the system for a fire simulation.

10.9 Program Output

The SES program has three categories of output which are used to provide the user with results of the simulation. These are: (1) second-by-second output, (2) summary output, and (3) environmental control output.

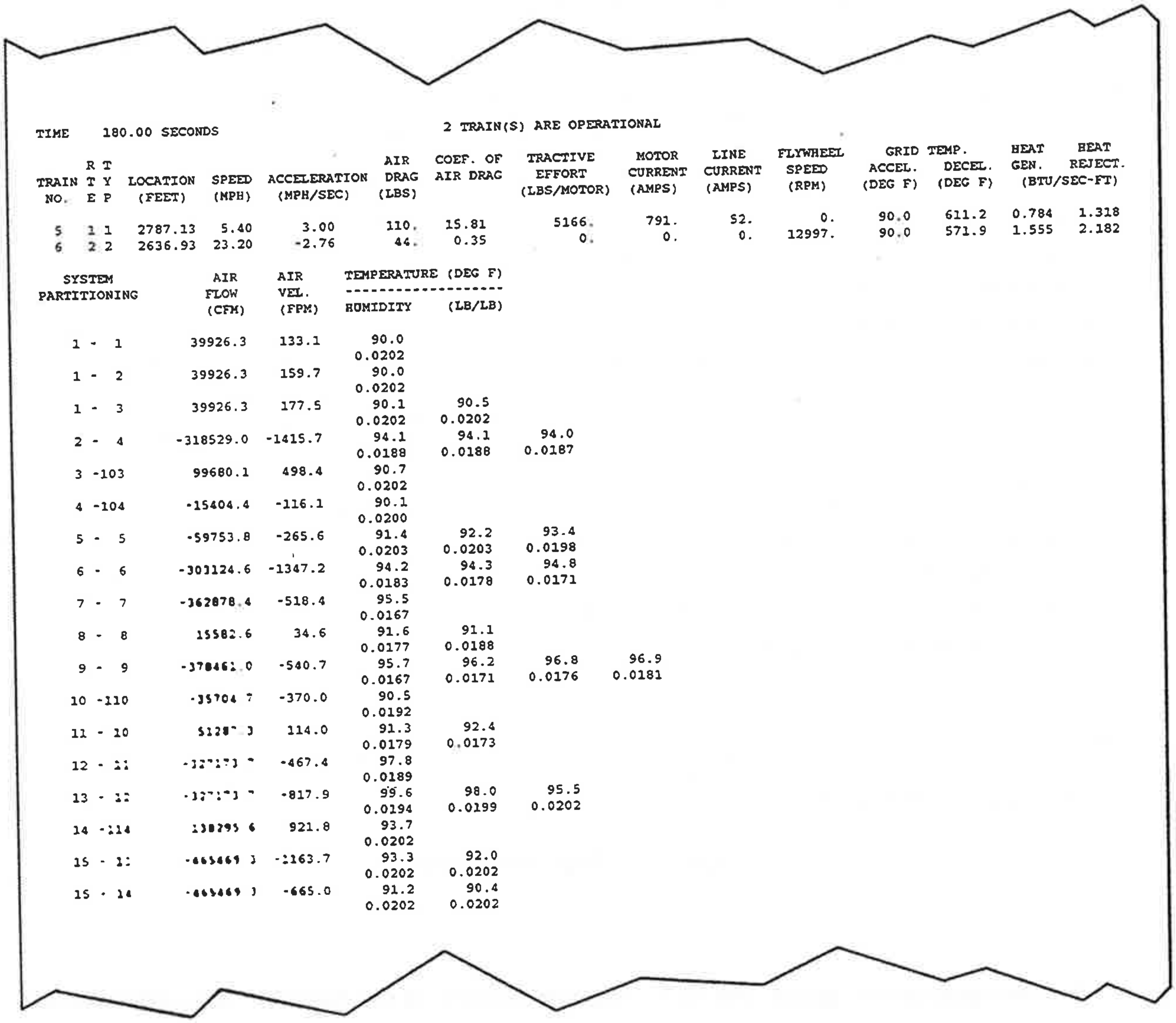
The second-by-second output prints the current status of conditions within the system at an instant in time. It consists of two types of printing format - a detailed format and an abbreviated format. Both printing formats give the status of the system at the instant they are produced (the bulk airflow rate and air velocity in all line segments and ventilation shafts in the system, the temperature and humidity in each subsegment in the system, and the location, speed, acceleration and other data for each train which is currently in operation). The detailed print has other data in addition to that contained in the abbreviated print format. This includes the rate of sensible and latent heat input into each subsegment and an indication of which trains, if any, are located in each subsegment. An example of a detailed print is shown in Figure 10.2, and an example of an abbreviated print is shown in Figure 10.3. Since the detailed print has a more expansive (but easier to read) format, each detailed print produces more sheets of printed output than each abbreviated print.

Two items printed as part of the second-by-second output - the heat generation and the heat rejection - describe the heat output of the trains. Heat generation (abbreviated HEAT GEN. on the output) is the instantaneous rate of sensible heat production. Sources of heat include: electrical and mechanical losses from the braking and propulsion systems, mechanical resistance, flywheel losses, and train auxiliary systems. Heat rejection (abbreviated HEAT REJECT. on the output) is the instantaneous rate of heat release to the air. Some sources of heat are assumed to be released to the air stream at nearly the same rate at which heat is being generated (e.g., the heat produced by mechanical and rolling resistance). Other sources of heat exhibit a time-delay between the rate at which heat is generated and the rate at which heat is released to the air. The prime example of the latter case is the heat released by the braking and accelerating (if any) resistor grids. Therefore, at any instant, the sensible heat generation and heat rejection rates differ by the time-delay effect caused by the thermal storage and heat transfer characteristics of the resistor grids (braking and accelerating). Latent heat sources are handled separately.

The summary output provides maximum, minimum and average values of the bulk airflow rate and air velocity in each line segment, and the temperature and humidity in each subsegment in the system. The simulation times at which the maximum and minimum values occurred is also given. A sample of the summary output for a station line segment is shown in Figure 10.4.

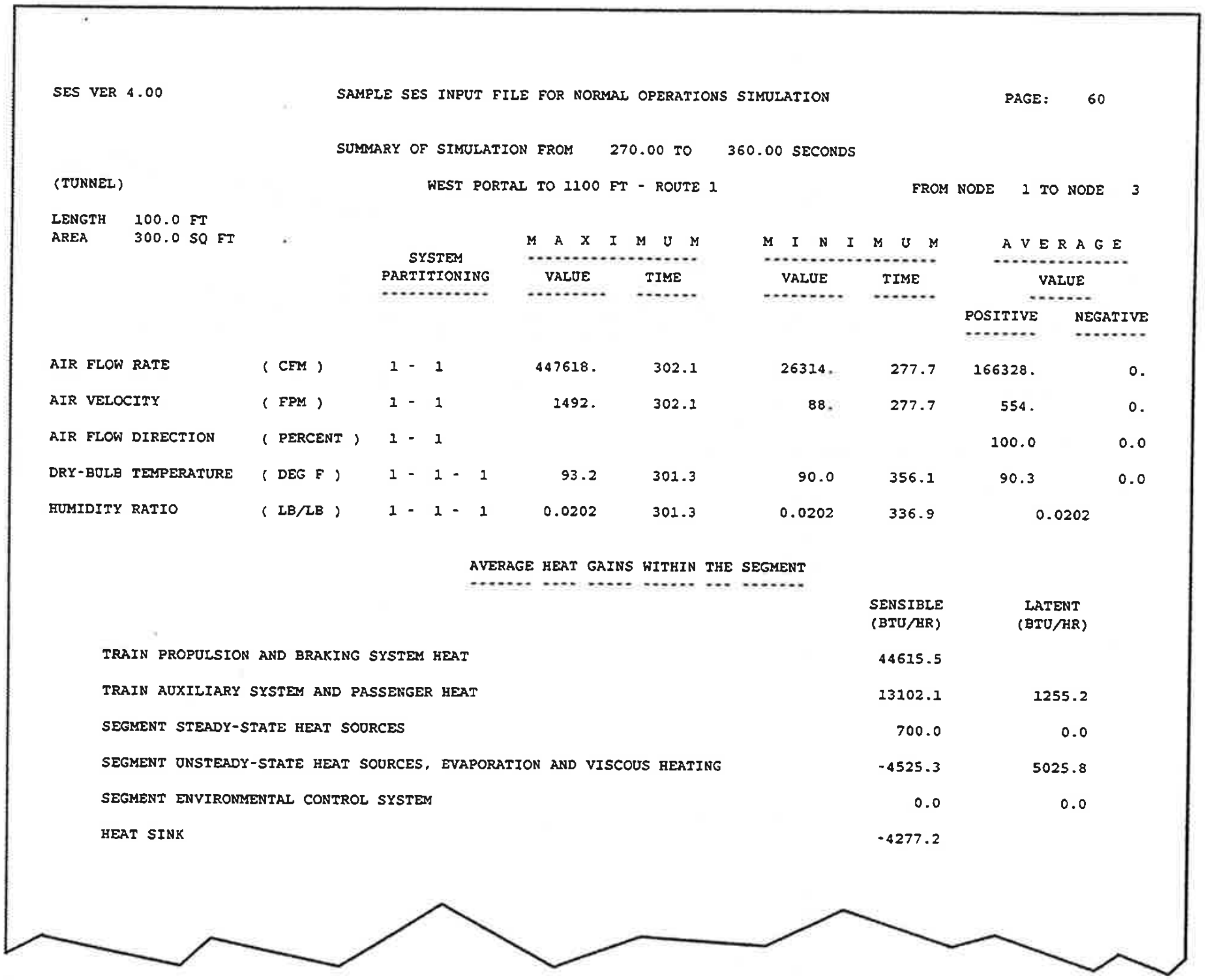
```
SES VER 4.00                   SAMPLE SES INPUT FILE FOR NORMAL OPERATIONS SIMULATION                   PAGE:  ____

TIME      0.00 SECONDS                            2 TRAIN(S) ARE OPERATIONAL

       R T                                         AIR   COEF. OF    TRACTIVE      MOTOR    LINE    FLYWHEEL     GRID TEMP.       HEAT    HEAT
TRAIN  T Y  LOCATION  SPEED  ACCELERATION  DRAG  AIR DRAG     EFFORT      CURRENT  CURRENT   SPEED     ACCEL.   DECEL.   GEN.   REJECT.
 NO.   E P   (FEET)   (MPH)   (MPH/SEC)    (LBS)            (LBS/MOTOR)   (AMPS)   (AMPS)    (RPM)    (DEG F)  (DEG F)   (BTU/SEC-FT)

  1    1 1  2877.21  19.25      3.00         0.     0.00        5412.       900.     959.         0.    276.0    740.1   0.434   0.434
  2    2 2  2744.71  11.00      3.00         0.     0.00        6693.       900.     756.     10000.    241.6    751.3   0.369   0.369
--------------------------------------------------------------------------------------------------------------------------------------------
            SYSTEM           SENSIBLE      LATENT            AIR       HUMIDITY     AIR        AIR      TRAIN POSITION-ROUTE NUMBER
LENGTH   PARTITIONING        HEAT LOAD    HEAT LOAD      TEMPERATURE    RATIO       FLOW     VELOCITY   0 0 0 0 0 0 0 0 0 1 1 1 1 1
 (FT)                        (BTU/SEC)    (BTU/SEC)        (DEG F)     (LB/LB)     (CFM)      (FPM)     1 2 3 4 5 6 7 8 9 0 1 2 3 4


 100.0    1 -  1      (TUNNEL)                WEST PORTAL TO 1100 FT - ROUTE 1

          1 -  1 -  1           0.2          0.0            90.00     0.02017        0.0        0.0

 100.0    1 -  2      (TUNNEL)                1100 TO 1200 FT - ROUTE 1

          1 -  2 -  1           0.2          0.0            90.00     0.02017        0.0        0.0

 400.0    1 -  3      (TUNNEL)                1200 TO 1600 FT - ROUTE 1

          1 -  3 -  1           0.4          0.0            90.00     0.02017        0.0        0.0
          1 -  3 -  2           0.4          0.0            90.00     0.02017

 600.0    2 -  4      (TUNNEL)                PORTAL TO 1600 FT - ROUTE 2

          2 -  4 -  1           2.5          0.0            90.00     0.02017        0.0        0.0
          2 -  4 -  2           2.5          0.0            90.00     0.02017
          2 -  4 -  3           2.5          0.0            90.00     0.02017

 110.0    3 -103      (VENTILATION SHAFT)     VENT SHAFT AT 1600 FT - ROUTE 1

          3 -103 -  1                                       90.00     0.03149        0.0        0.0

  95.1    4 -104      (VENTILATION SHAFT)     VENT SHAFT AT 1600 FT - ROUTE 2

          4 -104 -  1                                       90.00     0.02017        0.0        0.0

 600.0    5 -  5      (SPECIAL TUNNEL)        1600 TO 2200 FT(START OF STA) -RTE 1

          5 -  5 -  1           0.4          0.0            90.00     0.02017        0.0        0.0
          5 -  5 -  2           0.4          0.0            90.00     0.02017
          5 -  5 -  3           0.4          0.0            90.00     0.02017

 600.0    6 -  6      (SPECIAL TUNNEL)        1600 TO 2200 FT(START OF STA)- RTE 2

          6 -  6 -  1           2.5          0.0            90.00     0.02017        0.0        0.0
          6 -  6 -  2           2.5          0.0            90.00     0.02017
          6 -  6 -  3           2.5          0.0            90.00     0.02017

 100.0    7 -  7      (STATION)               START OF STATION TO WEST STAIRWAY

          7 -  7 -  1          32.6         11.7            80.00     0.01364        0.0        0.0       2

 200.0    8 -  8      (STATION)               WEST END OF MEZZANINE TO STREET EXIT


       FILE: NORMAL.INP                                                      SIMULATION TIME: 14 AUG 1997 08:20:24
```

Figure 10.2 Detailed Print



```
TIME    180.00 SECONDS                                         2 TRAIN(S) ARE OPERATIONAL

         R T                                           AIR   COEF. OF   TRACTIVE     MOTOR    LINE    FLYWHEEL     GRID  TEMP.     HEAT    HEAT
TRAIN  T Y  LOCATION  SPEED  ACCELERATION  DRAG  AIR DRAG    EFFORT    CURRENT  CURRENT   SPEED     ACCEL.   DECEL.   GEN.   REJECT.
 NO.   E P   (FEET)   (MPH)   (MPH/SEC)   (LBS)           (LBS/MOTOR)  (AMPS)   (AMPS)    (RPM)    (DEG F)  (DEG F)   (BTU/SEC-FT)

  5    1 1   2787.13   5.40      3.00      110.   15.81       5166.      791.      52.        0.      90.0     611.2   0.784   1.318
  6    2 2   2636.93  23.20     -2.76       44.    0.35          0.        0.       0.    12997.      90.0     571.9   1.555   2.182

  SYSTEM                AIR        AIR     TEMPERATURE (DEG F)
PARTITIONING           FLOW       VEL.    -------------------
                       (CFM)      (FPM)    HUMIDITY    (LB/LB)

    1 -   1          39926.3     133.1      90.0
                                           0.0202
    1 -   2          39926.3     159.7      90.0
                                           0.0202
    1 -   3          39926.3     177.5      90.1      90.5
                                           0.0202    0.0202
    2 -   4        -318529.0   -1415.7      94.1      94.1      94.0
                                           0.0188    0.0188    0.0187
    3 -103           99680.1     498.4      90.7
                                           0.0202
    4 -104          -15404.4    -116.1      90.1
                                           0.0200
    5 -   5         -59753.8    -265.6      91.4      92.2      93.4
                                           0.0203    0.0203    0.0198
    6 -   6        -303124.6   -1347.2      94.2      94.3      94.8
                                           0.0183    0.0178    0.0171
    7 -   7        -362878.4    -518.4      95.5
                                           0.0167
    8 -   8          15582.6      34.6      91.6      91.1
                                           0.0177    0.0188
    9 -   9        -378461.0    -540.7      95.7      96.2      96.8      96.9
                                           0.0167    0.0171    0.0176    0.0181
   10 -110          -35704.7    -370.0      90.5
                                           0.0192
   11 -  10          51287.3     114.0      91.3      92.4
                                           0.0179    0.0173
   12 -  11        -327173.7    -467.4      97.8
                                           0.0189
   13 -  12        -327173.7    -817.9      99.6      98.0      95.5
                                           0.0194    0.0199    0.0202
   14 -114          138295.6     921.8      93.7
                                           0.0202
   15 -  13        -665469.3   -1163.7      93.3      92.0
                                           0.0202    0.0202
   15 -  14        -665469.3    -665.0      91.2      90.4
                                           0.0202    0.0202
```

Figure 10.3 Abbreviated Output



```
SES VER 4.00              SAMPLE SES INPUT FILE FOR NORMAL OPERATIONS SIMULATION                      PAGE:    60

                          SUMMARY OF SIMULATION FROM    270.00 TO    360.00 SECONDS

(TUNNEL)                           WEST PORTAL TO 1100 FT - ROUTE 1                      FROM NODE   1 TO NODE   3

LENGTH     100.0 FT
AREA       300.0 SQ FT                              M A X I M U M          M I N I M U M        A V E R A G E
                                   SYSTEM        -------------------    -------------------    ---------------
                                 PARTITIONING      VALUE      TIME        VALUE      TIME           VALUE
                                 ------------    ---------   -------    ---------   -------        -------
                                                                                              POSITIVE   NEGATIVE
                                                                                              --------   --------

AIR FLOW RATE          ( CFM )      1 -  1       447618.      302.1      26314.      277.7    166328.        0.

AIR VELOCITY           ( FPM )      1 -  1         1492.      302.1         88.      277.7       554.        0.

AIR FLOW DIRECTION     ( PERCENT )  1 -  1                                                      100.0       0.0

DRY-BULB TEMPERATURE   ( DEG F )    1 -  1 -  1      93.2      301.3       90.0      356.1       90.3        0.0

HUMIDITY RATIO         ( LB/LB )    1 -  1 -  1    0.0202      301.3     0.0202      336.9          0.0202

                                          AVERAGE HEAT GAINS WITHIN THE SEGMENT
                                          ------- ----- ----- ------ --- -------
                                                                                   SENSIBLE        LATENT
                                                                                   (BTU/HR)       (BTU/HR)
       TRAIN PROPULSION AND BRAKING SYSTEM HEAT                                     44615.5

       TRAIN AUXILIARY SYSTEM AND PASSENGER HEAT                                    13102.1         1255.2

       SEGMENT STEADY-STATE HEAT SOURCES                                              700.0            0.0

       SEGMENT UNSTEADY-STATE HEAT SOURCES, EVAPORATION AND VISCOUS HEATING         -4525.3         5025.8

       SEGMENT ENVIRONMENTAL CONTROL SYSTEM                                             0.0            0.0

       HEAT SINK                                                                    -4277.2
```

Figure 10.4 Summary Output

Two averages are computed (one for the "positive" and one for the "negative" airflow direction) for each of the following quantities: airflow rate, air velocity and dry-bulb air temperature. The average airflow rate (and air velocity) in the positive direction is the summation of the instantaneous values over the summary interval divided by the entire summary interval. The averages in the negative direction are similarly computed. It should be noted that the airflows are averaged over the entire summary interval, rather than averaged over the time that the air is flowing in the positive (or negative) direction. The total quantity of air that has flowed in the positive (or negative) direction over the summary interval (in cubic feet) can be obtained by multiplying the average positive (or negative) airflow rate (in cubic feet per minute) by the summary interval in minutes. Similarly, the average positive (or negative) air velocity is computed as the average over the entire summary interval.

. The average positive (or negative) air velocity when the air is flowing in the positive (or negative) direction can be computed by dividing the average positive (or negative) air velocity over the summary interval (obtained from the summary printout) by the percentage of time the airflow is positive (or negative) and multiplying by one-hundred. For example, 200,000 cfm of airflows in a 200 sq.ft. tunnel for 60 seconds in the positive direction and immediately reverses for 40 seconds and flows in the negative direction at the same rate. This would show the following results over a 100-second summary interval:

	AVERAGE VALUE	
	POSITIVE	NEGATIVE
AIRFLOW RATE (CFM)	120000	80000
AIR VELOCITY (FPM)	600	400
AIRFLOW DIRECTION (PERCENT)	60	40

Over the 100-second summary interval, a total of 120,000 cfm times 1.67 (100/60) minutes, or 200,000 cubic feet of air flowed in the positive direction, and the average air velocity while it was flowing in the positive direction is 200,000 cfm divided by 200 sq. ft. or 1000 fpm.

The average dry-bulb temperature is also computed separately over the time that airflows in the positive direction and in the negative direction. However, the method of calculation differs from the average airflow rate and velocity in that the average temperature in the positive (or negative) direction is the average computed over the time period that the air is flowing in the positive (or negative) direction. For example, if a subsegment temperature is 70°F when air is flowing in the positive direction for 60 seconds, and instantly changes to 80°F when airflows in the negative direction for 40 seconds, then over a 100 second summary interval the average air temperature for positive airflow is 70°F, and the average air temperature for negative airflow is 80°F. The breakdown of these averages into those for positive and negative directions is provided to the user to assist in the preparation of a preliminary estimate of the breakdown of the convective loads for a zone. Determination of the overall average temperature can be made using a weighted average formula:

$$(70 \times 60) + (80 \times 40) / 100 = 74\ ^\circ\text{F average temperature}$$

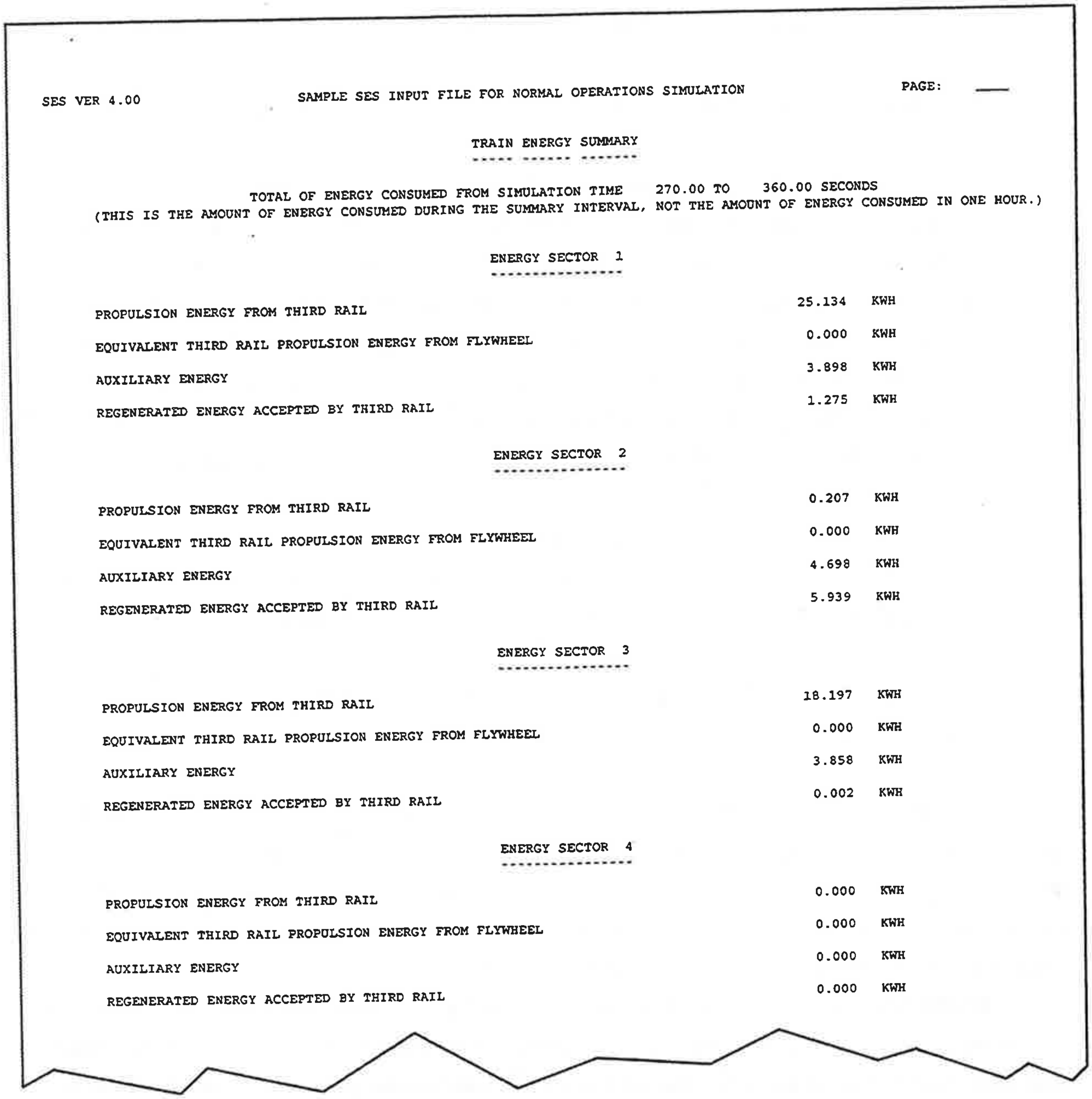
A frequency histogram is used to describe the temperature range for each subsegment in a line segment. This histogram is printed only for line segments located in Controlled (Type 1) environmental control zones. The design temperature, which may be either morning or evening/off-hour temperature depending on the design time, and the temperature tabulation increment (Input Form 12) are used to construct this histogram.

The average sensible and latent heat gains are printed for each line segment. These heat gains are averaged over the summary interval and divided into the following categories:

1. Train Propulsion and Braking System Heat: This is the total amount of heat released by the train(s) into the line segment and has not been reduced by the trackway exhaust system.
2. Train Auxiliary System and Passenger Heat: This is the total amount of heat released by the train(s) into the line segment and has not been reduced by the trackway exhaust system.
3. Segment Steady-State Heat Source: This is the sum of the Type 1 steady-state heat sources in the segment entered on Input Form 3D.
4. Segment Unsteady-State Heat Sources, Evaporation and Viscous Heating: This includes the sum of the unsteady heat sources (Input Form 4), evaporation (computed only if Temperature/Humidity Simulation Option on Input Form 1C is 2.0), and viscous heating due to air friction on the tunnel walls.
5. Segment Environmental Control System: This is the ECS heat load during the summary interval. This item is initially entered either as a Type 2 steady-state heat source on Input Form 3D, or read from an initialization file if Initialization File Reading Option 3.0 or 5.0 is specified on Input Form 1E. These initial values are revised during each Environmental Load Estimate (Summary Option 4.0 on Input Form 12).
6. Heat Sink: This is the average rate of heat transfer to/from the tunnel walls over the summary interval.
7. Heat Captured by Trackway Exhaust System: This item appears only for station line segments (Type 2), and is computed using the information from Input Form 1G.

If the sign of the heat gain is positive, it indicates that heat is released in the segment; if the sign is negative, it indicates that heat is removed from the line segment.

The <u>Train Energy Summary</u> gives the energy consumed by the train propulsion and auxiliary systems over the summary interval. This information is printed with each summary output. A separate tabulation is made for each <u>Energy Sector</u> which is defined by the user on Input Form 8C. Figure 10.5 shows a sample Train Energy Summary output.



```
SES VER 4.00                 SAMPLE SES INPUT FILE FOR NORMAL OPERATIONS SIMULATION                  PAGE:  ___

                                              TRAIN ENERGY SUMMARY
                                              ----- ------ -------

                          TOTAL OF ENERGY CONSUMED FROM SIMULATION TIME    270.00 TO    360.00 SECONDS
      (THIS IS THE AMOUNT OF ENERGY CONSUMED DURING THE SUMMARY INTERVAL, NOT THE AMOUNT OF ENERGY CONSUMED IN ONE HOUR.)

                                                ENERGY SECTOR  1
                                                ----------------

      PROPULSION ENERGY FROM THIRD RAIL                                              25.134   KWH

      EQUIVALENT THIRD RAIL PROPULSION ENERGY FROM FLYWHEEL                           0.000   KWH

      AUXILIARY ENERGY                                                                3.898   KWH

      REGENERATED ENERGY ACCEPTED BY THIRD RAIL                                       1.275   KWH

                                                ENERGY SECTOR  2
                                                ----------------

      PROPULSION ENERGY FROM THIRD RAIL                                               0.207   KWH

      EQUIVALENT THIRD RAIL PROPULSION ENERGY FROM FLYWHEEL                           0.000   KWH

      AUXILIARY ENERGY                                                                4.698   KWH

      REGENERATED ENERGY ACCEPTED BY THIRD RAIL                                       5.939   KWH

                                                ENERGY SECTOR  3
                                                ----------------

      PROPULSION ENERGY FROM THIRD RAIL                                              18.197   KWH

      EQUIVALENT THIRD RAIL PROPULSION ENERGY FROM FLYWHEEL                           0.000   KWH

      AUXILIARY ENERGY                                                                3.858   KWH

      REGENERATED ENERGY ACCEPTED BY THIRD RAIL                                       0.002   KWH

                                                ENERGY SECTOR  4
                                                ----------------

      PROPULSION ENERGY FROM THIRD RAIL                                               0.000   KWH

      EQUIVALENT THIRD RAIL PROPULSION ENERGY FROM FLYWHEEL                           0.000   KWH

      AUXILIARY ENERGY                                                                0.000   KWH

      REGENERATED ENERGY ACCEPTED BY THIRD RAIL                                       0.000   KWH
```

Figure 10.5 Train Energy Summary

The Train Energy Summary is computed by summing the train energy consumed within each energy sector. A train is considered to be entirely within an energy sector when the front of the train is located in the energy sector. Train energy consumption is considered to be concentrated at the point where the front of the train is located, unlike train heat release which is distributed uniformly over the length of the train. The user should be aware of this point-consumption of energy when defining the energy sectors and interpreting the results.

Train energy consumption is tabulated in the following categories for each energy sector:

1. Propulsion Energy from Third Rail: This item is computed from the line current which is entered on Input Form 9H for chopper-controlled trains or computed from the motor current (Input Form 9G) and transition speed (Input Form 9H) for cam-controlled trains.
2. Equivalent Third Rail Propulsion Energy from Flywheel: This is the amount of energy that would have been drawn from the third rail to produce the same propulsion effects as the energy which was drawn from the flywheel. The decrease in flywheel energy may be greater or less than the equivalent third rail energy depending upon the relative magnitude of the Efficiency of Power Transfer from Flywheel to Train (Input Form 9L) compared to the efficiency implied in the Tractive Effort curve (Input Form 9G) and Line Current curve (Input Form 9H). The equivalent third rail energy is useful for comparison purposes since it represents the reduction in energy drawn from the power supply system, rather than the quantity of energy transferred internally within the train.
3. Auxiliary Energy: This item is computed from the auxiliary system power consumption data (Input Form 9C) and the varying number of passengers on-board the train (Input Form 8D).
4. Regenerated Energy Accepted by Third Rail. This item is computed using the Regenerative Braking Effectiveness on Input Form 9H.

The Train Energy Summary reports the energy consumed in each energy sector during the summary period. The average rate of energy consumption (kW) can be computed by dividing the total amount consumed (kWh) by the summary period (seconds) and multiplying by 3600. This would result in the average rate; the maximum instantaneous rate can be obtained from analysis of the train performance output from closely-spaced second-by-second output.

Interpretation of the energy consumption results requires analysis of the train operations during the summary interval during which they were computed. If the summary interval is equal to the headway on a route, then during the summary interval exactly one train traveled past every point on that route (assuming steady-state operation has been reached and trains are being both dispatched and removed from operation at one-headway intervals). If trains are operating at different headways on different routes, then the summary statistics should be gathered over a system cycle. A system cycle is the smallest time interval over which all SES results repeat, and is usually equal to the smallest time period which is evenly divisible (divisible with a remainder of zero) by the headway of each operating route. The number of trains which pass any point on a route is equal to the system cycle time divided by the route headway. Furthermore, the train energy consumption in each energy sector is a function of the number of trains which pass through the energy sector.

The Train Energy Summary results can be used for comparative evaluation of train propulsion systems and/or track profiles. The results can be used to quantify the traction power savings achieved by using chopper control, regeneration, coasting, maximum speed restrictions, and changes in track profile. While the results are of sufficient accuracy to be used for comparisons and estimations, they may not be of sufficient accuracy for design of the electrical distribution system.

The Summary Results are given over an interval which is defined by the user. Two steps are necessary to produce a summary: initialization of the summary totals and printing of the summary. Initialization of the summary totals clears the program memory that is used for computing averages and erases any previous maximums and minimums that have occurred for the previous periods. Printing the summary displays the maximum, minimum, average and other results that have occurred since the summary was last initialized, but does not clear these totals unless the program is specifically instructed to "print and initialize". The summary interval, which is the interval over which the summary results are given, is the interval in time between when the summary totals were last initialized and the summary is printed.

The following summary options are provided in the SES program:

Option 0 - No Summary, Don't Initialize. This option allows the user to bypass the printing of the summary and to skip the initialization of the summary totals.

Option 1 - Initialize Only. This option initializes the summary totals but does not print the summary results.

Option 2 - Print Summary Only. This option prints the summary results for the interval of time that has elapsed since the summary totals were last initialized.

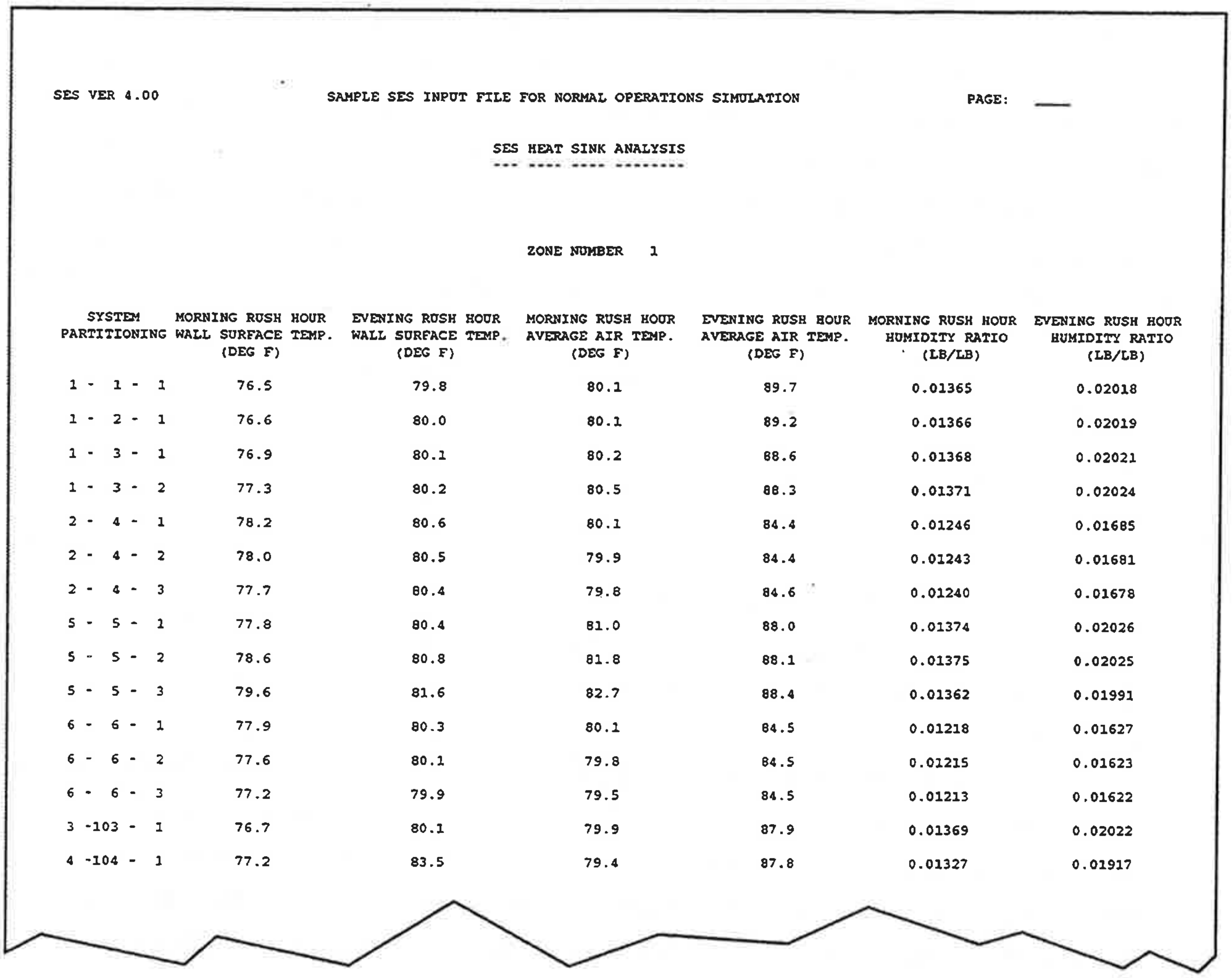
Option 3 - Print Summary and Initialize. The option causes the summary results to be printed and then the summary totals to be initialized. It is equivalent to executing Option 1 and Option 2 at the same instant in time.

Option 4 - Print summary, Perform Environmental Load Estimate, and Initialize. This option first prints the results of the summary. Next, the average values of all the results calculated in the summary are used in the environmental load evaluation procedure. The resulting wall surface temperatures and required heating or cooling loads that are computed are then fed back into the simulation by replacing the previous average wall surface temperatures and required heating or cooling loads with the newly computed values. Finally, the summary total are initialized.

The Environmental Control Load Evaluation Output consists of the results of the long-term heat sink analysis and the heating or cooling load estimation. The calculations are dependent on the season of the year and the time of day (morning, evening or off-hour). The inputs are the Design Month and the Design Hour on Input Form 1B.

The user has the option to choose either of two types of SES Heat Sink Analysis: rush-hour or off-hour. The user indicates the choice by entering the appropriate value for the Environmental Control Load Option on Input Form 1C. In both cases the analysis is performed for all "uncontrolled" (Type 2) environmental control zones (defined on Input Forms 11A and 11B).

A rush-hour heat sink analysis consists of the computation of the morning and evening wall surface temperatures, and morning and evening average air temperatures. The interdependence of the air temperature and wall surface temperature is considered in the heat sink computation procedure. The humidity ratios corresponding to morning and evening rush hour are also computed. Figure 10.6 shows a sample output from a rush-hour SES Heat Sink Analysis.



```
SES VER 4.00                 SAMPLE SES INPUT FILE FOR NORMAL OPERATIONS SIMULATION                    PAGE: ____

                                                 SES HEAT SINK ANALYSIS
                                                 --- ---- ---- --------


                                                    ZONE NUMBER    1

    SYSTEM      MORNING RUSH HOUR    EVENING RUSH HOUR    MORNING RUSH HOUR    EVENING RUSH HOUR   MORNING RUSH HOUR   EVENING RUSH HOUR
 PARTITIONING  WALL SURFACE TEMP.   WALL SURFACE TEMP.   AVERAGE AIR TEMP.    AVERAGE AIR TEMP.    HUMIDITY RATIO      HUMIDITY RATIO
                    (DEG F)              (DEG F)              (DEG F)              (DEG F)             (LB/LB)             (LB/LB)

  1 -   1 -  1        76.5                 79.8                 80.1                 89.7              0.01365             0.02018

  1 -   2 -  1        76.6                 80.0                 80.1                 89.2              0.01366             0.02019

  1 -   3 -  1        76.9                 80.1                 80.2                 88.6              0.01368             0.02021

  1 -   3 -  2        77.3                 80.2                 80.5                 88.3              0.01371             0.02024

  2 -   4 -  1        78.2                 80.6                 80.1                 84.4              0.01246             0.01685

  2 -   4 -  2        78.0                 80.5                 79.9                 84.4              0.01243             0.01681

  2 -   4 -  3        77.7                 80.4                 79.8                 84.6              0.01240             0.01678

  5 -   5 -  1        77.8                 80.4                 81.0                 88.0              0.01374             0.02026

  5 -   5 -  2        78.6                 80.8                 81.8                 88.1              0.01375             0.02025

  5 -   5 -  3        79.6                 81.6                 82.7                 88.4              0.01362             0.01991

  6 -   6 -  1        77.9                 80.3                 80.1                 84.5              0.01218             0.01627

  6 -   6 -  2        77.6                 80.1                 79.8                 84.5              0.01215             0.01623

  6 -   6 -  3        77.2                 79.9                 79.5                 84.5              0.01213             0.01622

  3 - 103 -  1        76.7                 80.1                 79.9                 87.9              0.01369             0.02022

  4 - 104 -  1        77.2                 83.5                 79.4                 87.8              0.01327             0.01917
```

Figure 10.6 Rush Hour Heat Sink Analysis

An off-hour heat sink analysis consists of the computation of the design-time average air temperatures and humidity ratios. The computation of the design-time wall surface temperatures is bypassed since the values of the wall surface temperatures which were entered on Input Form 3E and 5B or read from the initialization file remain unchanged throughout the simulation.

The Environmental Control Load Estimate gives an estimate of the sensible and latent cooling or heating loads required to maintain design conditions in "controlled" (Type 1) zones. A sample of the output is shown in Figure 10.7. Sensible and latent heat loads for each subsegment in the zone are given in the following categories:

1. Trains and Miscellaneous:

   This is the total amount of heat rejected from trains which enters the station or tunnel environment. This item is the sum of all on-board heat sources including propulsion, braking, auxiliary/passenger heat and miscellaneous heat sources. The heat load has already been adjusted to reflect the heat captured by the trackway exhaust system. (The heat captured by the trackway exhaust system is assumed to be carried outside the subway without placing a heat load on the environmental control system (ECS). If this heat is returned to the ECS then appropriate adjustment should be made to the ECS load figures.) Miscellaneous heat sources include viscous heating, evaporation, and unsteady heat sources.
2. Steady-State:

   This is the Miscellaneous (Type 2) Steady-State heat sources entered on Input Form 3D.
3. Heat Sink:

   This is the heat transfer to or from the tunnel walls. It is computed using the wall surface temperatures entered on Input Form 3E or read from an initialization file, the average heat transfer coefficient from the short-term simulation, and the design temperature (Input Form 11A) for the zone.
4. Airflow:

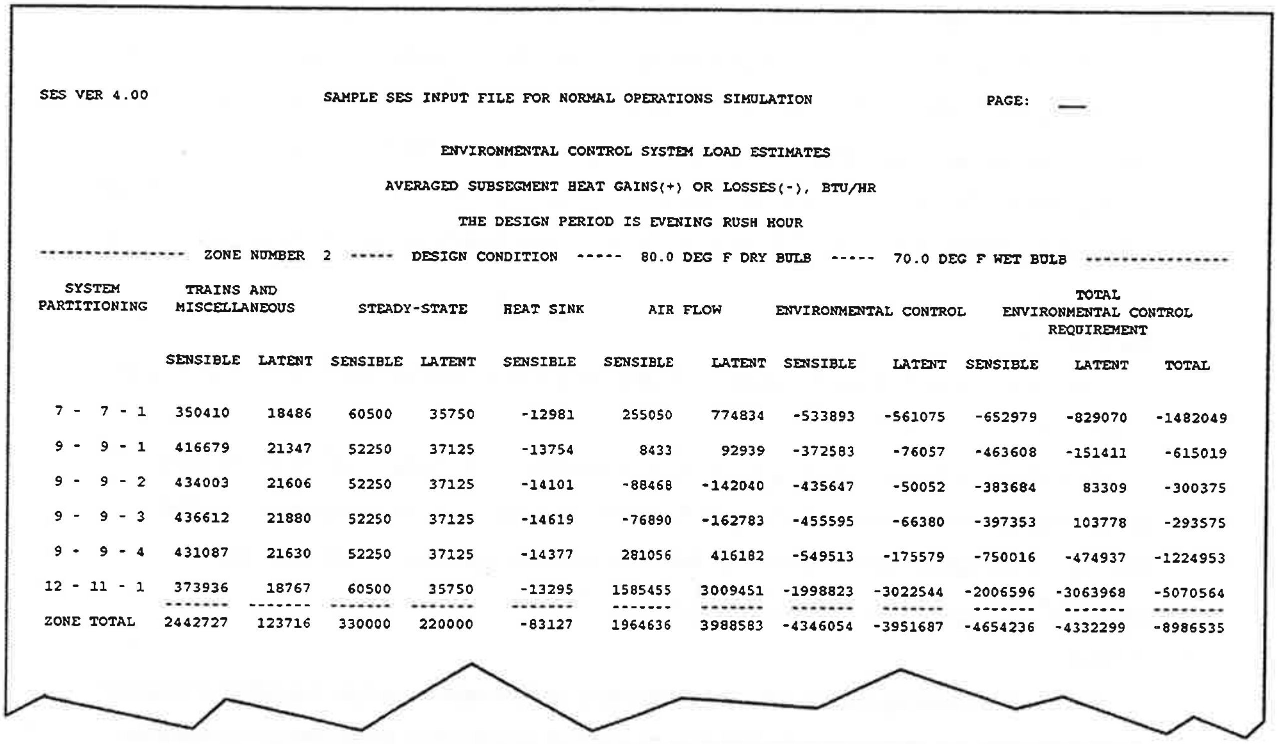
   This is the heating gain or loss resulting from airflow into or within the controlled zone. Air flowing into the zone requires heating or cooling to bring it to zone design conditions, and air flowing between subsegments within the zone may require heating or cooling to adjust for the effects of unsteady airflows and heat loads resulting from train operations.
5. Environmental Control:

   This is the ECS load in each subsegment during the summary interval. This number is obtained from either a heating or cooling (Type 2) steady-state heat source (entered on Input Form 3D), from an initialization file, or from a previous environmental control load evaluation.

6.. Total Environmental Control Requirement:

This is an estimate of the heating or cooling required to maintain average temperatures and humidities equal to the design conditions in the zone. A negative number indicates cooling is required; a positive number indicates heating is required.

The results of the heat sink analysis and heating or cooling load analysis are fed-back into the short-term simulation. The wall surface temperatures and average air temperature are used to initialize the subsegments in uncontrolled zones, and the total ECS heating or cooling requirement (both sensible and latent components) and design temperature and humidity are used to initialize the subsegments in controlled zones.



```
SES VER 4.00                   SAMPLE SES INPUT FILE FOR NORMAL OPERATIONS SIMULATION                    PAGE: ___

                                          ENVIRONMENTAL CONTROL SYSTEM LOAD ESTIMATES

                                 AVERAGED SUBSEGMENT HEAT GAINS(+) OR LOSSES(-), BTU/HR

                                             THE DESIGN PERIOD IS EVENING RUSH HOUR

---------------- ZONE NUMBER  2 ----- DESIGN CONDITION ----- 80.0 DEG F DRY BULB ----- 70.0 DEG F WET BULB ----------------

   SYSTEM       TRAINS AND                                                                                TOTAL
PARTITIONING  MISCELLANEOUS      STEADY-STATE     HEAT SINK      AIR FLOW      ENVIRONMENTAL CONTROL  ENVIRONMENTAL CONTROL
                                                                                                           REQUIREMENT

              SENSIBLE  LATENT  SENSIBLE  LATENT   SENSIBLE   SENSIBLE    LATENT  SENSIBLE    LATENT  SENSIBLE    LATENT     TOTAL

  7 -  7 - 1   350410    18486     60500   35750     -12981     255050    774834   -533893   -561075   -652979   -829070  -1482049
  9 -  9 - 1   416679    21347     52250   37125     -13754       8433     92939   -372583    -76057   -463608   -151411   -615019
  9 -  9 - 2   434003    21606     52250   37125     -14101     -88468   -142040   -435647    -50052   -383684     83309   -300375
  9 -  9 - 3   436612    21880     52250   37125     -14619     -76890   -162783   -455595    -66380   -397353    103778   -293575
  9 -  9 - 4   431087    21630     52250   37125     -14377     281056    416182   -549513   -175579   -750016   -474937  -1224953
 12 - 11 - 1   373936    18767     60500   35750     -13295    1585455   3009451  -1998823  -3022544  -2006596  -3063968  -5070564
              -------  -------   -------  -------   -------    -------   -------   -------   -------   -------   -------  --------
 ZONE TOTAL   2442727   123716    330000   220000    -83127    1964636   3988583  -4346054  -3951687  -4654236  -4332299  -8986535
```

Figure 10.7 Environmental Control System Load Estimate

10.10 Print Controls (Input Form 12)

The output of the SES program is divided into a number of "print groups". A "print group" is a number of second-by-second reports of the status of the system which are produced with the same interval between them. The Interval Length defines the length of time that is to elapse between successive prints of the status of the system. The Number of Intervals indicates how many time intervals of Interval Length are contained in the print group. The Number of Intervals may be one or more but never zero. (As a special case, the Number of Intervals may be entered as -1.0, which signifies that one interval is to elapse but the print of the status of the system at the end of the interval is to be suppressed.)

For each print group the user may specify the Number of Abbreviated Prints per Detail Print. This number defines the ratio of how many abbreviated prints are to be printed for each detailed print. The Number of Abbreviated Prints per Detail Print may range from zero to the Number of Intervals. An entry of zero indicates that no abbreviated prints are to be produced and that all of the prints of the status of the system from that group on will be detailed prints. When a non-zero number is entered for the Number of Abbreviated Prints per Detailed Print, the program first produces that number of abbreviated prints, then follows them by a detailed print, then that number of abbreviated prints followed by a detailed print, and so on until the Number of Intervals in the print group have been completed. If the Number of Abbreviated Prints per Detail Print is equal to the Number of Intervals, all of the prints produced by that print group will be abbreviated prints.

After all the intervals in a particular print group have been completed, the SES program performs the action specified in the Summary Option for that group before it goes on to the next group. The Summary Option may have any of five values, from zero to four (see Section 10.9). When the Summary Option is completed, the simulation continues with the printing as specified by the next print group.

Within each print group, the user has the ability to specify the Number of Cycles Per Aerodynamic Evaluation and the Number of Cycles Per Thermodynamic Evaluation. These values are referenced to the Time Increment per Cycle which is entered on Input Form 13. Multiples of the time increment per cycle are used to integrate the aerodynamic and thermodynamic equations within the program. For example, if the time increment per cycle is set to 0.1 seconds and the number of cycles per aerodynamic and thermodynamic evaluation is set to 2, evaluation of system aerodynamics and thermodynamics will be performed every 2 x 0.1 = 0.2 second (simulation time).

The number entered as the number of cycles per aerodynamic evaluation and the number of cycles per thermodynamic evaluation may change between print groups provided certain restrictions are observed. The first restriction is that the number of cycles per evaluation must not change during a period over which summary averages are being computed. This means that if a non-zero summary option is used for any print group in a simulation, then the number of cycles per aerodynamic or thermodynamic evaluation must not change from what was used in the preceding print group when the summary option of the preceding groups was entered as 2 or 0. The number of cycles per evaluation may change if all the summary options are zero, or if the summary option of the preceding print group was entered as 1, 3, or 4. The second restriction is that the results of the simulation immediately following a change in the number of cycles per aerodynamic or thermodynamic evaluation should not be used for design purposes. This restriction is imposed because an error may be temporarily introduced by changing the integration interval. It is recommended, therefore, that the results for the system cycle immediately following a change in the number of cycles be disregarded.

The importance of these three values: time increment per cycle, and the numbers of cycles per aerodynamic and thermodynamic evaluation cannot be stressed enough. Unlike some other inputs to the

SES, an unwise selection of these values will not cause results to be off by a few percent, but can make the difference between a meaningful and a meaningless run.

Obviously the higher these values are the lower the computer run time will be. It is therefore well worth the time to consider them carefully.

At the beginning of a simulation, and at the time a fan or an unsteady heat source starts to operate, transient conditions will occur within the system. The presence of transient conditions requires a small increment (and similarly a small number of cycles per aerodynamic and thermodynamic evaluations) to prevent the results of the integration from diverging. After a few system cycles, given the case where fan operation does not change (i.e. turn off or on), the transient conditions will "die down" and the system will begin to approach quasi-steady state conditions (conditions that repeat every system cycle). At this time in the simulation the number of cycles per evaluation may usually be increased without seriously affecting the results. Again, this is usually, not always.

An example of how the number of cycles per evaluation may increase is shown in Figure 10.8.

INPUT VERIFICATION OF CONTROL GROUP INFORMATION

FORM 12

TEMPERATURE TABULATION INCREMENT 5.0 DEG F
NUMBER OF CONTROL GROUPS 7

GROUP NUMBER	NUMBER OF INTERVALS	INTERVAL LENGTH	NUMBER OF ABBREVIATED PRINT PER DETAIL PRINT	SUMMARY OPTION	NUMBER OF CYCLES PER AERODYNAMIC EVALUATION	NUMBER OF CYCLES PER THERMODYNAMIC EVALUATION	TIME OF LAST PRINT IN GROUP (SEC)
1	2	100.00	0	1 - INITIALIZE ONLY	1	1	200.00
2	1	100.00	0	1 - INITIALIZE ONLY	1	2	300.00
3	1	100.00	0	4 - SUM., ENV. EVAL., INIT.	1	2	400.00
4	2	100.00	0	1 - INITIALIZE ONLY	2	4	600.00
5	1	100.00	0	4 - SUM., ENV. EVAL., INIT.	2	4	700.00
6	2	100.00	0	1 - INITIALIZEONLY	2	4	900.00
7	10	10.00	9	2 - SUMMARY ONLY	2	4	1000.00

Figure 10.8 Example of Control Group Information Showing Variation of the Number of Cycles per Aerodynamic and Thermodynamic Evaluation

Experience has shown that a time increment per cycle of 0.1 second is usually low enough to handle initial transient conditions for most simulations. As shown in Figure 10.8, for the first two system cycles the number of cycles per aerodynamic and thermodynamic evaluation is set at 1 and is gradually increased as the simulation progresses.

There is no standard formula for computing the most efficient value for the number of cycles per evaluation. As a suggestion, the user may make two identical short runs with different values of number ofcycles and compare the difference of the results. An investment of this type may reduce the total cost if a number of simulations of the same system are to be run.

The user must define enough print groups of sufficient duration to extend at least up to the Maximum Simulation Time (entered on Input Form 13). It is incorrect to specify a Maximum Simulation Time that is greater than the time at which the last print group will be completed. This is equivalent to asking the program to continue the simulation after the time of the last available print-out information on the status of the system. It is correct, however, to specify a Maximum Simulation Time that is equal to or less than the time at which the last print group is to be exhausted. If they are equal, the last print (including summary and environmental estimate when specified) will be performed and then the "end of simulation" will be reached. If the maximum simulation time is less than the time at which the last print group is exhausted, the simulation (with whatever printing that has been specified) will continue until the Maximum Simulation Time is reached, and then the simulation will be ended. The user must enter the Number of Print Groups to inform the program how many print group specifications are being defined for this simulation.

The summary output for line sections which are located within controlled zones of the system contains a tabulation of the percentage of time the temperatures are above (or below) certain selected temperatures. The Temperature Tabulation Increment defines the interval at which the temperature range within the line segment is to be tabulated. The sign of the Temperature Tabulation Increment indicates the design season: a plus sign (+) indicates summer with a tabulation of the percentage of time the temperature is above the indicated temperatures, and a minus sign (-) indicates winter with a tabulation of the percentage of time the temperature is below the indicated temperatures.

The design temperature in the line segment is used as the basis for defining the temperatures at which the percentage of occurrence is to be tabulated. If the design season is summer (+), the tabulation is produced with three increments above the design temperature and two increments below. If the design season is winter (-), the tabulation is produced with two increments above the design temperature and three below. The base temperature which is used in this tabulation is the design temperature for the period of the day (morning or evening) for which the simulation is being run, of the controlled zone in which the line segment is located. This tabulation is produced on the summary output only for line segments that are located within controlled zones.

For example, assume a line segment is located in a controlled zone with an evening design temperature of 80°F. Also, assume the simulation is being run for evening rush hour and the Temperature Tabulation Increment has been entered at +5.0. The percentage of time the temperature is above 70, 75, 80, 85, 90, and 95°F will be tabulated in the summary output. If, on the other hand, the Temperature Tabulation Increment had been entered as -3.0, the percentage of time the temperature is below 71, 74, 77, 80, 83 and 86°F will be tabulated.

Example of Print Control Data. An example of what one might enter for print control data is shown in Figure 10.8. In this example, the trains are operating on a 100-second headway which also sets the system repetition cycle at 100 seconds.

In this example there are 7 print groups. The first print group contains two intervals of 100 seconds each. Since the number of abbreviated prints per detailed print is zero, a detailed print will be produced at 100 and 200 seconds. (A detailed print is also performed at the end of the input verification, or at zero seconds.) At the completion of the print group at 200 seconds, the Summary Option 1 (initialize summary totals) was specified. This clears the summary totals. (The summary totals are also automatically cleared at time zero.)

The second print group consists of one interval of 100 seconds, after which a summary of the results from 200 to 300 seconds is printed and then the summary totals are again initialized. The third print group also consists of one interval of 100 seconds, after which a summary of the results from 300 to 400 seconds is printed, an environmental load evaluation is performed, and then the summary totals are again initialized. At this time, the newly computed wall surface temperatures which were computed for the uncontrolled zones in the system, and the newly computed heating or cooling loads that were computed for the controlled zones, are entered into the program in their respective subsegements and are used in the remainder of the simulation. The air temperatures within the system are also initialized to the values predicted by the environmental load estimate.

The fourth print group contains two intervals of 100 seconds each with a detailed print to be produced after each of the intervals. At the completion of this print group the summary totals are again initialized. It is hoped that the system would again reach aerodynamic and thermodynamic stabilization during this interval and a summary of the events in the stabilized system will be taken. The fifth print group consists of one interval of 100 seconds, after which a summary is printed, an environmental evaluation is performed, and the summary totals are initialized. This second environmental load estimate improves upon the heating or cooling load estimate that was taken previously. The wall surface temperatures and the heating or cooling load required to maintain design conditions within the system are re-computed, and these new values are inserted into their respective subsegments. The sixth print group contains two more intervals of 100 seconds each after which the summary totals are initialized. The seventh print group contains ten intervals of 10 seconds each with 9 abbreviated prints per detailed print. This will produce 10 prints of the status of the system spaced every 10 seconds over the 100-second system cycle. Since the train positions, airflows, temperatures, and humidities repeat in the period of the system cycle, a close look at only one of the cycles is sufficient to indicate the events in the stabilized system. Finally, a summary is printed to evaluate the temperatures within the system at design conditions with the results of the last environmental load estimate included within the system.

10.11 Program Control Data

The program control data is used to control the length of the SES simulation and the frequency of calculations during the simulation. The cost of the simulation is directly proportional to these entries and the proper choice of values is essential to keep computer costs down.

The Maximum Simulation Time defines the length of time for which the system is to be simulated. This time is the time which has "elapsed" in the real system during the simulation and is not be confused with the amount of computer time required to perform the necessary calculations. The Maximum Simulation Time is entered in seconds. The system is simulated until this time is reached, provided the simulation was not prevented by input errors or terminated due to simulation errors.

The Time Increment per Cycle is the smallest increment of time at which calculations are to be performed. The aerodynamic and thermodynamic portions of the simulation may be performed at integer multiples of this base cycle time increment. The basic train calculations, that is, the determination of the location, speed and acceleration of the trains, are performed at this time interval. The units in which this number must be entered is hundredths (1/100) of a second.

The Number of Cycles Per Complete Train Evaluation defines the multiple of the number of base cycles at which each complete train evaluation is to be performed. A complete train evaluation consists of checking if it is time to dispatch new trains into the system, remove from operation any trains that have gone past the last track section on their route, and determine if any trains must begin braking for an upcoming speed limit or station. These operations must be performed, but they need not be performed with the same frequency as the basic train calculations. As a rule of thumb, the complete train evaluations should be performed every one half to one second. This means that the product of the Number of Cycles per Complete Train Evaluation and the Time Increment per Cycle should usually be 0.50 to 1.00 second.

The current value of the Number of Cycles per Aerodynamic Evaluation (Input Form 12) defines the number of base cycles at which an aerodynamic evaluation is to be performed. An aerodynamic evaluation consists of the calculation of the airflow rates in all of the sections in the system. The frequency at which these calculations must be performed is dependent on the configurations of the particular system that is being simulated. If the system contains sections which are short (less than 200 feet) or experience rapid changes in the airflow rates (these may be caused by trains entering a portal at a high speed, a train passing beneath a ventilation shaft, a large fan switching on, or other events in the system), the aerodynamic calculations must be performed at small intervals (for example, every 0.10 second). If, on the other hand, the airflows do not experience rapid changes, the aerodynamic calculations can be performed less frequently (for example every 0.20 second). In most subway simulations, experience has shown the aerodynamic calculations should be performed at intervals less than 0.25 second. The interval at which the aerodynamic calculations are performed (in hundredths of a second) is equal to the product of the current value of the Number of Cycles per Aerodynamic Evaluation and the Time Increment per Cycle. It is often cost-effective to perform two or three partial SES simulations at different time increments to determine the largest time increment which will provide the required accuracy for the work being done.

The current value of the Number of Cycles per Thermodynamic Evaluation (Input Form 12) defines the number of base cycles at which a thermodynamic evaluation is to be performed. A thermodynamic evaluation consists of the calculation of the temperatures and humidities in all portions of the system. Since temperature and humidities do not change as rapidly as airflows, the thermodynamic calculations do not need to be performed as often as the aerodynamic calculations. A good rule is to perform a thermodynamic evaluation every 0.20 to 1.00 second. The time interval between thermodynamic cycles (in hundredths of a second) is equal to the product of the current value of the Number of Cycles per Thermodynamic Evaluation and the Time Increment per Cycle.

The Number of Thermodynamic Cycles per Wall Temperature Evaluation is entered only if the Fire Simulation Option on Form 1G is entered as 1.0 (i.e., a fire is being simulated). Its use is described in Chapter 9 of this manual.

11. SES INPUT MANAGER USER'S MANUAL

11.1 Introduction

The Subway Environment Simulation program (SES) is used by subway ventilation engineers as part of the design and analysis of subway ventilation systems. This analysis includes airflows and temperatures during both normal operations and emergency ventilation of fires.

The SES input data includes a general description of environmental and operational conditions, the geometry of the subway system, the physical and operational characteristics of the trains, the train routes and schedules, the fan operating characteristics, and heat loads, both routine heat loads from trains, equipment and passengers and emergency heat loads from fires. The input also includes simulation parameters and output requirements.

SESIN, the Windows interface for SES Version 4, provides an interactive Graphical User Interface (GUI) environment for entering and editing SES data and for initiating program execution. SESIN and SES Version 4 will read data files from Version 3. The data files for Version 4.0 may not be readable by older versions of SES (see SES program documentation).

The data is divided into several logical categories, each of which is entered on a separate screen or panel. The categories are very similar to the forms described for line oriented input. In some instances, items from a form have been moved to the screen where the associated data is entered (e.g., Fan windmilling/stop option and fire emissivity).

SESIN takes care of counting quantities, such as number of segments, nodes, fans, etc. and provides informational error messages when values entered are not within the documented allowable range. It does not force the values to be within the documented range. SESIN does not perform complete input validation, that is left to the SES program itself. Consequently, a data set created using SESIN may not be a valid SES input file if it is incomplete or contains invalid values.

11.2 System Requirements

SESIN requires Windows 95 or Windows NT 3.51 or higher. It should work satisfactorily on any system capable of running these operating systems. However, a Pentium processor is recommended.

It works best with small fonts selected for the display. Some labels and prompts may be partially obscured when displayed with the large fonts unless the form size is increased.

11.3 General Procedures

Many of the procedures for entering data via SESIN are common throughout the program.

- Move between fields using the Tab key, or the mouse. Typically the ENTER Key does not move from one field to another except in tables.
- It is a good practice to close each screen (by pressing the okay button) to ensure all data is updated before moving to another screen.

- Cut, Copy and Paste use the standard Microsoft Windows keys (Ctrl-X, Ctrl-C and Ctrl-V respectively) and menu items except for fans, routes and trains, where special buttons are provided.
- Prompt information, including the range of allowable values is displayed in the status line at the bottom of the screen.
- The data is grouped essentially (but not exactly) in the same manner as on the SES Forms. The SES Form number is usually shown at the left of the status line for reference.
- An incomplete data set may be saved and read back to be completed at a later time.
- Context sensitive help is available on any data item by pressing F1.

Text boxes

Most data is entered in text boxes. When text boxes receive the focus (the cursor is moved to the item), the entire data item is selected (highlighted) and a message specifying the allowable data range is displayed on the status bar. Most numeric data will be saved exactly as it is typed, except that a decimal point will be added at the end if it is missing. Range checking will be performed as each field is exited. If the entry is not a valid number or if the value is outside the allowable range, a warning message will be displayed. The user may choose to ignore the warning and continue, if necessary.

Tables (grids)

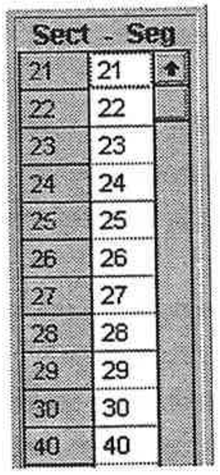
Much of the SES input data is presented in tables. The movement of the cursor is slightly different in tables than in other kinds of input. There is a browse mode in tables to move from one cell to another and an edit mode to modify the data in the cells. In the browse mode, the arrow keys move the focus from one cell of the table to another; in the edit mode, the left and right arrow keys move within the field just as they do in a text box. To enter new data in a cell, simply start typing, the current contents of the cell will be replaced with what you type. To edit the contents of a cell without retyping it, double-click on the cell or press either ENTER or F2 to enter edit mode. When the data entry in a cell is complete, press ENTER or TAB to update the cell and move to the next cell to the right or select another cell with the mouse. Entering data in any cell of the last row of a table adds a new row. Entering data in the last cell of a row moves the cursor to the first cell of the next row.

To move from a table to the next item, use either the mouse or the appropriate hot-key (ALT and the underlined letter of the label), if any.

Line and Vent Sections

Line and Vent sections are treated very similarly. Adding, deleting or copying sections includes the associated line segments or vent shafts. You may also redefine the default section that is copied when a new line or vent section is added. Simply select (click on) an existing or newly entered section and select Set as Default from the Edit menu. The values from the selected section and all its segments or its shaft will become the new default. When entering new data, it may therefore be useful to first enter a common section and its segments to use as a template, and set it as the default before entering more sections.

Item Selection

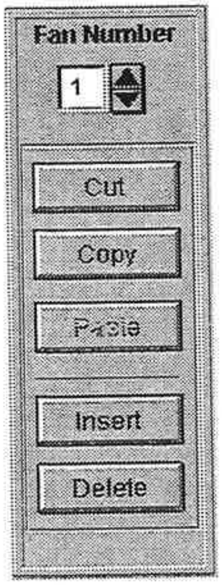


Sect	Seg
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
40	40

For data types where only one item at a time is displayed (segments, trains, fans, etc), one of two methods is used to select the particular item to edit depending upon the type of item involved.

Line Segments, Vent Shafts and Nodes use a <u>pick list</u> (such as that shown at the left) to select the item to be edited. For Line Segments and Vent Shafts, the section number and the segment or shaft number are both shown, but only the segment/shaft number can be modified. Use the same methods as for any table (see above) to move within the pick list and change the section numbers. You may move up and down with the arrow keys, use the mouse with the scroll bar, or pick a specific item with the mouse. Note that scrolling the scroll bar does not change the selected item, but simply moves the list within the window. You must pick the desired item to be displayed with the mouse.

When the focus is on the pick list, the Cut, Copy, Paste, Insert and Delete functions apply to the entire data item (line segment, shaft or node). When the focus is on a particular data item on the data portion of the panel, the edit functions apply to the data field or the row of the table.



For items such as Fans, Trains, Routes, and Environmental Control Zones, a <u>Selection Panel</u> (such as that shown at the left) is used to select, cut, copy, paste insert and delete the entire item. The Edit menu items and shortcuts only apply to specific data fields.

The Spin Buttons may be used to select the item to be displayed. When the cursor is in the item number text box, the up and down arrow keys may also be used. To add a new item at the end of the list, spin up to the blank item at the end and enter the appropriate data. Typically, at least an ID must be entered for a new item before spinning up to another blank entry.

The Cut, Copy, Paste, Insert and Delete buttons apply to the entire fan, train, route, etc. The Edit menu or the standard shortcut keys can be used to Cut, Copy and Paste individual fields.

The CUT and COPY buttons copy the entire currently displayed item to a buffer. CUT then deletes the item; COPY does not.

The PASTE button is only enabled after an item has been cut or copied. Pressing PASTE <u>inserts</u> the item from the buffer at the current position. Other items are <u>pushed up</u> and renumbered. References to the items (for instance fan shaft numbers in vent shafts) are <u>NOT</u> updated!

The INSERT button may be used to insert a new item at the current position instead of at the end of the list. As with Paste, other items will be pushed up and renumbered.

. The DELETE button deletes the currently displayed item without saving it to the buffer. THERE IS NO UNDO.

11.4 Getting Started

The most efficient way to approach SES data entry is to create a master file containing the basic description of the system and then modify this file to create separate files for specific scenarios to be analyzed.

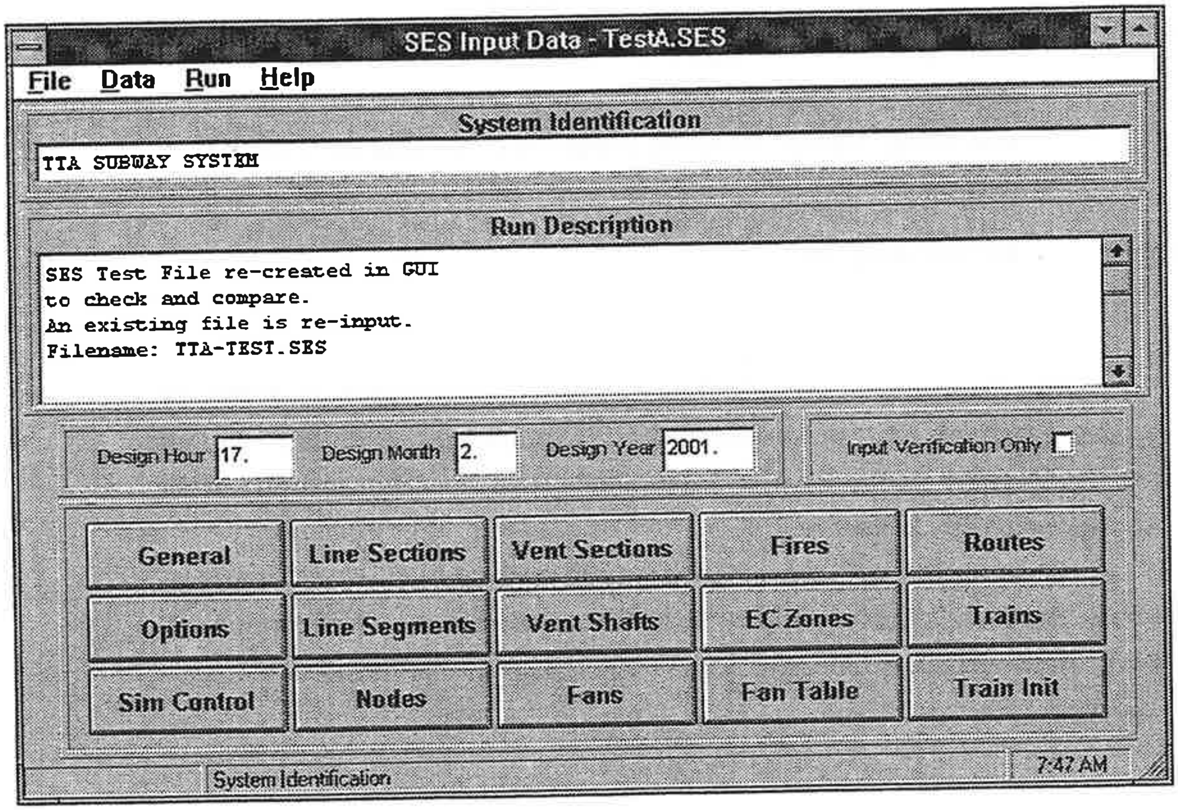
When creating a new data set, start by entering the System ID and a basic Problem Description, then set the Options on the Option Panel to identify the options that will be used for the analysis. This ensures the correct panels will be displayed and the correct data items will be requested and saved to the data file.

Enter a common Line Section and its segments and set this to the default, then continue entering additional sections. Make use of copy and paste where several sections have similar characteristics.

You may find it more convenient to define all the fan types that will be used in the system before entering vent sections and shafts so that you may select the fans from the drop down list on the shaft data screen and avoid confusing fan numbers.

When using one file to create another, it is a good practice to open the original file and immediately do a File/ Save As to save it under the new name before making any changes. This will prevent accidentally replacing the original file by a File/Save after making changes but before changing the name.

11.5 Main Screen



System Identification

```
TTA SUBWAY SYSTEM
```

Run Description

```
SES Test File re-created in GUI
to check and compare.
An existing file is re-input.
Filename: TTA-TEST.SES
```

Design Hour 17. Design Month 2. Design Year 2001. Input Verification Only ☐

System Identification

The Main screen is displayed at the start of the program. It provides the main menu functions and access to all of the other input data screens through either the Button panel or the Data menu option.

Menus:

File

NEW	Deletes any existing data and initializes all data elements.
OPEN	On the File Menu opens a standard Windows File Open dialog box. The default file types are .SES and .INP. To list and open files with different file extensions, select all files in the “List Files of Type” combo box.
SAVE	Saves the current file under the same name as it was read from or previously saved to. If the file has not yet been saved, the Save As dialog box is opened.
SAVE AS	Opens a standard window Save As dialog box with a default file extension of .SES. The file may be saved with any name and extension acceptable to the system. NOTE: It is permissible to save an incomplete file. SESIN will save the

file in such a manner that it can be read back for further input, even though it may not be usable by the SES program.

PRINT	Prints an unannotated copy of the current file with page headers and footers. This is a simple listing of the file as it will be saved for SES processing. Data is not labeled or explained. See Chapter 12 for the input file format.
EXIT	Exits the program.

Data

The Data menu on the Main SESIN screen provides an alternate method of accessing the other program screens. Each of the data categories is listed. This menu provides access to the Impulse Fan screen and the Data Count Screen which are not represented on the button panel.

The Impulse Fan Screen can also be reached by pressing F2 from the Main screen. The Data Count Screen lists the current values for most of the Form 1 count fields. These values are for information only and cannot be modified since they are calculated by the program.

Run

The Run menu on the Main SESIN screen offers 2 choices: Current File and Batch Mode. The Current File option saves the current file (if it has been modified) and starts the SES program processing it. Any subsequent changes to the current file cannot be saved until the SES processing is complete.

The Batch Mode option starts the SESBATCH program which allows you to identify a list of SES input files to be run sequentially. The SES program will then process these files without further intervention. You may continue using SESIN to enter and modify other files while the SES program is running. You will not be able to open the file currently executing and it is not recommended to open any of the other files in the list until they have been processed. Instructions for SESBATCH are provided at the end of this manual.

Help

The Help menu choices are typical of most Microsoft Windows applications and are common to each screen in the program.

Data Items

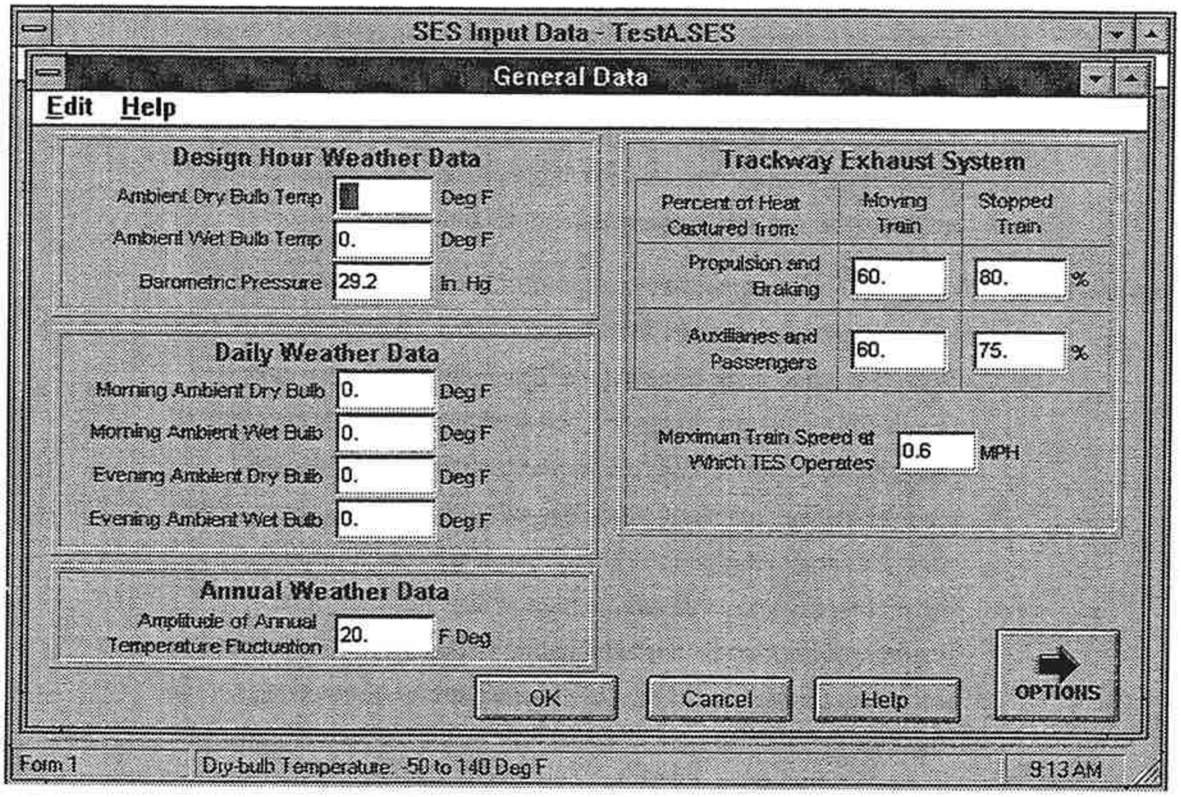
The data items on the Main Screen describe the problem to be run.

System Identification	One line (80 characters max.) description of the system. This text will be included at the top of each page of the output listing.
Run Description	May be up to 19 additional lines of up to 80 characters each. When entering the data, you may press enter to begin a new line or text will automatically wrap at the end of the dialog box. This may be more or less than 80 characters if the size of the dialog box has been changed. SESIN will re-wrap long lines to 80 characters or less when you exit the Run Description text box and redisplay the text as it will appear in the data file.
Design Hour	Enter the hour as a whole number from 0 to 24 and enter the minutes in the decimal portion; i.e., 3:30 P.M. is entered as 15.30. If the Environmental Control Load Option is 1.0 and the user wishes the heat sink analysis to be performed for the morning rush hour, the user must enter 8.0 for the design hour. If the user wishes the heat sink analysis to be performed for the evening rush hour, the user must enter 17.0 for the design hour. If the environmental load evaluation option is 2.0 (off-hour), the environmental control load evaluation will be performed for the exact hour entered and will use the wall temperatures assigned by the user.
Design Month	In the Northern Hemisphere, the month of July (month number 7.) is the hottest month of the year and the month of January (month number 1.) is the coldest month of the year. Regardless of where the system is located in the world, if the simulation is to be done for the hottest month, the number 7. must be entered for the design month, and the number 1. must be entered for the design month if the simulation is to be done for the coldest month.
Design Year	The year for which the analysis is being performed.
Input Verification Only	Check this box to force SES to terminate at the end of input verification. Checking this box sets the number of allowable input errors to -1. Clearing this check box sets the number of allowable input errors to 0.

Button Panel

These buttons are used to access the various data types. Some buttons (EC Options and Train and Route buttons) will not be enabled unless the appropriate options are selected on the Options Screen.

11.6 General Data



Design Hour Weather Data

Ambient Dry Bulb Temp Deg F
Ambient Wet Bulb Temp 0. Deg F
Barometric Pressure 29.2 In. Hg

Daily Weather Data

Morning Ambient Dry Bulb 0. Deg F
Morning Ambient Wet Bulb 0. Deg F
Evening Ambient Dry Bulb 0. Deg F
Evening Ambient Wet Bulb 0. Deg F

Annual Weather Data

Amplitude of Annual Temperature Fluctuation 20. F Deg

Trackway Exhaust System

Percent of Heat Captured from:	Moving Train	Stopped Train	
Propulsion and Braking	60.	80.	%
Auxiliaries and Passengers	60.	75.	%

Maximum Train Speed at Which TES Operates 0.6 MPH

Form 1 Dry-bulb Temperature: -50 to 140 Deg F 9:13 AM

This form provides weather and trackway exhaust system data previously found on Form 1. The OPTIONS button saves the data entered on this screen, closes it and proceeds to the Simulation Options screen.

Weather Data

Ambient Air Dry-Bulb Temperature	Outside air temperature entered as dry-bulb degrees F. This outside air temperature remains constant for the program computations. $-50. \le X \le 140.$ °F
Ambient Air Wet-Bulb Temperature	Outside air temperature entered as wet-bulb degrees F. Used in the computations of the ambient humidity ratio (specific humidity) and the relative humidity. $-50. \le X \le$ Amb. Air Dry-Bulb Temp. °F
Ambient Barometric Pressure	Outside air pressure entered in inches of mercury. Remains a constant in the program computations. $20. \le X \le 32.$ in. Hg
Morning Ambient Air Dry-Bulb Temp	Outside air temperature corresponding to the morning rush hour. $-50. \le X \le 140.$ °F
Morning Ambient Air Wet-Bulb Temp	Outside air temperature corresponding to the morning rush hour $-50. \le X \le$ Morn. Amb. Air Dry-Bulb Temp. °F
Evening Ambient Air Dry-Bulb Temp	Outside air temperature corresponding to the evening rush or off hour. $-50. \le X \le 140.$ °F
Evening Ambient Air Wet-Bulb Temp	Outside air temperature corresponding to the evening rush or off hour. $-50. \le X \le$ Eve. Amb. Air Dry-Bulb Temp. °F
Amplitude Of Annual Temperature Fluctuation	The program assumes the annual fluctuation of daily normal average temperature to be sinusoidal. Enter the amplitude of this sinusoid. $0. \le X \le 50.$ °F

Trackway Exhaust System Data

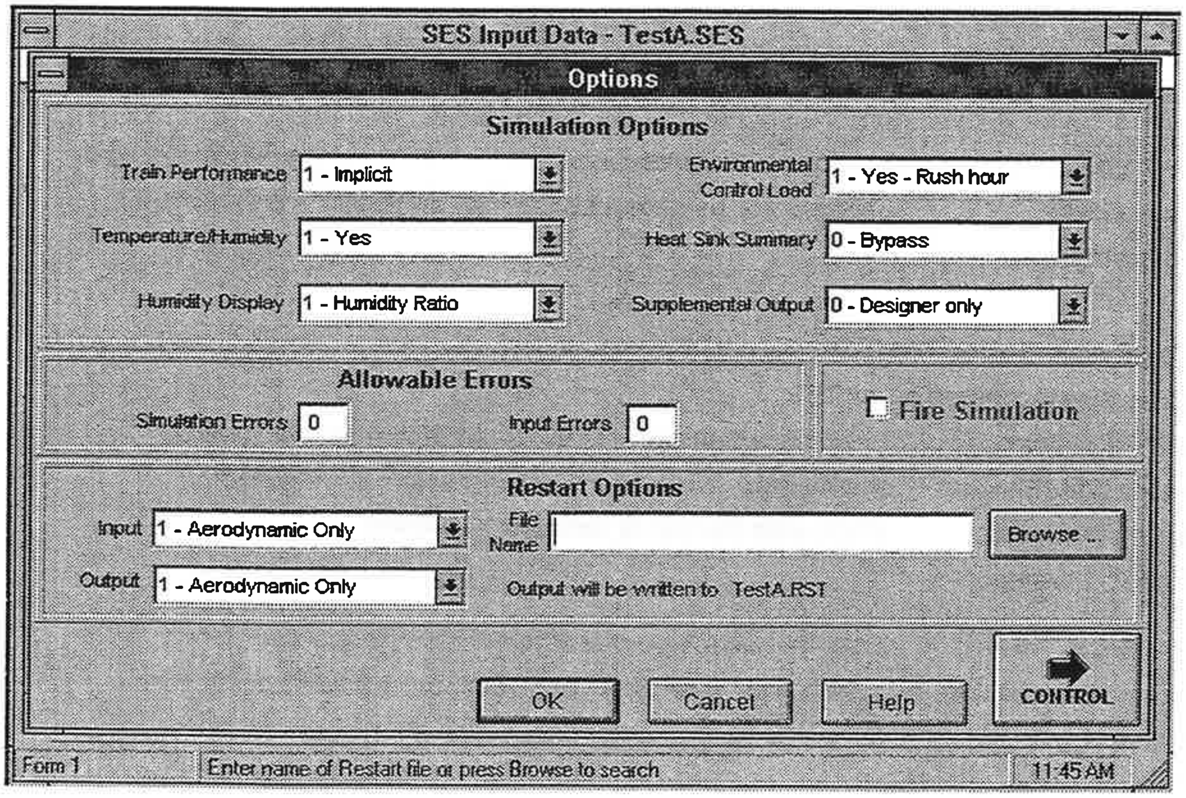
Percent of heat captured by the TES:

Heat From Train Propulsion / Braking System When The Train Is Stopped	Enter the percentage of heat from the train propulsion/braking system which is removed by the trackway exhaust system (TES) while the train is stationary in a station. $0. \le X \le 100.$ percent
Heat From Train Propulsion / Braking System When The Train Is Moving	Enter the percentage of heat from the train propulsion/braking system which is removed by the trackway exhaust system while the train is moving during entry and/or exit from a station. $0. \le X \le 100.$ percent
Sensible Heat From Train Auxiliaries &	Enter the percentage of sensible heat from the train auxiliaries and passengers which is removed by the trackway exhaust

PASSENGERS WHEN TRAIN IS STOPPED	system while the train is stationary in a station. 0. ≤ X ≤ 100. percent
SENSIBLE HEAT FROM TRAIN AUXILIARIES & PASSENGERS WHEN TRAIN IS MOVING	Enter the percentage of sensible heat from the train auxiliaries and passengers which is removed by the trackway exhaust system while the train is moving during entry and/or exit from a station. 0. ≤ X ≤ 100. percent
MAXIMUM TRAIN SPEED AT WHICH THE TES OPERATES	The maximum speed at which the trackway exhaust system operates while trains are entering and/or leaving a station. 0. ≤ X ≤ 250. mph

The OPTIONS button saves any changes to the General data, closes the screen and opens the Options Screen.

11.7 Options



Train Performance: 1 - Implicit
Temperature/Humidity: 1 - Yes
Humidity Display: 1 - Humidity Ratio
Environmental Control Load: 1 - Yes - Rush hour
Heat Sink Summary: 0 - Bypass
Supplemental Output: 0 - Designer only

Simulation Errors: 0
Input Errors: 0

☐ Fire Simulation

Input: 1 - Aerodynamic Only
Output: 1 - Aerodynamic Only
File Name:
Output will be written to TestA.RST

Form 1 | Enter name of Restart file or press Browse to search | 11:45 AM

The Options screen is accessed from the Main screen or from the General Data screen. These options affect the nature of the calculations performed in the simulation.

Train Performance	0 - Bypass train simulation 1 - Implicit 2 - Explicit (Train heat rejection computed) 3 - Explicit (Train heat rejection input)
Temperature/ Humidity	0 - Bypass 1 - Yes 2 - Yes - evaporation
Humidity Display	1 - Humidity ratio 2 - Wet-bulb temperature 3 - Relative humidity (N/A if Temp/Humid = 0)
Environmental Control Load Evaluation	0 - Bypass 1 - Yes - evening or morning rush hour 2 - Off hour (N/A if Temp/Humid = 0)
Heat Sink Summary	0 - Bypass 1 - Heat sink summary output 2 - Heat sink summary output and heat sink arrays (N/A if Temp/Humid = 0)
Supplementary Output	0 - Designer Oriented output only 1 - Level 1 (Input Verification) 2 - Level 2 (Train Sim.) 3 - Level 3 (Aerodynamic Sim.) 4 - Level 4 (Thermodynamic Sim.) 5 - Level 5 (All of the Above)
Allowable Simulation Errors	0 - Stop simulation if any simulation errors are found N - Allow up to "N" simulation errors $0. \leq N \leq 50$
Allowable Input Errors	+N Allow Simulation to continue if N or fewer non-critical errors are found. Critical errors will always prevent simulation. 0 Prevent simulation if any errors are found. -1 Perform input verification only. Do not perform simulation.
Fire Simulation Option	Check this box if fire simulation is to be performed.

USE RESTART FILE
SAVE RESTART FILE

Enter the number of the option desired to write and/or read an initialization file. The options are:

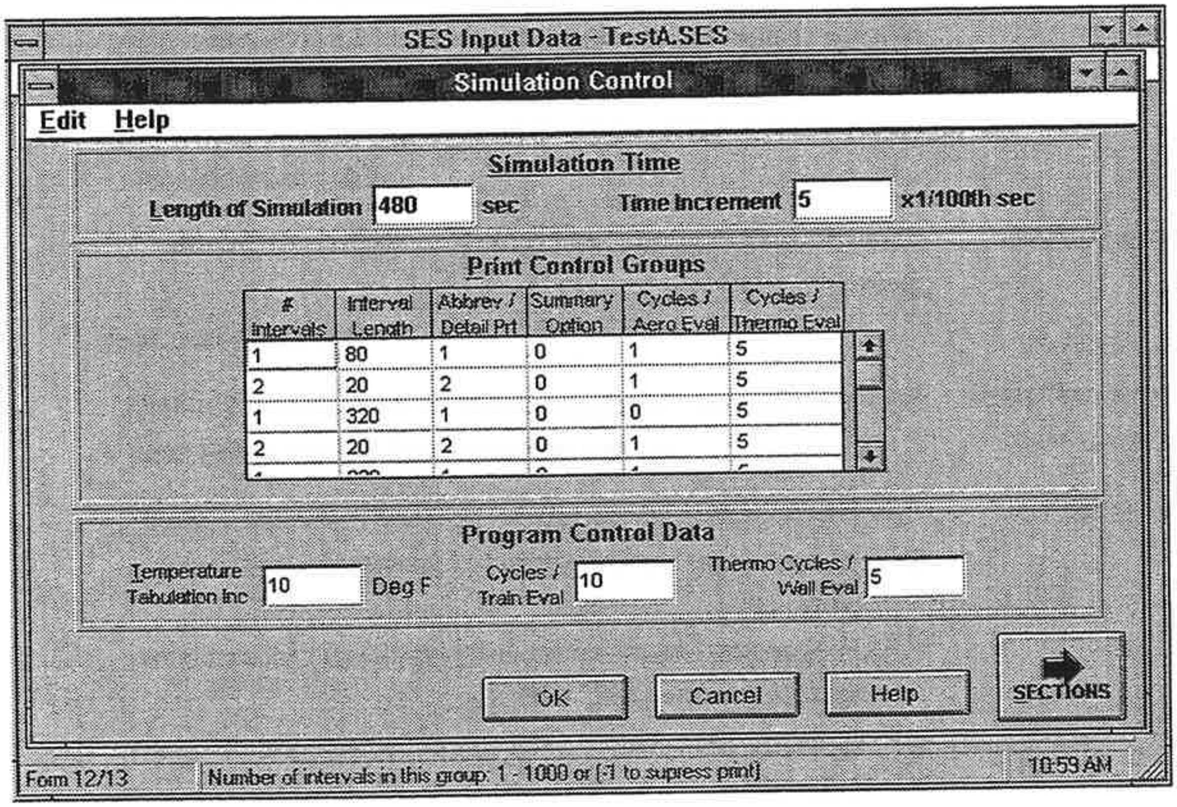
0 - None
1 - Aerodynamic initialization only
2 - Train initialization only
3 - Thermodynamic initialization only
4 - Aerodynamic and train initialization
5 - Aerodynamic, train, and thermodynamic initialization

If a file is being read, enter the name of the file or press the BROWSE button to open a file selection dialog box. This must be a file created by the Save Restart File option of a previous simulation.

If a file is being saved, the file name will be the same as the input file name with the file extension changed to .RST.

The CONTROL button saves any changes to the Options data, closes the screen and opens the Simulation Control Screen.

11.8 Simulation Control



SES Input Data - TestA.SES

Simulation Control

Simulation Time

Length of Simulation: 480 sec

Time Increment: 5 x1/100th sec

Print Control Groups

# Intervals	Interval Length	Abbrev / Detail Prt	Summary Option	Cycles / Aero Eval	Cycles / Thermo Eval
1	80	1	0	1	5
2	20	2	0	1	5
1	320	1	0	0	5
2	20	2	0	1	5

Program Control Data

Temperature Tabulation Inc: 10 Deg F

Cycles / Train Eval: 10

Thermo Cycles / Wall Eval: 5

Form 12/13 | Number of intervals in this group: 1 - 1000 or [-1 to supress print] | 10:59 AM

The Simulation Control screen contains data items which control the simulation timing and print output intervals. It is accessed from the Main screen or from the Options screen.

LENGTH OF SIMULATION	Enter the maximum time for which the simulation is to be performed. 0. ≤ N ≤ Time of last print-out
TIME INCREMENT	This is the basic time interval over which the location, speed, and acceleration of all the trains in the system is calculated. The aerodynamic, thermodynamic, and complete train evaluation calculations are performed at user-specified integer multiples of this basic calculation time interval. This number is entered in 100ths (1/100) of a second. For example, if the user enters 10.0 (equivalent to 10/100 of a second), the location, speed, and acceleration of all trains will be calculated every tenth of a second. 1. ≤ N (equivalent to: 0.01 sec ≤ X)

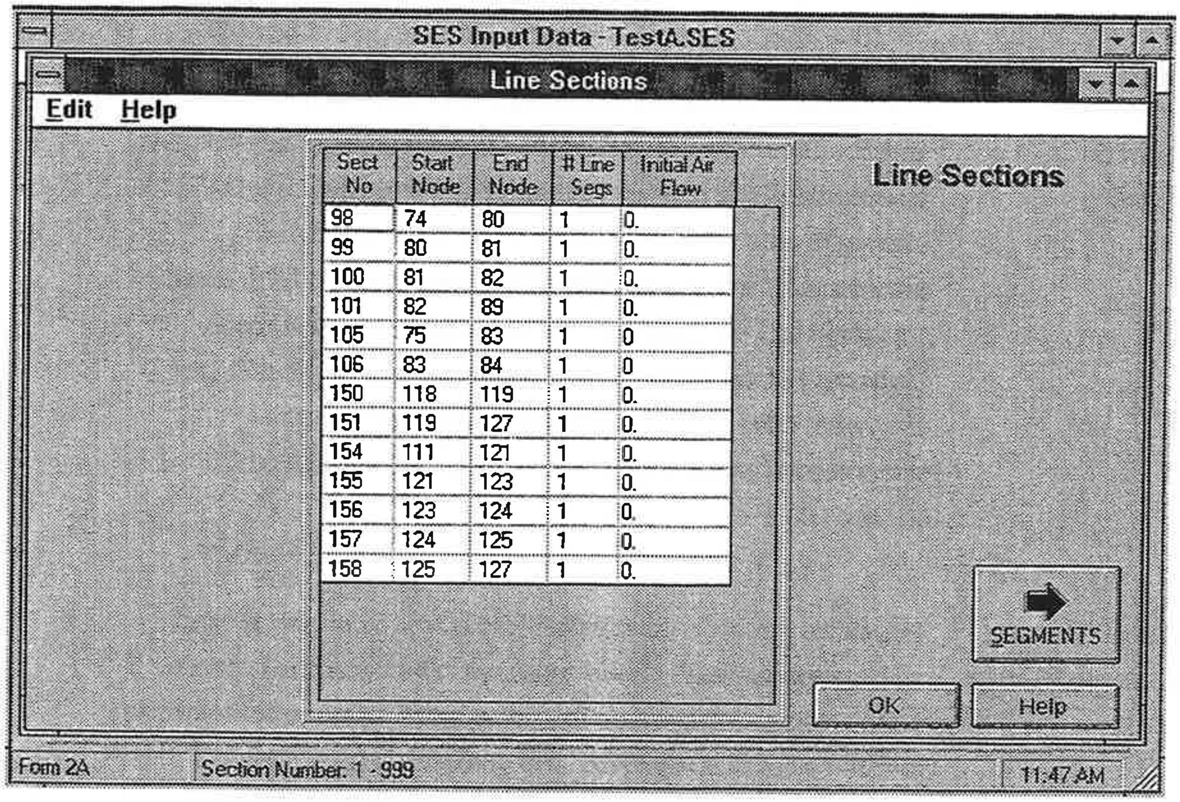
Printer Control Data

Number Of Intervals	Enter the number of equally-spaced time intervals in this print group. After each interval a detailed or abbreviated print will be made. This number cannot be zero. An entry of -1. indicates there is one interval in this group, but printout should be bypassed. $0. \le N \le 1,000.$ or -1.
Interval Length	Enter the length of time in each of the print intervals for this print group. $0.1 \le N \le 3600.$ sec
Abbreviated Prints Per Detail Print	This entry describes the <u>ratio</u> of abbreviated prints to detailed prints. $0. \le N \le$ Number of print intervals in this group.
Summary Option	The following options are available at the end of each print group: 0 - <u>No summaries</u> - only the detailed or abbreviated prints will be performed. 1 - <u>Initialize</u> - this resets the summary totals, and a new summary begins at this time. 2 - <u>Summary</u> - this prints a summary starting from the most recent initialization. 3 - <u>Summary and Initialize</u> - this performs options 2 and 1 (in that order). 4 - <u>Summary, Environmental Estimate and Initialize</u> - this performs option 2, then prints an environmental control estimate, and then performs option 1.
Cycles Per Aerodynamic Evaluation Cycles Per Thermodynamic Evaluation	These numbers are integer multiples of the time increment per cycle and determine when a complete aerodynamic and thermodynamic evaluation for the system is to be performed. For example, if the user has entered 10. for the time increment per cycle, and enters a 1. here, a complete aerodynamic or thermodynamic evaluation will be performed every (1) x (0.1 sec)= 0.1 sec. If a zero is entered in the first print group, zero must be entered in all print groups. If a non-zero value is entered in the first print group, a non-zero value must be entered in all print groups. If the summary option in the previous print group is zero, but is non-zero in any other group, or the summary option in the previous print group is 2, the number of

	cycles per evaluation must be the same as in the previous print group. $0. \leq N \leq 100.$
Temperature Tabulation Increment	The number entered here determines the increments for which the variations from design temperature are printed within the summary. To illustrate, if it is summer and the design temperature is 80 °F, the user might enter +10. The summary would then print the percentage of time the air temperature goes above 60, 70, 80, 90, 100, and 110°F for each subsegment of each controlled zone. Conversely, if it is winter and the design temperature is 80°F, the user might enter -10. The summary would then print the percentage of time the air temperature goes below 50, 60, 70, 80, 90, and 100 °F. $-10. \leq X \leq 10.$ °F
Number Of Cycles Per Complete Train Evaluation	This number is an integer multiple of the time increment per cycle and determines when a) new trains are to be dispatched into the system; b) trains that have traveled beyond the last track section on their route are to be removed; and c) checks for upcoming train speed restrictions to be made and whether or not braking is necessary. For example, if the user has entered 10.0 for the time increment per cycle and enters a 5.0 for this entry, a complete train evaluation will be performed every (5) x (0.10 sec) = 0.5 second. $1. \leq N \leq 100.$
Number Of Thermodynamic Cycles Per Wall Temperature Evaluation (Entered only if the Fire Simulation Option on Form 1G is 1)	This number is an integer multiple of the number of cycles per thermodynamic evaluation entered on Form 12, and determines the frequency of wall temperature calculations for each subsegment of a segment which is designated as a fire segment on Form 3A. For example, if the user has entered 10.0 for the time increment per cycle, 2.0 for the number of cycles per thermodynamic evaluation and 5.0 for this entry, the wall temperature calculations in the prescribed subsegments will be performed every (0.10 sec) x (2.0) x (5.0) = 1 second. $N \geq 0.0$

The SECTIONS button saves any changes to the Simulation Control data, closes the screen and opens the Line Sections Screen.

11.9 Line Sections



Sect No	Start Node	End Node	# Line Segs	Initial Air Flow
98	74	80	1	0.
99	80	81	1	0.
100	81	82	1	0.
101	82	89	1	0.
105	75	83	1	0
106	83	84	1	0
150	118	119	1	0.
151	119	127	1	0.
154	111	121	1	0.
155	121	123	1	0.
156	123	124	1	0.
157	124	125	1	0.
158	125	127	1	0.

Entering New Section Data:

The grid for section data initially contains one blank row. When data is entered in the last field in a row, the focus moves to the first field in the next row. If there are no more rows, a blank row is added. When the section number is entered in the first column of a new row (one beyond the end of existing data), a new section is added to the data set from the default section, and the default data is displayed in the remainder of the row. If numerous similar sections are being entered, the segment data for the first of those sections may be entered and then that section (and its segments) may be used as the default section. Sections and their segments may also be copied using standard Windows Cut/Copy and Paste techniques.

Whenever the number of segments is increased in the Section Table, the appropriate number of segments are added and initialized with data copied from the last segment. The number of segments may not be decreased in this table. Individual segments must be deleted from the segment panel.

Cutting or Copying Section Data:

When section data is cut or copied, the entire section, including all its segment data, is copied to the programs buffer section. The text from the grid row is copied to the Windows Clipboard as text, but the associated segment data is not. For Cut, the row is deleted from the grid and the section and its segments are deleted from the data set.

Pasting Section Data:

When pasting section data, a new row is inserted at the current position and the section that was most recently cut or copied to the buffer section is copied to the new row along with all its segments. The section ID and all the segment IDs are set to 0.

Inserting Section Data:

When a new section is added at the end of the list or inserted in the middle, a new section is created and initialized from the default section. You may change the contents of the default section as described below.

Deleting Section Data:

A section and all its segments may be deleted by pressing the Delete key or selecting Delete row from the menu with the cursor on the selected row (not in Edit mode).

Setting the Default Section Data:

The default section data is initialized when the program is started, with most data being set to 0. Once a common section has been entered, it and its associated segments may be used as the default section by clicking on the selected row and then selecting the Set Default Section from the Edit menu.

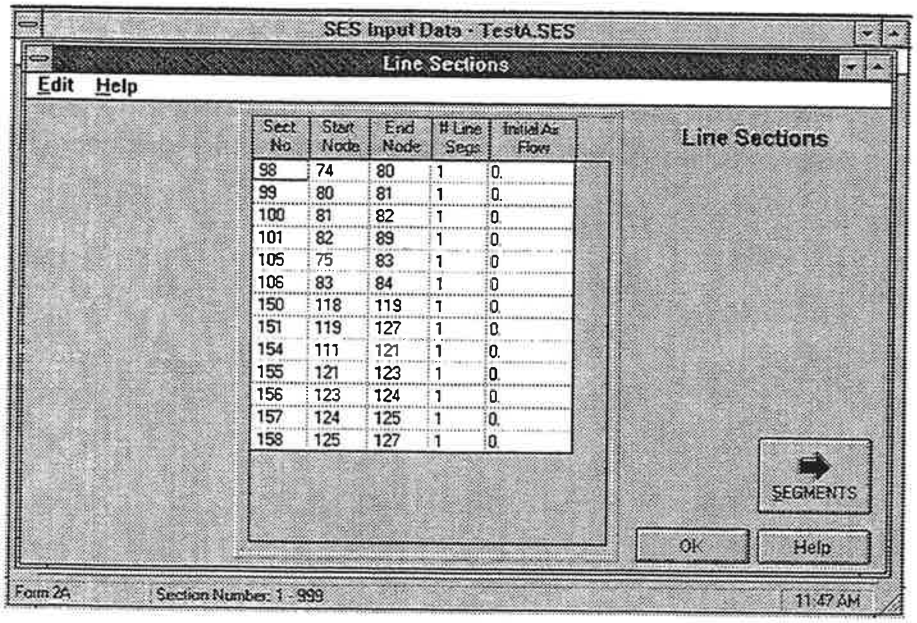
Segment Button

The segment button opens the segment screen with the first segment of the currently selected section displayed. The Section screen remains open and control will return here when the segment screen is closed.

Data Fields

SECTION NUMBER	This number identifies the tunnel section being described. 1. ≤ N ≤ 999.
STARTING NODE	This number is the identification number of the node at the beginning or backward end of the line section. 1. ≤ N ≤ 999.
ENDING NODE	This number is the identification number of the node at the forward end of the line section. 1. ≤ N ≤ 999.
NUMBER OF LINE SEGMENTS	Enter the total number of line segments within the line section. 1. ≤ N ≤ Number of Line Segments in System
INITIAL AIRFLOW	Enter the airflow that exists in the line section at the beginning of the simulation. -10,000,000. ≤ X ≤ 10,000,000. cfm

11.10 Line Segments



Sect No	Start Node	End Node	# Line Segs	Initial Air Flow
98	74	80	1	0.
99	80	81	1	0.
100	81	82	1	0
101	82	89	1	0
105	75	83	1	0
106	83	84	1	0
150	118	119	1	0.
151	119	127	1	0
154	111	121	1	0.
155	121	123	1	0.
156	123	124	1	0.
157	124	125	1	0.
158	125	127	1	0.

The line segment data screen uses a tabbed format to enter line segment data. Only the tabs appropriate to the currently selected simulation options will be enabled. For example, if the Environmental Control Load option is 0, the EC Data tab will be disabled.

The segment numbers are automatically set to the line number for new segments. One or more of these must be changed when there is more than one segment in a section.

Edit Menu

CUT, COPY, PASTE	The standard Windows Cut, Copy and Paste functions are available when editing individual data fields or table cells. When the focus is on the Segment List, these functions apply to the entire segment. When in Browse mode in a table (SubSegments or Heat Loads), they apply to the entire row. (See below)
DELETE SEGMENT	Deletes the currently selected segment.
INSERT SEGMENT AFTER	Inserts a new segment after the currently selected segment in the same section.
INSERT SEGMENT BEFORE	Inserts a new segment before the currently selected segment in the same section.
SET AS DEFAULT	Sets the default segment used when inserting new segments, to the values in the current segment (including subsegments and heat loads).

Data Items

SEGMENT LIST	Used to enter or modify segment numbers and to select the segment to be modified. The left hand column is the line number and the right hand column is the segment number. The segment number is used to identify this particular line segment in subsequent references to it. Note that only the Segment Number may be changed here. Section Numbers may only be changed on the Line Section screen. 1. ≤ N ≤ 999. NOTE: Segment numbers are not currently checked for uniqueness.
IDENTIFICATION TITLE	Enter an alphanumeric character title (up to 36 characters) describing this line segment.

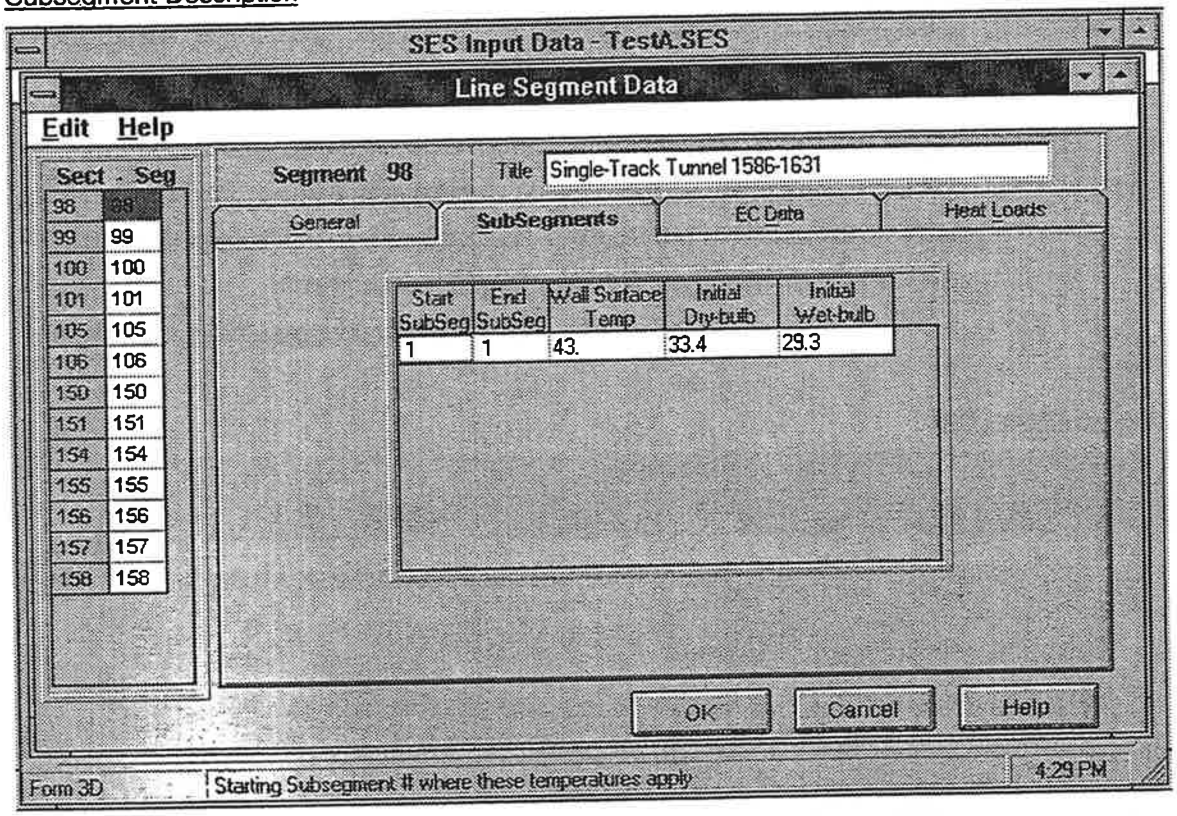
Segment Panel

LINE SEGMENT TYPE	Select the segment type from the list box 1 = Tunnel segment - Does not contain trackway exhaust system (TES) or an IFS. 2 = Station segment - Contains TES that captures prop/brkg and aux/pass heat. 3 = Station segment - Contains TES that captures prop/brkg heat only. 4 = Station segment - Contains TES that captures aux/pass heat only. 9 through 14 = Special tunnel segment - Contains an impulse fan system (IFS). Type No. 9 contains IFS type 1, type No. 10 contains IFS type 2, etc. 5 through 8, 15 and 16 = Reserved for future use. If entered, treated as a type 1. 1 ≤ N ≤ 16.
LENGTH	Enter the length of the line segment. 10. ≤ X ≤ 100,000. ft

CROSS SECTION AREA	Enter the area of the line segment cross-section. $75. \le X \le 10,000.$ ft^2
STACK HEIGHT	Enter the difference in elevation between the forward and backward ends of the line segment. This value should only be input if the Fire Simulation Option is selected. $\lvert X \rvert \le$ Length of line segment, ft
WETTED WALL SURFACE	The percent of wall surface that is constantly wet in the line segment. $0. \le X \le 100.$ percent
FIRE SEGMENT	Check this box if fire related calculations are to be performed for this segment.
SEGMENT PERIMETERS	The physical perimeter of a line segment may be entered in from one to eight portions, each of which will correspond to a roughness length. The total length of the perimeters must add up to the physical perimeter of the line segment. For each perimeter length supplied, a roughness length must be supplied. Based on these input data, a perimeter weighted average Darcy-Weisbach effective friction factor will be computed internally. The purpose of this procedure is to allow the program user to provide different roughnesses for the tunnel sides, ceiling, trackbed, etc. $30. \le X \le 1000.$ ft The total perimeter must be greater than $(4\pi \text{ x Segment Area})^{0.5}$
ROUGHNESS LENGTHS	Roughness length or, in the case of a ribbed tunnel, equivalent roughness length. $0. \le X \le 2.0$ ft
HEAD LOSS COEFFICIENTS	Pressure losses due to flow turning, abrupt expansions or contractions in segment cross section areas, and obstructions in the flow, etc., are expressed as linear functions of the pertinent velocity heads of the moving air by the use of coefficients that are constants for a given geometry. These coefficients are known as head loss or "minor" loss coefficients. They are used herein to describe the losses at the portals and intersections with other segments. Note that positive flow refers to flow from the section start node toward the section end node. The Forward Limit is at the end toward the end node and the Back Limit at the end toward the start node. $0. \le X \le 1000.$

The FIRE button provides access to the Fire screen to enter fire data. The Segment screen is not closed and when the Fire screen is closed, the program returns to the segment screen.

Subsegment Description



Segment 98

Title: Single-Track Tunnel 1586-1631

Sect	Seg
98	98
99	99
100	100
101	101
105	105
106	106
150	150
151	151
154	154
155	155
156	156
157	157
158	158

Start SubSeg	End SubSeg	Wall Surface Temp	Initial Dry-bulb	Initial Wet-bulb
1	1	43.	33.4	29.3

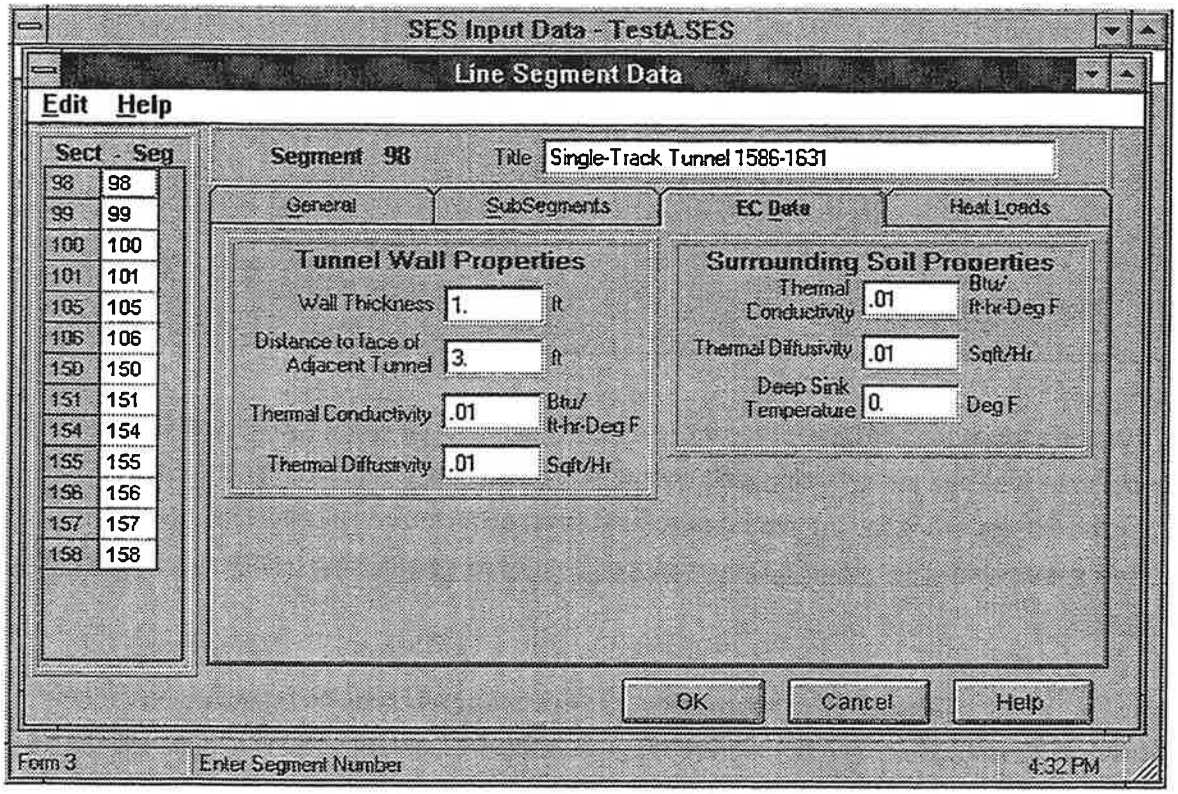
Starting Subsegment # where these temperatures apply

The wall surface temperature and initial air temperature must be specified for each subsegment. One or more rows may be used providing the first starting subsegment is number one, the ending subsegment on the last row is the highest subsegment in the segment, and all of the intermediate subsegments are defined. The highest subsegment on the last row defines the number of subsegments in the segment.

STARTING SUBSEGMENT NUMBER	This is the first subsegment in which the initial conditions specified below are valid. The starting and ending subsegment numbers locate the positioning within the line segment for which the initial conditions are valid. 1. ≤ N ≤ Number of subsegments in this segment
ENDING SUBSEGMENT NUMBER	This is the last subsegment in which the initial conditions specified below are valid. The starting and ending subsegment numbers locate the positioning within the line segment for which the initial conditions are valid. Starting subsegment number ≤ N ≤ Number of subsegments in this line segment
WALL SURFACE TEMPERATURE	Used in the computation of convective heat transfer between the system air and the walls. 0. ≤ X ≤ 130. °F

INITIAL DRY-BULB AIR TEMPERATURE	Initial value for the dry-bulb temperature in the segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. 0. ≤ X ≤ 130. °F
INITIAL WET-BULB AIR TEMPERATURE	Initial value for the wet-bulb temperature in the segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. Both the initial dry-bulb and wet-bulb temperatures are assumed to be homogeneous over the length of segment. 0. ≤ X ≤ Initial dry-bulb air temperature, °F

Environmental Control Data



Segment 98

Title: Single-Track Tunnel 1586-1631

Sect	Seg
98	98
99	99
100	100
101	101
105	105
106	106
150	150
151	151
154	154
155	155
156	156
157	157
158	158

Tunnel Wall Properties

Wall Thickness: 1. ft

Distance to face of Adjacent Tunnel: 3. ft

Thermal Conductivity: .01 Btu/ft-hr-Deg F

Thermal Diffusivity: .01 Sqft/Hr

Surrounding Soil Properties

Thermal Conductivity: .01 Btu/ft-hr-Deg F

Thermal Diffusivity: .01 Sqft/Hr

Deep Sink Temperature: 0. Deg F

Form 3 | Enter Segment Number | 4:32 PM

This tab is only enabled if the Environmental Control Load Evaluation Option is equal to 1 or 2.

Tunnel Wall Properties:

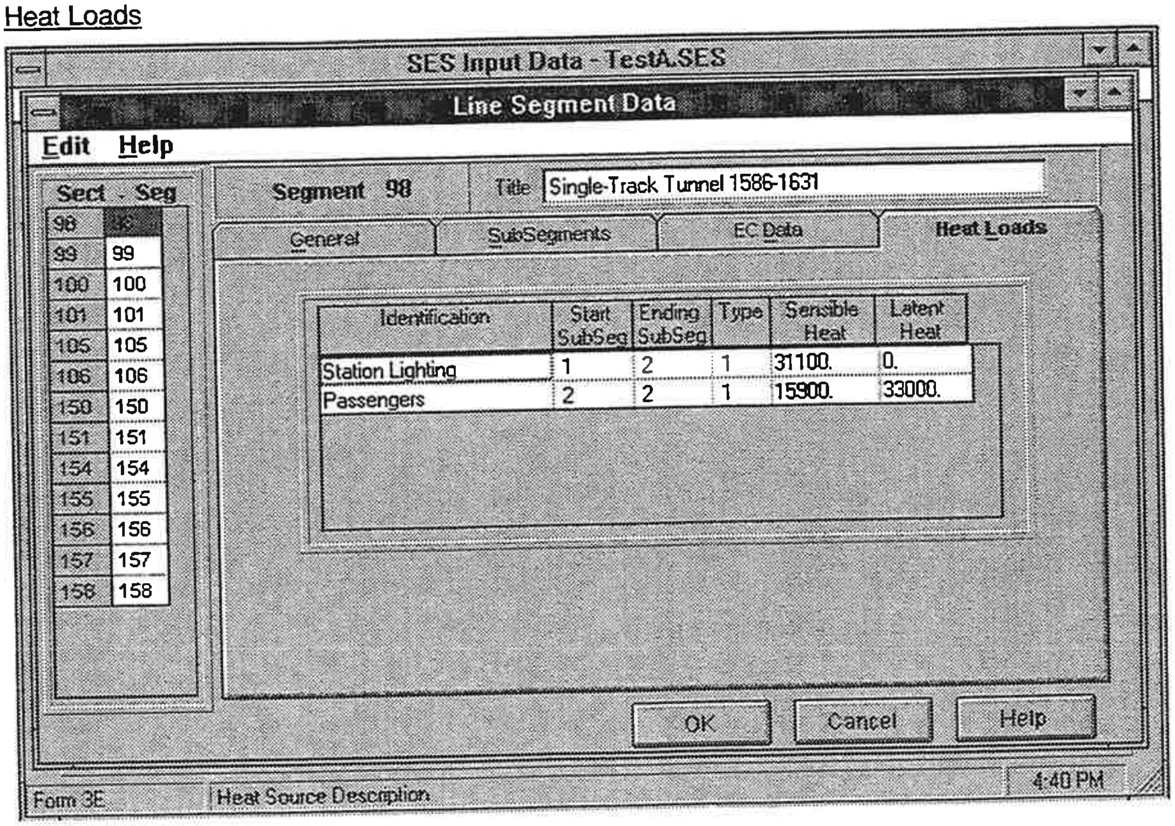
WALL THICKNESS	Enter the thickness of the tunnel wall in the line segment. 0. ≤ X ≤ 30. ft
DISTANCE TO FACE OF ADJACENT TUNNELS	Enter the minimum distance between the inside wall surfaces of this line segment and that of any adjacent tunnel. Enter a zero if there is no adjacent tunnel. 0. ≤ X ≤ 100. ft

THERMAL CONDUCTIVITY	Enter the thermal conductivity of the tunnel wall for the line segment. $0.005 \leq X \leq 2.$ Btu/ft-hr-°F
THERMAL DIFFUSIVITY	Enter the thermal diffusivity of the tunnel wall for the line segment. $0.005 \leq X \leq 1.$ ft^2/hr

Surrounding Soil Properties:

THERMAL CONDUCTIVITY	Enter the thermal conductivity of the soil surrounding the line segment. $0.005 \leq X \leq 2.$ Btu/ft-hr-°F
THERMAL DIFFUSIVITY	Enter the thermal diffusivity of the soil surrounding the line segment. $0.005 \leq X \leq 1.$ ft^2/hr
DEEP SINK TEMPERATURE	Enter the deep sink temperature of the soil surrounding the line segment. $0. \leq X \leq 100.$ °F

Heat Loads



Segment 98

Title Single-Track Tunnel 1586-1631

Sect	Seg
98	98
99	99
100	100
101	101
105	105
106	106
150	150
151	151
154	154
155	155
156	156
157	157
158	158

Identification	Start SubSeg	Ending SubSeg	Type	Sensible Heat	Latent Heat
Station Lighting	1	2	1	31100.	0.
Passengers	2	2	1	15900.	33000.

Form 3E

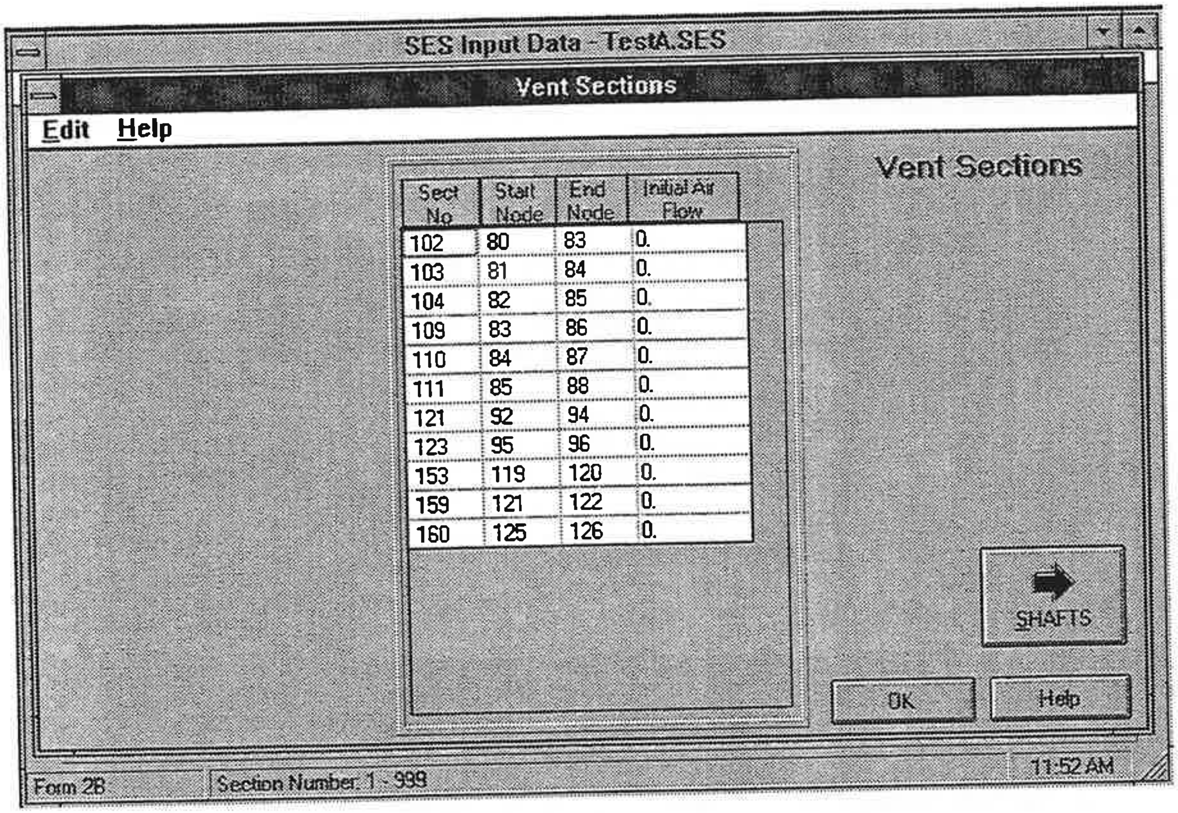
Heat Source Description

4:40 PM

Describe each steady-state heat source (if any) in this line segment:

Identification	Up to 30 alphanumeric characters can be used as an identification of the heat source or sink which is printed on the program input verification.
Starting Subsegment Number	This is the first subsegment in which this steady-state heat source is found. The starting and ending subsegment numbers indicate the region over which the entire source is uniformly distributed. 1. ≤ N ≤ Number of subsegments in this segment
Ending Subsegment Number	This is the last subsegment in which this steady-state heat source is found. Starting subsegment number ≤ N ≤ Number of subsegments in this segment
Source Type	Enter the source type: 1. = miscellaneous heat source 2. = heating or cooling source
Sensible Heat Rate	The rate of sensible heat addition or removal in Btu/hr corresponding to the named source. Heat removal is signified by a negative rate.
Latent Heat Rate	The rate of latent heat addition or removal in Btu/hr corresponding to the named source. Heat removal is signified by a negative rate.

11.11 Vent Sections



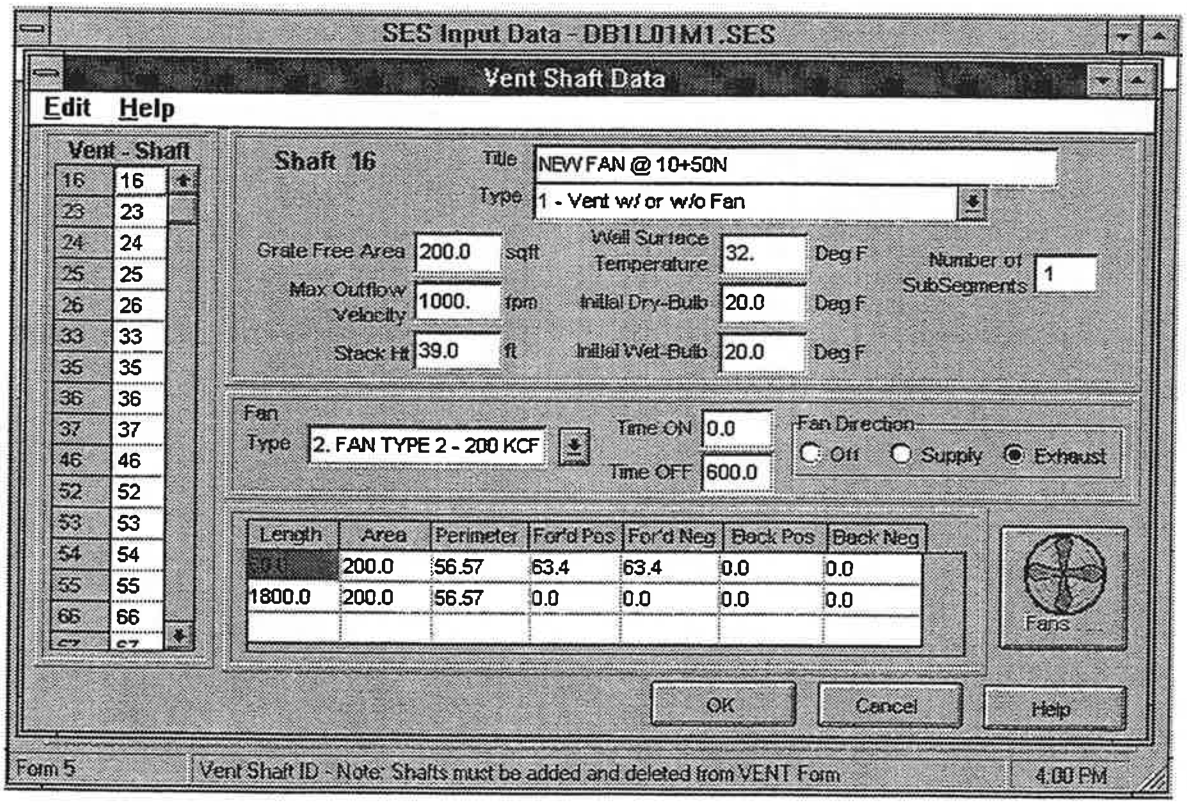
Sect No	Start Node	End Node	Initial Air Flow
102	80	83	0.
103	81	84	0.
104	82	85	0.
109	83	86	0.
110	84	87	0.
111	85	88	0.
121	92	94	0.
123	95	96	0.
153	119	120	0.
159	121	122	0.
160	125	126	0.

Data entry for vent sections is essentially identical to that for line sections except that the number of segments is not required since there is only one vent shaft per vent section. The SHAFTS button opens the Vent Shafts screen with the shaft for the currently selected vent section selected and displayed.

Data Fields

SECTION IDENTIFICATION NUMBER	This number identifies the tunnel section being described. 1. ≤ N ≤ 999.
STARTING NODE NUMBER	This number is the identification number of the node at the beginning or backward end of the line section. 1. ≤ N ≤ 999.
ENDING NODE NUMBER	This number is the identification number of the node at the forward end of the line section. 1. ≤ N ≤ 999.
INITIAL AIRFLOW	Enter the airflow that exists in the line section at the beginning of the simulation. -10,000,000. ≤ X ≤ 10,000,000. cfm

11.12 Vent Shafts



Vent	Shaft
16	16
23	23
24	24
25	25
26	26
33	33
35	35
36	36
37	37
46	46
52	52
53	53
54	54
55	55
66	66

Shaft 16

Title NEW FAN @ 10+50N

Type 1 - Vent w/ or w/o Fan

Grate Free Area 200.0 sqft

Max Outflow Velocity 1000. fpm

Stack Ht 39.0 ft

Wall Surface Temperature 32. Deg F

Initial Dry-Bulb 20.0 Deg F

Initial Wet-Bulb 20.0 Deg F

Number of SubSegments 1

Fan Type 2. FAN TYPE 2 - 200 KCF

Time ON 0.0

Time OFF 600.0

Fan Direction ○ Off ○ Supply ● Exhaust

Length	Area	Perimeter	For'd Pos	For'd Neg	Back Pos	Back Neg
[illegible]	200.0	56.57	63.4	63.4	0.0	0.0
1800.0	200.0	56.57	0.0	0.0	0.0	0.0

Form 5 Vent Shaft ID - Note: Shafts must be added and deleted from VENT Form 4:00 PM

The Vent Shaft data entry is very similar to that for line segments. The Shaft List is used to enter and modify shaft numbers and to select the shaft to be displayed. Since there is only one shaft per section, shafts may not be entered or deleted on this screen. Vent sections must be added and deleted on the Vent Section Screen.

SHAFT NUMBER LIST	The number by which this vent shaft is identified. This number may not be used to identify any other line segment or ventilation shaft. The same number as the Vent Section is assigned for new shafts but may be changed as necessary. 1. ≤ N ≤ 999.
TITLE	This will identify the ventilation shaft, and may be used to indicate its proximity to physical landmarks. The alphanumeric information entered will be printed out during data input verification and on the output forms. Up to 36 characters may be used.

Type	Select the ventilation shaft type from the list box: 1 - ventilation shaft or blast shaft (may or may not contain a fan) 2 - stairway or escalator 1. ≤ N ≤ 2.
Grate Free Area	This area corresponds to the total free area open to airflow of the vent shaft grating. 3. ≤ X ≤ 3000. ft^2
Maximum Outflow Velocity	This number corresponds to the design maximum outflow air velocity at the vent shaft grating. 0. ≤ X ≤ 6000. fpm
Stack Height	This number corresponds to the difference in height between the node at the tunnel/vent shaft junction and the node at the surface of the vent shaft where the vent discharges to the atmosphere. The stack height should not be greater than the sum of the lengths of the individual segments in this shaft (see Segment Data below). Enter a zero if buoyancy effects within the shaft are negligible. 0. ≤ X ≤ 1000. ft
Wall Surface Temperature	Since heat transfer is computed across ventilation shaft walls, the program must be supplied with a value for the wall surface temperature. 0. ≤ X ≤ 130. °F
Initial Dry-Bulb Temperature	Initial value for the dry-bulb temperature in the ventilation shaft segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. 0. ≤ X ≤ 130. °F
Initial Wet-Bulb Temperature	Initial value for the wet-bulb temperature in the ventilation shaft segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. 0. ≤ X ≤ Initial air dry-bulb temp. °F
Number Of Subsegments	This number corresponds to the total number of subsegments the user desires to have in the equivalent straight-through vent shaft calculated by the SES. 1. ≤ N ≤ 1600.

If this is a fan shaft, enter the data for the fan to be simulated. It is helpful to enter the fans in all fan shafts, whether or not they will be used in a particular simulation, and then use the Fan Table to control fan operation for a given simulation.

Fan Type

Select the fan type being used in this fan shaft in this particular simulation from the list. If the fan has not yet been defined, you may use the FAN button to go to the fan entry screen and enter the fan data or you may type in the number of the fan and enter fan data later.

0. ≤ N ≤ Number of fan types

Time On

This entry allows the user to define the operating period of the fan. Enter the time in the simulation the fan switches on. X ≥ 0. sec

Time Off

This entry allows the user to define the operating period of the fan. Enter the time in the simulation the fan switches off.

Time fan switches on ≤ X

Fan Direction

Enter the direction of fan operation or 0. if the fan is off (not used in this simulation).

<u>Shaft open to atmosphere:</u>

+1. - outflow (exhaust) direction
-1. - inflow (supply) direction

<u>Cross passage shaft Not directly open to atmosphere:</u>

+1. - fan operates in the direction of positive airflow in the shaft
-1. - fan operates in the direction of negative airflow in the shaft

Segment Descriptions - Enter a separate row for each unique segment of the shaft.

Length

Enter the length of the ventilation shaft segment 0. ≤ X ≤ 2000. ft

10. ≤ Total length of all segments in vent shaft ≤ 2000. ft

Area

Enter the cross-sectional area of the ventilation shaft segment. The area of the first segment is used as the equivalent vent shaft area, and all velocities in the vent shaft are given with respect to this area.

3. ≤ X ≤ 3000. ft^2

Perimeter

Enter the perimeter of the ventilation shaft segment.

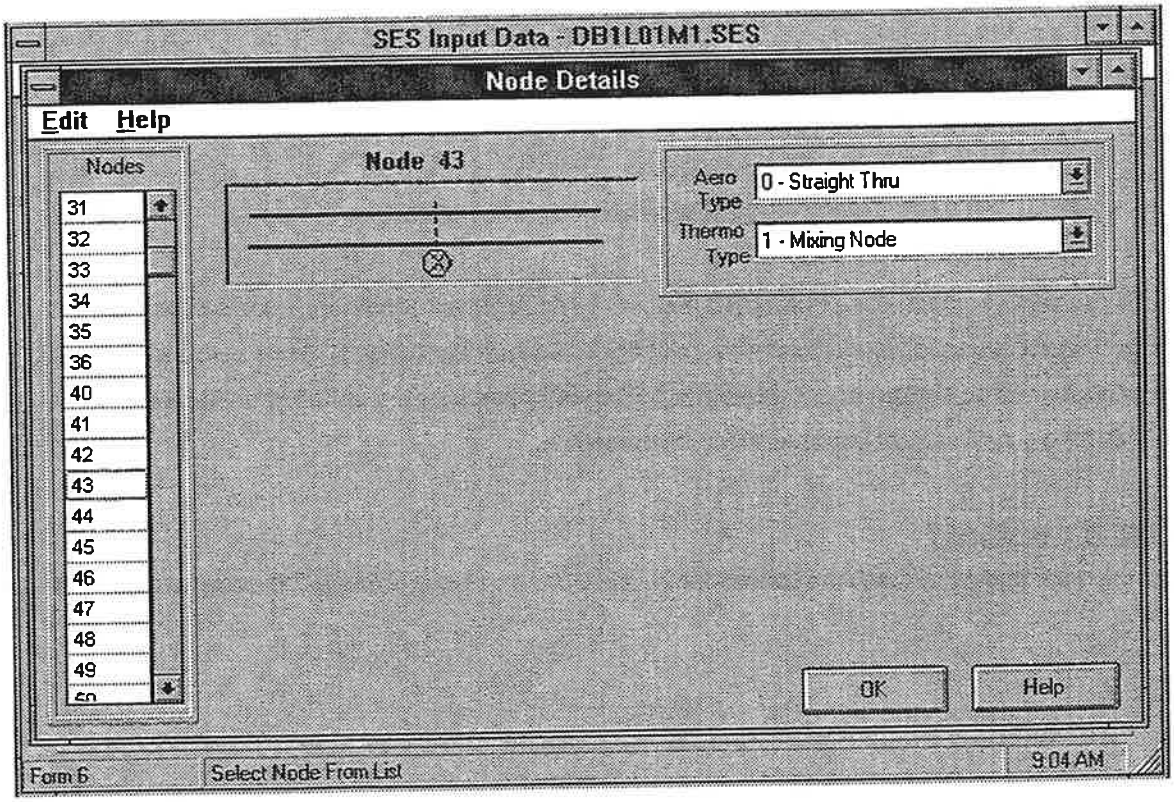
5. ≤ X ≤ 500. ft

Segment Head Loss Coefficients

Pressure losses due to flow turning, abrupt expansions or contractions in ventilation shaft cross-section areas, and obstructions in the flow, etc., are expressed as linear functions of the pertinent velocity heads of the moving air by the use of coefficients that are constants for a given geometry. These coefficients are known as head loss or minor loss coefficients. They are used herein to describe the losses in the shafts and their junctions with line segments. Each of the head loss coefficients are entered with reference to the area of the segment with which they are entered.

$0. \leq X \leq 1000.$

11.13 Nodes



Aero Type: 0 - Straight Thru

Thermo Type: 1 - Mixing Node

Node data must be entered for each node in the system. The particular data required is dependent on the node Aerodynamic and Thermodynamic types. Nodes may be entered, inserted, deleted, cut, copied and pasted in the Node List using the Edit menu or the standard shortcut keys. The default node used for new nodes (added at the end) and for inserted nodes may also be defined based upon an existing node.

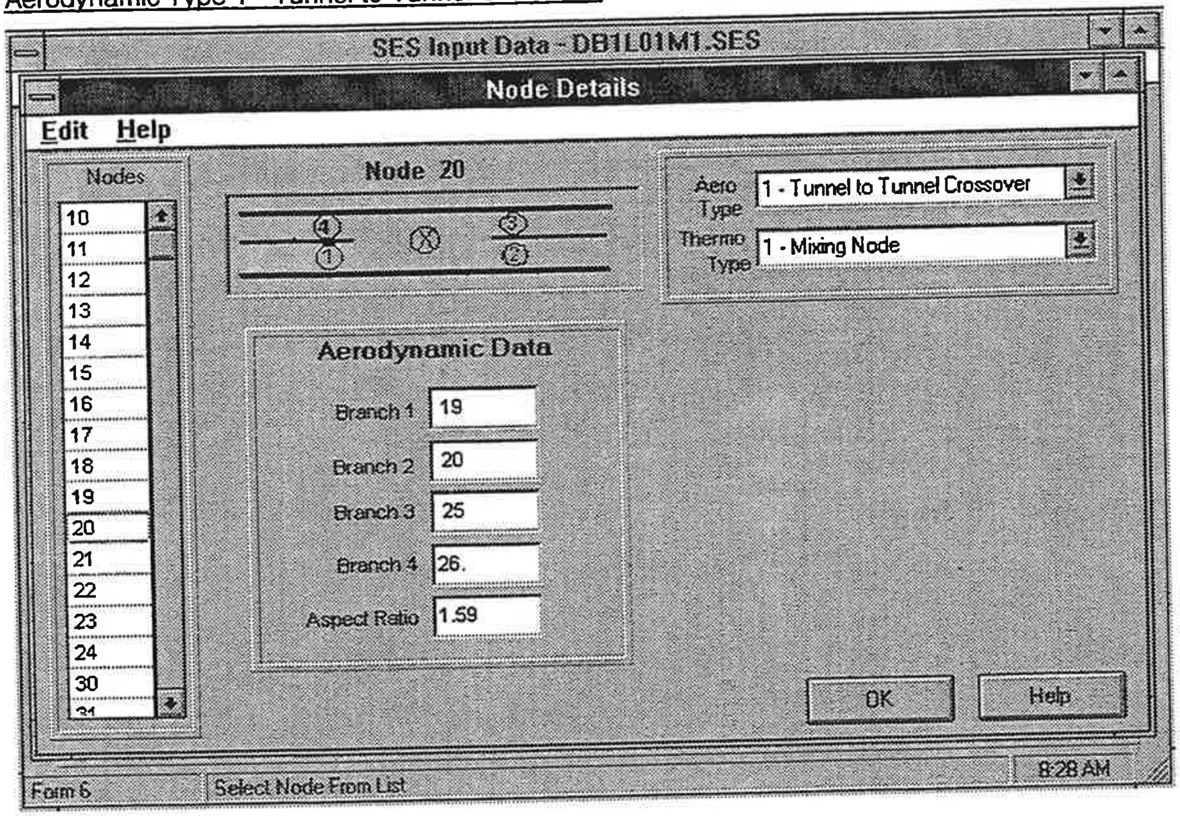
Nodes	Enter the identifying number of the node.	1. ≤ N ≤ 999.
Aerodynamic Type	Select the node aerodynamic type from the list: 0 - straight-through junction or portal 1 - tunnel to tunnel crossover junction 2 - dividing wall termination junction 3 - "T" junction 4 - angled junction 5 - "Y" junction 7 - zero total pressure change junction	
Thermodynamic Type	Select the node thermodynamic type from the list: 1 - mixing node 2 - partial-mixing node 3 - temperature/humidity boundary condition	

Only certain combinations of aerodynamic and thermodynamic node types are permitted. Specifically, Thermodynamic type 3 can only be used with Aerodynamic type 0 (for a portral, vent shaft, station entry/exit or other system boundaries) and Thermodynamic type 2 can only be used with Aerodynamic type 1 or 7 since it requires 4 or 5 branches.

Aerodynamic Types 0 and 7

These aerodynamic types require no special input when used as Mixing Nodes (Thermodynamic Type 1).

Aerodynamic Type 1 - Tunnel to Tunnel Crossover



Node 20

Aero Type: 1 - Tunnel to Tunnel Crossover

Thermo Type: 1 - Mixing Node

Aerodynamic Data

Branch 1: 19

Branch 2: 20

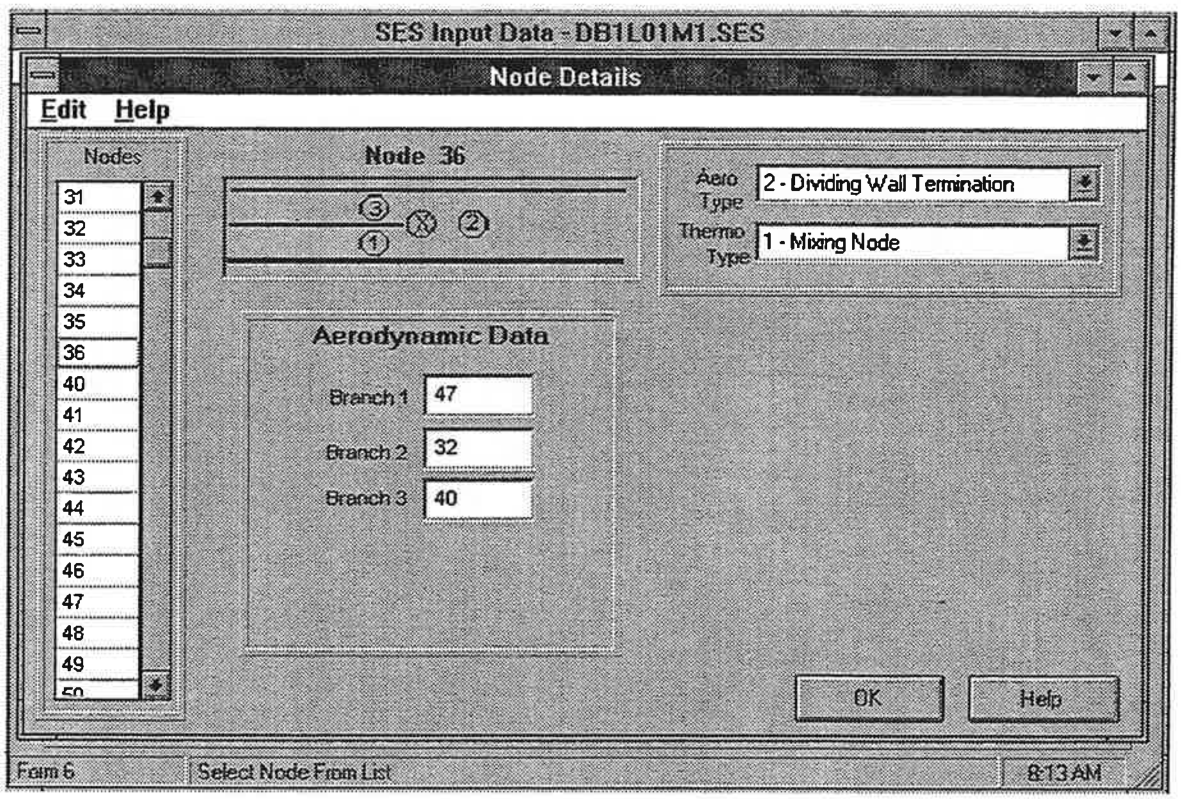
Branch 3: 25

Branch 4: 26.

Aspect Ratio: 1.59

Branch 1 Branch 2 Branch 3 Branch 4	Enter the section identification number of the sections that constitutes Branches 1 through 4 for this node as shown in the diagram. must be a valid Section ID number
Aspect Ratio	Enter the ratio of the length of the crossover opening to twice the height of the tunnel (L/2H). $0.1 \le X \le 50$.

Aerodynamic Type 2 - Dividing Wall Terminator



Node 36

Aero Type: 2 - Dividing Wall Termination

Thermo Type: 1 - Mixing Node

Branch 1: 47

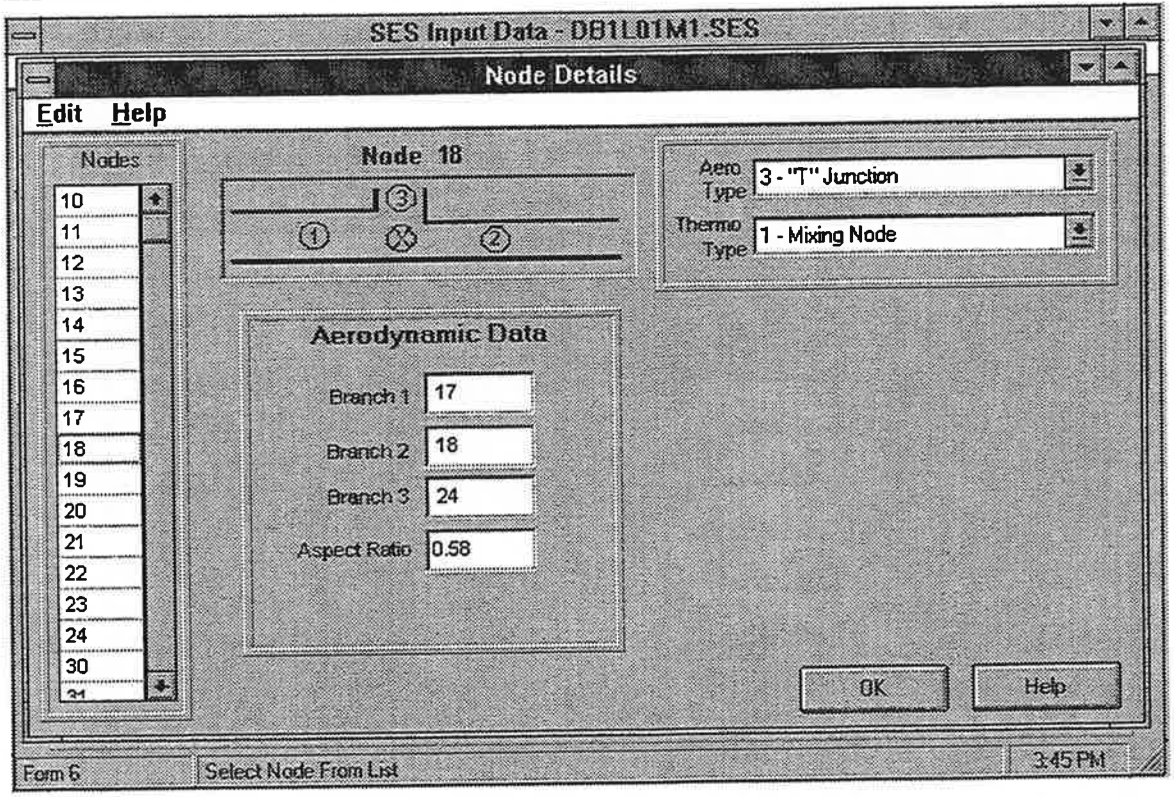
Branch 2: 32

Branch 3: 40

BRANCH 1	Enter the section identification number of the sections that constitutes Branches 1 through 3 for this node as shown in the diagram.
BRANCH 2	
BRANCH 3	

must be a valid Section ID number

Aerodynamic Type 3 - "T" Junction



Node 18

Aero Type: 3 - "T" Junction

Thermo Type: 1 - Mixing Node

Aerodynamic Data

Branch 1: 17

Branch 2: 18

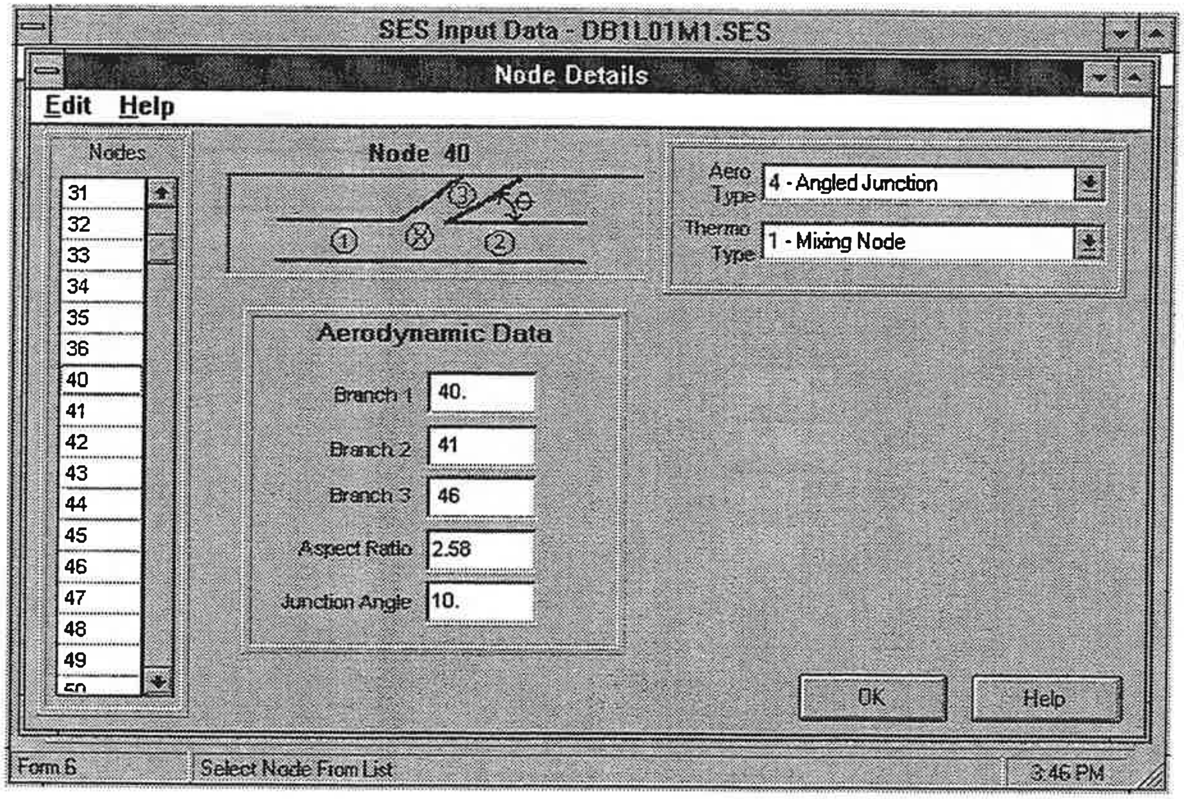
Branch 3: 24

Aspect Ratio: 0.58

Form 6 | Select Node From List | 3:45 PM

Branch 1 Branch 2 Branch 3	Enter the section identification number of the sections that constitutes Branches 1 through 3 for this node as shown in the diagram. must be a valid Section ID number
Aspect Ratio	Enter the ratio of the axial length of the vent shaft along the tunnel to the vent shaft width at the vent opening to the tunnel (L/W). $0.1 \le X \le 30.$

Aerodynamic Type 4 - Angled Junction



Node 40

Aero Type: 4 - Angled Junction

Thermo Type: 1 - Mixing Node

Aerodynamic Data

Branch 1: 40.

Branch 2: 41

Branch 3: 46

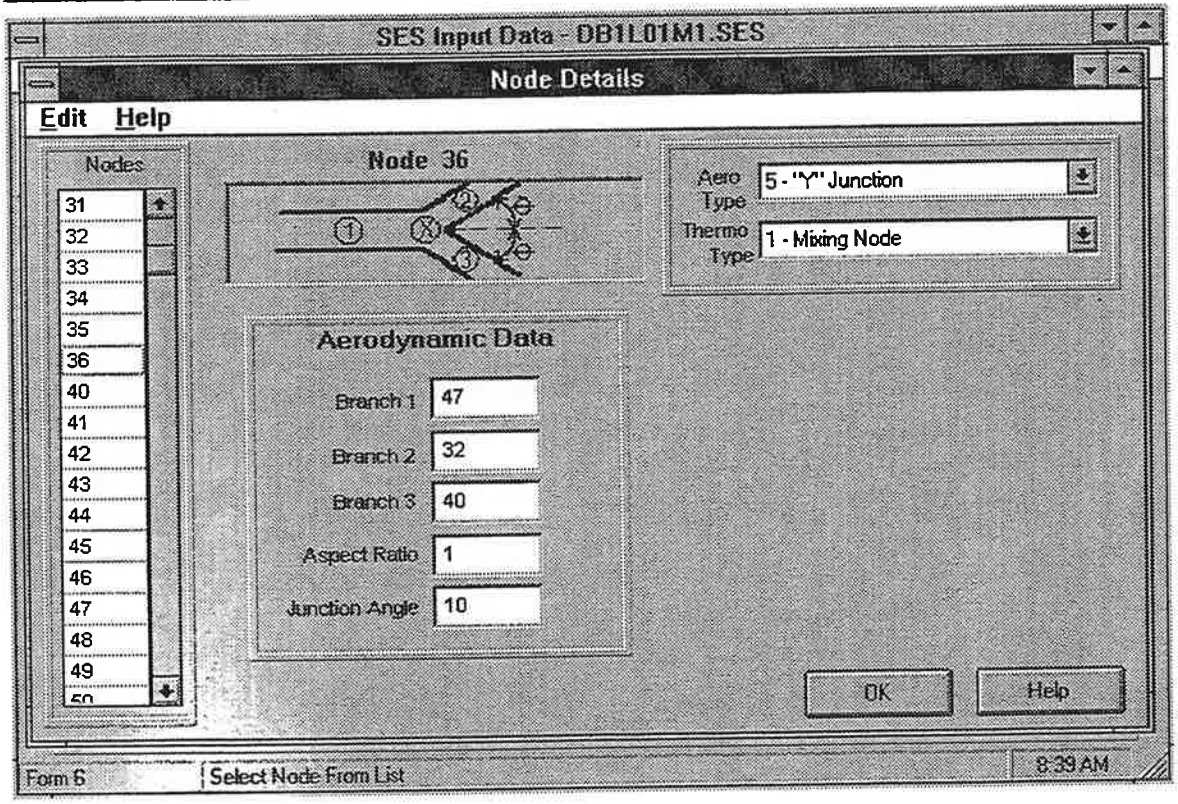
Aspect Ratio: 2.58

Junction Angle: 10.

Form 6 | Select Node From List | 3:46 PM

BRANCH 1 BRANCH 2 BRANCH 3	Enter the section identification number of the sections that constitutes Branches 1 through 3 for this node as shown in the diagram. must be a valid Section ID number
ASPECT RATIO	Enter the ratio of the axial length of the angled tunnel opening to its height. 0.1 ≤ X ≤ 30.
JUNCTION ANGLE θ	Enter the angle between Branch 2 and Branch 3. This angle may only be entered as either 10, 20, or 30 degrees.

Aerodynamic Type 5



SES Input Data - DB1L01M1.SES

Node Details

Node 36

Aero Type: 5 - "Y" Junction

Thermo Type: 1 - Mixing Node

Aerodynamic Data

Branch 1: 47

Branch 2: 32

Branch 3: 40

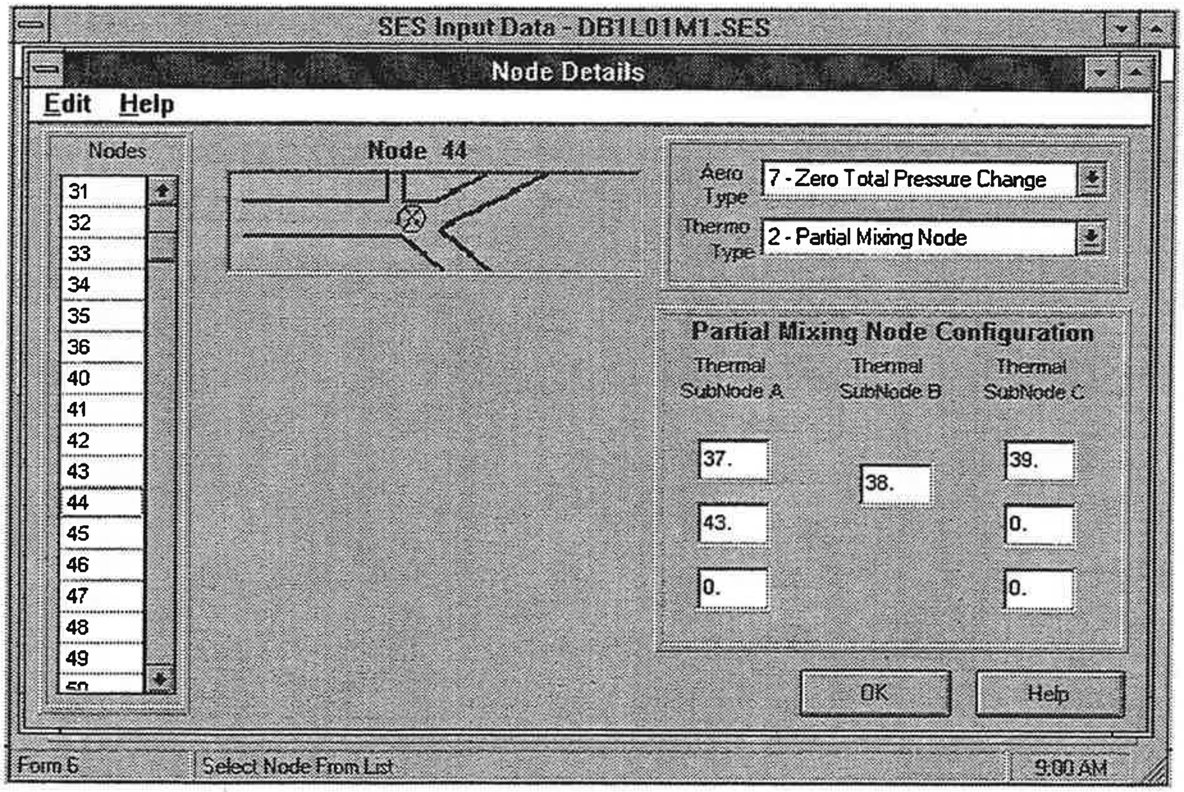
Aspect Ratio: 1

Junction Angle: 10

Form 6 | Select Node From List | 8:39 AM

BRANCH 1 BRANCH 2 BRANCH 3	Enter the section identification number of the sections that constitutes Branches 1 through 3 for this node as shown in the diagram. must be a valid Section ID number
ASPECT RATIO	Enter the ratio of the axial length of the angled tunnel opening to its height. $0.1 \leq X \leq 30.$
JUNCTION ANGLE θ	Enter <u>1/2</u> the angle between Branch 2 and Branch 3. This angle may only be entered as either 10, 20, or 30 degrees.

Thermodynamic Type 2 - Partial Mixing Node



Node 44

Aero Type: 7 - Zero Total Pressure Change

Thermo Type: 2 - Partial Mixing Node

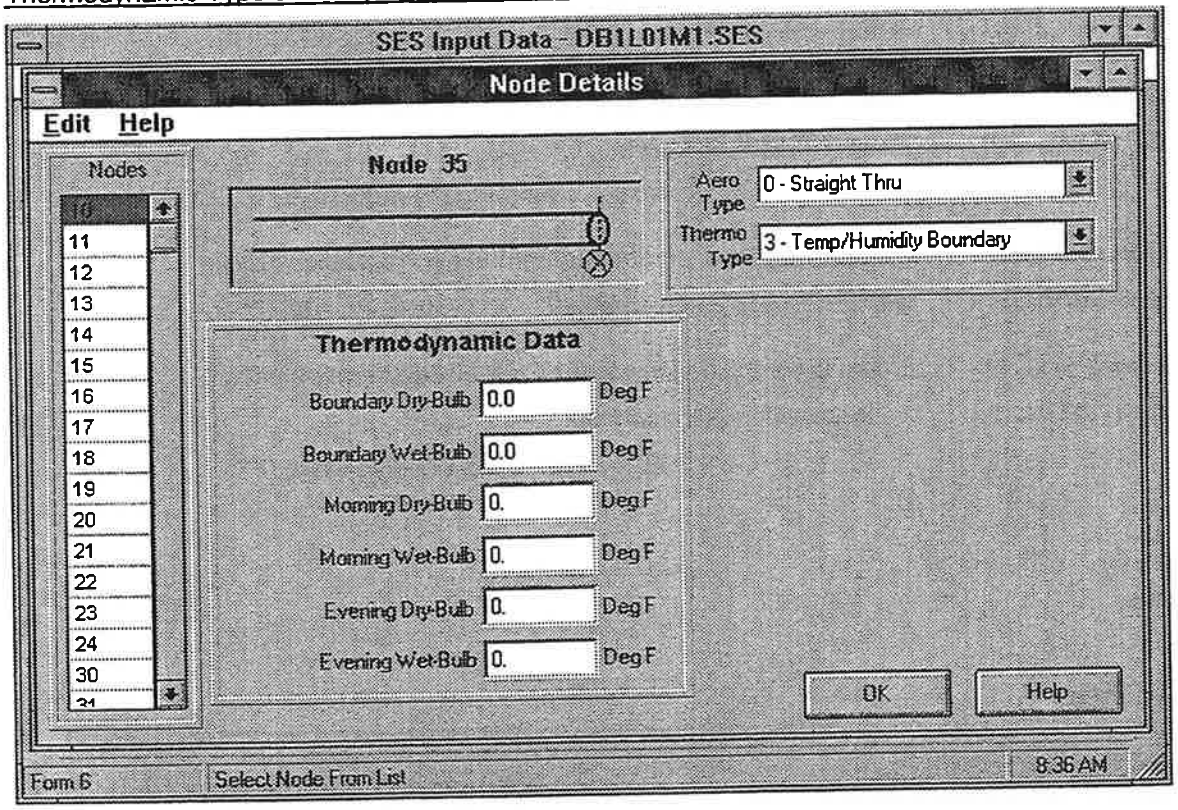
Partial Mixing Node Configuration

Thermal SubNode A	Thermal SubNode B	Thermal SubNode C
37.	38.	39.
43.		0.
0.		0.

Thermodynamic Type 2 may only be used with Aerodynamic Types 1 or 7. See the SESDH for a more detailed description of Partial Mixing Nodes.

THERMAL SUBNODE "A"	Enter the identification numbers of the sections connected to the thermal subnode "A".
THERMAL SUBNODE "B"	Enter the identification numbers of the section connected to the thermal subnode "B".
THERMAL SUBNODE "C"	Enter the identification numbers of the sections connected to the thermal subnode "C".

Thermodynamic Type 3 - Temperature/Humidity Boundary Nodes



Node 35

Aero Type: 0 - Straight Thru

Thermo Type: 3 - Temp/Humidity Boundary

Thermodynamic Data

Boundary Dry-Bulb: 0.0 Deg F
Boundary Wet-Bulb: 0.0 Deg F
Morning Dry-Bulb: 0. Deg F
Morning Wet-Bulb: 0. Deg F
Evening Dry-Bulb: 0. Deg F
Evening Wet-Bulb: 0. Deg F

This data is requested for boundary nodes only. Thermodynamic Type 3 is only permitted with aerodynamic node Type 0.

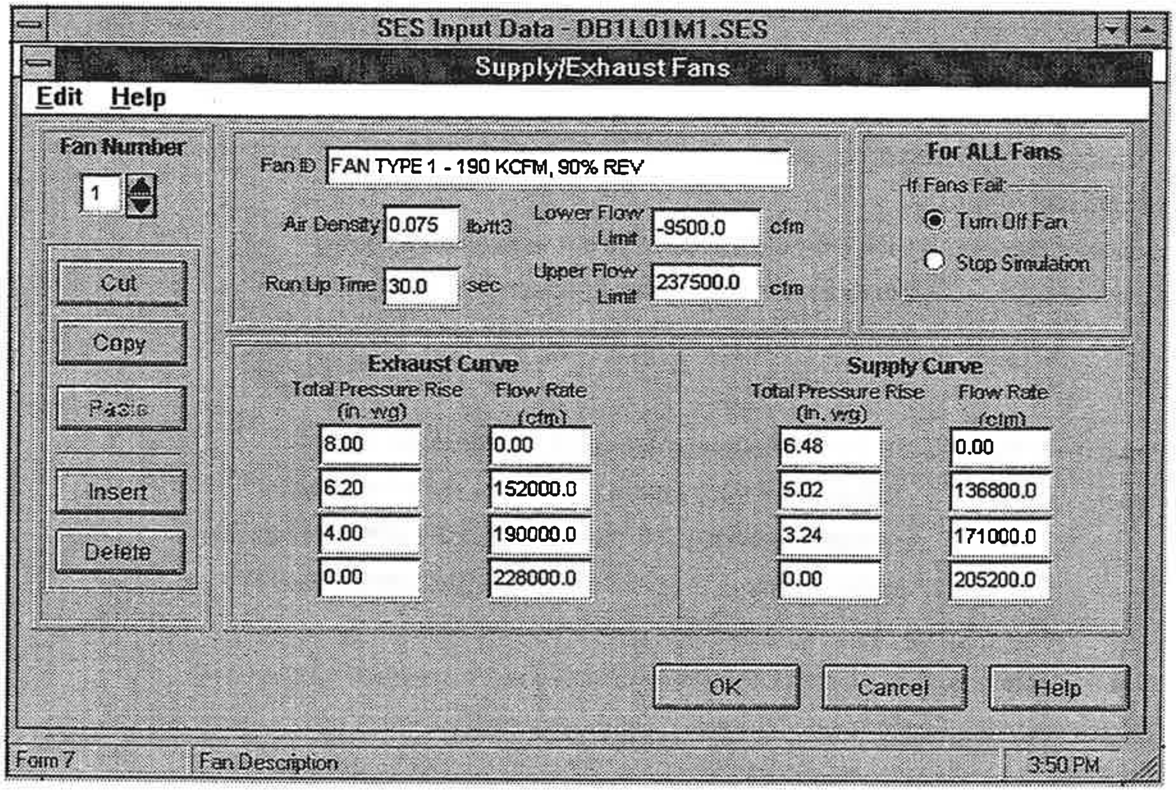
BOUNDARY DRY-BULB	If the dry-bulb temperature at this boundary node is different from the ambient condition, enter the dry-bulb temperature here. If it is the same as the ambient condition, enter zero (0). -50. ≤ X ≤ 140. °F
BOUNDARY WET-BULB	If the wet-bulb temperature at this boundary node is different from the ambient condition, enter the wet-bulb temperature here. If it is the same as the ambient condition, enter zero (0). -50. ≤ X ≤ Dry-bulb temperature °F

The next four entries are also for Thermodynamic Type 3 nodes only, but are only requested when the Environmental Control Load Evaluation Option is 1 or 2. If the morning and evening dry-bulb and wet-bulb temperature conditions are different from the corresponding ambient conditions entered on the General Data screen, enter all four conditions below. If the conditions are the same as the ambient conditions, enter zeros.

MORNING DRY-BULB	Enter the dry-bulb temperature for the node corresponding to the morning rush hour. -50. ≤ X ≤ 140. °F
MORNING WET-BULB	Enter the wet-bulb temperature for the node corresponding to the morning rush hour. -50. ≤ X ≤ Morning dry-bulb temp. °F
EVENING OR OFF HOUR DRY-BULB	Enter the dry-bulb temperature for the node corresponding to the evening rush or off hour. -50. ≤ X ≤ 140. °F
EVENING OR OFF HOUR WET-BULB	Enter the wet-bulb temperature for the node corresponding to the evening rush or off hour. -50. ≤ X ≤ Evening dry-bulb temp. °F

11.14 Fans

Supply/ Exhaust



Fan Number: 1

Fan ID: FAN TYPE 1 - 190 KCFM, 90% REV

Air Density: 0.075 lb/ft3

Run Up Time: 30.0 sec

Lower Flow Limit: -9500.0 cfm

Upper Flow Limit: 237500.0 cfm

For ALL Fans

If Fans Fail

● Turn Off Fan

○ Stop Simulation

Exhaust Curve

Total Pressure Rise (in. wg)	Flow Rate (cfm)
8.00	0.00
6.20	152000.0
4.00	190000.0
0.00	228000.0

Supply Curve

Total Pressure Rise (in. wg)	Flow Rate (cfm)
6.48	0.00
5.02	136800.0
3.24	171000.0
0.00	205200.0

The Supply/Exhaust Fan data is accessed from the Main screen using either the Button Panel or the Data Menu and is displayed for one fan at a time. Use the spin buttons to select the desired fan.

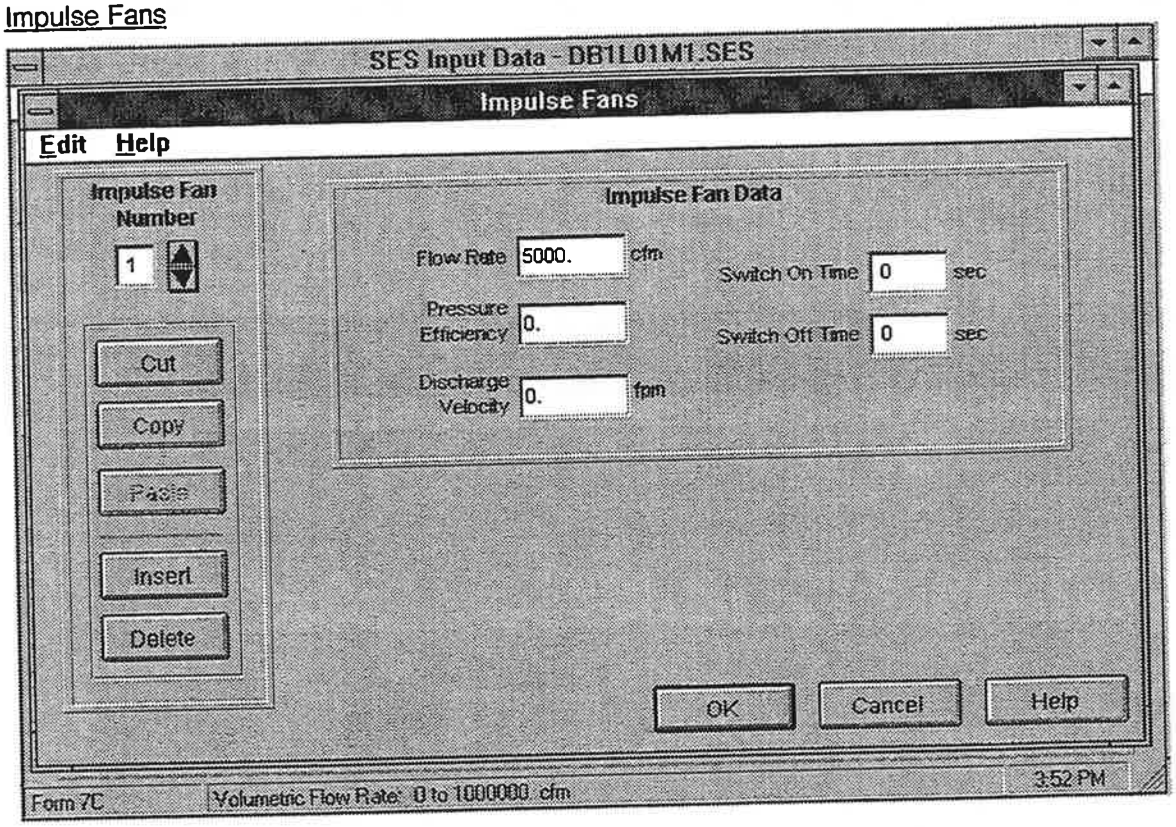
To add a new fan, use the spin button to select the blank fan and enter the data.

Use the Cut, Copy, Paste, Insert and Delete buttons to cut, copy, paste, insert and delete entire fans. Use the Edit menu entries or the standard shortcut keys to cut, copy and paste individual fields.

Fan Identification	Information identifying the fan being described will appear in the list of fan types on the Vent Shaft and Fan Table screens as well as on the input verification printout. Up to 36 alphanumeric characters can be used.
Air Density	Enter the air density for which the manufacturer determined the fan performance curve. The program will internally adjust the fan performance curve to adjust for the difference between this density and the system ambient density. $0.040 \leq X \leq 0.085$ lb/ft^3
Run-up Time	This number corresponds to the amount of time required for the fan to overcome the inertial effects of its blades and motor, in reaching its full operating speed, and in slowing down from full operating speed to stop. $0. \leq X \leq 300.$ sec
Fan Lower Flow Limit	Enter the minimum volume flowrate that may be obtained by this fan. If this fan falls below this limiting flowrate, the simulation will either turn off the fan or stop the simulation, depending on the Fan Failure Mode defined below. $-100{,}000. \leq X \leq 0.$ cfm
Fan Upper Flow Limit	Enter the maximum volume flowrate that may be obtained by this fan. If this fan exceeds this limiting flowrate the simulation will either turn off the fan or stop the simulation, depending on the Fan Failure Mode defined below. $1{,}000. \leq X \leq 2{,}000{,}000.$ cfm

FAN FAILURE MODE	This option (described in the Form 1 definitions as the Fan Stopping/Windmilling Option) determines the action taken by the program if <u>any</u> fan drops below the Lower Flow Limit or rises above the Upper Flow Limit described above. <u>Turn Fan Off</u> - the fan will shut off and the simulation will continue. <u>Stop Simulation</u> - the fan will shut off and the simulation will terminate immediately.
TOTAL PRESSURE RISE	This fan characteristic curve is described by the cubic polynomial curve fitting of four data points. The data is usually taken from manufacturer supplied fan curves. The data points entered should cover the range of fan volume flow rates from zero cfm to the point where the total pressure rise across the fan is 0 inches of water (in. wg). Also, the points entered should be about the same distance apart on the CFM scale. The program assumes all fans are bi-directional, operating on identical fan curves for both inflow and outflow unless the user supplies different fan curves for both directions. If the fan operates in the outflow (exhaust) direction only, all zeros may be entered for the curve data points specified for the inflow (supply) direction, and vice versa. Total pressure rise: -15. $\leq X \leq$ 50. in. wg Volume flowrate : 0. $\leq X \leq$ 2,000,000. cfm Note: If the Fire Simulation Option on the Options Screen is checked, fan curves and ventilation shaft pressure losses are adjusted due to temperature-related changes in air density.

Impulse Fans



Impulse Fan Number: 1

Flow Rate: 5000. cfm

Pressure Efficiency: 0.

Discharge Velocity: 0. fpm

Switch On Time: 0 sec

Switch Off Time: 0 sec

Form 7C | Volumetric Flow Rate: 0 to 1000000 cfm | 3:52 PM

Impulse fan data is handled similarly to the Supply/Exhaust fans. There is no button for impulse fans on the Button panel. The Impulse fan data is accessed only from the Data menu on the Main Screen and is displayed for one fan at a time. Use the spin buttons to select the desired fan.

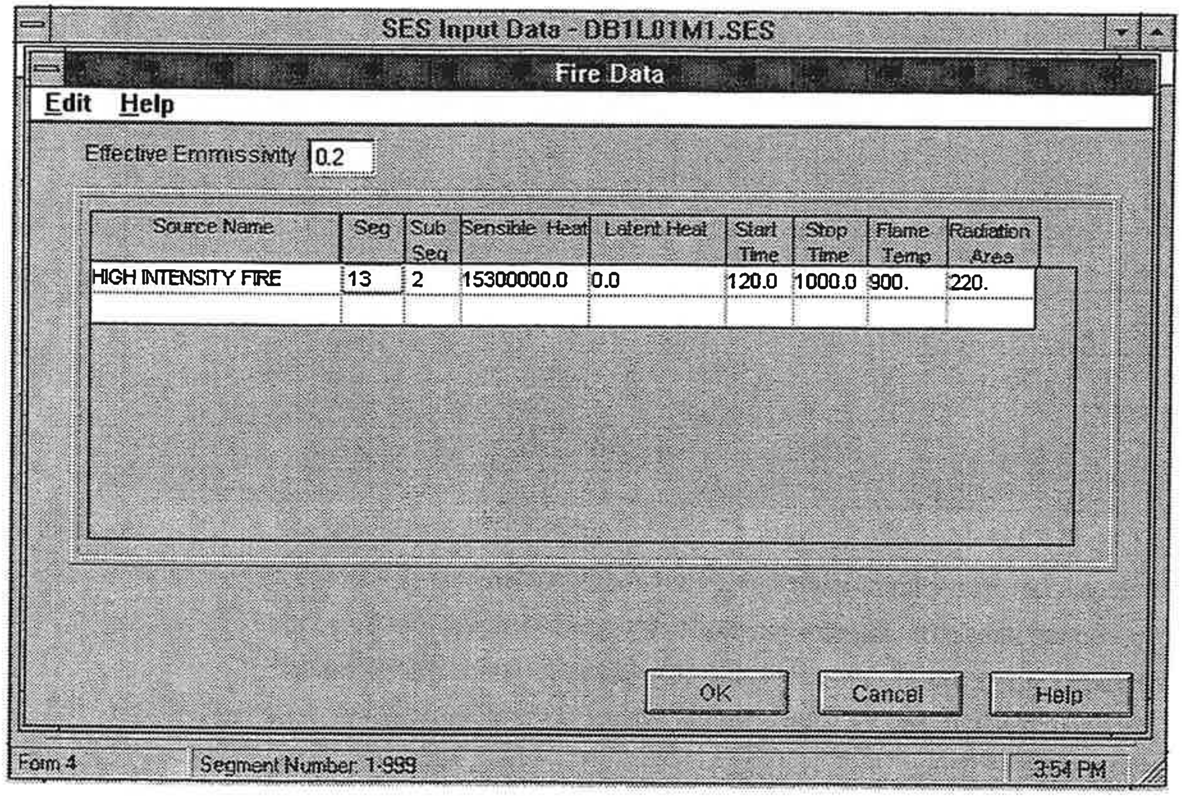
To add a new fan, use the spin button to select the blank fan and enter the data. Use the CUT, COPY, PASTE, INSERT and DELETE buttons to cut, copy, paste, insert and delete entire fans. Use the Edit menu entries or the standard shortcut keys to cut, copy and paste individual fields.

FLOW RATE	Enter the volumetric flow rate of the impulse fan. 0. ≤ X ≤ 1,000,000. cfm
PRESSURE EFFICIENCY	Enter the pressure efficiency of the impulse fan. This is the ratio of actual to theoretical pressure rise. 0.1 ≤ X ≤ 1.0
NOZZLE DISCHARGE VELOCITY	Enter the velocity of the impulse fan airflow at the discharge. -10,000. ≤ X ≤ 10,000. fpm
SWITCH ON TIME	This entry allows the user to define the operating period of the fan. Enter the time in the simulation that the fan switches on. 0. ≤ X ≤ 10,000. sec

SWITCH OFF TIME This entry allows the user to define the operating period of the fan. Enter the time in the simulation that the fan switches off.

Switch On Time ≤ X ≤ 10,000. sec

11.15 Fires



Effective Emmissivity 0.2

Source Name	Seg	Sub Seg	Sensible Heat	Latent Heat	Start Time	Stop Time	Flame Temp	Radiation Area
HIGH INTENSITY FIRE	13	2	15300000.0	0.0	120.0	1000.0	900.	220.

Form 4

Segment Number: 1-999

3:54 PM

EFFECTIVE EMISSIVITY Enter the effective emissivity of the combustion products downstream of the fire site. Applies to all fire sources. (Form 1G)

0. ≤ X ≤ 1.

Enter the data describing the fire heat source (previously referred to as unsteady heat source) in the table. Multiple fire heat sources, if used, are entered in separate rows.

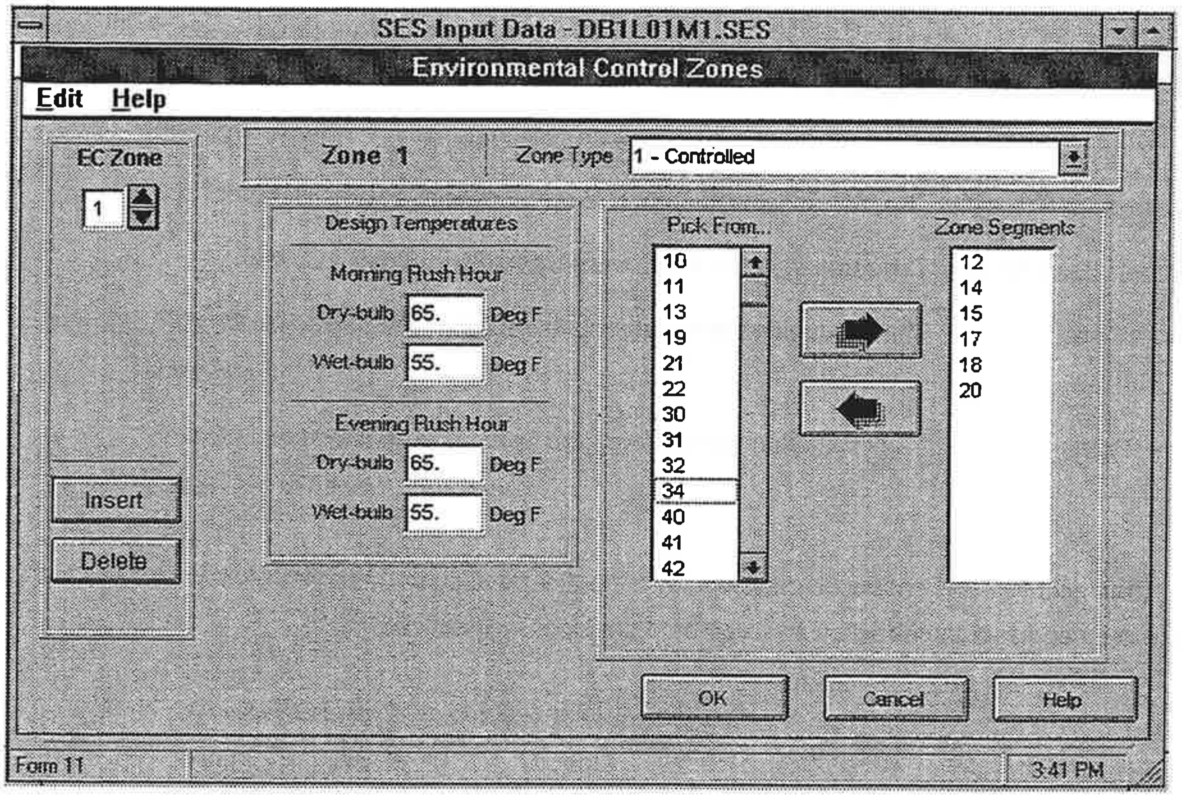
SOURCE NAME Name identifying source. This information will appear in the input verification printout. Up to 36 alphanumeric characters may be used.

SEGMENT	The identification number of the line segment in which the fire source is located. N may be any valid line segment ID number
SUBSEGMENT	The number of the subsegment within the segment in which the fire source is located. 1. ≤ N ≤ Number of subsegments in this line segment
SENSIBLE HEAT RATE	The rate of sensible heat release by the fire source in Btu/hr.
LATENT HEAT RATE	The rate of latent heat release by the fire source in Btu/hr.
START TIME	The simulation time after which the fire source becomes active. 0. ≤ X sec.
STOP TIME	The simulation time after which the fire source becomes inactive. Start Time ≤ X sec.

The next two items should be entered only if the Fire Simulation Option is selected and this fire source is in a segment marked as a Fire Segment (see Line Segment data).

FLAME TEMPERATURE	Enter the effective temperature of the flame for the fire source. 500. ≤ X ≤ 2000. °F
RADIATION AREA	Enter that area of the fire through which radiation to the tunnel wall surfaces can take place. For example, for a fire within a vehicle, this would be equal to the total area of the car's windows and open doors. 0. ≤ X ≤ Surface area of the subsegment ft^2

11.16 Environmental Control Zones



EC Zone: 1

Zone 1

Zone Type: 1 - Controlled

Design Temperatures

Morning Rush Hour

Dry-bulb: 65. Deg F

Wet-bulb: 55. Deg F

Evening Rush Hour

Dry-bulb: 65. Deg F

Wet-bulb: 55. Deg F

Pick From...	Zone Segments
10	12
11	14
13	15
19	17
21	18
22	20
30	
31	
32	
34	
40	
41	
42	

Environmental Control Zones are displayed one zone at a time. The CUT, COPY and PASTE buttons are missing from the Selection Panel because copying zones would result in the same sections occurring in different zones (which is not meaningful). The INSERT and DELETE buttons apply to the entire zone. It is not possible to cut, copy or paste sections. They may only be added to and removed from the zone using the arrow buttons.

The sections displayed in the pick list are dependent on the type of zone selected as described below under Zone Type. Only the sections which are appropriate for the selected zone type and which have not been used in another zone will be displayed in the Pick From list, so select the appropriate Zone Type before adding sections to the zone.

To add sections to the zone, select the sections to be added by using Standard MS Windows multi-selection procedures[1]. Click on the Right Arrow button to move the sections to the Zone Sections list. Repeat as necessary to add additional sections. To remove sections from the Zone Section list,

---

[1] To select more than one item in a list, select the first item then hold down the Control key while clicking on additional items. Clicking on an item which is already selected will Unselect it. To select a consecutive group of items, select the first item, then hold down the shift key while clicking on the last item. You may then use the Control-Click procedure to add or delete additional items.

select the section or sections to be removed and press the Left Arrow button. The sections will be removed from the Zone Sections list and restored to the Pick From list.

ZONE TYPE	Select the zone type: 1 = Controlled zone (Line Sections only) 2 = Uncontrolled zone (Line and Vent Sections) 3 = Non-inertial ventilation shaft zone (Vent Sections only)

Design Temperatures

The Design Temperatures data is only required for zone type 1. The panel is not displayed for zone types 2 or 3.

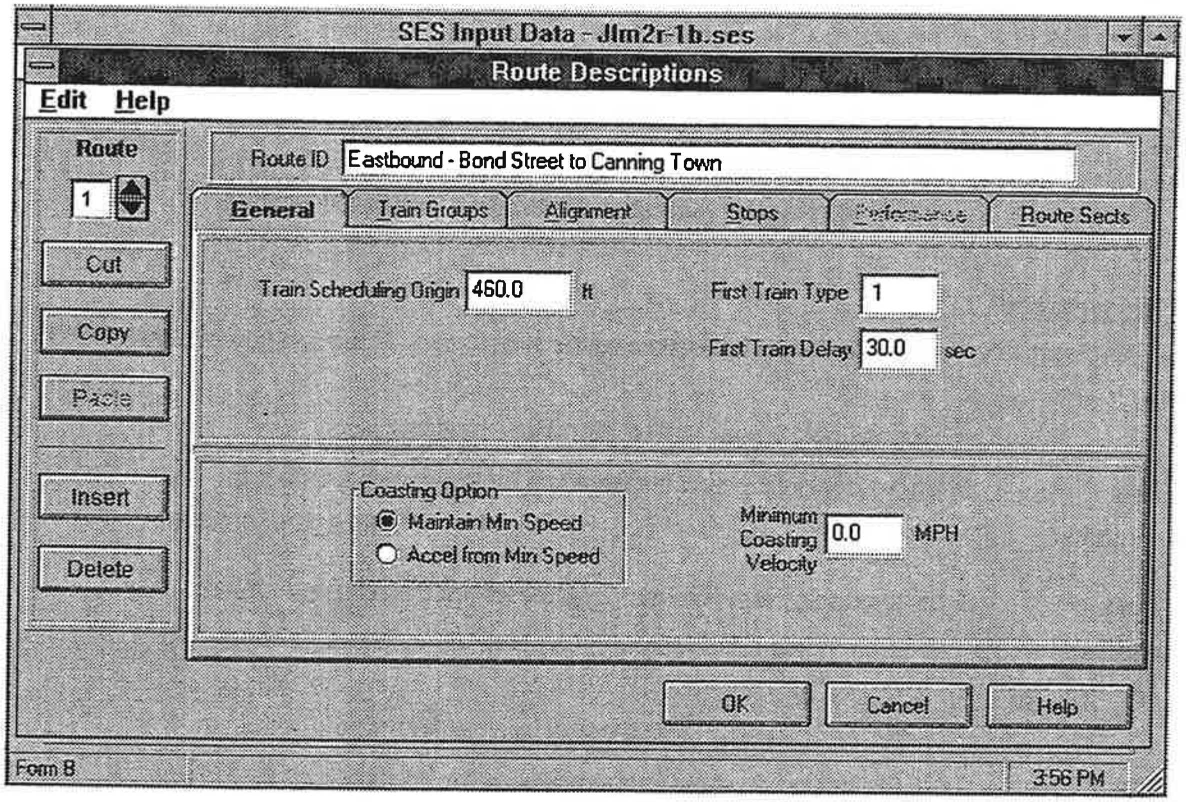
MORNING RUSH HOUR DESIGN CONDITIONS

Dry-Bulb Temperature	Enter the design dry-bulb temperature for the morning rush hour. 40. ≤ X ≤ 100. °F
Wet-Bulb Temperature	Enter the design wet-bulb temperature for the morning rush hour. 40. ≤ X ≤ Morning rush hour dry-bulb design temp. °F

EVENING RUSH HOUR DESIGN CONDITIONS

Dry-Bulb Temperature	Enter the design dry-bulb temperature for the evening rush or off hour. 40. ≤ X ≤ 100. °F
Wet-Bulb Temperature	Enter the design wet-bulb temperature for the evening rush or off hour. 40. ≤ X ≤ Evening rush/off hour dry-bulb design temp. °F

11.17 Routes



Route: 1

Route ID: Eastbound - Bond Street to Canning Town

Train Scheduling Origin: 460.0 ft

First Train Type: 1

First Train Delay: 30.0 sec

Coasting Option:
● Maintain Min Speed
○ Accel from Min Speed

Minimum Coasting Velocity: 0.0 MPH

Route data is displayed for one route at a time using a six-tab display. Tabs are only enabled if the data is required by the current Train Control Option. You may select tabs by clicking on them with the mouse, pressing ALT with the underlined letter, or, in some cases, by tabbing from the last field on the screen (if it is not a table).

The Selection Panel is used to select, cut, copy, paste, insert and delete entire routes.

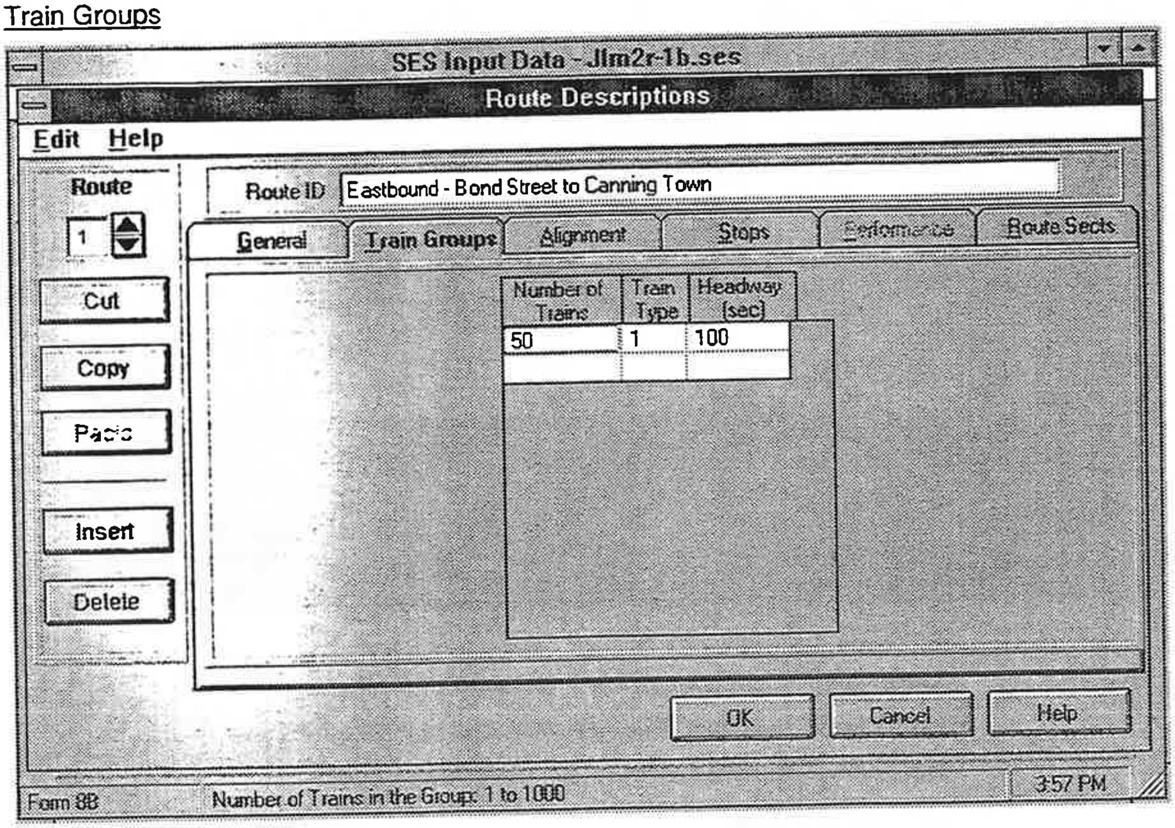
ROUTE IDENTIFICATION	Any alphanumeric description of the route. This information will be printed in the input verification. The Route I.D. must be entered for each new route before another route may be added.

General

TRAIN ORIGIN	Indicates the position along the track route from which train operation originates. It must be greater than or equal to 0. feet. 0. ≤ X ≤ 1,000,000. ft

FIRST TRAIN TYPE	Enter the type number (N=1,2,3,4,5) of the first train dispatched into the system on this route. 1. ≤ N ≤ "Number of Train Types" on Form 1E
FIRST TRAIN DELAY	Enter the amount of time after the beginning of the simulation the user wishes to delay the dispatching into the system of the first train on this route. 0. ≤ X ≤ 10,000. sec
MINIMUM COASTING VELOCITY	Enter the minimum train velocity permitted on this route during coasting. 0. ≤ X ≤ 250. mph
COASTING OPTION	Enter the mode of operation for the train if the minimum speed is reached while coasting. 0. - Maintain minimum speed 1. - Accelerates from minimum speed

Train Groups



Route: 1

Route ID: Eastbound - Bond Street to Canning Town

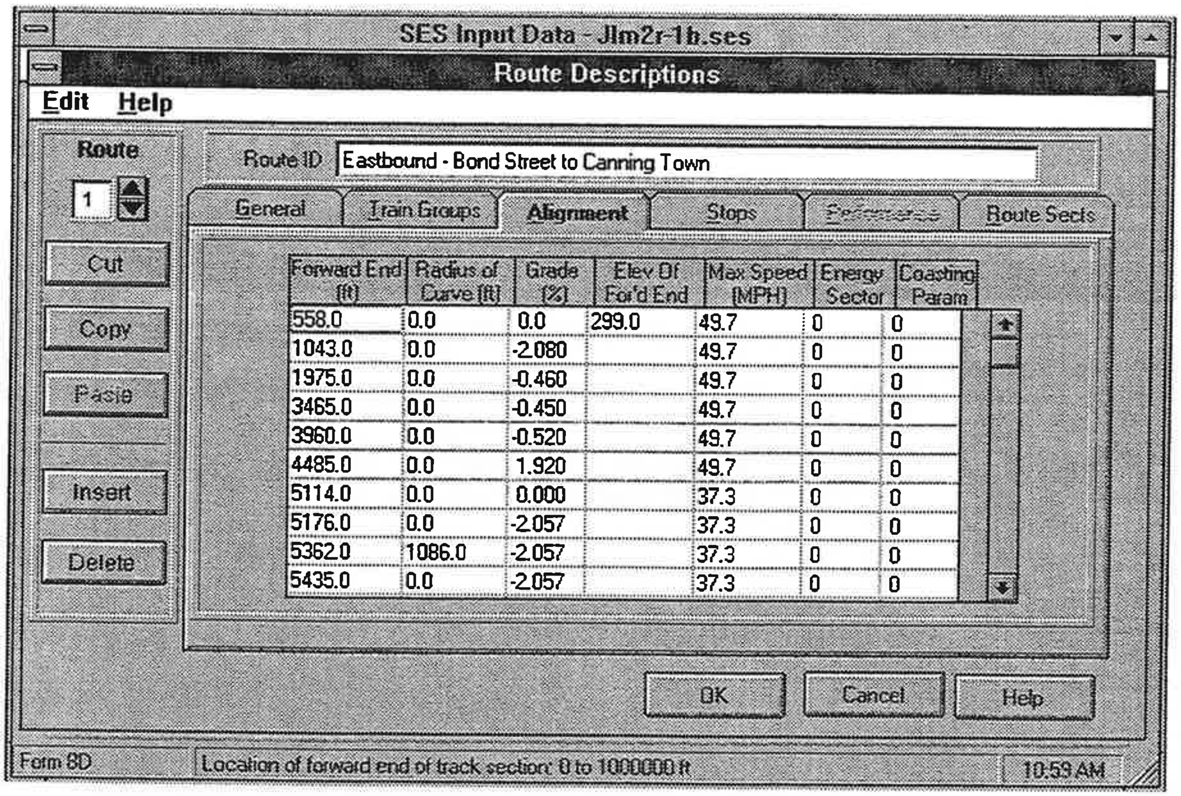
Number of Trains	Train Type	Headway (sec)
50	1	100

Form 8B   Number of Trains in the Group: 1 to 1000   3:57 PM

If there is more than one train dispatch group, enter all the groups on this screen. If there is only one, leave this screen blank.

NUMBER OF TRAINS	This number corresponds to the total number of trains in the train dispatcher group. 1. ≤ N ≤ 1,000.
TRAIN TYPE	Enter the type identification number (N=1,2,3,4,5....) of all the trains in this group. 1. ≤ N ≤ "Number of Train Types" on Form 1E
HEADWAY	Enter the headway of the trains in the group. The headway is defined as the time interval between this train and the preceding train. 0. ≤ X ≤ 10,000. sec

Alignment



Route 1

Route ID Eastbound - Bond Street to Canning Town

Forward End (ft)	Radius of Curve (ft)	Grade (%)	Elev Of For'd End	Max Speed (MPH)	Energy Sector	Coasting Param
558.0	0.0	0.0	299.0	49.7	0	0
1043.0	0.0	-2.080		49.7	0	0
1975.0	0.0	-0.460		49.7	0	0
3465.0	0.0	-0.450		49.7	0	0
3960.0	0.0	-0.520		49.7	0	0
4485.0	0.0	1.920		49.7	0	0
5114.0	0.0	0.000		37.3	0	0
5176.0	0.0	-2.057		37.3	0	0
5362.0	1086.0	-2.057		37.3	0	0
5435.0	0.0	-2.057		37.3	0	0

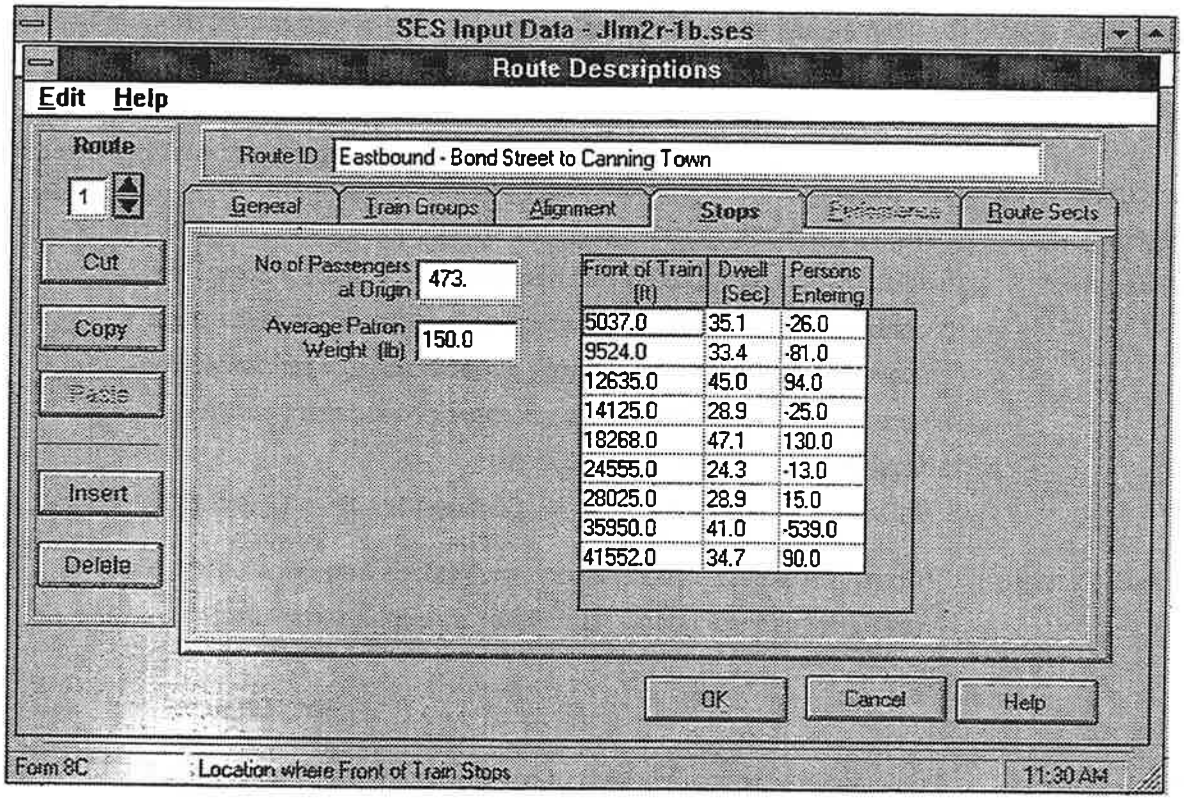
Form 8D

Location of forward end of track section: 0 to 1000000 ft

FORWARD END	The location of a track section is defined as the distance between the route origin and the forward end of the track section. The forward end of a track section is the end which is farthest from the origin for that route. 0. ≤ X ≤ 1,000,000. ft

Radius Of Curvature	Horizontal curves are described using the radius of curvature. When the track section is straight, the radius is entered as zero or as a blank. 75. ≤ X ; or X = 0.
Grade Or Elevation Of Forward End	The grade of the track section may be entered as a positive or negative percentage or as the elevation of the forward end of the section measured positively with respect to an arbitrary datum. The program automatically computes the percent grade when the track elevation is supplied and <u>vice versa</u>. An elevation of zero cannot be entered. It must be entered as a number close to zero, but with an absolute value greater than 0.02 feet. Grade: -10. ≤ X ≤ 10. percent
Maximum Speed	This quantity must be supplied for each track section when using Train Performance Option 1, and must be skipped when using option 2 or 3. 1. ≤ X ≤ 250. mph
Energy Sector Number	This number indicates in which energy sector the track section is located. A summary of train power consumption is printed for each energy sector. An entry of zero indicates that a summary is not requested for this track section. 0. ≤ N ≤ 50.
Coasting Parameter	0. - No coasting permitted in this track section. 1. - Coasting is permitted in this track section. Coasting can only be simulated when using Train Performance Option 1.

Stops



Route: 1

Route ID: Eastbound - Bond Street to Canning Town

No of Passengers at Origin: 473.

Average Patron Weight (lb): 150.0

Front of Train (ft)	Dwell (Sec)	Persons Entering
5037.0	35.1	-26.0
9524.0	33.4	-81.0
12635.0	45.0	94.0
14125.0	28.9	-25.0
18268.0	47.1	130.0
24555.0	24.3	-13.0
28025.0	28.9	15.0
35950.0	41.0	-539.0
41552.0	34.7	90.0

Form 8C : Location where Front of Train Stops

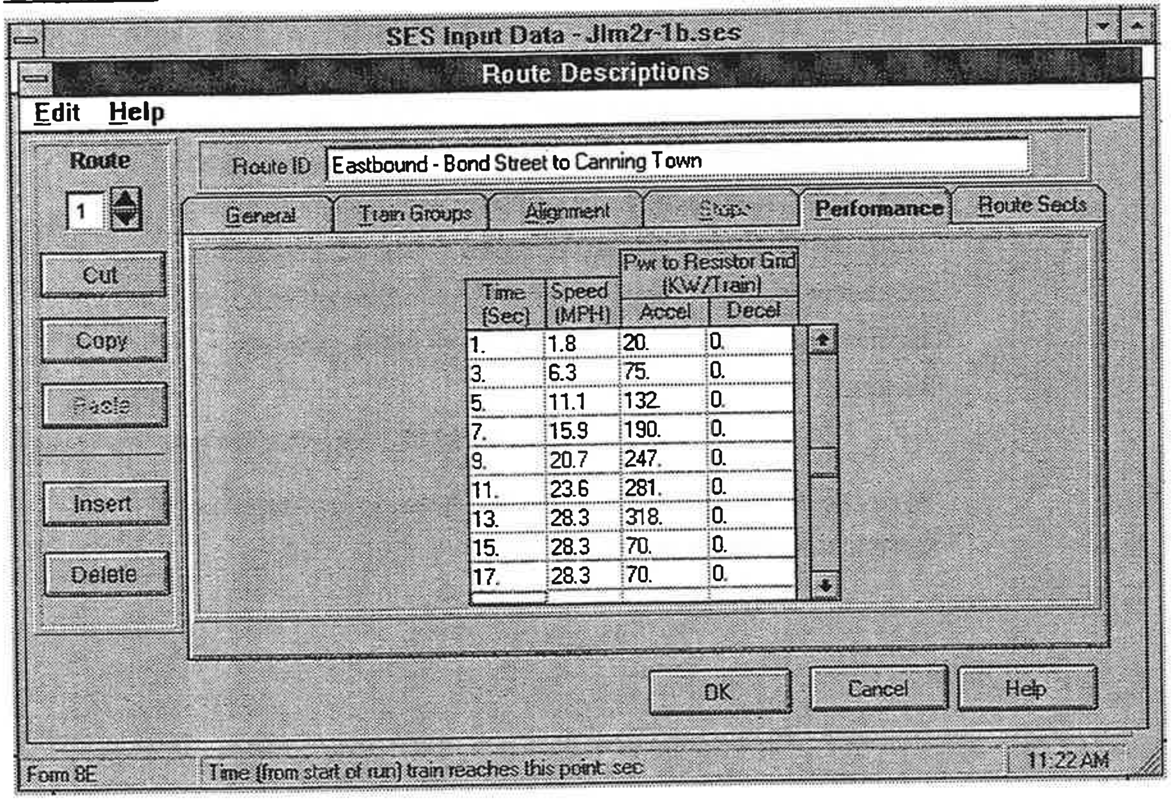
NUMBER OF PASSENGERS AT ORIGIN	Enter the total number of persons aboard the train at the train scheduling origin. The number of people leaving the train at a stop must be less than or equal to the number of people already onboard the train prior to the stop. 0. ≤ X ≤ 4000. people
AVERAGE PATRON WEIGHT	The average weight of patrons entering the trains at a stop, or on board the train at dispatch time. 50. ≤ X ≤ 200. lbs.

The data fields in the table are:

FRONT OF TRAIN	This indicates the location along the system coordinate (in feet) at which the front of all trains on the route must come to a complete stop. Beginning of the first track section ≤ X ≤ End of the last track section

DWELL TIME	Each stop is characterized by an individual dwell time or length of pause in seconds. For example, passenger flow may dictate a dwell time of 20 seconds at one station and 40 seconds at another. 0. ≤ X ≤ 900. sec
NUMBER OF PERSONS ENTERING TRAIN AT STOP	Enter the net gain or loss of people from the train at the stop. The net loss of passengers cannot exceed the number of persons on board the train prior to the stop. -4000. ≤ X ≤ 4000. people

Performance



Route ID: Eastbound - Bond Street to Canning Town

Time (Sec)	Speed (MPH)	Pwr to Resistor Grid (KW/Train)	
		Accel	Decel
1.	1.8	20.	0.
3.	6.3	75.	0.
5.	11.1	132	0.
7.	15.9	190.	0.
9.	20.7	247.	0.
11.	23.6	281.	0.
13.	28.3	318.	0.
15.	28.3	70.	0.
17.	28.3	70.	0.

Time (from start of run) train reaches this point: sec

TIME VS. TRAIN SPEED	Each data point consists of entries of time in seconds vs. train velocity in mph. Previous time ≤ Time (time must not be entered in decreasing order) Train speed: 0. ≤ X ≤ 250. mph

POWER INPUT TO RESISTOR GRIDS

This item is required only for Train Performance Option 3.

ACCELERATION: This is the rate of dissipation of electrical power in the acceleration resistor grids and motors. The value can be computed as $N*I^2*R/1000.$, where I is the current in amperes through the motors, R is the sum of the electrical resistance in ohms of the motor windings and the resistor grids in series with each motor, N is the number of motors in the entire train.

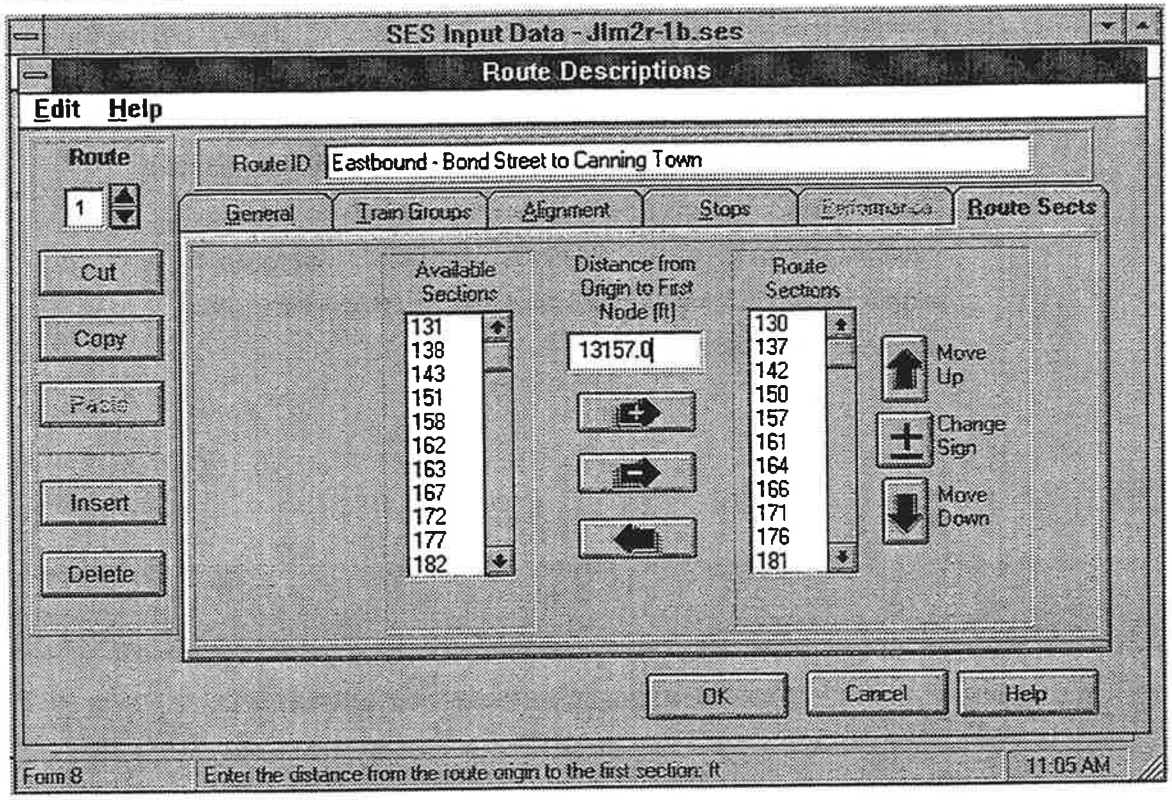
$0. \leq X \leq 20{,}000.$ kilowatts per train

DECELERATION: This is the rate of energy dissipation in the deceleration resistor grids. It is equal to the rate of change of kinetic energy minus the change in potential energy. The kinetic energy dissipation rate is JMVA*0.001285 , where J is the number of cars in the train, M is the mass of a car plus the equivalent translational mass of rotating parts in slugs, V is the train speed in ft/sec, and A is the acceleration of the train in ft/sec^2. The change in potential energy is JWV x 0.001285 x SIN(α) where J is the number of cars in the train, W is the weight of the car in lbs, V is the train speed in ft/sec, and α is the angle of the track with horizontal.

$0. \leq X \leq 20{,}000.$ kilowatts per train

At any point in time, power can go into either the acceleration grid or the deceleration grid, but not both.

Route Sections



Route: 1

Route ID: Eastbound - Bond Street to Canning Town

Available Sections: 131, 138, 143, 151, 158, 162, 163, 167, 172, 177, 182

Distance from Origin to First Node [ft]: 13157.0

Route Sections: 130, 137, 142, 150, 157, 161, 164, 166, 171, 176, 181

Enter the distance from the route origin to the first section: ft

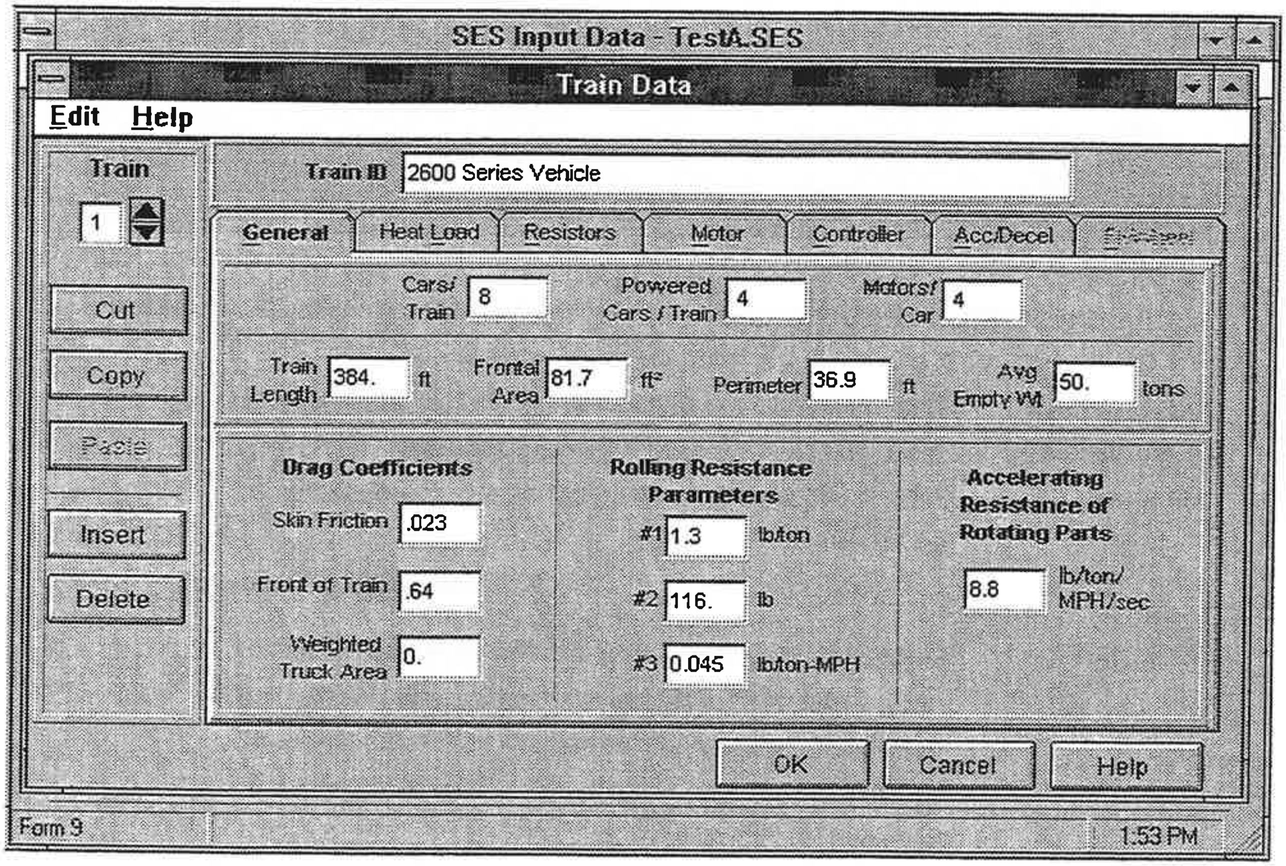
The data on this panel establishes the relationship of the train route to the tunnel system.

DISTANCE FROM ROUTE ORIGIN TO FIRST NODE	Enter the location along the route where the front of the train first enters the tunnel system. If the route originates within the system, enter a zero since the route origin must be located at the first node on the route. 0. ≤ X ≤ Entire length of the route, ft
ROUTE SECTIONS	Select the sections from the Available Sections list to add to the Route Sections list. The sections must be listed in order in the direction of travel, with a minus sign if the direction of travel through the section is from the ending node to the beginning node as defined in the section data. If the direction of travel on the route is from the beginning of the section to the end, use the + arrow button to move it to the Route Sections list; if the direction of travel is from the end of the section to the beginning, use the - arrow button and a minus sign will be added. Use the left arrow button to delete sections from the Route

Sections list. Sections removed will be placed at the end of the Available Sections list.

You may use the extended multiple selection techniques described previously for Environmental Control Zones to select more than one section at a time to be moved. They will be added to the Route Sections list in the order they appear in the Available Sections list. Use the MOVE UP, MOVE DOWN and CHANGE SIGN buttons to make adjustments to the Route Sections list as necessary after sections have been added.

11.18 Trains



Train: 1

Train ID: 2600 Series Vehicle

Cars/Train: 8

Powered Cars / Train: 4

Motors/Car: 4

Train Length: 384. ft

Frontal Area: 81.7 ft²

Perimeter: 36.9 ft

Avg Empty Wt: 50. tons

Skin Friction: .023

Front of Train: .64

Weighted Truck Area: 0.

#1: 1.3 lb/ton

#2: 116. lb

#3: 0.045 lb/ton-MPH

8.8 lb/ton/MPH/sec

Train data is displayed for one train at a time using a seven-tab display. Tabs are only enabled if the data is required by the current Train Control Option. You may select tabs by clicking on them with the mouse, pressing ALT with the underlined letter, or, in some cases, by tabbing from the last field on the screen (if it is not a table). The Selection Panel is used to select, cut, copy, paste, insert and delete entire trains.

Train Identification	This is the identifying designation for the train type being utilized. Any combination of up to 36 alphanumeric characters may be used.

General

Cars Per Train	This indicates the number of cars in the train type being described. $1. \leq N \leq 20.$
Powered Cars Per Train	Enter the number of cars in the train that contain an operational propulsion system. $1. \leq N \leq$ Total no. of cars in train
Motors Per Powered Car	Enter the number of operational motors per powered car for this train type. Rapid transit vehicles normally have four motors per car, although any number of motors may be entered. $1. \leq N \leq 10.$
Total Train Length	Enter the total length of this train type. $25. \leq X \leq 1{,}500.$ ft
Frontal Area Of Train	Enter the frontal silhouette of the train including the average area of undercar equipment and trucks for this train type. $25. \leq X \leq 300.$ ft^2
Perimeter Of Car	Enter the perimeter associated with the average cross-sectional area of this train type. $20. \leq X \leq 200.$ ft
Average Empty Car Weight	This number is the average unloaded weight of a single car for this train type. $5. \leq X \leq 150.$ tons

Physical Resistance Parameters

Skin Friction Coefficient	Enter the skin friction coefficient which relates drag to the sides, roof and bottom surface area of the train. $0. \leq X \leq 0.20$
Front Of Train Drag Coefficient	Enter the front of train drag coefficient which relates drag to the shape of the front of the train. $0. \leq X \leq 1.5$

Drag Coefficient Weighted Total Truck Area

Enter the drag coefficient weighted truck area which relates drag to the total area of the trucks and their respective drag coefficients.

$0. \leq X \leq 500.$

Train Rolling Resistance Coefficients

These are the constants in the equation for computing the rolling resistance of the vehicle.

Typical values of these coefficients are:

	Steel Wheel Vehicle	Rubber Tire Vehicle	
Coeff. #1	1.3	3.9	lb/ton
Coeff. #2	116.0	350.0	lb
Coeff. #3	0.045	0.135	lb/ton-mph

$0.5 \leq$ Coeff. #1 $\leq 50.$ lbs/ton

$0.1 \leq$ Coeff. #2 $\leq 500.$ lbs

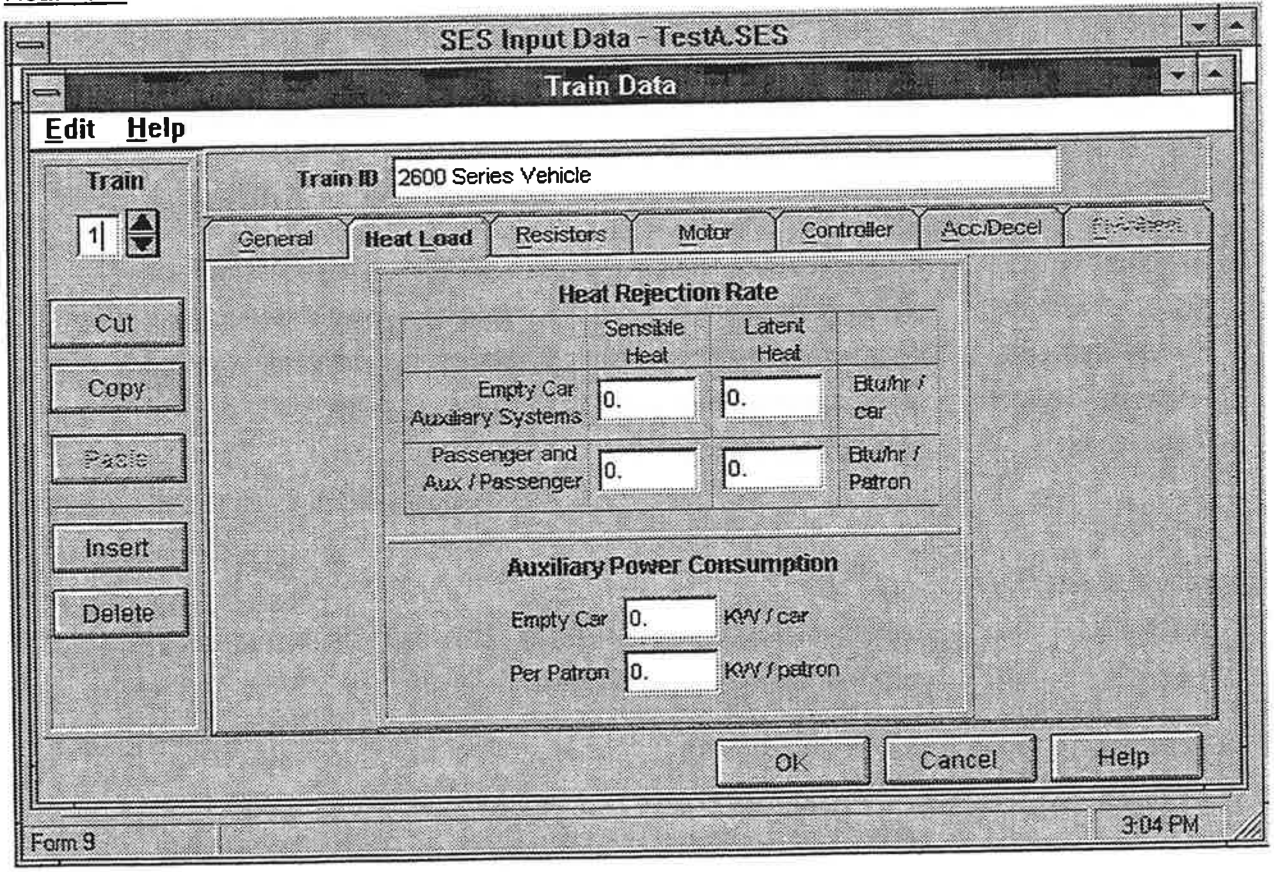
$0.001 \leq$ Coeff. #3 ≤ 1.000 lbs/(ton-mph)

Acceleration Resistance Of Rotating Parts

This value represents the rotational inertia of rotating parts (wheels, motor armatures, gears, etc.) in terms of an equivalent mass for translational acceleration. You may enter the value to be used, or you may leave this entry blank and a commonly used value of 8.8 will be supplied by the program.

$0.1 \leq X \leq 30.0$ lbs per ton/(mph/sec)

Heat Load



Train: 1

Train ID: 2600 Series Vehicle

Heat Rejection Rate

	Sensible Heat	Latent Heat	
Empty Car Auxiliary Systems	0.	0.	Btu/hr / car
Passenger and Aux / Passenger	0.	0.	Btu/hr / Patron

Auxiliary Power Consumption

Empty Car: 0. KW / car

Per Patron: 0. KW / patron

HEAT REJECTION RATE

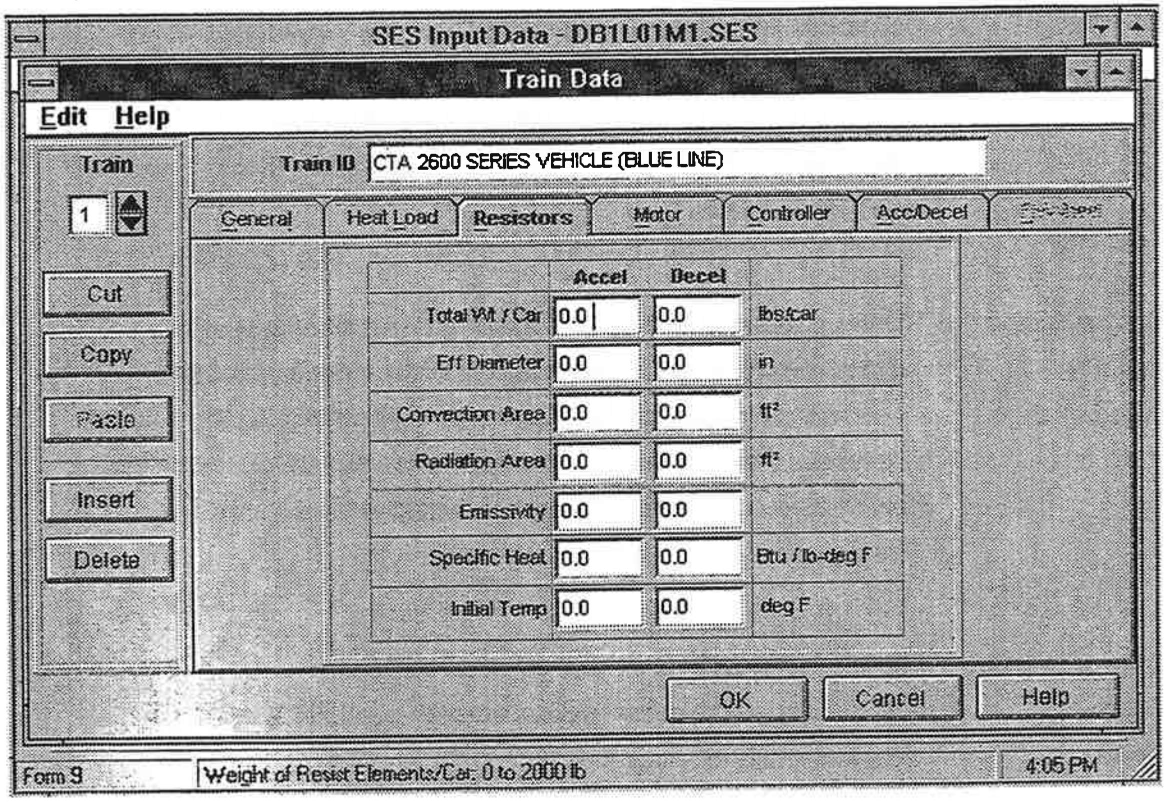
SENSIBLE HEAT FROM EMPTY CAR AUXILIARY SYSTEMS	Enter the sensible heat rejection from auxiliary systems (air conditioning condensers and compressors, lighting, motors and other equipment) while train is stationary and there are no passengers on board. Do not include propulsion. 0. ≤ X ≤ 1,000,000. Btu/hr per car
LATENT HEAT FROM EMPTY CAR AUXILIARY SYSTEMS	Enter the latent heat rejection from auxiliary systems (air conditioning condensers and compressors, lighting, motors and other equipment) while train is stationary and there are no passengers on board. Do not include propulsion. -50,000. ≤ X ≤ 200,000. Btu/hr per car

Sensible Heat Rejection From Passengers And Auxiliary Systems Per Patron	Enter the additional sensible heat rejection from a car caused by each passenger on board the car. This heat may be released directly from the passengers, or from the vehicle air conditioning system, if present. This number should be entered only when the Train Performance Option is 1. -100. ≤ X ≤ 1000. Btu/hr per patron
Latent Heat Rejection From Passengers And Auxiliary Systems Per Patron	Enter the additional latent heat rejection from a car caused by each passenger on board the car. This heat may be released directly from the passengers, or from the vehicle air conditioning system, if present. This number should be entered only when the Train Performance Option is 1. -100. ≤ X ≤ 1000. Btu/hr per patron

Auxiliary Power Consumption

Empty Car	Enter the average auxiliary systems power consumption for each car when there are no passengers on board. 0. ≤ X ≤ 100. kW per car
Per Patron	Enter the additional average auxiliary systems power consumption caused by each passenger on board the car. This number should be entered only when the Train Performance Option is 1. -2. ≤ X ≤ 5. kW per patron.

Resistors



Train: 1

Train ID: CTA 2600 SERIES VEHICLE (BLUE LINE)

	Accel	Decel	
Total Wt / Car	0.0	0.0	lbs/car
Eff Diameter	0.0	0.0	in
Convection Area	0.0	0.0	ft²
Radiation Area	0.0	0.0	ft²
Emissivity	0.0	0.0	
Specific Heat	0.0	0.0	Btu / lb-deg F
Initial Temp	0.0	0.0	deg F

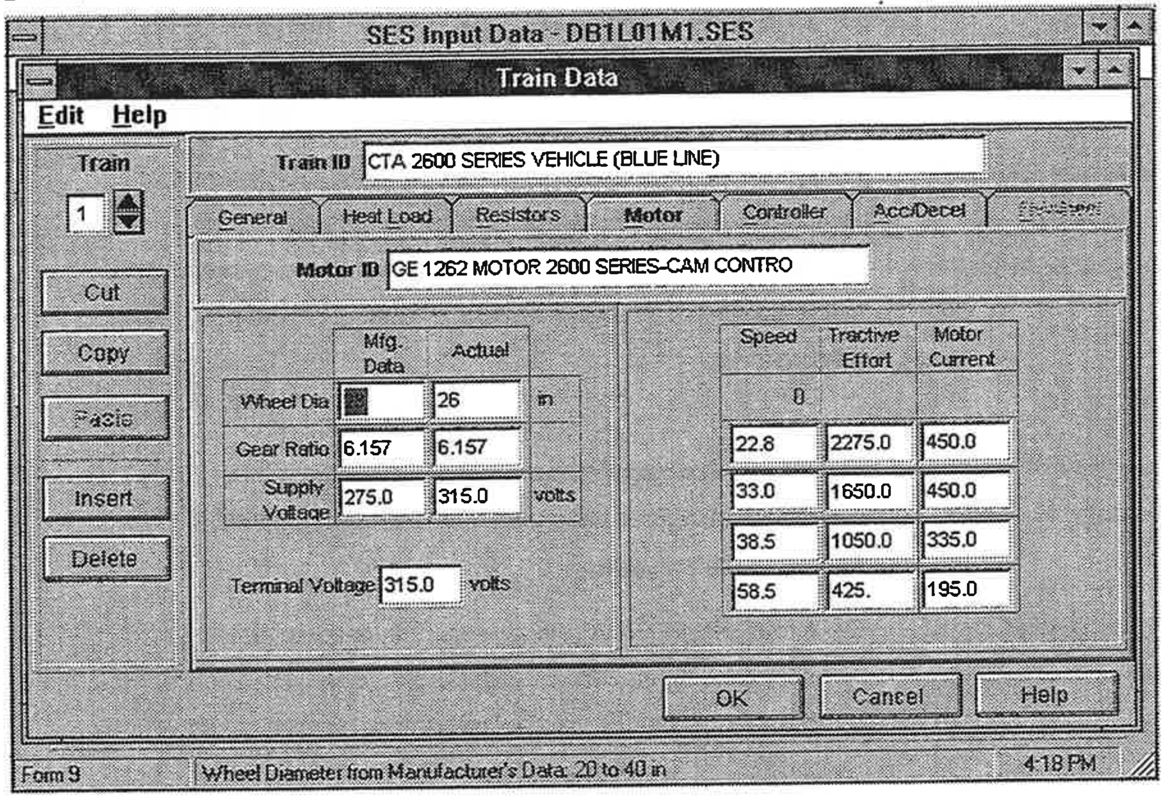
Weight of Resist Elements/Car: 0 to 2000 lb

ACCELERATION AND DECELERATION RESISTOR GRIDS:

TOTAL WEIGHT OF RESISTANCE ELEMENTS PER CAR	This value represents the weight of all the acceleration and/or deceleration resistor grid elements which actually resist current flow in a resistor grid arrangement for this train type. This value does not include any weight of the resistor grid supporting structure. A value of zero (0.) indicates an instantaneous heat release mechanism is to be used for that grid. If a 0. is entered for a grid, the remaining entries for the grid may be 0. $0. \leq X \leq 2{,}000.$ lbs
EFFECTIVE DIAMETER OF AN ELEMENT	This value represents a characteristic resistor grid element diameter for all the acceleration and/or deceleration grids in this train type. $0. \leq X \leq 24.$ in.

Effective Surface Area For Convection Per Car	This value represents the sum of the effective surface area for convection calculations of each element in the acceleration and/or deceleration resistor grid arrangement for this train type. This value is a function of the physical geometry of each element and the location of the resistor grid arrangement relative to the underside of the car. $0. \le X \le 500.$ ft^2
Effective Surface Area For Radiation Per Car	This value represents the sum of the effective surface area for radiation calculations of each element in the acceleration and/or deceleration resistor grid arrangement for this train type. The effective area is defined as the product of the actual surface area of an element and its shape factor with regard to the surroundings enclosing the resistor grid arrangement. $0. \le X \le 500.$ ft^2
Emissivity Of The Resistance Element	This value represents the emissivity of a typical acceleration and/or deceleration resistor grid element surface evaluated at an average grid temperature for this train type. $0. \le X \le 1.$
Specific Heat Of The Resistance Element	This value represents the specific heat of an acceleration and/or deceleration resistor grid element evaluated at an effective grid temperature. $0. \le X \le 1.$ Btu/(lb-°F)
Initial Grid Temperatures	The initial temperature of the acceleration and/or deceleration resistor grids corresponds to the temperature of the grids at the time the trains are dispatched onto their respective route. A blank entry or zero indicates that the resistor grid is to be initialized at ambient temperature.

Motor



Train: 1

Train ID: CTA 2600 SERIES VEHICLE (BLUE LINE)

Motor ID: GE 1262 MOTOR 2600 SERIES-CAM CONTRO

	Mfg. Data	Actual	
Wheel Dia		26	in
Gear Ratio	6.157	6.157	
Supply Voltage	275.0	315.0	volts

Terminal Voltage: 315.0 volts

Speed	Tractive Effort	Motor Current
0		
22.8	2275.0	450.0
33.0	1650.0	450.0
38.5	1050.0	335.0
58.5	425.	195.0

Wheel Diameter from Manufacturer's Data: 20 to 40 in

MOTOR IDENTIFICATION	This identifies the motor(s) being used on the train. Any combination of alphanumeric characters may be used. The motor identification will be printed in the input verification.
WHEEL DIAMETER SUPPLIED WITH MANUFACTURER'S DATA	Enter the wheel diameter given with the manufacturer-supplied motor performance curves. Motor performance curves provided by manufacturers normally are computed for a specified size of vehicle wheel. See note[2]. $20. \le X \le 40.$ in.

---

[2] Note: Should the train under consideration have a different wheel size, gear ratio or supply voltage other than those at which the motor performance curves are supplied, the program will automatically scale the motor performance curves by the ratio of the manufacturer-supplied values to the actual values.

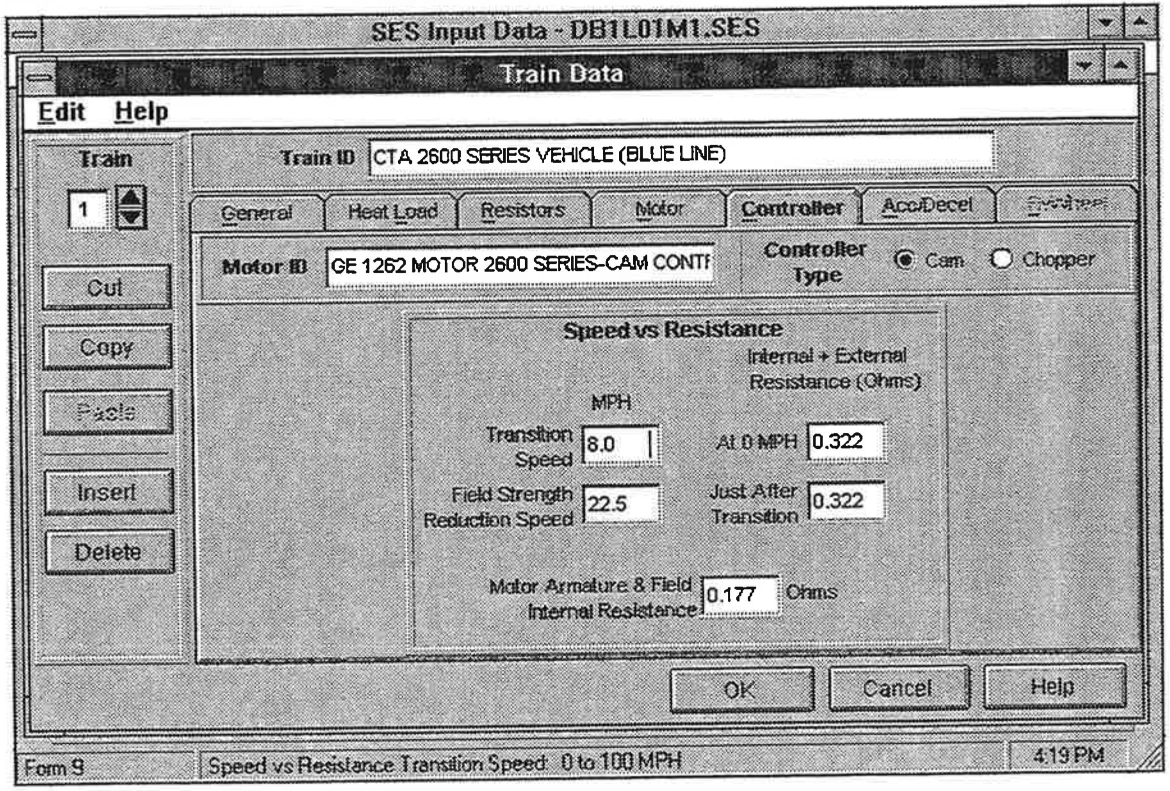
Actual Wheel Diameter Of Vehicle	Enter the actual diameter of the wheels for the vehicle type being described. The actual wheel diameter must be entered even if it is the same as the one given. $20. \leq X \leq 40.$ in.
Gear Ratio - To 1 Supplied With Manufacturer's Data	Enter the gear ratio (number of motor revolutions per wheel revolution) given with the manufacturer-supplied motor performance curves. Motor performance curves provided by the manufacturer normally are computed for a specified gear ratio. See note[2]. $1. \leq X \leq 20.$
Actual Gear Ratio - To 1 Of Vehicle	The actual gear ratio of the train being considered must be provided. This actual gear ratio must be entered even if it is the same as the one given. $1. \leq X \leq 20.$
Supply Voltage Given With Manufacturer's Data	Enter the voltage given with the manufacturer-supplied motor performance curves. Motor performance curves provided by the manufacturer normally are computed for a specified voltage. See note[2]. $100. \leq X \leq 1500.$ volts
Actual Supply Voltage At Which Vehicle Operates	Enter the actual voltage for the vehicle type being described. The actual voltage must be entered even if it is the same as the one given. $100. \leq X \leq 1500.$ volts
Motor Terminal Voltage At Base Speed	Enter motor voltage corresponding to train base speed. $100. \leq X \leq 1500.$ volts/motor
Train Speed	Points are taken from the motor performance curves supplied by motor manufacturers. These points should be: 1) the speed at which field strength reduction begins, 2) the speed at which field strength reduction is completed, 3) a speed at approximately the midpoint of the minimum field strength operating curve (usually about 40 mph), 4) a speed which represents the maximum design speed of the vehicle. The vehicle would not normally exceed this last speed. $0. \leq X \leq 250.$ mph

TRACTIVE EFFORT	These data points are taken from the motor performance curves and should correspond to the MPH points supplied above. X ≥ 0. lbs.
MOTOR CURRENT	These data points are taken from the motor performance curves and should correspond to the tractive effort data supplied above. X ≥ 0. amperes
LINE CURRENT	These data points are only required for chopper control. They are taken from the motor performance curves. The first value is the current at zero speed and others correspond to the train speeds supplied above. The values entered are amperes per powered car. X ≥ 0. amperes

Controller

The data required for cam control and chopper control is different. Changing the controller type changes the data panel.

Cam



Train: 1

Train ID: CTA 2600 SERIES VEHICLE (BLUE LINE)

Motor ID: GE 1262 MOTOR 2600 SERIES-CAM CONTF

Controller Type: ● Cam ○ Chopper

Speed vs Resistance

MPH

Transition Speed: 8.0

Field Strength Reduction Speed: 22.5

Internal + External Resistance (Ohms)

At 0 MPH: 0.322

Just After Transition: 0.322

Motor Armature & Field Internal Resistance: 0.177 Ohms

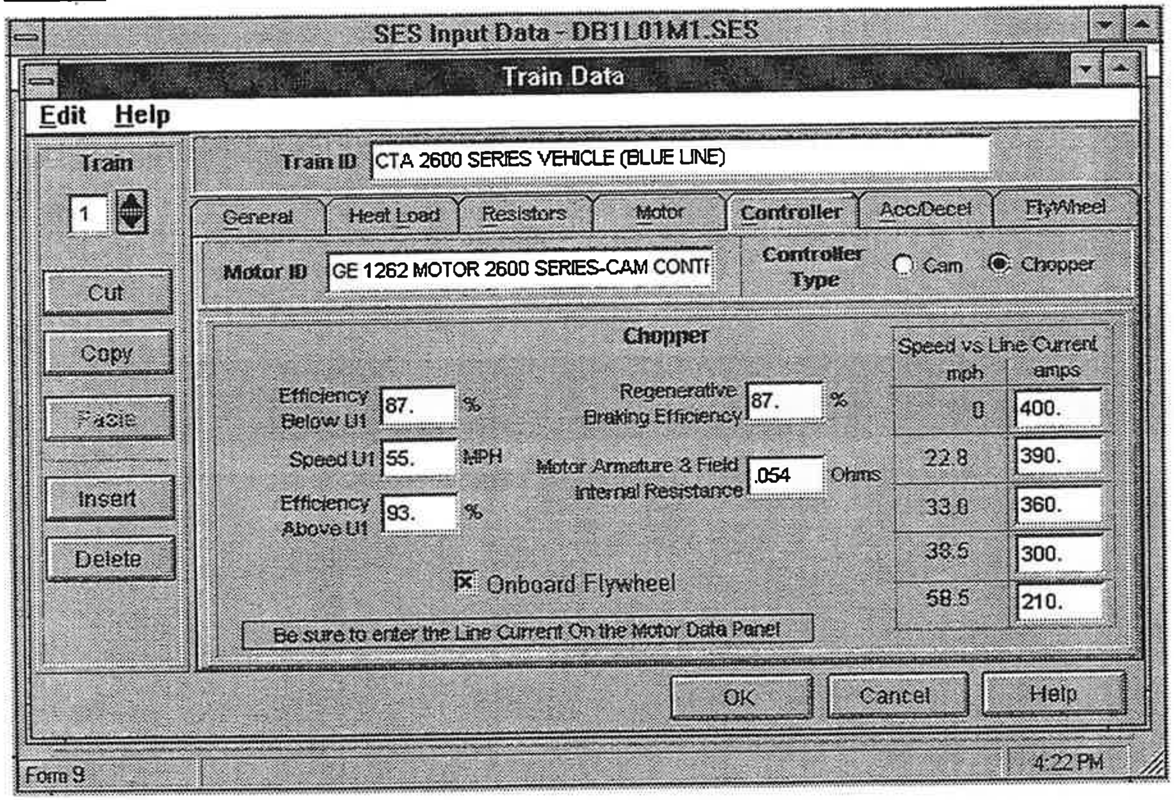
Form 9 | Speed vs Resistance Transition Speed: 0 to 100 MPH | 4:19 PM

MOTOR IDENTIFICATION	The motor I.D. is displayed here for information purposes only. It cannot be changed from this panel.
CONTROLLER TYPE	Select the type of motor controller being used; Cam or Chopper. The data panel will change accordingly. See below for the Chopper data panel.

The Cam controller requires Train Speed vs Resistance information as follows:

RESISTANCE SPEEDS	The two train speeds entered here are used in the definition of the external resistance versus train speed curve. The first entry is the speed at which transition occurs, the second is the speed at which field strength reduction begins. 0. ≤ X ≤ 100. mph
RESISTANCE	Three resistance values must be given to describe the motor circuit resistance. The first is the external plus internal resistance at zero train speed; the second is the external plus internal resistance just after transition has occurred; and the third is the internal resistance of the motor armature and field. 0.001 ≤ X ≤ 3. ohms

Chopper



Train 1

Train ID: CTA 2600 SERIES VEHICLE (BLUE LINE)

Motor ID: GE 1262 MOTOR 2600 SERIES-CAM CONTI

Controller Type: ○ Cam ● Chopper

Efficiency Below U1: 87. %

Speed U1: 55. MPH

Efficiency Above U1: 93. %

Regenerative Braking Efficiency: 87. %

Motor Armature & Field Internal Resistance: .054 Ohms

☒ Onboard Flywheel

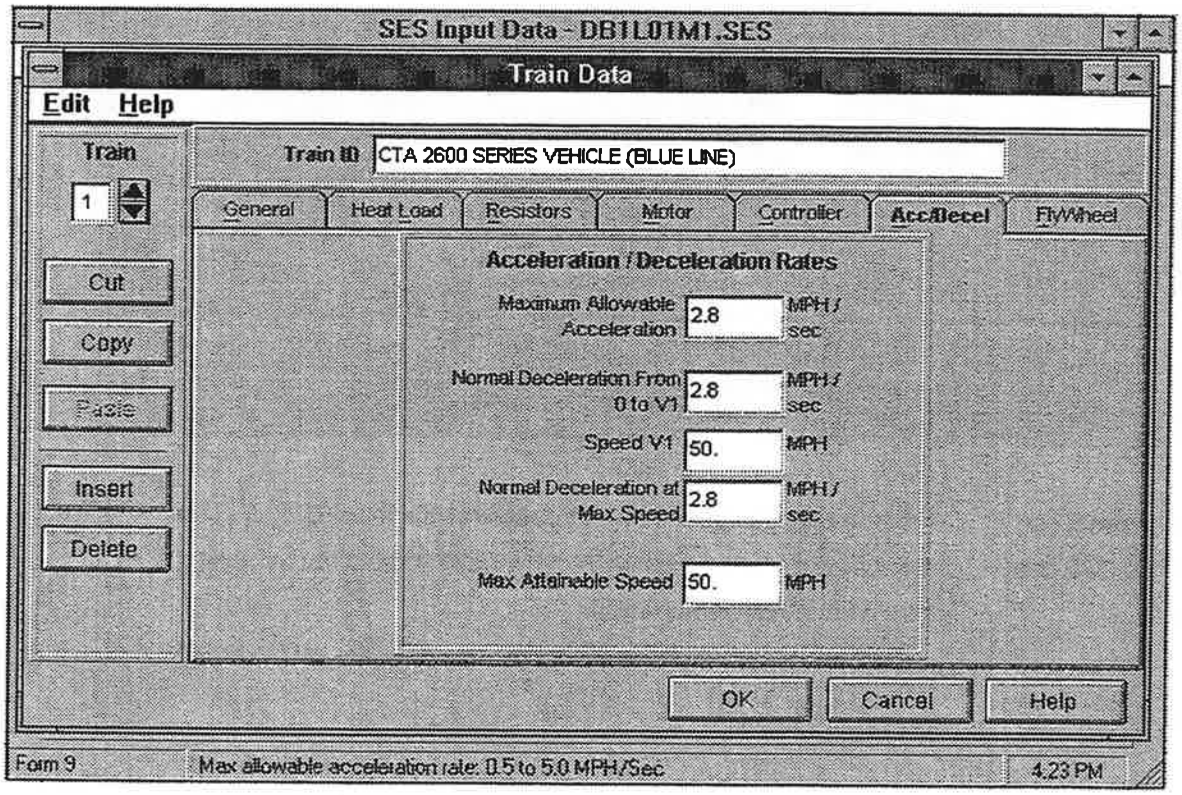
Be sure to enter the Line Current On the Motor Data Panel

Speed vs Line Current	
mph	amps
0	400.
22.8	390.
33.8	360.
38.5	300.
58.5	210.

EFFICIENCY FOR SPEEDS OF ZERO TO U_1	Enter the chopper efficiency for speeds ranging from 0 to U_1. The efficiency is defined as the ratio of the power output to the power input to the chopper times 100. $0. \leq X \leq 100.$ percent
SPEED U_1	Enter the value of U_1. $0. \leq X \leq 100.$ mph
EFFICIENCY FOR SPEEDS GREATER THAN U_1	Enter the chopper efficiency for speeds exceeding U_1. $0. \leq X \leq 100.$ percent
REGENERATIVE BRAKING EFFECTIVENESS	Enter the regenerative braking effectiveness. This effectiveness is defined as the ratio of the total energy regenerated to the total energy available for regeneration times 100. Enter zero if the Onboard Flywheel Simulation Option is 2. $0. \leq X \leq 100.$ percent

MOTOR ARMATURE & FIELD INTERNAL RESISTANCE	Enter the internal resistance of the motor armature and field. $0.001 \leq X \leq 3.$ ohms
ONBOARD FLYWHEEL	Check this box if the train has flywheels which are to be simulated.

Acceleration/Deceleration



Train: 1

Train ID: CTA 2600 SERIES VEHICLE (BLUE LINE)

Acceleration / Deceleration Rates

Maximum Allowable Acceleration: 2.8 MPH / sec

Normal Deceleration From 0 to V1: 2.8 MPH / sec

Speed V1: 50. MPH

Normal Deceleration at Max Speed: 2.8 MPH / sec

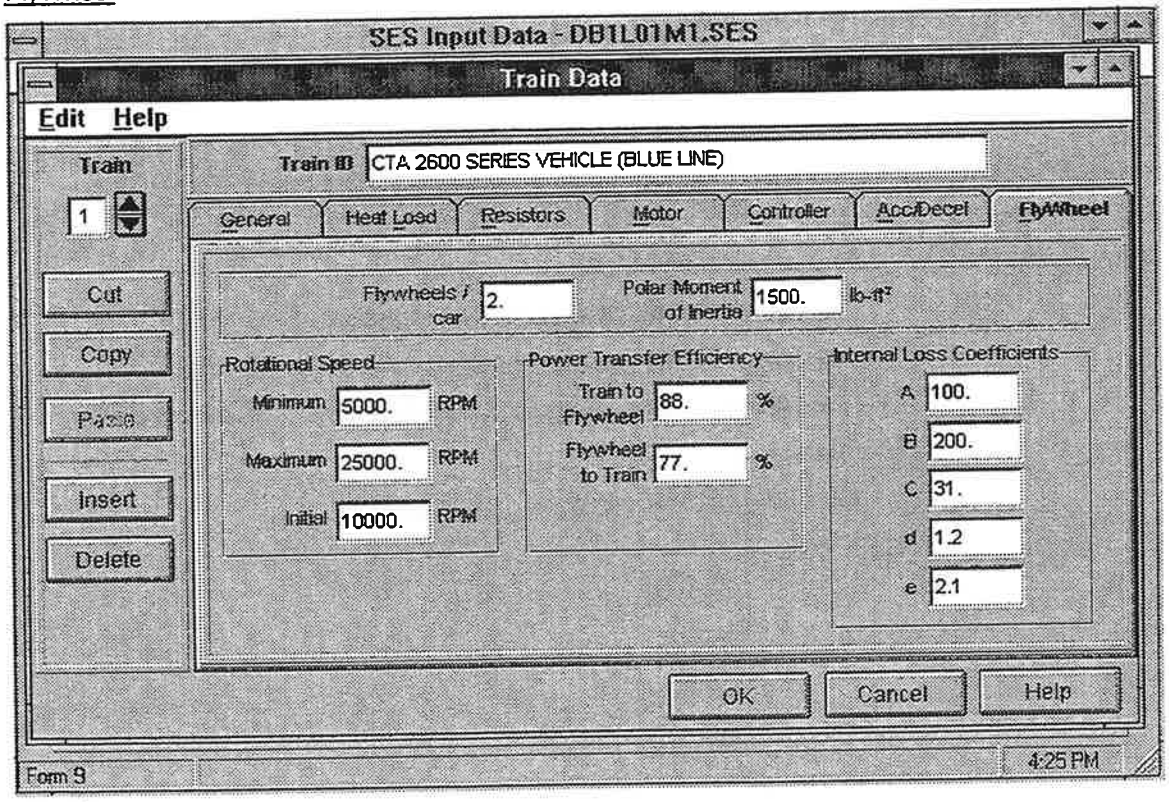
Max Attainable Speed: 50. MPH

Max allowable acceleration rate: 0.5 to 5.0 MPH/Sec

MAXIMUM ALLOWABLE ACCELERATION RATE	This is the maximum rate of acceleration for this train type. This rate would not be exceeded even though the train might be capable of greater acceleration in some situations. $0.5 \leq X \leq 5.0$ mph/sec
NORMAL DECELERATION RATE FROM SPEED V_1 TO 0	As a train decelerates under normal operation, there is a speed (V_1) below which the train's deceleration becomes constant. Enter this constant rate of deceleration between 0 and V_1 mph for the train type. $0.5 \leq X \leq 5.0$ mph/sec

SPEED V_1	As a train decelerates under normal operation, there is a speed V_1 below which the train's deceleration becomes constant. Enter the speed V_1 for this train type. $10. \leq X \leq 100.$ mph
NORMAL DECELERATION RATE AT MAXIMUM SPEED	At high speeds, a train cannot decelerate at as high a rate as is possible at lower speeds. Enter the train deceleration rate for normal operation at the maximum speed (V_2) attainable by this train type. This deceleration rate is never greater than, and is most often less than, the normal deceleration rate from 0 to V_1 mph. $0.5 \leq X \leq 5.0$ mph/sec
MAXIMUM ATTAINABLE SPEED	Enter the maximum speed attainable by this train type. This maximum speed will almost always be higher than the maximum train speed. $V_1 \leq X \leq 250.$ mph

FlyWheel



Train: 1

Train ID: CTA 2600 SERIES VEHICLE (BLUE LINE)

Flywheels / car: 2.

Polar Moment of Inertia: 1500. lb-ft²

Rotational Speed

Minimum: 5000. RPM

Maximum: 25000. RPM

Initial: 10000. RPM

Power Transfer Efficiency

Train to Flywheel: 88. %

Flywheel to Train: 77. %

Internal Loss Coefficients

A: 100.

B: 200.

C: 31.

d: 1.2

e: 2.1

POLAR MOMENT OF INERTIA	Enter the polar moment of inertia of a flywheel assembly (i.e. rotor, shaft, etc.). $50. \le X \le 4000.$ lb-ft^2
NUMBER OF FLYWHEELS PER CAR	Enter the number of flywheel units on-board each car. $1. \le N \le 4.$
MINIMUM ALLOWABLE ROTATIONAL SPEED	Enter the minimum allowable rotational speed of a flywheel. $0. \le X \le 20{,}000.$ rpm
MAXIMUM ALLOWABLE ROTATIONAL SPEED	Enter the maximum allowable rotational speed of a flywheel. Minimum allowable speed $\le X \le 30{,}000.$ rpm
INITIAL ROTATIONAL SPEED	Enter the initial rotational speed of a flywheel. Minimum allowable speed $\le X \le$ Maximum allowable speed
EFFICIENCY OF POWER TRANSFER FROM TRAIN TO FLYWHEEL	Enter the overall efficiency of power transfer from the train wheel to the flywheel. $0. \le X \le 100.$ percent
EFFICIENCY OF POWER TRANSFER FROM FLYWHEEL TO TRAIN	Enter the overall efficiency of power transfer from the flywheel to the train wheel. $0. \le X \le 100.$ percent
COEFFICIENTS OF EQUATION FOR INTERNAL LOSSES OF FLYWHEEL AS A FUNCTION OF SPEED	Enter the coefficients of the equation for the internal losses (i.e. windage, bearings, etc.) of the flywheel. The form of the equation is: $F(\omega) = A*\omega^d + B*\omega^e + C$ Due to the fact that time within the program is measured in seconds, ω is in units of revolutions per second (rps). The coefficients must be defined to give $F(\omega)$ in units of kilowatts (kW), therefore: $A = kW/(rps)^d$, $B = kW/(rps)^e$, and $C = kW$

Typical coefficient values for a Garret Flywheel are given below.* Note that not all coefficients need to be used to describe the internal losses. The coefficients A, B, and C must be entered in Scientific Notation (E-Format). For example, if $A = 3.53 \times 10^{-6}$, It should be entered as 3.53 E-06.

$A = 3.536 \times 10^{-6}$

$B = 0$

$C = 0$

$d = 2.5$

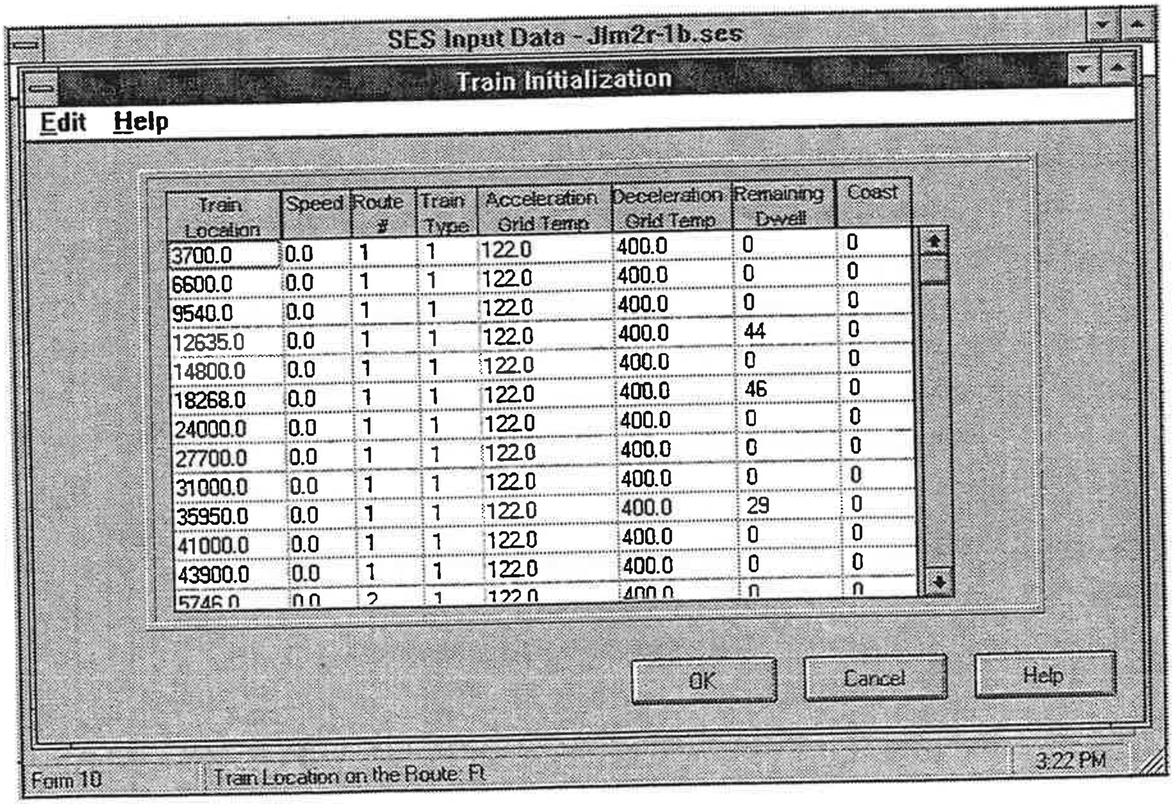
$e = 0$

$0. \leq A, B, C$

$0. \leq d, e \leq 3.0$

* Refer to Chapter 8 reference 5 of the SES User's Manual.

11.19 Initial Trains



Train Location	Speed	Route #	Train Type	Acceleration Grid Temp	Deceleration Grid Temp	Remaining Dwell	Coast
3700.0	0.0	1	1	122.0	400.0	0	0
6600.0	0.0	1	1	122.0	400.0	0	0
9540.0	0.0	1	1	122.0	400.0	0	0
12635.0	0.0	1	1	122.0	400.0	44	0
14800.0	0.0	1	1	122.0	400.0	0	0
18268.0	0.0	1	1	122.0	400.0	46	0
24000.0	0.0	1	1	122.0	400.0	0	0
27700.0	0.0	1	1	122.0	400.0	0	0
31000.0	0.0	1	1	122.0	400.0	0	0
35950.0	0.0	1	1	122.0	400.0	29	0
41000.0	0.0	1	1	122.0	400.0	0	0
43900.0	0.0	1	1	122.0	400.0	0	0
5746.0	0.0	2	1	122.0	400.0	0	0

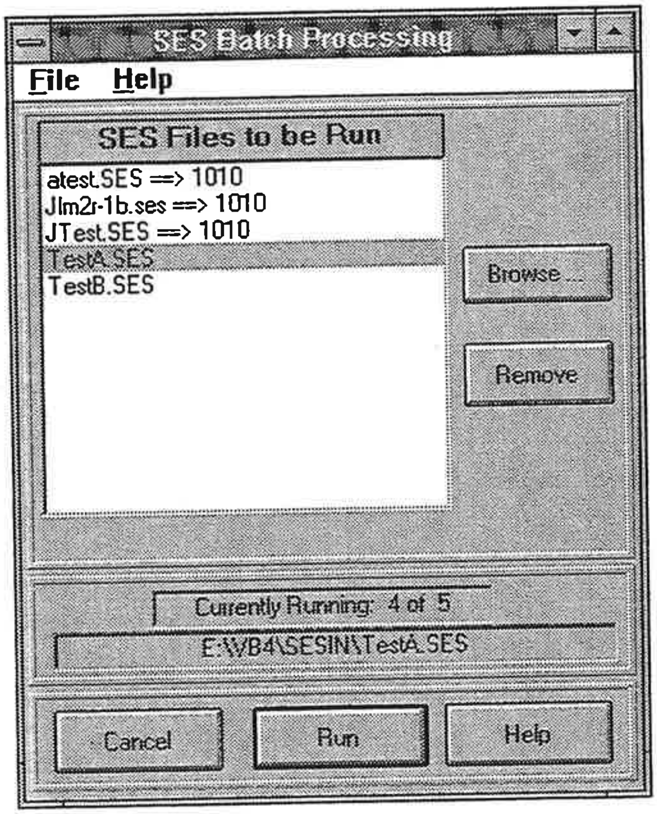
Train Location on the Route: Ft

- Enter one row for each train present on the route at the beginning of the simulation.

TRAIN LOCATION ON ROUTE	Enter the location along the route where the front of the initialized train is situated at the beginning of the simulation. Scheduling origin $\leq X \leq$ Forward end of last track section, ft
TRAIN SPEED	Enter the speed of the initialized train at the beginning of the simulation. $0. \leq X \leq 250.$ mph
ROUTE NUMBER	Enter the route identification number of the initialized train. $1. \leq N \leq$ "Number of train routes" on Form 1E
TRAIN TYPE	Enter the train type identification number of the initialized train. $1. \leq N \leq$ "Number of train types" on Form 1E
ACCELERATION GRID TEMPERATURE	Enter the temperature of the acceleration grids at the instant in time that the simulation begins, °F
DECELERATION GRID TEMPERATURE	Enter the temperature of the deceleration grids at the instant in time that the simulation begins, °F
REMAINING DWELL TIME	If the initialized train is at a stopping point along the route, the user must enter the amount of time the train is to remain stationary at that stopping point after the beginning of the simulation. If there is no remaining dwell time, this entry may be entered as zero or left blank. A negative value indicates that the train is to remain in the initialized location for the duration of the simulation. (This is only applicable for Train Performance Option 1.) $X \leq 900.$
TRAIN COASTING INDICATOR	Enter a 1. - if the initialized train is coasting at the beginning of the simulation. 0. - if the initialized train is not coasting.

11.20 SESBATCH

The SESBATCH program may be initiated from the RUN menu of SESIN or directly from Windows. SESBATCH supports processing a number of SES files sequentially and recording the results of each.



atest.SES ==> 1010
Jlm2r-1b.ses ==> 1010
JTest.SES ==> 1010
TestA.SES
TestB.SES

Currently Running: 4 of 5
E:\VB4\SESIN\TestA.SES

The BROWSE button opens a standard Windows file open dialog box with multiple selection enabled. Select the SES files to be run and press OPEN. The list of files will be displayed in the SES Files to be Run list box. You may repeatedly select BROWSE to add additional files to the list. Only the filenames are displayed but the path is also saved so you may select files from more than one drive or directory. To remove a file from the list, select the file in the list and press REMOVE.

When all files have been selected, press RUN to begin processing. Each file will be run in order. The file being processed will be highlighted in the list and its full name displayed in the status panel below the list.

When the processing of a file is complete, its return code will be displayed and processing will continue on to the next file. Pressing CANCEL while anlaysis is in progress will not stop the current analysis run, but will prevent any additional files in the list from being processed.

A list of the files processed and their return codes is written to a file named SESBATCH.LOG in the directory of the first file processed. To view the log file, select File/View Log from the menu. Subsequent batches will be added to the end of the log; it is not automatically cleared. To clear the log, select File/Clear Log from the menu. The log file will be deleted.

When all files have been processed, the labels on the RUN and CANCEL buttons change to CLEAR and DONE, respectively. Pressing CLEAR clears the list box to permit setting up of another batch. DONE exits the program.

12. INPUT FORMS

The input forms provided in this section are designed to permit easy modification of a given subway system's physical parameters. These input forms only have to be used if the SES Input Manager, (SESIN), is not used. After a system is described on these input forms, modifications can be made in the system design by changing only the quantities that are pertinent. Therefore, by using these input forms, an initial "base" subway system can be modified many times in an efficient and expedient manner.

The brief description accompanying each input item is provided as an aid to the user when filling out the input forms. If a user has digested and understood the information within this User's Manual, these brief descriptions will in general be able to provide the user with enough information to avoid having to reread the pertinent sections in the Manual when filling in each input item. The actual use of these input forms is explained below.

Using the Input Forms

All numbers must be entered with a decimal point. Any number that is not entered with a decimal point will cause an error in the program. Only Arabic numerals (0 through 9) may be used, and each input item may only possess one decimal point. Each numeral or decimal point uses one space within the spaces allotted for each input item.

The SES program often requires some type of description or identification of the input data being entered. These descriptions entered by the user help to identify the particular simulation being performed and to interpret the results of the simulation. The brief input instructions accompanying the input forms for each of these identifying or descriptive type entries advises the user that any alphanumeric character may be used when entering the data. An alphanumeric character can be any of the following three types:

1. Any letter from A to Z
2. Any numeral from 0 through 9
3. The following special characters:

(blank) = . ! ,
\+ ? / $ -
( ) ” % ' (apostrophe)
< > * & :
; \ [ ] #
_ | { } ^
@ ` ~

A box with an "X" in it at the end of an input item indicates the end of an input line. No more than eight input items may ever be placed on a single line.

The SES program often requires the user to supply certain design parameters for the entire system all at once. When this occurs the user will in general have to make duplicates of certain forms supplied in this manual. An example of this is when the user must describe all the line segments within the system in the series 3 forms (forms 3A through 3F). The input forms supplied provide the user with only one complete set of series 3 forms. Each line segment requires the use of an entire set of series 3 forms. Obviously the user must make as many duplicates of the series 3 forms as necessary to describe the system. Similarly, all forms that are used for repetitive type input have an "etc." placed at the end of the form after each repetitive input item. This signifies to the user that if there is more data than room on the form, this data should be filled out continually in the same manner on a duplicate of the original form. Only the repetitive data is filled in on the duplicate forms. All unnecessary data (nonrepetitive) on the duplicate forms must be crossed out to avoid confusion.

Special Instruction. The input forms provided are general input forms that can be used for any system with any program option. Each of the program options calls for a specific data set that requires the user to exclude certain input items from various input forms. Any form that has input data that is not to be filled out for one or more of the program options has instructions in the accompanying brief input descriptions pertaining to when to fill out the form and which input items to skip or leave blank. The user should consult Tables 6.1 and 6.2 when filling out the series 8 and 9 forms.

When there are instructions to leave an entry blank, the user must make certain the corresponding spaces on the corresponding input line are left blank. If the user is instructed to skip or ignore a form, the entire form must be omitted when preparing the input data. A blank line should never be placed in the input file to account for a form that has been skipped.

Descriptions of the Input Items. The accompanying descriptions of the input items also contain instructions for filling out the forms. These descriptions include the limits for each input parameter and the error message types that result when the user exceeds these limits. This error type listing in the descriptions of the input may be used as a cross-reference when correcting any unintentional errors found while performing an input verification (see Section 13.3). The limits for each input parameter are generally given in the following manner:

For real numbers: lower limit $\leq X \leq$ upper limit
Or for integers: lower limit $\leq N \leq$ upper limit

where X and N are the particular input parameters being described. Similarly, these symbols are used in the actual input descriptions.

INPUT FORMS

FORM 1A - GENERAL DATA

SYSTEM IDENTIFICATION	Appears on all pages of the input verification and program output. Up to 80 alphanumeric characters may be used.
ADDITIONAL TITLE	Including the system identification above, a maximum of 20 title lines can be used. Each line can be up to 80 alphanumeric characters.

FORM 1A - GENERAL DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

1 System Identification 40

41 80 ☒

1 Additional Title Lines (Maximum 19 Lines) 40

41 80 ☒

FORM 1B - GENERAL DATA

DESIGN HOUR, MONTH AND YEAR

These data define the period for which the simulation is being performed. The hour is entered as a whole number from 0 to 24 with the minutes entered in the decimal portion; i.e., 3:30 P.M. is entered as 15.30. If the environmental control load evaluation option is 1.0 and the user wishes the heat sink analysis to be performed for the morning rush hour, the user must enter 8.0 for the design hour. If the user wishes the heat sink analysis to be performed for the evening rush hour, the user must enter 17.0 for the design hour. If the environmental control load evaluation option is 2.0 (off-hour), the environmental control load evaluation will be performed for the exact hour entered and will use the wall temperatures assigned by the user for the SES simulation.

In the Northern Hemisphere, the month of July (month number 7.) is the hottest month of the year and the month of January (month number 1.) is the coldest month of the year. Regardless of where the system is located in the world, if the simulation is to be done for the hottest month, the number 7. must be entered for the design month, and the number 1. must be entered for the design month if the simulation is to be done for the coldest month.

If no environmental control load evaluation is to be performed, this information is used solely for identification of the time of the SES simulation.

Error Type 32, 33, 36

FORM 1B - GENERAL DATA

Sheet ________ of ________
Made by: ________________
Checked by: ______________
Date: __________________

1 Design Hour 10
☐☐☐☐☐☐☐☐☐☐

11 Design Month 20
☐☐☐☐☐☐☐☐☐☐

21 Design Year 30
☐☐☐☐☐☐☐☐☐☐☒

FORM 1C - GENERAL DATA

TRAIN PERFORMANCE OPTION	0 - Bypass train simulation 1 - Implicit 2 - Explicit (Train heat rejection computed) 3 - Explicit (Train heat rejection input) Error Type 17, 73
TEMPERATURE/HUMIDITY SIMULATION OPTION	0 - Bypass 1 - Yes 2 - Yes - evaporation Error Type 126, 253
HUMIDITY DISPLAY OPTION	1 - Humidity ratio 2 - Wet-bulb temperature 3 - Relative humidity (N/A if Temp/Humid = 0) Error Type 94
ENVIRONMENTAL CONTROL LOAD EVALUATION OPTION	0 - Bypass 1 - Yes - evening or morning rush hour 2 - Off hour (N/A if Temp/Humid = 0) Error Type 126
HEAT SINK SUMMARY PRINT OPTION	0 - Bypass 1 - Heat sink summary output 2 - Heat sink summary output and heat sink arrays (N/A if Temp/Humid = 0) Error Type 126
SUPPLEMENTARY OUTPUT OPTION	0 - Designer Oriented output only 1 - Level 1 (Input Verification) 2 - Level 2 (Train Sim.) 3 - Level 3 (Aerodynamic Sim.) 4 - Level 4 (Thermodynamic Sim.) 5 - Level 5 (All of the Above) Error Type 152
ALLOWABLE SIMULATION ERRORS	0 - Stop simulation if any simulation errors are found N - Allow up to "N" simulation errors $0. \leq N \leq 50.$ Error Type 186
ALLOWABLE INPUT ERRORS	+N Allow up to "N" input errors 0 Simulate system if no input errors are found -1 Input verification only (No simulation)

FORM 1C - GENERAL DATA

Sheet ________ of ________
Made by: ________________
Checked by: ________________
Date: ________________

Train Performance Option	1	☐☐☐☐☐☐☐☐☐☐	10
Temperature/Humidity Simulation Option	11	☐☐☐☐☐☐☐☐☐☐	20
Humidity Display Option	21	☐☐☐☐☐☐☐☐☐☐	30
Environmental Control Load Evaluation Option	31	☐☐☐☐☐☐☐☐☐☐	40
Heat Sink Summary Print Option	41	☐☐☐☐☐☐☐☐☐☐	50
Supplementary Output Option	51	☐☐☐☐☐☐☐☐☐☐	60
Allowable Simulation Errors	61	☐☐☐☐☐☐☐☐☐☐	70
Allowable Input Errors	71	☐☐☐☐☐☐☐☐☐☐☒	80

FORM 1D - GENERAL DATA

NUMBER OF LINE SEGMENTS	This number corresponds to the total number of line segments in the system. 0. ≤ N ≤ 620.	Error Type 1, 73
NUMBER OF SECTIONS	This number corresponds to the sum of the total number of line sections and ventilation shaft sections in the system. 0. ≤ N ≤ 900.	Error Type 127, 73
NUMBER OF VENTILATION SHAFT SECTIONS	This number corresponds to the total number of ventilation shafts in the system. 0. ≤ N ≤ 406.	Error Type 2, 73
NUMBER OF NODES	This number coresponds to the total number of nodes in the system. 2. ≤ N ≤ Number of Sections +1	Error Type 73, 128
NUMBER OF BRANCHED JUNCTIONS	This number corresponds to the total number of branched junctions in the system. 0. ≤ N ≤ Number of nodes	Error Type 73, 129
NUMBER OF PORTALS	This number is no longer used. Maintained only for combatibility with Version 3.0 input files.	
NUMBER OF UNSTEADY HEAT SOURCES	This number corresponds to the total number of fire/unsteady heat sources in the system. 0. ≤ N ≤ 50.	Error Type 132, 257
NUMBER OF FAN TYPES	This number corresponds to the total number of fan types used in the system. 0. ≤ N ≤ 75.	Error Type 133

FORM 1D - GENERAL DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Number of Line Segments 1 ☐☐☐☐☐☐☐☐☐☐ 10

Total Number of Sections 11 ☐☐☐☐☐☐☐☐☐☐ 20

Number of Ventilation Shaft Sections 21 ☐☐☐☐☐☐☐☐☐☐ 30

Number of Nodes 31 ☐☐☐☐☐☐☐☐☐☐ 40

Number of Branched Junctions 41 ☐☐☐☐☐☐☐☐☐☐ 50

Number of Portals 51 ☐☐☐☐☐☐☐☐☐☐ 60

Number of Unsteady Heat Sources 61 ☐☐☐☐☐☐☐☐☐☐ 70

Number of Fan Types 71 ☐☐☐☐☐☐☐☐☐☐ 80 ☒

FORM 1E - GENERAL DATA

NUMBER OF TRAIN ROUTES	This number corresponds to the total number of train routes in the system. $0. \le N \le 20.$	Error Type 73, 134, 135 202
NUMBER OF TRAIN TYPES	This number corresponds to the total number of train types in the system. $0. \le N \le 16.$	Error Type 73, 136, 137
NUMBER OF ENVIRONMENTAL CONTROL ZONES	This number corresponds to the total number of environmental control zones in the system. $0. \le N \le 75.$	Error Type 100
FAN STOPPING/ WINDMILLING OPTION	If a fan either exceeds its upper or lower fan operating limits, the program provides two options: 1. The simulation will stop immediately. 2. The fan will be turned off, but the simulation will continue.	Error Type 11
NUMBER OF TRAINS IN OPERATION AT INITIALIZATION	Enter the total number of trains, regardless of their route, that have been dispatched and are operating within the system prior to the beginning of the simulation. $0. \le N \le 75.$	Error Type 41
NUMBER OF IMPULSE FAN TYPES	Enter the total number of impulse fan types in the system. $0. \le N \le 6.$	Error Type 216
INITIALIZATION FILE WRITING OPTION INITIALIZATION FILE READING OPTION	Enter the number of the option desired to write and/or read an initialization file. The name of the initialization file must be inserted after Form 13. The choice of options is: 0 - None 1 - Aerodynamic initialization only 2 - Train initialization only 3 - Thermodynamic initialization only 4 - Aerodynamic and train initialization 5 - Aerodynamic, train, and thermodynamic initialization $0. \le N \le 5.$	Error Type 217, 223, 224, 225, 226, 227

FORM 1E - GENERAL DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Number of Train Routes	1	☐☐☐☐☐☐☐☐☐☐ 10
Number of Train Types	11	☐☐☐☐☐☐☐☐☐☐ 20
Number of Environmental Control Zones	21	☐☐☐☐☐☐☐☐☐☐ 30
Fan Stopping/Windmilling Option	31	☐☐☐☐☐☐☐☐☐☐ 40
Number of Trains In Operation at Initialization	41	☐☐☐☐☐☐☐☐☐☐ 50
Number of Impulse Fan Types	51	☐☐☐☐☐☐☐☐☐☐ 60
Initialization File Writing Option	61	☐☐☐☐☐☐☐☐☐☐ 70
Initialization File Reading Option	71	☐☐☐☐☐☐☐☐☐☐ 80 ☒

FORM 1F - GENERAL DATA

AMBIENT AIR DRY-BULB TEMPERATURE	Outside air temperature entered as dry-bulb degrees F. This outside air temperature remains constant for the program computations. -50. ≤ X ≤ 140. °F	Error Type 7
AMBIENT AIR WET-BULB TEMPERATURE	Outside air temperature entered as wet-bulb degrees F. Used in the computations of the ambient humidity ratio (specific humidity) and the relative humidity. -50. ≤ X ≤ Amb. Air Dry-Bulb Temp. °F	Error Type 8
AMBIENT BAROMETRIC PRESSURE	Outside air pressure entered in inches of mercury. Remains a constant in the program computations. 20. ≤ X ≤ 32. in. Hg	Error Type 5
MORNING AMBIENT AIR DRY-BULB TEMPERATURE	Outside air temperature corresponding to the morning rush hour. -50. ≤ X ≤ 140. °F	Error Type 7
MORNING AMBIENT AIR WET-BULB TEMPERATURE	Outside air temperature corresponding to the morning rush hour. -50. ≤ X ≤ Morning Amb. Air Dry-Bulb Temp. °F	Error Type 8
EVENING OR OFF HOUR AMBIENT AIR DRY-BULB TEMPERATURE	Outside air temperature corresponding to the evening rush or off hour. -50. ≤ X ≤ 140. °F	Error Type 7
EVENING OR OFF HOUR AMBIENT AIR WET-BULB TEMPERATURE	Outside air temperature corresponding to the evening rush or off hour. -50. ≤ X ≤ Evening Amb. Air Dry-Bulb Temp. °F	Error Type 8
AMPLITUDE OF ANNUAL TEMPERATURE FLUCTUATION	The program assumes the annual fluctuation of daily normal average temperature to be sinusoidal. Enter the amplitude of this sinusoid. 0. ≤ X ≤ 50. °F	Error Type 192

FORM 1F - GENERAL DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Design Hour Weather Data:

Ambient Air Dry-Bulb Temperature (^{o}F) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Ambient Air Wet-Bulb Temperature (^{o}F) 11 ☐☐☐☐☐☐☐☐☐☐ 20

Ambient Barometric Pressure (in. Hg) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Daily Weather Data:

Morning Ambient Air Dry-Bulb Temperature (^{o}F) 31 ☐☐☐☐☐☐☐☐☐☐ 40

Morning Ambient Air Wet-Bulb Temperature (^{o}F) 41 ☐☐☐☐☐☐☐☐☐☐ 50

Evening or Off Hour Ambient Air Dry-Bulb Temperature (^{o}F) 51 ☐☐☐☐☐☐☐☐☐☐ 60

Evening or Off Hour Ambient Air Wet-Bulb Temperature (^{o}F) 61 ☐☐☐☐☐☐☐☐☐☐ 70

Annual Weather Data:

Amplitude of Annual Temperature Fluctuation (^{o}F) 71 ☐☐☐☐☐☐☐☐☐☐ 80 ☒

FORM 1G - GENERAL DATA

AVERAGE PATRON WEIGHT	The average weight of patrons entering the trains at a stop, or on board the train at dispatch time. 50. ≤ X ≤ 200. lbs.	Error Type 4
PERCENT OF HEAT FROM TRAIN PROPULSION / BRAKING SYSTEM CAPTURED BY THE TES WHEN THE TRAIN IS STOPPED.	Enter the percentage of heat from the train propulsion/braking system which is removed by the trackway exhaust system (TES) while the train is stationary in a station. 0. ≤ X ≤ 100. percent	Error Type 151
PERCENT OF HEAT FROM TRAIN PROPULSION / BRAKING SYSTEM CAPTURED BY THE TES WHEN THE TRAIN IS MOVING.	Enter the percentage of heat from the train propulsion/braking system which is removed by the trackway exhaust system while the train is moving during entry and/or exit from a station. 0. ≤ X ≤ 100. percent	Error Type 151
PERCENT OF SENSIBLE HEAT FROM TRAIN AUXILIARIES & PASSENGERS CAPTURED BY THE TES WHEN TRAIN IS STOPPED.	Enter the percentage of sensible heat from the train auxiliaries and passengers which is removed by the trackway exhaust system while the train is stationary in a station. 0. ≤ X ≤ 100. percent	Error Type 151
PERCENT OF SENSIBLE HEAT FROM TRAIN AUXILIARIES & PASSENGERS CAPTURED BY THE TES WHEN TRAIN IS MOVING.	Enter the percentage of sensible heat from the train auxiliaries and passengers which is removed by the trackway exhaust system while the train is moving during entry and/or exit from a station. 0. ≤ X ≤ 100. percent	Error Type 151
MAXIMUM TRAIN SPEED AT WHICH THE TES OPERATES	The maximum speed at which the trackway exhaust system operates while trains are entering and/or leaving a station. 0. ≤ X ≤ 250. mph	Error Type 145
FIRE SIMULATION OPTION	Enter a 1. if a fire <u>is</u> being simulated 0. if a fire <u>is not</u> being simulated	Error Type 247, 248, 253, 257, 259
EFFECTIVE EMISSIVITY OF COMBUSTION PRODUCTS	Enter the effective emissivity of the combustion products downstream of the fire site. 0. ≤ X ≤ 1.	Error Type 262

FORM 1G - GENERAL DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Average Patron Weight (lbs)	1	☐☐☐☐☐☐☐☐☐☐	10
Percent of Heat from Train Propulsion/Braking System Captured by the Trackway Exhaust System when Train is Stopped	11	☐☐☐☐☐☐☐☐☐☐	20
Percent of Heat from Train Propulsion/Braking System Captured by the Trackway Exhaust System when Train is Moving	21	☐☐☐☐☐☐☐☐☐☐	30
Percent of Sensible Heat from Train Auxillaries and Passengers Captured by the Trackway Exhaust System when Train is Stopped	31	☐☐☐☐☐☐☐☐☐☐	40
Percent of Sensible Heat from Train Auxiliaries and Passengers Captured by the Trackway Exhaust System when Train is Moving	41	☐☐☐☐☐☐☐☐☐☐	50
Maximum Train Speed at Which the Trackway Exhaust System Operates (mph)	51	☐☐☐☐☐☐☐☐☐☐	60
Fire Simulation Option	61	☐☐☐☐☐☐☐☐☐☐	70
Effective Emissivity of Combustion Products	71	☐☐☐☐☐☐☐☐☐☐☒	80

FORM 2A - SYSTEM GEOMETRY

LINE SECTIONS

SECTION IDENTIFICATION NUMBER	This number identifies the tunnel section being described. $1. \le N \le 999.$	Error Type 153, 156
STARTING NODE NUMBER	This number is the identification number of the node at the beginning or backward end of the line section. $1. \le N \le 999.$	Error Type 154, 155, 157, 158
ENDING NODE NUMBER	This number is the identification number of the node at the forward end of the line section. $1. \le N \le 999.$	Error Type 154, 155, 157, 158
NUMBER OF SEGMENTS	Enter the total number of line segments within the line section. $1. \le N \le$ Number of Line Segments in system	Error Type 160, 161
INITIAL AIRFLOW	Enter the airflow that exists in the line section at the beginning of the simulation. $-10{,}000{,}000. \le X \le 10{,}000{,}000.$ cfm	Error Type 174, 175

The following errors are caused by exceeding program array sizes, and improper or illogical system arrangement:

Array sizes exceeded	Error Type 41, 188, 199, 200, 202
Improper system arrangement	Error Type 189, 196, 197

FORM 2A - SYSTEM GEOMETRY

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Line Sections

Section Identification Number	Starting Node Number	Ending Node Number	Number of Segments	Initial Airflow (cfm)
1 ☐☐☐☐☐ 5	11 ☐☐☐☐☐ 15	21 ☐☐☐☐☐ 25	31 ☐☐☐☐☐ 35	41 ☐☐☐☐☐☐☐☐☐☒ 50
1 ☐☐☐☐☐ 5	11 ☐☐☐☐☐ 15	21 ☐☐☐☐☐ 25	31 ☐☐☐☐☐ 35	41 ☐☐☐☐☐☐☐☐☐☒ 50
1 ☐☐☐☐☐ 5	11 ☐☐☐☐☐ 15	21 ☐☐☐☐☐ 25	31 ☐☐☐☐☐ 35	41 ☐☐☐☐☐☐☐☐☐☒ 50
1 ☐☐☐☐☐ 5	11 ☐☐☐☐☐ 15	21 ☐☐☐☐☐ 25	31 ☐☐☐☐☐ 35	41 ☐☐☐☐☐☐☐☐☐☒ 50
1 ☐☐☐☐☐ 5	11 ☐☐☐☐☐ 15	21 ☐☐☐☐☐ 25	31 ☐☐☐☐☐ 35	41 ☐☐☐☐☐☐☐☐☐☒ 50
1 ☐☐☐☐☐ 5	11 ☐☐☐☐☐ 15	21 ☐☐☐☐☐ 25	31 ☐☐☐☐☐ 35	41 ☐☐☐☐☐☐☐☐☐☒ 50
1 ☐☐☐☐☐ 5	11 ☐☐☐☐☐ 15	21 ☐☐☐☐☐ 25	31 ☐☐☐☐☐ 35	41 ☐☐☐☐☐☐☐☐☐☒ 50
etc.	etc.	etc.	etc.	etc.

FORM 2B - SYSTEM GEOMETRY

VENTILATION SHAFT SECTIONS

SECTION IDENTIFICATION NUMBER	This number identifies the ventilation shaft section being described. 1. ≤ N ≤ 999.	Error Type 153, 156
STARTING NODE NUMBER	This number is the identification number of the node at the beginning or backward end of the ventilation shaft section. 1. ≤ N ≤ 999.	Error Type 154, 155, 157, 158
ENDING NODE NUMBER	This number is the identification number of the node at the forward end of the ventilation shaft section. 1. ≤ N ≤ 999.	Error Type 154, 155, 157, 158
INITIAL AIRFLOW	This number corresponds to the airflow that exists in the ventilation shaft section at the beginning of the simulation. -10,000,000. ≤ X ≤ 10,000,000. cfm	Error Type 174, 175

The following errors are caused by exceeding program array sizes, and improper or illogical system arrangement:

Array sizes exceeded	Error Type 41, 188, 199, 200, 202
Improper system arrangement	Error Type 189, 196, 197

FORM 2B - SYSTEM GEOMETRY

Sheet ________ of ________
Made by: ________________
Checked by: ________________
Date: ________________

Ventilation Shaft Sections

Section Identification Number	Starting Node Number	Ending Node Number	Initial Airflow (cfm)
1 7 ☐☐☐☐☐☐☐	11 17 ☐☐☐☐☐☐☐	21 27 ☐☐☐☐☐☐☐	31 40 ☐☐☐☐☐☐☐☐☐☐☒
1 7 ☐☐☐☐☐☐☐	11 17 ☐☐☐☐☐☐☐	21 27 ☐☐☐☐☐☐☐	31 40 ☐☐☐☐☐☐☐☐☐☐☒
1 7 ☐☐☐☐☐☐☐	11 17 ☐☐☐☐☐☐☐	21 27 ☐☐☐☐☐☐☐	31 40 ☐☐☐☐☐☐☐☐☐☐☒
1 7 ☐☐☐☐☐☐☐	11 17 ☐☐☐☐☐☐☐	21 27 ☐☐☐☐☐☐☐	31 40 ☐☐☐☐☐☐☐☐☐☐☒
1 7 ☐☐☐☐☐☐☐	11 17 ☐☐☐☐☐☐☐	21 27 ☐☐☐☐☐☐☐	31 40 ☐☐☐☐☐☐☐☐☐☐☒
1 7 ☐☐☐☐☐☐☐	11 17 ☐☐☐☐☐☐☐	21 27 ☐☐☐☐☐☐☐	31 40 ☐☐☐☐☐☐☐☐☐☐☒
1 7 ☐☐☐☐☐☐☐	11 17 ☐☐☐☐☐☐☐	21 27 ☐☐☐☐☐☐☐	31 40 ☐☐☐☐☐☐☐☐☐☐☒
etc.	etc.	etc.	etc.

FORM 3A - LINE SEGMENT DATA

The series 3 forms must be filled out for each line segment in the system. All the necessary series 3 forms are filled out for the first line segment, and then this procedure is repeated for the second line segment and so on, until all the line segments have been described. The line segments must be entered in the same order as were the line sections. Within each line section, the segment located at the backward end must be described first, and then each successive line segment in the direction of positive airflow must be described until the segment at the forward end of the section has been described.

IDENTIFICATION NUMBER	This number is used to identify this particular line segment in subsequent references to it. The number that identifies each particular line segment is the line segment identification number. $1. \le N \le 999.$	Error Type 149, 162
LINE SEGMENT TYPE	Enter the segment type: 1 = Tunnel segment - Does not contain trackway exhaust system (TES) or an impulse fan system (IFS). 2 = Station segment - Contains TES that captures prop/brkg and aux/pass heat. 3 = Station segment - Contains TES that captures prop/brkg heat only. 4 = Station segment - Contains TES that captures aux/pass heat only. 9 through 14 = Special tunnel segment - Contains an IFS. Type no. 9 contains IFS type 1, type no. 10 contains IFS type 2, etc. 5 through 8, 15 and 16 = Reserved for future use. If entered, treated as a type 1. $1. \le N \le 6.$	Error Type 10, 251, 256
IDENTIFICATION TITLE	Enter an alphanumeric character title describing this line segment.	
LENGTH	Enter the length of the line segment. $10. \le X \le 100{,}000.$ ft	Error Type 19
CROSS SECTION AREA	Enter the area of the line segment cross-section. $75. \le X \le 10{,}000.$ ft^2	Error Type 20
STACK HEIGHT	Enter the difference in elevation between the forward and backward ends of the line segment. This value should only be input if the Fire Simulation Option on Form 1G is 1. $\lvert X \rvert \le$ Length of line segment, ft	Error Type 255
FIRE SEGMENT	Enter a 1. if fire related calculations <u>are</u> to be performed for this segment. 0. if fire related calculations <u>are not</u> to be performed for this line segment	Error Type 228, 252

FORM 3A - LINE SEGMENT DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Identification Number 1 ☐☐☐☐☐☐☐☐☐☐ 10

Line Segment Type 11 ☐☐☐☐☐☐☐☐☐☐ 20

21 Identification Title ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ 56 ☒

Length (ft) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Cross Section Area (ft^2) 11 ☐☐☐☐☐☐☐☐☐☐ 20

Stack Height (ft) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Fire Segment 31 ☐☐☐☐☐☐☐☐☐☐ 40 ☒

FORM 3B - LINE SEGMENT DATA

SEGMENT PERIMETERS	The physical perimeter of a line segment may be entered in from one to eight portions, each of which will correspond to a roughness length. The total length of the perimeters must add up to the physical perimeter of the line segment. For each perimeter length supplied, a roughness length must be supplied. Based on these input data, a perimeter weighted average Darcy-Weisbach effective friction factor will be computed internally. The purpose of this procedure is to allow the program user to provide different roughnesses for the tunnel sides, ceiling, trackbed, etc. $30. \leq X \leq 1000.$ ft	Error Type 21
	The total perimeter must be greater than $\sqrt{4\pi \text{ x Segment Area}}$	Error Type 70
ROUGHNESS LENGTHS	Roughness length, or in the case of a ribbed tunnel, equivalent roughness length. $0 \leq X \leq 2.0$ ft	Error Type 22

FORM 3B - LINE SEGMENT DATA

Sheet ________ of ________
Made by: ____________________
Checked by: ____________________
Date: ____________________

Segment
Perimeters (ft)

21 ☐☐☐☐☐☐☐☐☐☐ 30
51 ☐☐☐☐☐☐☐☐☐☐ 60

Roughness
Lengths (ft)

21 ☐☐☐☐☐☐☐☐☐☐ 30
51 ☐☐☐☐☐☐☐☐☐☐ 60

1 ☐☐☐☐☐☐☐☐☐☐ 10
31 ☐☐☐☐☐☐☐☐☐☐ 40
61 ☐☐☐☐☐☐☐☐☐☐ 70
1 ☐☐☐☐☐☐☐☐☐☐ 10
31 ☐☐☐☐☐☐☐☐☐☐ 40
61 ☐☐☐☐☐☐☐☐☐☐ 70

11 ☐☐☐☐☐☐☐☐☐☐ 20
41 ☐☐☐☐☐☐☐☐☐☐ 50
71 ☐☐☐☐☐☐☐☐☐☐ 80 ☒
11 ☐☐☐☐☐☐☐☐☐☐ 20
41 ☐☐☐☐☐☐☐☐☐☐ 50
71 ☐☐☐☐☐☐☐☐☐☐ 80 ☒

FORM 3C - LINE SEGMENT DATA

SEGMENT HEAD LOSS COEFFICIENTS	Pressure losses due to flow turning, abrupt expansions or contractions in segment cross section areas, and obstructions in the flow, etc., are expressed as linear functions of the pertinent velocity heads of the moving air by the use of coefficients that are constants for a given geometry. These coefficients are known as head loss or "minor" loss coefficients. They are used herein to describe the losses at the portals and intersections with other segments. $0. \leq X \leq 1000.$	Error Type 28
WETTED WALL SURFACE	The percent of wall surface that is constantly wet in the line segment. $0. \leq X \leq 100.$ percent	Error Type 151
NUMBER OF SUBSEGMENTS	The number of sub-divisions into which this segment is partitioned for thermodynamic calculations. $1. \leq N \leq 1200.$	Error Type 29, 30, 43
NUMBER OF STEADY-STATE HEAT SOURCES	The number of fixed sources or sinks of sensible and/or latent heat in each segment. $0. \leq N$	

FORM 3C - LINE SEGMENT DATA

Sheet ________ of ________
Made by: ________________
Checked by: ________________
Date: ________________

Segment Head Loss Coefficients

	1 Positive Flow 10	11 Negative Flow 20
At Forward Limit	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐
	21 30	31 40
At Backward Limit	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐
		41 50
Wetted Wall Surface (percent)		☐☐☐☐☐☐☐☐☐☐
		51 60
Number of Subsegments		☐☐☐☐☐☐☐☐☐☐
		61 70
Number of Steady-State Heat Sources		☐☐☐☐☐☐☐☐☐☐☒

FORM 3D - LINE SEGMENT DATA

Steady-State Heat Source Description

Describe each steady-state heat source in this line segment. The number of times this form is completed should be equal to the "number of steady-state heat sources" on Form 3C. If that number is 0, skip this form.

STARTING SUBSEGMENT NUMBER	This is the first subsegment in which this steady-state heat source is found. The starting and ending subsegment numbers indicate the region over which the entire source is uniformly distributed. 1. ≤ N ≤ Number of subsegments in this segment	Error Type 31
ENDING SUBSEGMENT NUMBER	This is the last subsegment in which this steady-state heat source is found. The starting and ending subsegment numbers indicate the region over which the entire source is uniformly distributed. Starting subsegment number ≤ N ≤ Number of subsegments in this segment	Error Type 31
SOURCE TYPE	Enter the source type. 1 = miscellaneous heat source 2 = heating or cooling source	Error Type 6
SENSIBLE HEAT RATE	The rate of sensible heat addition or removal in Btu/hr corresponding to the source named below. Heat removal is signified by a negative rate.	
LATENT HEAT RATE	The rate of latent heat addition or removal in Btu/hr corresponding to the source named below. Heat removal is signified by a negative rate.	
IDENTIFICATION	Up to 30 alphanumeric characters can be used as an identification of the heat source or sink which is printed on the program input verification.	

FORM 3D - LINE SEGMENT DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Steady-State Heat Source Description

Starting Subsegment Number 1 ☐☐☐☐☐☐☐☐☐☐ 10

Ending Subsegment Number 11 ☐☐☐☐☐☐☐☐☐☐ 20

Source Type 1 = Misc. Heat Source
2 = Heating or Cooling Source 21 ☐☐☐☐☐☐☐☐☐☐ 30

Sensible Heat Rate (Btu/hr) 31 ☐☐☐☐☐☐☐☐☐☐ 40

Latent Heat Rate (Btu/hr) 41 ☐☐☐☐☐☐☐☐☐☐ 50

Identification 51 ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☒ 80

FORM 3E - LINE SEGMENT DATA

Wall Surface Temperature and Initial Air Temperature.

The wall surface temperature and initial air temperature must be specified for each subsegment. One or more forms may be used providing the first starting subsegment is number one, the ending subsegment on the last form is the highest subsegment in the segment, and all of the intermediate subsegments are defined.

STARTING SUBSEGMENT NUMBER	This is the first subsegment in which the initial conditions specified below are valid. The starting and ending subsegment numbers locate the positioning within the line segment for which the initial conditions are valid. $1. \le N \le$ Number of subsegments in this segment Error Type 139, 150
ENDING SUBSEGMENT NUMBER	This is the last subsegment in which the initial conditions specified below are valid. The starting and ending subsegment numbers locate the positioning within the line segment for which the initial conditions are valid. Starting subsegment number $\le N \le$ Number of subsegments in this line segment Error Type 139, 150
WALL SURFACE TEMPERATURE	Used in the computation of convective heat transfer between the system air and the walls. $0. \le X \le 130.$ °F Error Type 23
INITIAL DRY-BULB AIR TEMPERATURE	Initial value for the dry-bulb temperature in the segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. $0. \le X \le 130.$ °F Error Type 24
INITIAL WET-BULB AIR TEMPERATURE	Initial value for the wet-bulb temperature in the segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. Both the initial dry-bulb and wet-bulb temperatures are assumed to be homogeneous over the length of segment. $0. \le X \le$ Initial dry-bulb air temperature °F Error Type 25

FORM 3E - LINE SEGMENT DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Wall Surface Temperature and Initial Air Temperature

Starting Segment Number	1	10
Ending Segment Number	11	20
Wall Surface Temperature (°F)	21	30
Initial Dry-Bulb Air Temperature (°F)	31	40
Initial Wet-Bulb Air Temperature (°F)	41	50 ☒

FORM 3F - LINE SEGMENT DATA

Complete this form if the Environmental Control Load Evaluation Option is equal to 1 or 2.

TUNNEL WALL THICKNESS	Enter the thickness of the tunnel wall in the line segment. $0. \le X \le 30.$	Error Type 63
DISTANCE BETWEEN THE INSIDE WALL SURFACES OF ADJACENT TUNNELS	Enter the minimum distance between the inside wall surfaces of this line segment and that of any adjacent tunnel. Enter a zero if there is no adjacent tunnel. $0. \le X \le 100.$ ft	Error Type 131
TUNNEL WALL THERMAL CONDUCTIVITY	Enter the thermal conductivity of the tunnel wall for the line segment. $0.005 \le X \le 2.$ Btu/ft-hr-^{o}F	Error Type 34
TUNNEL WALL THERMAL DIFFUSIVITY	Enter the thermal diffusivity of the tunnel wall for the line segment. $0.005 \le X \le 1.$ ft^2/hr	Error Type 35
SURROUNDING SOIL THERMAL CONDUCTIVITY	Enter the thermal conductivity of the soil surrounding the line segment. $0.005 \le X \le 2.$ Btu/ft-hr-^{o}F	Error Type 34
SURROUNDING SOIL THERMAL DIFFUSIVITY	Enter the thermal diffusivity of the soil surrounding the line segment. $0.005 \le X \le 1.$ ft^2/hr	Error Type 35
DEEP SINK TEMPERATURE	Enter the deep sink temperature of the soil surrounding the line segment. $0. \le X \le 100.$ ^{o}F	Error Type 159

FORM 3F - LINE SEGMENT DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Tunnel Wall Thickness (ft) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Distance Between the Inside Wall Surfaces of Adjacent Tunnels (ft) 11 ☐☐☐☐☐☐☐☐☐☐ 20

TUNNEL WALL PROPERTIES:

Thermal Conductivity (Btu/ft-hr-°F) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Thermal Diffusivity (ft^2/hr) 31 ☐☐☐☐☐☐☐☐☐☐ 40

SURROUNDING SOIL PROPERTIES:

Thermal Conductivity (Btu/ft-hr-°F) 41 ☐☐☐☐☐☐☐☐☐☐ 50

Thermal Diffuslvity (ft^2/hr) 51 ☐☐☐☐☐☐☐☐☐☐ 60

Deep Sink Temperature (°F) 61 ☐☐☐☐☐☐☐☐☐☐ 70 ☒

FORM 4 - FIRE/UNSTEADY HEAT SOURCES

This form must be filled out for each unsteady heat source entered in the "Number of Unsteady Heat Sources" on form 1D. If a 0. was entered on form 1D, skip to the next form.

SOURCE NAME	Name identifying source. This information will appear in the Input verification printout. Up to 36 alphanumeric characters may be used.	
SOURCE LOCATION SEGMENT	The identification number of the line segment in which the unsteady heat source is located. N may be any valid line segment I.D. number	Error Type 138
SOURCE LOCATION SUBSEGMENT WITHIN THE SEGMENT	The number of the subsegment within the segment in which the unsteady heat source is located. 1. ≤ N ≤ Number of subsegments in this line segment	Error Type 139, 260
SENSIBLE HEAT RATE	The rate of sensible heat release by the unsteady heat source in Btu/hr.	
LATENT HEAT RATE	The rate of latent heat release by the unsteady heat source in Btu/hr.	
SIMULATION TIME AFTER WHICH SOURCE BECOMES ACTIVE	The simulation time after which the unsteady heat source becomes active. 0. ≤ X sec.	Error Type 260
SIMULATION TIME AFTER WHICH SOURCE BECOMES INACTIVE	The simulation time after which the unsteady heat source becomes inactive. Time after which source becomes active ≤ X sec.	Error Type 140, 260

The next two items should be entered only if the Fire Simulation Option on Form 1G is 1, and this unsteady state heat source is located within a Fire Segment (See Form 3A).

EFFECTIVE FLAME TEMPERATURE OF FIRE SOURCE	Enter the effective temperature of the flame for the fire source. 500. ≤ X ≤ 2000. °F	Error Type 249
EFFECTIVE AREA FOR RADIATION	Enter that area of the fire through which radiation to the tunnel wall surfaces can take place. For example, for a fire within a vehicle, this would be equal to the total area of the car's windows and open doors. 0. ≤ X ≤ Surface area of the subsegment	Error Type 250

FORM 4 - UNSTEADY HEAT SOURCES

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Source Name	1	36
Source Location Segment	41	50
Source Location Subsegment Within the Segment	51	60 ☒
Sensible Heat Rate (Btu/hr)	1	10
Latent Heat Rate (Btu/hr)	11	20
Simulation Time After which Source Becomes Active (sec)	21	30
Simulation Time After which Source Becomes Inactive (sec)	31	40
Effective Flame Temperature of Fire Source (^{o}F)	41	50
Effective Area for Radiation (ft^2)	51	60 ☒

FORM 5A - VENTILATION SHAFT DATA

The series 5 forms must be filled out for each ventilation shaft in the system. The order in which these ventilation shafts are described must be in the same sequential order that the ventilation shaft sections were entered on form 2B. All the necessary series 5 forms are filled out for the first ventilation shaft and then this procedure is repeated for the second ventilation shaft and so on until all of the ventilation shafts have been described.

IDENTIFICATION NUMBER	The number by which this vent shaft is identified. This number may not be used to identify any other line segment or ventilation shaft. $1. \le N \le 999.$	Error Type 149, 162
SECTION TYPE	Enter the ventilation shaft type: 1 - ventilation shaft or blast shaft (may or may not contain a fan) 2 - stairway or escalator $1. \le N \le 999.$	Error Type 167
IDENTIFICATION TITLE	This will identify the ventilation shaft, and may be used to indicate its proximity to physical landmarks. The alphanumeric information entered will be printed out during data input verification and on the output forms. Up to 36 characters may be used.	

FORM 5A - VENTILATION SHAFT DATA

Sheet ________ of ________
Made by: ________________
Checked by: ________________
Date: ________________

Identification Number 1 ☐☐☐☐☐☐☐☐☐☐ 10

Section Type 1 = Vent (Fan or No Fan)
2 = Stairwav

11 ☐☐☐☐☐☐☐☐☐☐ 20

Identification Title

21 ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ 56 ☒

FORM 5B - VENTILATION SHAFT DATA

NUMBER OF SEGMENTS IN THIS VENT SHAFT	This number corresponds to the total number of segments in the vent shaft. $1. \leq N$	Error Type 172
NUMBER OF SUBSEGMENTS IN RESULTING EQUIVALENT VENT SHAFT	This number corresponds to the total number of subsegments the user desires to have in the equivalent straight-through vent shaft calculated by the SES. $1. \leq N \leq 1600.$	Error Type 42, 43
GRATE FREE AREA	This area corresponds to the total free area open to airflow of the vent shaft grating. $3. \leq X \leq 3000.$ ft^2	Error Type 38
DESIGN MAXIMUM OUTFLOW AIR VELOCITY AT GRATE	This number corresponds to the design maximum outflow air velocity at the vent shaft grating. $0. \leq X \leq 6000.$ fpm	Error Type 169
WALL SURFACE TEMPERATURE	Since heat transfer is computed across ventilation shaft walls, the program must be supplied with a value for the wall surface temperature. $0. \leq X \leq 130.$ °F	Error Type 23
INITIAL AIR DRY-BULB TEMPERATURE	Initial value for the dry-bulb temperature in the ventilation shaft segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. $0. \leq X \leq 130.$ °F	Error Type 24
INITIAL AIR WET-BULB TEMPERATURE	Initial value for the wet-bulb temperature in the ventilation shaft segment. If this value is unknown, a value equal to the outside ambient temperature is recommended as a first approximation. $0. \leq X \leq$ Initial air dry-bulb temp. °F	Error Type 25
STACK HEIGHT	This number corresponds to the difference in height between the node at the tunnel/vent shaft junction and the node at the surface of the vent shaft where the vent discharges to the atmosphere. The stack height should not be greater than the sum of the lengths of the individual segments in this shaft (see Form 5D). Enter a zero if buoyancy effects within the shaft are negligible. $-1000. \leq X \leq 1000.$ ft	Error Type 37, 173

FORM 5B - VENTILATION SHAFT DATA

Sheet ________ of ________
Made by: ____________________
Checked by: ____________________
Date: ____________________

Number of Segments in this Vent Shaft	1 ☐☐☐☐☐☐☐☐☐☐ 10
Number of Subsegments in Resulting Equivalent Vent Shaft	11 ☐☐☐☐☐☐☐☐☐☐ 20
Grate Free Area (ft^2)	21 ☐☐☐☐☐☐☐☐☐☐ 30
Design Maximum Outflow Air Velocity at Grate (fpm)	31 ☐☐☐☐☐☐☐☐☐☐ 40
Wall Surface Temperature (°F)	41 ☐☐☐☐☐☐☐☐☐☐ 50
Initial Air Dry-Bulb Temperature (°F)	51 ☐☐☐☐☐☐☐☐☐☐ 60
Initial Air Wet-Bulb Temperature (°F)	61 ☐☐☐☐☐☐☐☐☐☐ 70
Stack Height (ft)	71 ☐☐☐☐☐☐☐☐☐☐ 80 ☒

FORM 5C - VENTILATION SHAFT DATA

Skip this form if the "Number of Fan Types" on form 1D is 0.

FAN TYPE	This number identifies which fan type is being used in this particular vent shaft. If there is NO fan, enter a zero and skip the remainder of this form. If there IS a fan, enter the fan type number (N = 1,2,3,...) and complete the rest of this form. 0. ≤ N ≤ Number of fan types Error Type 170, 171
SIMULATION TIME AFTER WHICH FAN SWITCHES ON	This entry allows the user to define the operating period of the fan. Enter the time in the simulation the fan switches on. X ≥ 0. sec. Error Type 76
SIMULATION TIME AFTER WHICH FAN SWITCHES OFF	This entry allows the user to define the operating period of the fan. Enter the time in the simulation the fan switches off. Time fan switches on ≤ X Error Type 76
DIRECTION OF FAN OPERATION	Enter the direction of fan operation. Shaft open to Atmosphere: +1 - outflow (exhaust) direction -1 - inflow (supply) direction 0 - off Cross Passage shaft Not Directly open to Atmosphere: +1 - fan operates in the direction of positive airflow in the shaft -1 - fan operates in the direction of negative airflow in the shaft 0 - off

FORM 5C - VENTILATION SHAFT DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Fan Information

Fan Type
0 = No Fan
1,2,3... = Type of Fan

1 ☐☐☐☐☐☐☐☐☐☐ 10

Simulation Time After which Fan Switches On (sec)

11 ☐☐☐☐☐☐☐☐☐☐ 20

Simulation Time After which Fan Switches Off (sec)

21 ☐☐☐☐☐☐☐☐☐☐ 30

Initial Wet-Bulb Air Temperature (°F)
+1.0 = Exhaust or Outflow
-1.0 = Supply or Inflow

31 ☐☐☐☐☐☐☐☐☐☐ 40 ☒

FORM 5D - VENTILATION SHAFT DATA

Ventilation Shaft Segment Description

This form is used to describe each of the segments counted in the "Number of Segments in this vent shaft" on Form 5B.

LENGTH	Enter the length of the ventilation shaft segment 0. ≤ X ≤ 2000. ft 10. ≤ Total length of all segments in vent shaft ≤ 2000. Ft	 Error Type 40 Error Type 190
AREA	Enter the cross-sectional area of the ventilation shaft segment. The area of the first segment Is used as the equivalent vent shaft area, and all velocities in the vent shaft are given with respect to this area. 3. ≤ X ≤ 3000. ft^2	 Error Type 38
PERIMETER	Enter the perimeter of the ventilation shaft segment. 5. ≤ X ≤ 500. ft	 Error Type 39, 70
SEGMENT HEAD LOSS COEFFICIENTS	Pressure losses due to flow turning, abrupt expansions or contractions in ventilation shaft cross-section areas, and obstructions in the flow etc. are expressed as linear functions of the pertinent velocity heads of the moving air by the use of coefficients that are constants for a given geometry. These coefficients are known as head loss or minor loss coefficients. They are used herein to describe the losses in the shafts and their junctions with line segments. Each of the head loss coefficients are entered with reference to the area of the segment with which they are entered. 0. ≤ X ≤ 1000.	 Error Type 28

FORM 5D - VENTILATION SHAFT DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Segment Description

Length (ft) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Area (ft^2) 11 ☐☐☐☐☐☐☐☐☐☐ 20

Perimeter (ft) 21 ☐☐☐☐☐☐☐☐☐☐ 30

SEGMENT HEAD LOSS COEFFICIENTS:

Forward End, Positive Flow 31 ☐☐☐☐☐☐☐☐☐☐ 40

Forward End, Negative Flow 41 ☐☐☐☐☐☐☐☐☐☐ 50

Backward End, Positive Flow 51 ☐☐☐☐☐☐☐☐☐☐ 60

Backward End, Negative Flow 61 ☐☐☐☐☐☐☐☐☐☐ 70 ☒

FORM 6A - NODE DATA

Series 6 forms must be completed for each node in the system.

NODE NUMBER	Enter the identifying number of the node. 1. ≤ N ≤ 999. N must be any node identification number	Error Type 154, 165, 183
NODE AERODYNAMIC TYPE	Enter the node aerodynamic type. 0 - straight-through junction or portal 1 - tunnel to tunnel crossover junction 2 - dividing wall termination junction 3 - "T" junction 4 - angled junction 5 - "Y" junction 7 - zero total pressure change junction	Error Type 177, 214
NODE THERMODYNAMIC TYPE	Enter the node thermodynamic type. 1 - mixing node 2 - partial-mixing node 3 - temperature/humidity boundary condition	Error Type 166, 178, 179, 184, 198

FORM 6A - NODE DATA

Sheet ________ of ________
Made by: ____________________
Checked by: ________________
Date: ______________________

Node Number 1 ☐☐☐☐☐☐☐☐☐☐ 10

Node Aerodynamic Type 11 ☐☐☐☐☐☐☐☐☐☐ 20

Node Thermodynamic Type 21 ☐☐☐☐☐☐☐☐☐☐☒ 30

1 = Mixing
2 = Partial Mixing
3 = Temp/Humidity Boundary Condition or Portal

FORM 6B - NODE DATA

Complete this form for thermodynamic Type 3 nodes only

DRY-BULB TEMPERATURE AT BOUNDARY	If the dry-bulb temperature at this boundary node is different from the ambient condition, enter the dry-bulb temperature here. If it is the same as the ambient condition, enter zero (0). -50. ≤ X ≤ 140. °F	Error Type 7
WET-BULB TEMPERATURE AT BOUNDARY	If the wet-bulb temperature at this boundary node is different from the ambient condition, enter the wet-bulb temperature here. If it is the same as the ambient condition, enter zero (0). -50. ≤ X ≤ Dry-bulb temperature °F	Error Type 8

Complete the next 4 entries only when the Environmental Control Load Evaluation Option is 1 or 2. If the morning and evening dry-bulb and wet-bulb temperature conditions are different from the corresponding ambient conditions entered on Form 1F, enter all four conditions below. If the conditions are the same as the ambient conditions, enter zeros.

MORNING DRY-BULB BOUNDARY CONDITION TEMPERATURE	Enter the dry-bulb temperature for the node corresponding to the morning rush hour. -50. ≤ X ≤ 140. °F	Error Type 7
MORNING WET-BULB BOUNDARY CONDITION TEMPERATURE	Enter the wet-bulb temperature for the node corresponding to the morning rush hour. -50. ≤ X ≤ Morning dry-bulb temp. °F	Error Type 8
EVENING OR OFF HOUR DRY-BULB BOUNDARY CONDITION TEMPERATURE	Enter the dry-bulb temperature for the node corresponding to the evening rush or off hour. -50. ≤ X ≤ 140. °F	Error Type 7
EVENING OR OFF HOUR WET-BULB BOUNDARY CONDITION TEMPERATURE	Enter the wet-bulb temperature for the node corresponding to the evening rush or off hour. -50. ≤ X ≤ Evening dry-bulb temp. °F	Error Type 8

FORM 6B - NODE DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Daily Boundary Condition Data
(Complete this form for thermodynamic Type 3 nodes only.)

Dry-Bulb Temperature at Boundary (°F) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Wet-Bulb Temperature at Boundary (°F) 11 ☐☐☐☐☐☐☐☐☐☐ 20

Complete the next 4 entries only if the Environmental Control Load Evaluation Option is 1 or 2.

Morning Dry-Bulb Temperature (°F) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Morning Wet-Bulb Temperature (°F) 31 ☐☐☐☐☐☐☐☐☐☐ 40

Evening or Off Hour Dry-Bulb Boundary Condition Temperature (°F) 41 ☐☐☐☐☐☐☐☐☐☐ 50

Evening or Off Hour Wet-Bulb Boundary Condition Temperature (°F) 51 ☐☐☐☐☐☐☐☐☐☐ 60 ☒

FORM 6C - NODE DATA

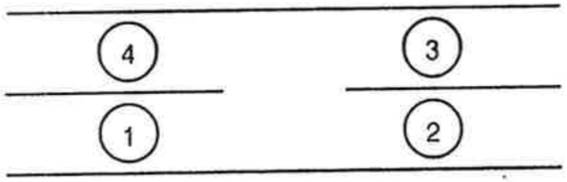
This Form is filled in for type 1 Aerodynamic Nodes _only_.

SECTION IDENTIFICATION NUMBER OF BRANCH 1	Enter the section identification number of the section that constitutes Branch 1 for this aerodynamic type 1 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 2	Enter the section identification number of the section that constitutes Branch 2 for this aerodynamic type 1 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 3	Enter the section identification number of the section that constitutes Branch 3 for this aerodynamic type 1 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 4	Enter the section identification number of the section that constitutes Branch 4 for this aerodynamic type 1 node. N must be any valid Section I.D. number Error Type 203
ASPECT RATIO	Enter the ratio of the length of the crossover opening to twice the height of the tunnel (L/2H). $0.1 \le X \le 50$. Error Type 206

FORM 6C - NODE DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Aerodynamic Node Type 1
Tunnel to Tunnel Crossover Junction



Section Identification Number of Branch 1 — 1 ☐☐☐☐☐☐☐☐☐☐ 10

Section Identification Number of Branch 2 — 11 ☐☐☐☐☐☐☐☐☐☐ 20

Section Identification Number of Branch 3 — 21 ☐☐☐☐☐☐☐☐☐☐ 30

Section Identification Number of Branch 4 — 31 ☐☐☐☐☐☐☐☐☐☐ 40

Aspect Ratio — 41 ☐☐☐☐☐☐☐☐☐☐ 50 ☒

FORM 6D - NODE DATA

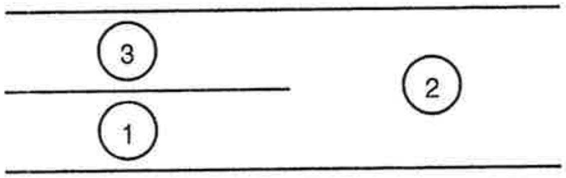
This Form is filled in for type 2 Aerodynamic Nodes only.

SECTION IDENTIFICATION NUMBER OF BRANCH 1	Enter the section identification number of the section that constitutes Branch 1 for this aerodynamic type 2 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 2	Enter the section identification number of the section that constitutes Branch 2 for this aerodynamic type 2 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 3	Enter the section identification number of the section that constitutes Branch 3 for this aerodynamic type 2 node. N must be any valid Section I.D. number Error Type 203

FORM 6D - NODE DATA

Sheet ________ of ________
Made by: ________________
Checked by: ________________
Date: ________________

Aerodynamic Node Type 2
Dividing Wall Termination Junction



Section Identification Number of Branch 1 — 1 ☐☐☐☐☐☐☐☐☐☐ 10

Section Identification Number of Branch 2 — 11 ☐☐☐☐☐☐☐☐☐☐ 20

Section Identification Number of Branch 3 — 21 ☐☐☐☐☐☐☐☐☐☐ 30 ☒

FORM 6E - NODE DATA

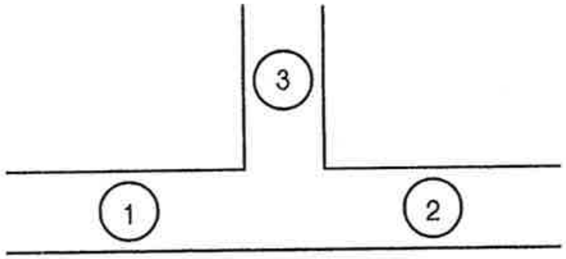
This Form is filled in for type 3 Aerodynamic Nodes <u>only</u>.

SECTION IDENTIFICATION NUMBER OF BRANCH 1	**Enter the section identification number of the section that constitutes Branch 1 for this aerodynamic type 3 node. Area Branch 1 ≥ Area Branch 2. N must be any valid Section I.D. number** Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 2	Enter the section identification number of the section that constitutes Branch 2 for this aerodynamic type 3 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 3	Enter the section identification number of the section that constitutes Branch 3 for this aerodynamic type 3 node. N must be any valid Section I.D. number Error Type 203
ASPECT RATIO	Enter the ratio of the axial length of the vent shaft along the tunnel to the vent shaft width at the vent opening to the tunnel (L/W). $0.1 \leq X \leq 30$. Error Type 207

FORM 6E - NODE DATA

Sheet ________ of ________
Made by: ____________________
Checked by: ____________________
Date: ____________________

Aerodynamic Node Type 3



"T" Junction

Section Identification Number of Branch 1 — 1 ☐☐☐☐☐☐☐☐☐☐ 10

Section Identification Number of Branch 2 — 11 ☐☐☐☐☐☐☐☐☐☐ 20

Section Identification Number of Branch 3 — 21 ☐☐☐☐☐☐☐☐☐☐ 30

Aspect Ratio — 31 ☐☐☐☐☐☐☐☐☐☐ 40 ☒

FORM 6F - NODE DATA

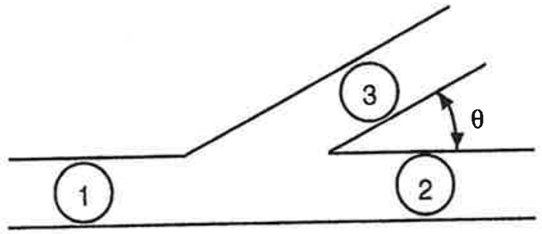
This Form Is filled in for type 4 Aerodynamic Nodes <u>only.</u>

SECTION IDENTIFICATION NUMBER OF BRANCH 1	Enter the section identification number of the section that constitutes Branch 1 for this aerodynamic type 4 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 2	Enter the section identification number of the section that constitutes Branch 2 for this aerodynamic type 4 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 3	Enter the section identification number of the section that constitutes Branch 3 for this aerodynamic type 4 node. N must be any valid Section I.D. number Error Type 203
ASPECT RATIO	Enter the ratio of the axial length of the angled tunnel opening to its height. $0.1 \leq X \leq 30.$ Error Type 207
JUNCTION ANGLE θ	Enter the angle between Branch 2 and Branch 3. This angle may only be entered as either 10, 20, or 30 degrees. Error Type 205

FORM 6F - NODE DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Aerodynamic Node Type 4



Angled Junction

Section Identification Number of Branch 1 — 1 ☐☐☐☐☐☐☐☐☐☐ 10

Section Identification Number of Branch 2 — 11 ☐☐☐☐☐☐☐☐☐☐ 20

Section Identification Number of Branch 3 — 21 ☐☐☐☐☐☐☐☐☐☐ 30

Aspect Ratio — 31 ☐☐☐☐☐☐☐☐☐☐ 40

Junction Angle θ — 41 ☐☐☐☐☐☐☐☐☐☐ 50 ☒

FORM 6G - NODE DATA

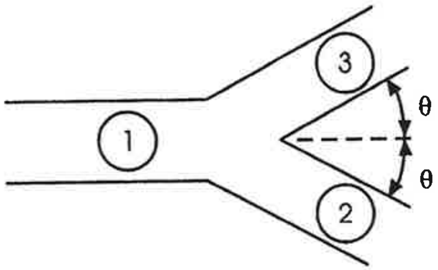
This Form is filled in for type 5 Aerodynamic Nodes <u>only</u>.

SECTION IDENTIFICATION NUMBER OF BRANCH 1	Enter the section identification number of the section that constitutes Branch 1 for this aerodynamic type 5 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 2	Enter the section identification number of the section that constitutes Branch 2 for this aerodynamic type 5 node. N must be any valid Section I.D. number Error Type 203
SECTION IDENTIFICATION NUMBER OF BRANCH 3	Enter the section identification number of the section that constitutes Branch 3 for this aerodynamic type 5 node. N must be any valid Section I.D. number Error Type 203
ASPECT RATIO	Enter the ratio of the axial length of the angled tunnel opening to its height. $0.1 \leq X \leq 30$. Error Type 207
JUNCTION ANGLE θ	Enter one-half the angle between Branch 2 and Branch 3. This angle may only be entered as either 10, 20, or 30 degrees. Error Type 205

FORM 6G - NODE DATA

Sheet ________ of ________
Made by: ________________
Checked by: ________________
Date: ________________

Aerodynamic Node Type 5



"Y" Junction

Section Identification Number of Branch 1 — 1 ☐☐☐☐☐☐☐☐☐☐ 10

Section Identification Number of Branch 2 — 11 ☐☐☐☐☐☐☐☐☐☐ 20

Section Identification Number of Branch 3 — 21 ☐☐☐☐☐☐☐☐☐☐ 30

Aspect Ratio — 31 ☐☐☐☐☐☐☐☐☐☐ 40

Junction Angle θ — 41 ☐☐☐☐☐☐☐☐☐☐ 50 ☒

FORM 6H - NODE DATA

Complete this form only if the node thermodynamic type is 2.

SECTIONS CONNECTED TO THERMAL SUBNODE “A”	Enter the identification number of the sections connected to the thermal subnode "A". N must be an identification number of a section connected to this node. Error Type 153, 181, 182
SECTIONS CONNECTED TO THERMAL SUBNODE “B”	Enter the identification number of the section connected to the thermal subnode "B". N must be an identification number of a section connected to this node. Error Type 153, 181, 182
SECTIONS CONNECTED TO THERMAL SUBNODE “C”	Enter the identification number of the sections connected to the thermal subnode "C". N must be an identification number of a section connected to this node. Error Type 153, 181, 182

FORM 6H - NODE DATA

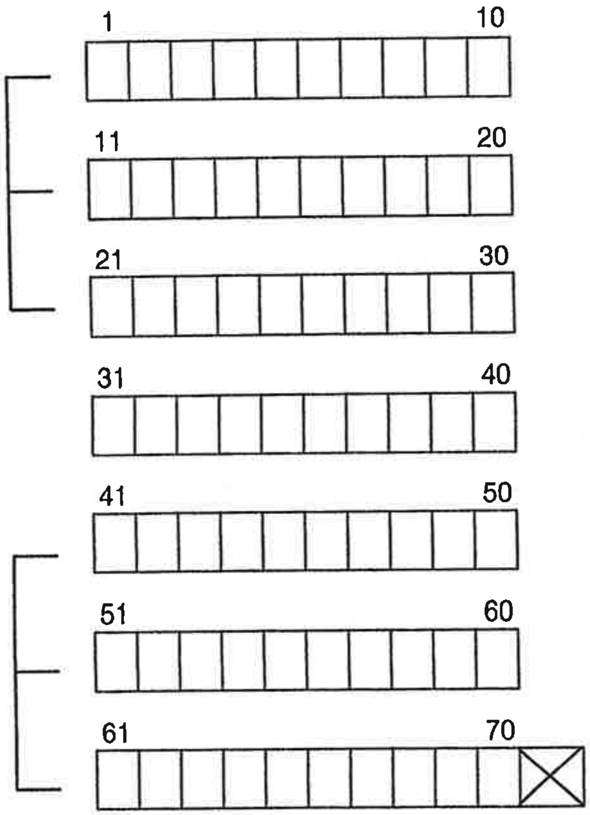
Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Geometrical Configuration of Thermodynamic Type 2 Nodes

Sections Connected to Thermal Subnode "A"

Sections Connected to Thermal Subnode "B"

Sections Connected to Thermal Subnode "C"



FORM 7A - FAN DESCRIPTION

Skip Forms 7A & 7B if the Number of Fan Types on Form 1D is zero.

FAN IDENTIFICATION	Information identifying the fan being described will appear on the input verification printout. Up to 36 alphanumeric characters can be used.
AIR DENSITY AT WHICH THE FAN PERFORMANCE CURVE WAS MEASURED	Enter the air density for which the manufacturer determined the fan performance curve. The program will internally adjust the fan performance curve to adjust for the difference between this density and the system ambient density. $0.040 \leq X \leq 0.085$ lb/ft^3 Error Type 187
TIME REQUIRED FOR THE FAN TO REACH FULL OPERATING SPEED	This number corresponds to the amount of time required for the fan to overcome the inertial effects of its blades and motor, in reaching its full operating speed, and in slowing down from full operating speed to stop. $0. \leq X \leq 300.$ sec Error Type 176
FAN LOWER FLOW LIMIT	Enter the minimum volume flowrate that may be obtained by this fan. If this fan falls below this limiting flowrate, the simulation will do one of the following, depending upon the Fan Stopping/Windmilling Option entered on Form 1E. 1 - If Fan Stopping/Windmilling Option is 1, the fan will shut off and the simulation will terminate immediately. 2 - If Fan Stopping/Windmilling Option is 2, the fan will shut off and the simulation will continue. $-100,000. \leq X \leq 0.$ cfm Error Type 193
FAN UPPER FLOW LIMIT	Enter the maximum volume flowrate that may be obtained by this fan. If this fan exceeds this limiting flowrate, the simulation will do one of the above, depending upon the Fan Stopping/Windmilling Option entered on Form 1E. $1,000. \leq X \leq 2,000,000.$ cfm Error Type 194

FORM 7A - FAN DESCRIPTION

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

1 Fan Identification 36

Air Density at which the Fan Performance Curve was determined (lb/ft^3) 41 50

Time Required for Fan to Reach Full Operating Speed (sec) 51 60

FAN OPERATING LIMITS (cfm):

Lower Flow Limit 61 70

Upper Flow Limit 71 80 ☒

FORM 7B - FAN DESCRIPTION

Skip this form if the Number of Fan Types entered on Form 1D is zero.

TOTAL PRESSURE RISE

This fan characteristic curve is described by the cubic polynomial curve fitting of four data points. The data is usually taken from manufacturer-supplied fan curves. The data points entered should cover the range of fan volume flowrates from zero CFM to the point where the total pressure rise across the fan is 0 inches of water (in. w.g.). Also, the points entered should be about the same distance apart on the CFM scale. The program assumes all fans are bi-directional, operating on identical fan curves for both inflow and outflow unless the user supplies different fan curves for both directions. If the fan operates in the outflow (exhaust) direction only, a blank line or all zeros may be entered for the curve data points specified for the inflow (supply) direction, and vice versa.
Total pressure rise: $-15. \leq X \leq 50.$ in. w.g.
Volume flowrate : $0. \leq X \leq 2,000,000.$ cfm

Error Type 68, 69, 75, 85, 163

Note: If the Fire Simulation Option on Form 1G is 1, fan curves and ventilation shaft pressure losses are adjusted due to temperature-related changes in air density.

FORM 7B - FAN DESCRIPTION

Sheet ________ of ________
Made by: ______________
Checked by: ______________
Date: ______________

	Total Pressure Rise (in. wg)		Flow Rate (cfm)	
Fan Curve when Operating in Outflow (Exhaust) Direction +1.0	1	10	11	20
	21	30	31	40
	41	50	51	60
	61	70	71	80
Fan Curve when Operating in Inflow (Supply) Direction -1.0	1	10	11	20
	21	30	31	40
	41	50	51	60
	61	70	71	80 ☒

FORM 7C - IMPULSE FAN DATA

Skip this form if the number of Impulse Fan Types on Form 1E is zero. Fill out one form for each Impulse Fan Type entered on Form 1E. All Forms 7A and 7B must be completed before the first Form 7C is entered, that is, all supply/exhaust fan data must be entered before the data on the first impulse fan is entered.

IMPULSE FAN FLOW RATE	Enter the volumetric flow rate of the impulse fan. $0. \le X \le 1,000,000.$ cfm	Error Type 218
IMPULSE FAN PRESSURE EFFICIENCY	Enter the pressure efficiency of the impulse fan. This is the ratio of actual to theoretical pressure rise. $0.1 \le X \le 1.0$	Error Type 219
IMPULSE FAN NOZZLE DISCHARGE VELOCITY	Enter the velocity of the impulse fan airflow at the discharge. $-10.000. \le X \le 10,000.$ fpm	Error Type 220
TIME AT WHICH THE IMPULSE FAN IS SWITCHED ON	This entry allows the user to define the operating period of the fan. Enter the time in the simulation that the fan switches on. $0. \le X \le 10,000.$ sec	Error Type 221
TIME AT WHICH THE IMPULSE FAN IS SWITCHED OFF	This entry allows the user to define the operating period of the fan. Enter the time in the simulation that the fan switches off. Time at which impulse fan is switched on $\le X \le 10,000.$ sec	Error Type 221

FORM 7C - IMPULSE FAN DATA

Sheet ________ of ________
Made by: ________________
Checked by: ________________
Date: ________________

Impulse Fan Flow Rate (cfm) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Impulse Fan Pressure Efficiency 11 ☐☐☐☐☐☐☐☐☐☐ 20

Impulse Fan Nozzle Discharge Velocity (fpm) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Time at which the Impulse Fan is switched on (sec) 31 ☐☐☐☐☐☐☐☐☐☐ 40

Time at which the Impulse Fan is switched off (sec) 41 ☐☐☐☐☐☐☐☐☐☐ 50 ☒

FORM 8A - TRAIN ROUTE DESCRIPTION

Skip this form if the Train Performance Option is zero.

ROUTE IDENTIFICATION	Any alphanumeric description of the route. This information will be printed in the input verification.	
TRAIN SCHEDULING ORIGIN	Indicates the position along the track route from which train operation originates. It must be greater than or equal to 0. feet. 0. ≤ X ≤ 1,000,000. ft	Error Type 71, 120
NUMBER OF GROUPS OF TRAINS THAT COULD ENTER ROUTE	This indicates to the program the number of train dispatcher groups which may be simulated on this route. 1. ≤ N ≤ 25.	Error Type 64
NUMBER OF TRACK SECTIONS IN THIS ROUTE	Enter the total number of track sections in the route. 1. ≤ N ≤ 619.	Error Type 3, 48, 93
DELAY TIME BEFORE DISPATCHING FIRST TRAIN	Enter the amount of time after the beginning of the simulation the user wishes to delay the dispatching of the first train into the system on this route. 0. ≤ X ≤ 10,000. sec	Error Type 67
FIRST TRAIN TYPE	Enter the type number (N=1,2,3,4,5) of the first train dispatched into the system on this route. 1. ≤ N ≤ "Number of Train Types" on Form 1E	Error Type 65
MINIMUM COASTING VELOCITY	Enter the minimum train velocity permitted on this route during coasting. 0. ≤ X ≤ 250. mph	Error Type 211
COASTING OPTION	Enter the mode of operation for the train if the minimum speed is reached while coasting. 0 - Maintain minimum speed 1 - Accelerates from minimum speed	Error Type 215

FORM 8A - TRAIN ROUTE DESCRIPTION

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

1 Route Identification 34

35 68 ☒

Train Scheduling Origin (ft) 1 10

Number of Groups of Trains that could Enter Route 11 20

Number of Track Sections in this Route 21 30

Delay Time Before Dispatching First Train (sec)
(Train Performance Option No. 1 and 2 only) 31 40

First Train Type 41 50

Minimum Coasting Velocity (mph) 51 60

Coasting Option
0.0 = maintain minimum speed
1.0 = accelerate from minimum speed
61 70 ☒

FORM 8B - TRAIN ROUTE DESCRIPTION

Skip this form if the Train Performance Option is 0.

NUMBER OF TRAINS	This number corresponds to the total number of trains in the train dispatcher group. $1. \leq N \leq 1{,}000.$	Error Type 66
TRAIN TYPE	Enter the type identification number (N=1,2,3,4,5....) of all the trains in this group. $1. \leq N \leq$ "Number of Train Types" on Form 1E	Error Type 65
HEADWAY	Enter the headway of the trains in the group. The headway is defined as the time interval between this train and the preceding train. $0. \leq X \leq 10{,}000.$ sec	Error Type 67

FORM 8B - TRAIN ROUTE DESCRIPTION

Sheet ________ of ________
Made by: ________________
Checked by: ______________
Date: ___________________

Train Group Data

This form is filled out only if two or more trains are to be defined for this route.

Group	Number of Trains 1–10	Train Type 11–20	Headway (Seconds) 21–30
2	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☒
3	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☒
4	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☒
5	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☒
6	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☒
7	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☒
8	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐☐☒
	etc.	etc.	etc.

FORM 8C - TRAIN ROUTE DESCRIPTION

Skip this form if the Train Performance Option is 0 or 3.

LOCATION OF FORWARD END OF TRACK SECTION	The location of a track section is defined as the distance between the route origin and the forward end of the track section. The forward end of a track section is the end which is farthest from the origin for that route. $0. \leq X \leq 1{,}000{,}000.$ ft Error Type 12, 13, 71
RADIUS OF CURVATURE	Horizontal curves are described using the radius of curvature. When the track section is straight, the radius is entered as zero or as a blank. $75. \leq X$; or $X = 0.$ Error Type 14 , 245
GRADE OR ELEVATION OF FORWARD END	The grade of the track section may be entered as a positive or negative percentage or as the elevation of the forward end of the section measured positively with respect to an arbitrary datum. The program automatically computes the percent grade when the track elevation is supplied and <u>vice versa</u>. An elevation of zero cannot be entered. It must be entered as a number close to zero, but with an absolute value greater than 0.02 feet. Grade: $-10. \leq X \leq 10.$ percent Error Type 15
MAXIMUM ALLOWABLE TRAIN VELOCITY	This quantity must be supplied for each track section when using Train Performance Option 1., and must be skipped when using option 2. or 3. $1. \leq X \leq 250.$ mph Error Type 16
ENERGY SECTOR NUMBER	This number indicates in which energy sector the track section is located. A summary of train power consumption is printed for each energy sector. An entry of zero indicates that a summary is not requested for this track section. $0. \leq N \leq 50.$ Error Type 243
COASTING PARAMETER	This quantity indicates whether coasting is permitted in this track section. 0 - No coasting permitted in this track section. 1 - Coasting is permitted in this track section. Coasting can be simulated only when using Train Performance Option 1. Error Type 212, 213

FORM 8C - TRAIN ROUTE DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Track Section Data
(Fill one sheet for each track section on route)

Location of Forward End of Track Section (ft) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Radius of Curvature (ft) 11 ☐☐☐☐☐☐☐☐☐☐ 20

Grade (Percent) 21 ☐☐☐☐☐☐☐☐☐☐ 30

or

Elevation of Forward End (ft) 31 ☐☐☐☐☐☐☐☐☐☐ 40

Maximum Allowable Train Velocity (mph) 41 ☐☐☐☐☐☐☐☐☐☐ 50

Energy Sector Number 51 ☐☐☐☐☐☐☐☐☐☐ 60

Coasting Parameter 61 ☐☐☐☐☐☐☐☐☐☐ 70 ☒

FORM 8D - TRAIN ROUTE DESCRIPTION

Skip this form if Train Performance Option is 0., 2., or 3.

The subway system being simulated can contain a number of locations at which the front of all trains operating on that route will stop. These stops need not necessarily correspond to stations, but rather can occur at any desired location throughout the system.

NUMBER OF SCHEDULED STOPS	This signifies the total number of scheduled stops (if any) in the system. A corresponding number of stop locations and dwell times must be provided. $0. \le N \le 124.$	Error Type 48
NUMBER OF PERSONS ABOARD TRAIN AT SCHEDULING ORIGIN	Enter the total number of persons aboard the train at the train scheduling origin. The number of people leaving the train at a stop must be less than or equal to the number of people already onboard the train prior to the stop. $0. \le X \le 4000.$ People	Error Type 9, 121
LOCATION ON ROUTE WHERE FRONT OF TRAINS STOP	This indicates the location along the system coordinate (in feet) at which the front of all trains on the route must come to a complete stop. Beginning of the first track section $\le X \le$ End of the last track section	Error Type 49
DWELL TIME	Each stop is characterized by an individual dwell time or length of pause in seconds. For example, passenger flow may dictate a dwell time of 20 seconds at one station and 40 seconds at another. $0. \le X \le 900.$ sec	Error Type 50
NUMBER OF PERSONS ENTERING TRAIN AT STOP	Enter the net gain or loss of people from the train at the stop. The net loss of passengers cannot exceed the number of persons on board the train prior to the stop. $-4000. \le X \le 4000.$ People	Error Type 9, 121

FORM 8D - TRAIN ROUTE DESCRIPTION

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Scheduled Stops

Number of Scheduled Stops 1 ☐☐☐☐☐☐☐☐☐☐ 10

Number of Persons Aboard Train at Scheduling Origin 11 ☐☐☐☐☐☐☐☐☐☐☒ 20

Location on Route where Front of Trains Stop	Dwell Time (sec)	Number of Persons Entering Train at Stop
1 ☐☐☐☐☐☐☐☐☐☐ 10	11 ☐☐☐☐☐☐☐☐☐☐ 20	21 ☐☐☐☐☐☐☐☐☐☐☒ 30
1 ☐☐☐☐☐☐☐☐☐☐ 10	11 ☐☐☐☐☐☐☐☐☐☐ 20	21 ☐☐☐☐☐☐☐☐☐☐☒ 30
1 ☐☐☐☐☐☐☐☐☐☐ 10	11 ☐☐☐☐☐☐☐☐☐☐ 20	21 ☐☐☐☐☐☐☐☐☐☐☒ 30
1 ☐☐☐☐☐☐☐☐☐☐ 10	11 ☐☐☐☐☐☐☐☐☐☐ 20	21 ☐☐☐☐☐☐☐☐☐☐☒ 30
1 ☐☐☐☐☐☐☐☐☐☐ 10	11 ☐☐☐☐☐☐☐☐☐☐ 20	21 ☐☐☐☐☐☐☐☐☐☐☒ 30
etc.	etc.	etc.

FORM 8E - TRAIN ROUTE DESCRIPTION

Fill this form out only for Train Performance Options:
2 - (Explicit - Train heat rejection computed) and
3 - (Explicit - Train heat rejection input).

NUMBER OF SPEED-TIME PROFILE POINTS

Enter the total number of explicit data points for the case of Train Performance Option 2 or 3. The program will use linear interpolation when data is required between the points supplied by the user.

2. ≤ N ≤ 100. Error Type 45

TRAIN SPEED VS. TIME

Each data point consists of entries of train velocity in MPH vs. time in seconds. This information can be obtained either from a recording speedometer aboard a train or from a manufacturer's supplied data. The program uses this information to compute the acceleration, speed and location of the train at any point in its operating cycle.

Previous time ≤ Time (Time must not be entered in decreasing order)

Train speed: 0. ≤ X ≤ 250. mph Error Type 46, 47, 71

POWER INPUT TO RESISTOR GRIDS

This item is required only if the Train Performance Option is 3.

ACCELERATION: This is the rate of dissipation of electrical power in the acceleration resistor grids and motors. The value can be computed as $N*I^2*R/1000.$, where I is the current in amperes through the motors, R is the sum of the electrical resistance in ohms of the motor windings and the resistor grids in series with each motor, N is the number of motors in the entire train.

0. ≤ X ≤ 20,000. Kilowatts per train Error Type 90, 92

DECELERATION: This is the rate of energy dissipation in the deceleration resistor grids. It is equal to the rate of change of kinetic energy minus the change in potential energy. The kinetic energy dissipation rate is JMVA*0.001285 , where J is the number of cars in the train, M is the mass of a car plus the equivalent translational mass of rotating parts in slugs, V is the train speed in ft/sec, and A is the acceleration of the train in ft/sec^2. The change in potential energy is JWV x 0.001285 x SIN(α) where J is the number of cars in the train, W is the weight of the car in lbs, V is the train speed in ft/sec, and α is the angle of the track with horizontal.

0. ≤ X ≤ 20,000. Kilowatts per train Error Type 91, 92

At any point in time, power can go into either the acceleration grid or the deceleration grid, but not both.

FORM 8E - TRAIN ROUTE DESCRIPTION

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Explicit Train Performance Data

Number of Speed-Time Profile Points 1 ☐☐☐☐☐☐☐☐☐☒ 10

Power Input to Resistor Grids (Kilowatts per Train)

Time (sec)	Train Speed (mph)	Acceleration	Deceleratioin
1 ☐☐☐☐☐☐☐☐ 8	11 ☐☐☐☐☐☐☐☐ 18	21 ☐☐☐☐☐☐☐☐ 28	31 ☐☐☐☐☐☐☐☐☒ 38
1 ☐☐☐☐☐☐☐☐ 8	11 ☐☐☐☐☐☐☐☐ 18	21 ☐☐☐☐☐☐☐☐ 28	31 ☐☐☐☐☐☐☐☐☒ 38
1 ☐☐☐☐☐☐☐☐ 8	11 ☐☐☐☐☐☐☐☐ 18	21 ☐☐☐☐☐☐☐☐ 28	31 ☐☐☐☐☐☐☐☐☒ 38
1 ☐☐☐☐☐☐☐☐ 8	11 ☐☐☐☐☐☐☐☐ 18	21 ☐☐☐☐☐☐☐☐ 28	31 ☐☐☐☐☐☐☐☐☒ 38
1 ☐☐☐☐☐☐☐☐ 8	11 ☐☐☐☐☐☐☐☐ 18	21 ☐☐☐☐☐☐☐☐ 28	31 ☐☐☐☐☐☐☐☐☒ 38
1 ☐☐☐☐☐☐☐☐ 8	11 ☐☐☐☐☐☐☐☐ 18	21 ☐☐☐☐☐☐☐☐ 28	31 ☐☐☐☐☐☐☐☐☒ 38
etc.	etc.	etc.	etc.

FORM 8F — TRAIN ROUTE DESCRIPTION

Skip this form if no tunnel system has been defined for this simulation or if the Train Performance Option is 0.

NUMBER OF SECTIONS THROUGH WHICH ROUTE PASSES	Enter the total number of line sections through which the route passes. An entry of zero indicates that the route does not enter the tunnel network and runs in open air only. $0. \leq N \leq$ Max. No. of line sections Error Type 48, 125
DISTANCE FROM ROUTE ORIGIN TO PORTAL OR FIRST NODE ON ROUTE	Enter the location along the route where the front of the train first enters the tunnel system. If the route originates within the system, enter a zero since the route origin must be located at the first node on the route. $0. \leq X \leq$ Entire length of the route, ft Error Type 122
IDENTIFICATION NUMBERS OF THE SECTIONS THROUGH WHICH ROUTE PASSES	Enter the identification numbers of the line sections through which the route passes. These sections must be entered in the order in which the trains pass through them as the trains travel along the route. The section identification numbers must be positive numbers if the train route travels in the positive direction with respect to the section coordinate system, and negative if the train travels in the negative direction with respect to the section coordinate system. Error Type 48, 124, 125, 153, 164, 180

FORM 8F - TRAIN ROUTE DESCRIPTION

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Section Sequencing for Route

Number of Sections through which Route Passes
1 ☐☐☐☐☐☐☐☐☐☐ 10

Distance from Route Origin to Portal or First Node on Route
11 ☐☐☐☐☐☐☐☐☐☐☒ 20

Identification Numbers of the Sections through which Route Passes
(Column 1 must contain either a "+" or "-")
1 ☐☐☐☐☐☐☐☐☐☐☒ 10
1 ☐☐☐☐☐☐☐☐☐☐☒ 10
1 ☐☐☐☐☐☐☐☐☐☐☒ 10
1 ☐☐☐☐☐☐☐☐☐☐☒ 10
1 ☐☐☐☐☐☐☐☐☐☐☒ 10

etc.

FORM 9A - TRAIN DATA

Skip this form if the Train Performance Option is 0.

TRAIN IDENTIFICATION	This is the identifying designation for the train type being utilized. Any combination of up to 36 alphanumeric characters may be used.	
TOTAL NUMBER OF CARS PER TRAIN	This indicates the number of cars in the train type being described. $1. \leq N \leq 20.$	Error Type 51
NUMBER OF POWERED CARS PER TRAIN	Enter the number of cars in the train that contain an operational propulsion system. $1. \leq N \leq$ Total No. of cars in train	Error Type 116
TOTAL LENGTH OF TRAIN	Enter the total length of this train type. $25. \leq X \leq 1{,}500.$ ft	Error Type 52
FRONTAL AREA OF TRAIN	Enter the frontal silhouette of the train including the average area of undercar equipment and trucks for this train type. $25. \leq X \leq 300.$ ft^2	Error Type 53

FORM 9A - TRAIN DATA

Sheet ________ of ________
Made by: ____________________
Checked by: ____________________
Date: ____________________

1 Train Identification 36
☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Total Number of Cars per Train 41 ☐☐☐☐☐☐☐☐☐☐ 50

Number of Powered Cars per Train 51 ☐☐☐☐☐☐☐☐☐☐ 60

Total Length of Train (ft) 61 ☐☐☐☐☐☐☐☐☐☐ 70

Frontal Area of Train (ft^2) 71 ☐☐☐☐☐☐☐☐☐☐ 80 ☒

FORM 9B - TRAIN DATA

Skip this form if the Train Performance Option is 0.

PERIMETER OF CAR	Enter the perimeter associated with the average cross sectional area of this train type. $20. \leq X \leq 200.$ ft	Error Type 70, 78
SKIN FRICTION COEFFICIENT	Enter the skin friction coefficient which relates drag to the sides, roof and bottom surface area of the train. $0. \leq X \leq 0.20$	Error Type 55 .
DRAG COEFFICIENT WEIGHTED TOTAL TRUCK AREA	Enter the drag coefficient weighted truck area which relates drag to the total area of the trucks and their respective drag coefficients. $0. \leq X \leq 500.$	Error Type 201
FRONT OF TRAIN DRAG COEFFICIENT	Enter the front of train drag coefficient which relates drag to the shape of the front of the train. $0. \leq X \leq 1.5$	Error Type 115

FORM 9B - TRAIN DATA

Sheet ________ of ________
Made by: ____________________
Checked by: __________________
Date: _______________________

Perimeter of Car (ft) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Skin Friction Coefficient 11 ☐☐☐☐☐☐☐☐☐☐ 20

Drag Coefficient Weighted Total Truck Area (ft^2) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Front of Train Drag Coefficient 31 ☐☐☐☐☐☐☐☐☐☐ 40 ☒

FORM 9C - TRAIN DATA

Skip this form if the Train Performance Option Is 0.

SENSIBLE HEAT REJECTION FROM AUXILIARY SYSTEMS FOR AN EMPTY CAR EXCLUDING PROPULSION SYSTEM	Enter the sensible heat rejection from auxiliary systems (air conditioning condensers and compressors, lighting, motors and other equipment) while train is stationary and there are no passengers on board. 0. ≤ X ≤ 1,000,000. Btu/hr per car Error Type 57
LATENT HEAT REJECTION FROM AUXILIARY SYSTEMS FOR AN EMPTY CAR EXCLUDING PROPULSION SYSTEM	Enter the latent heat rejection from auxiliary systems (air conditioning condensers and compressors, lighting, motors and other equipment) while train is stationary and there are no passengers on board. -50,000. ≤ X ≤ 200,000. Btu/hr per car Error Type 58
SENSIBLE HEAT REJECTION FROM PASSENGERS AND AUXILIARY SYSTEMS PER PATRON	Enter the additional sensible heat rejection from a car caused by each passenger on board the car. This heat may be released directly from the passengers, or from the vehicle air conditioning system, if present. This number should be entered only when the Train Performance Option is 1. -100. ≤ X ≤ 1000. Btu/hr per patron Error Type 222, 244
LATENT HEAT REJECTION FROM PASSENGERS AND AUXILIARY SYSTEMS PER PATRON	Enter the additional latent heat rejection from a car caused by each passenger on board the car. This heat may be released directly from the passengers, or from the vehicle air conditioning system, if present. This number should be entered only when the Train Performance Option Is 1. -100. ≤ X ≤ 1000. Btu/hr per patron Error Type 222, 244
POWER CONSUMPTION BY AUXILIARY SYSTEMS FOR AN EMPTY CAR	Enter the average auxiliary systems power consumption for each car when there are no passengers on board. 0. ≤ X ≤ 100. kW per car Error Type 241
POWER CONSUMPTION BY AUXILIARY SYSTEMS PER PATRON	Enter the additional average auxiliary systems power consumption caused by each passenger on board the car. This number should be entered only when the Train Performance Option is 1. -2. ≤ X ≤ 5. kW per patron. Error Type 242, 244

FORM 9C - TRAIN DATA

Sheet ________ of ________
Made by: ______________
Checked by: ______________
Date: ______________

Sensible Heat Rejection from Auxiliary Systems for an Empty Car excluding Propulsion System (Btu/hr per car)

1 ☐☐☐☐☐☐☐☐☐☐ 10

Latent Heat Rejection from Auxiliary Systems for an Empty Car excluding Propulsion System (Btu/hr per car)

11 ☐☐☐☐☐☐☐☐☐☐ 20

Sensible Heat Rejection from Passengers and Auxiliary Systems per Patron in Car (Btu/hr per patron)
(Does not apply if Train Performance Option is 2 or 3)

21 ☐☐☐☐☐☐☐☐☐☐ 30

Latent Heat Rejection from Passengers and Auxiliary Systems per Patron in Car (Btu/hr per patron)
(Does not apply if Train Performance Option is 2 or 3)

31 ☐☐☐☐☐☐☐☐☐☐ 40

Power Consumption by Auxiliary Systems for an Empty Car (kW per car)

41 ☐☐☐☐☐☐☐☐☐☐ 50

Power Consumption by Auxiliary Systems per Patron in Car (kW per patron)
(Does not apply if Train Performance Option is 2 or 3)

51 ☐☐☐☐☐☐☐☐☐☐ 60 ☒

FORM 9D - TRAIN DATA

Skip this form if the Train Performance Option is 0.

TOTAL WEIGHT OF RESISTANCE ELEMENTS PER CAR	This value represents the weight of all the acceleration and/or deceleration resistor grid elements which actually resist current flow in a resistor grid arrangement for this train type. This value does not include any weight of the resistor grid supporting structure. A value of zero (0.) indicates an instantaneous heat release mechanism is to be used for that grid. If a 0. is entered for a grid, the remaining entries for the grid may be 0. $0. \leq X \leq 2{,}000.$ lbs	Error Type 101, 102
EFFECTIVE DIAMETER OF AN ELEMENT	This value represents a characteristic resistor grid element diameter for all the acceleration and/or deceleration grids in this train type. $0. \leq X \leq 24.$ in.	Error Type 103, 104
EFFECTIVE SURFACE AREA FOR CONVECTION PER CAR	This value represents the sum of the effective surface area for convection calculations of each element in the acceleration and/or deceleration resistor grid arrangement for this train type. This value is a function of the physical geometry of each element and the location of the resistor grid arrangement relative to the underside of the car. $0. \leq X \leq 500.\ \text{ft}^2$	Error Type 105, 106
EFFECTIVE SURFACE AREA FOR RADIATION PER CAR	This value represents the sum of the effective surface area for radiation calculations of each element in the acceleration and/or deceleration resistor grid arrangement for this train type. The effective area is defined as the product of the actual surface area of an element and its shape factor with regard to the surroundings enclosing the resistor grid arrangement. $0. \leq X \leq 500.\ \text{ft}^2$	Error Type 107, 108
EMISSIVITY OF THE RESISTANCE ELEMENT	This value represents the emissivity of a typical acceleration and/or deceleration resistor grid element surface evaluated at an average grid temperature for this train type. $0. \leq X \leq 1.$	Error Type 109, 110
SPECIFIC HEAT OF THE RESISTANCE ELEMENT	This value represents the specific heat of an acceleration and/or deceleration resistor grid element evaluated at an effective grid temperature. $0. \leq X \leq 1.$ Btu/(lb-^{o}F)	Error Type 111, 112
INITIAL GRID TEMPERATURES	The initial temperature of the acceleration and/or deceleration resistor grids corresponds to the temperature of the grids at the time the trains are dispatched onto their respective route. A blank entry or zero indicates that the resistor grid is to be initialized at ambient temperature.	

FORM 9D - TRAIN DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Resistor Grid Physical Characteristics

Total Weight of Resistance Elements per Car (lbs)	1 ☐☐☐☐☐☐☐☐☐☐ 10	11 ☐☐☐☐☐☐☐☐☐☐ 20
Effective Diameter of an Element (in.)	21 ☐☐☐☐☐☐☐☐☐☐ 30	31 ☐☐☐☐☐☐☐☐☐☐ 40
Effective Surface Area for Convection per Car (ft^2)	41 ☐☐☐☐☐☐☐☐☐☐ 50	51 ☐☐☐☐☐☐☐☐☐☐ 60
Effective Surface Area for Radiation per Car (ft^2)	61 ☐☐☐☐☐☐☐☐☐☐ 70	71 ☐☐☐☐☐☐☐☐☐☐ 80 ☒
Emissivity of the Surface Element	1 ☐☐☐☐☐☐☐☐☐☐ 10	11 ☐☐☐☐☐☐☐☐☐☐ 20
Specific Heat of the Resistance Element (Btu/lb-°F)	21 ☐☐☐☐☐☐☐☐☐☐ 30	31 ☐☐☐☐☐☐☐☐☐☐ 40
Initial Grid Temperature (°F)	41 ☐☐☐☐☐☐☐☐☐☐ 50	51 ☐☐☐☐☐☐☐☐☐☐ 60 ☒

FORM 9E - TRAIN DATA

Skip this form if the Train Performance Option is 0.

AVERAGE EMPTY CAR WEIGHT

This number is the average unloaded weight of a single car for this train type.
5. ≤ X ≤ 150. tons
Error Type 56

NUMBER OF MOTORS PER POWERED CAR

Enter the number of operational motors per powered car for this train type. Rapid transit vehicles normally have four motors per car, although any number of motors may be entered.
1. ≤ N ≤ 10.
Error Type 72

TRAIN ROLLING RESISTANCE COEFFICIENTS

These values are the constants in the equation for computing the rolling resistance of the vehicle. Typical values of these coefficients are:

	Steel Wheel Vehicle	Rubber Tire Vehicle	
Coeff. #1	1.3	3.9	lb/ton
Coeff. #2	116.0	350.0	lb
Coeff. #3	0.045	0.135	lb/ton-mph

0.5 ≤ Coeff. #1 ≤ 50. lbs/ton
0.1 ≤ Coeff. #2 ≤ 500. lbs
0.001 ≤ Coeff. #3 ≤ 1.000 lbs/(ton-mph)
Error Type 88, 89, 99

ACCELERATION RESISTANCE OF ROTATING PARTS

This value represents the rotational inertia of rotating parts (wheels, motor armatures, gears, etc.) in terms of an equivalent mass for translational acceleration. The user may enter the value to be used, or leave this entry blank and a commonly used value of 8.8 will be supplied by the program.
0.1 ≤ X ≤ 30.0 lbs per ton/(mph/sec)
Error Type 77

FORM 9E - TRAIN DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Average Empty Car Weight (tons)	1 ☐☐☐☐☐☐☐☐☐☐ 10	
Number of Motors per Powered Car	11 ☐☐☐☐☐☐☐☐☐☐ 20	
Train Rolling Resistance Coefficient #1	21 ☐☐☐☐☐☐☐☐☐☐ 30	
Train Rolling Resistance Coefficient #2	31 ☐☐☐☐☐☐☐☐☐☐ 40	
Train Rolling Resistance Coefficient #3	41 ☐☐☐☐☐☐☐☐☐☐ 50	
Acceleration Resistance of Rotating Parts (lbs/ton)/(mph/sec)	51 ☐☐☐☐☐☐☐☐☐☐ 60	☒

FORM 9F - TRAIN DATA

Skip this form if the Train Performance Option is 0 or 3.

MOTOR IDENTIFICATION	This identifies the motor(s) being used on the train. Any combination of alphanumeric characters may be used. The motor identification will be printed in the input verification.	
WHEEL DIAMETER SUPPLIED WITH MANUFACTURER'S DATA	Enter the wheel diameter given with the manufacturer supplied motor performance curves. Motor performance curves provided by manufacturers normally are computed for a specified size of vehicle wheel. See note at bottom of page. $20. \le X \le 40.$ in.	Error Type 59
ACTUAL WHEEL DIAMETER OF VEHICLE	Enter the actual diameter of the wheels for the vehicle type being described. The actual wheel diameter must be entered even if it is the same as the one given. $20. \le X \le 40.$ in.	Error Type 59
GEAR RATIO - TO 1 SUPPLIED WITH MANUFACTURER'S DATA	Enter the gear ratio (number of motor revolutions per wheel revolution) given with the manufacturer supplied motor performance curves. Motor performance curves provided by the manufacturer normally are computed for a specified gear ratio. See note at bottom of page. $1. \le X \le 20.$	Error Type 60
ACTUAL GEAR RATIO - TO 1 OF VEHICLE	The actual gear ratio of the train being considered must be provided. This actual gear ratio must be entered even if it is the same as the one given. $1. \le X \le 20.$	Error Type 60
SUPPLY VOLTAGE GIVEN WITH MANUFACTURER'S DATA	Enter the voltage given with the manufacturer supplied motor performance curves. Motor performance curves provided by the manufacturer normally are computed for a specified voltage. See note at bottom of page. $100. \le X \le 1500.$ Volts	Error Type 117
ACTUAL SUPPLY VOLTAGE AT WHICH VEHICLE OPERATES	Enter the actual voltage for the vehicle type being described. The actual voltage must be entered even if it is the same as the one given. $100. \le X \le 1500.$ Volts	Error Type 117
MOTOR TERMINAL VOLTAGE AT BASE SPEED	Enter motor voltage corresponding to train base speed. $100. \le X \le 1500.$ Volts/Motor	Error Type 238

Note: Should the train under consideration have a different wheel size, gear ratio or supply voltage, other than those at which the motor performance curves are supplied, then the program will automatically scale the motor performance curves by the ratio of the manufacturer supplied values to the actual values.

FORM 9F - TRAIN DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

MOTOR CHARACTERISTICS

1 Motor Identification 36

Wheel Diameter Supplied With Manufacturer's Data (in.)	41	50	
Actual Wheel Diameter of Vehicle (in.)	51	60	☒
Gear Ratio - To 1 Supplied With Manufacturer's Data	1	10	
Actual Gear Ratio - To 1 of Vehicle	11	20	
Supply Voltage Given With Manufacturer's Data (Volts)	21	30	
Actual Supply Voltage at Which Vehicle Operates (Volts)	31	40	
Motor Terminal Voltage at Base Speed (Volts/Motor)	41	50	☒

FORM 9G - TRAIN DATA

Skip this form if the Train Performance Option Is 0. or 3.

The program computes the relationship between the train speed, tractive effort, and amperage required from the four data points supplied by the user in each of the three categories below.

TRAIN SPEED	Points are taken from the motor performance curves supplied by motor manufacturers. These points should be: 1) the speed at which field strength reduction begins, 2) the speed at which field strength reduction is completed, 3) a speed at approximately the midpoint of the minimum field strength operating curve (usually about 40 MPH), 4) a speed which represents the maximum design speed of the vehicle. The vehicle would not normally exceed this last speed. $0. \le X \le 250.$ mph	Error Type 86
TRACTIVE EFFORT	These data points are taken from the motor performance curves and should correspond to the MPH points supplied above. $X \ge 0.$ lbs.	Error Type 86, 87
MOTOR CURRENT	These data points are taken from the motor performance curves and should correspond to the tractive effort data supplied above. $X \ge 0.$ amperes	Error Type 87
TRAIN CONTROLLER OPTION	Enter the method used for controlling the train speed. 1 - Cam Control 2 - Chopper Control	Error Type 209

FORM 9G - TRAIN DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ______________

MOTOR CHARACTERISTICS

Train Speed (mph)

1 ☐☐☐☐☐☐☐☐☐☐ 10   11 ☐☐☐☐☐☐☐☐☐☐ 20
21 ☐☐☐☐☐☐☐☐☐☐ 30   31 ☐☐☐☐☐☐☐☐☐☐☒ 40

Tractive Effort (lbs/motor)

1 ☐☐☐☐☐☐☐☐☐☐ 10   11 ☐☐☐☐☐☐☐☐☐☐ 20
21 ☐☐☐☐☐☐☐☐☐☐ 30   31 ☐☐☐☐☐☐☐☐☐☐☒ 40

Motor Current (amps)

1 ☐☐☐☐☐☐☐☐☐☐ 10   11 ☐☐☐☐☐☐☐☐☐☐ 20
21 ☐☐☐☐☐☐☐☐☐☐ 30   31 ☐☐☐☐☐☐☐☐☐☐☒ 40

Train Controller Option
1.0 = Cam Control
2.0 = Chopper Conrol

1 ☐☐☐☐☐☐☐☐☐☐☒ 10

FORM 9H - TRAIN DATA

Skip this form if:
1) The Train Performance Option is 0 or 3.
2) The Train Controller Option Is 1.

LINE CURRENT	These data points are taken from the motor performance curves. They are as follows: 1) the current at zero speed, and 2) through 5) correspond to the train speeds supplied on Form 9G. The values entered are amperes per powered car. $X \geq 0.$ amperes	Error Type 208
CHOPPER EFFICIENCY FOR SPEEDS OF ZERO TO U_1	Enter the chopper efficiency for speeds ranging from 0 to U_1. The efficiency is defined as the ratio of the power output to the power input to the chopper times 100. $0. \leq X \leq 100.$ percent	Error Type 151
SPEED U_1	Enter the value of U_1. $0. \leq X \leq 100.$ mph	Error Type 210
CHOPPER EFFICIENCY FOR SPEEDS GREATER THAN U_1	Enter the chopper efficiency for speeds exceeding U_1. $0. \leq X \leq 100.$ percent	Error Type 151
REGENERATIVE BRAKING EFFECTIVENESS	Enter the regenerative braking effectiveness. This effectiveness is defined as the ratio of the total energy regenerated to the total energy available for regeneration times 100. Enter zero if the Onboard Flywheel Simulation Option is 2. $0. \leq X \leq 100.$ percent	Error Type 151
ONBOARD FLYWHEEL SIMULATION OPTION	Enter the simulation option of the train flywheels. If there are no flywheels on this train enter 1. 1 - Bypass 2 - Simulation	Error Type 230. 231

FORM 9H - TRAIN DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Skip this form if the Train Controller Option is 1.

Line Current (amps/powered car)
1 ☐☐☐☐☐☐☐☐☐☐ 10
11 ☐☐☐☐☐☐☐☐☐☐ 20
21 ☐☐☐☐☐☐☐☐☐☐ 30
31 ☐☐☐☐☐☐☐☐☐☐ 40
41 ☐☐☐☐☐☐☐☐☐☐ 50 ☒

Chopper Efficiency for Speeds of Zero to U_1 (percent)
1 ☐☐☐☐☐☐☐☐☐☐ 10

Speed U_1 (mph)
11 ☐☐☐☐☐☐☐☐☐☐ 20

Chopper Efficiency for Speeds Greater than U_1 (percent)
21 ☐☐☐☐☐☐☐☐☐☐ 30

Regenerative Braking Effectiveness (percent)
31 ☐☐☐☐☐☐☐☐☐☐ 40

Onboard Flywheel Simulation Option
41 ☐☐☐☐☐☐☐☐☐☐ 50 ☒

FORM 9I - TRAIN DATA

Skip this form if the Train Performance Option is 0 or 3.

RESISTANCE SPEEDS

The two train speeds entered here are used in the definition of the external resistance versus train speed curve. The first entry is the speed at which transition occurs, the second is the speed at which field strength reduction begins. If a chopper-controlled train is being simulated, zero must be entered for the two resistance speeds.

0. ≤ X ≤ 100. mph

Error Type 62

RESISTANCE

Three resistance values must be given to describe the motor circuit resistance. The first is the external plus internal resistance at zero train speed; the second is the external plus internal resistance just after transition has occurred; and the third is the internal resistance of the motor armature and field. If a chopper-controlled train is being simulated, zero must be entered for the first two entries, but the third entry, the internal resistance of the motor armature and field, must still be entered.

0.001 ≤ X ≤ 3. ohms

Error Type 61

FORM 9I - TRAIN DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Resistance Speeds (mph)

1									10

11									20

Resistances (ohms)

21									30

31									40

41									50	
										☒

FORM 9J - TRAIN DATA

Skip this form if the Train Performance Option is 0, 2, or 3.

MAXIMUM ALLOWABLE ACCELERATION RATE	This is the maximum rate of acceleration for this train type. This rate would not be exceeded even though the train might be capable of greater acceleration in some situations. $0.5 \leq X \leq 5.0$ mph/sec	Error Type 74
NORMAL DECELERATION RATE FROM SPEED V_1 TO 0	As a train decelerates under normal operation, there is a speed (V_1) below which the train's deceleration becomes constant. Enter this constant rate of deceleration between 0 and V_1 MPH for the train type. $0.5 \leq X \leq 5.0$ mph/sec	Error Type 54
SPEED V_1	As a train decelerates under normal operation, there is a speed V_1 below which the train's deceleration becomes constant. Enter the speed V_1 for this train type. $10. \leq X \leq 100.$ mph	Error Type 118
NORMAL DECELERATION RATE AT SPEED V_2	At high speeds, a train cannot decelerate at as high a rate as is possible at lower speeds. Enter the train deceleration rate for normal operation at the maximum speed (V_2) attainable by this train type. This deceleration rate is never greater than, and is most often less than, the normal deceleration rate from 0 to V_1 MPH. $0.5 \leq X \leq 5.0$ mph/sec	Error Type 54
SPEED V_2	Enter the maximum speed attainable by this train type. This maximum speed will almost always be higher than the maximum train speed. $V_1 \leq X \leq 250.$ mph	Error Type 119

FORM 9J - TRAIN DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Maximum Allowable Acceleration Rate (mph/sec) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Normal Deceleration Rate From Speed V_1 to 0 (mph/sec) 11 ☐☐☐☐☐☐☐☐☐☐ 20

Speed V_1 (mph) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Normal Deceleration Rate at Speed V_2 (mph/sec) 31 ☐☐☐☐☐☐☐☐☐☐ 40

Speed V_2 (mph) 41 ☐☐☐☐☐☐☐☐☐☐ 50 ☒

FORM 9K - FLYWHEEL DATA

Skip this form if the Train Performance Option is 0, 2, or 3, or if the Onboard Flywheel Simulation Option is 1.

POLAR MOMENT OF INERTIA	Enter the polar moment of inertia of a flywheel assembly (i.e. rotor, shaft, etc.) $50. \leq X \leq 4000.$ lb-ft^2	Error Type 232
NUMBER OF FLYWHEELS PER CAR	Enter the number of flywheel units on-board each car. $1. \leq N \leq 4.$	Error Type 233
MINIMUM ALLOWABLE ROTATIONAL SPEED	Enter the minimum allowable rotational speed of a flywheel $0. \leq X \leq 20.000.$ rpm	Error Type 234
MAXIMUM ALLOWABLE ROTATIONAL SPEED	Enter the maximum allowable rotational speed of a flywheel. Minimum allowable speed $\leq X \leq 30,000.$ rpm	Error Type 235
INITIAL ROTATIONAL SPEED	Enter the initial rotational speed of a flywheel. Minimum allowable speed $\leq X \leq$ Maximum allowable speed	Error Type 236

FORM 9K - FLYWHEEL DATA

Sheet ________ of ________

Made by: ____________________

Checked by: ____________________

Date: ____________________

Polar Moment of Inertia (lb-ft^2) 1 ☐☐☐☐☐☐☐☐☐☐ 10

Number of Flywheels per Car 11 ☐☐☐☐☐☐☐☐☐☐ 20

Minimum Allowable Rotational Speed (rpm) 21 ☐☐☐☐☐☐☐☐☐☐ 30

Maximum Allowable Rotational Speed (rpm) 31 ☐☐☐☐☐☐☐☐☐☐ 40

Initial Rotational Speed (rpm) 41 ☐☐☐☐☐☐☐☐☐☐☒ 50

FORM 9L - FLYWHEEL DATA

Skip this form if the Train Performance Option is 0, 2 or 3 or if the Onboard Flywheel Simulation Option is 1.

EFFICIENCY OF POWER TRANSFER FROM TRAIN TO FLYWHEEL

Enter the overall efficiency of power transfer from the train wheel to the flywheel.

$0. \leq X \leq 100.$ percent — Error Type 237

EFFICIENCY OF POWER TRANSFER FROM FLYWHEEL TO TRAIN

Enter the overall efficiency of power transfer from the flywheel to the train wheel.

$0. \leq X \leq 100.$ percent — Error Type 237

COEFFICIENTS OF EQUATION FOR INTERNAL LOSSES OF FLYWHEEL AS A FUNCTION OF SPEED

Enter the coefficients of the equation for the internal losses (i.e. windage, bearings, etc.) of the flywheel. The form of the equation is:

$$F(\omega) = A*\omega^{d} + B*\omega^{e} + C$$

Due to the fact that time within the program is measured in seconds, ω is in units of revolutions per second (RPS). The coefficients must be defined to give F(ω) in units of Kilowatts (kW), therefore:

$$A = kW/(RPS)^{d}\ ,\ B = kW/(RPS)^{e}\ ,\ \text{and } C = kW$$

*Typical coefficient values for a Garret Flywheel are given below. Note that not all coefficients need to be used to describe the internal losses. The coefficients A, B, and C must be entered in Scientific Notation (E - Format). For example, if $A = 3.53 \times 10^{-6}$, it should be entered as 3.53 E - 06.

$A = 3.536 \times 10^{-6}$
$B = 0$
$C = 0$
$d = 2.5$
$e = 0$

$0. \leq A, B, C$ — Error Type 239
$0. \leq d, e \leq 3.0$ — Error Type 240

* Refer to chapter 8 reference 5 of the SES User's Manual.

FORM 9L - FLYWHEEL DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Efficiency of Power Transfer from Train to Flywheel (percent)
1 ☐☐☐☐☐☐☐☐☐☐ 10

Efficiency of Power Transfer from Flywheel to Train (percent)
11 ☐☐☐☐☐☐☐☐☐☐ 20

Coefficients of Equation for Internal Losses of Flywheel, as a Function of Speed

$$F(\omega) = A\omega^{d} + B\omega^{e} + C$$

A - 21 ☐☐☐☐☐☐ E (±) ☐☐☐ 30
B - 31 ☐☐☐☐☐☐ E (±) ☐☐☐ 40
C - 41 ☐☐☐☐☐☐ E (±) ☐☐☐ 50
d - 51 ☐☐☐☐☐☐☐☐☐☐ 60
e - 61 ☐☐☐☐☐☐☐☐☐☐ 70 ☒

FORM 10 - TRAIN INITIALIZATION DATA

Skip this form if the Train Performance Option is 0.

The following information is only entered for initialized trains. If there are no trains in operation at initialization, this form is to be skipped. One complete form is filled out for each initialized train.

TRAIN LOCATION ON ROUTE	Enter the location along the route where the front of the initialized train is situated at the beginning of the simulation. Scheduling origin $\le X \le$ Forward end of last track section, ft	Error Type 18, 144
TRAIN SPEED	Enter the speed of the initialized train at the beginning of the simulation. $0. \le X \le 250.$ mph	Error Type 145
ROUTE NUMBER	Enter the route identification number of the initialized train. $1. \le N \le$ "Number of train routes" on Form 1E	Error Type 142
TRAIN TYPE	Enter the train type identification number of the initialized train. $1. \le N \le$ "Number of train types" on Form 1E	Error Type 143
ACCELERATION GRID TEMPERATURE	Enter the temperature of the acceleration grids at the instant in time that the simulation begins. °F	
DECELERATION GRID TEMPERATURE	Enter the temperature of the deceleration grids at the instant in time that the simulation begins. °F	
REMAINING DWELL TIME	If the initialized train is at a stopping point along the route, the user must enter the amount of time the train is to remain stationary at that stopping point after the beginning of the simulation. If there is no remaining dwell time this entry may be entered as zero or left blank. A negative value indicates that the train is to remain in the initialized location for the duration of the simulation. (This is only applicable for Train Performance Option 1.) $X \le 900.$	Error Type 50
TRAIN COASTING INDICATOR	Enter a 1 - if the initialized train is coasting at the beginning of the simulation. 0 - if the initialized train <u>is not</u> coasting.	Error Type 258

FORM 10 - TRAIN INITIALIZATION DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Skip this form if the number of initialized trains entered in form 1E is 0.0

Train Location on Route (ft)	1 ☐☐☐☐☐☐☐☐☐☐ 10	
Train Speed (mph)	11 ☐☐☐☐☐☐☐☐☐☐ 20	
Route Number	21 ☐☐☐☐☐☐☐☐☐☐ 30	
Train Type	31 ☐☐☐☐☐☐☐☐☐☐ 40	
Acceleration Grid Temperature (^{o}F)	41 ☐☐☐☐☐☐☐☐☐☐ 50	
Deceleration Grid Temperature (^{o}F)	51 ☐☐☐☐☐☐☐☐☐☐ 60	
Remaining Dwell Time (sec) (applicable only if train is stopped)	61 ☐☐☐☐☐☐☐☐☐☐ 70	
Train Coasting Indicator	71 ☐☐☐☐☐☐☐☐☐☐ 80	☒

FORM 11A - ENVIRONMENTAL CONTROL ZONES

This form is filled out only when the Environmental Control Load Evaluation option on Form 1C is 1 or 2.

ZONE TYPE	Enter the zone type: 1 = Controlled zone 2 = Uncontrolled zone 3 = Non-inertial ventilation shaft zone	Error Type 204
NUMBER OF LINE SEGMENTS AND VENTILATION SHAFTS IN ZONE	Enter the sum of the total number of line segments and the total number of ventilation shafts within this zone. $1. \le N \le$ Total number of line segments and vent shafts in the system	Error Type 204

The following information is only filled out if the zone is type 1:

MORNING RUSH HOUR DESIGN CONDITIONS

DRY-BULB TEMPERATURE	Enter the design dry-bulb temperature for the morning rush hour. $40. \le X \le 100.$ °F	Error Type 26
WET-BULB TEMPERATURE	Enter the design wet-bulb temperature for the morning rush hour. $40. \le X \le$ Morning rush hour dry-bulb design temperature, °F	Error Type 26

EVENING RUSH HOUR DESIGN CONDITIONS

DRY-BULB TEMPERATURE	Enter the design dry-bulb temperature for the evening rush or off hour. $40. \le X \le 100.$ °F	Error Type 26
WET-BULB TEMPERATURE	Enter the design wet-bulb temperature for the evening rush or off hour. $40. \le X \le$ Evening rush or off hour dry-bulb design temperature, °F	Error Type 27

FORM 11A - ENVIRONMENTAL CONTROL ZONES

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Zone Data

Zone Type
1 = Controlled
2 = Uncontrolled
3 = Non-inertial ventilation shaft

1 ☐☐☐☐☐☐☐☐☐☐ 10

Number of Line Segments and Ventilation Shafts in Zone

11 ☐☐☐☐☐☐☐☐☐☐ 20

Type 1 Zone Data:

Morning Rush Hour Design Conditions

Dry-Bulb Temperature (^oF)

21 ☐☐☐☐☐☐☐☐☐☐ 30

Wet-Bulb Temperature (^oF)

31 ☐☐☐☐☐☐☐☐☐☐ 40

Evening Rush Hour or Off Hour Design Conditions

Dry-Bulb Temperature (^oF)

41 ☐☐☐☐☐☐☐☐☐☐ 50

Wet-Bulb Temperature (^oF)

61 ☐☐☐☐☐☐☐☐☐☐☒ 60

FORM 11B - ENVIRONMENTAL CONTROL ZONES

The number of entries on this form must equal the number of line segments and ventilation shafts entered in Form 11A for this zone. If the number of Environmental Control Zones on Form 1E is 1, skip this form.

IDENTIFICATION NUMBERS OF LINE SEGMENTS AND VENTILATION SHAFTS IN ZONE	Enter the identification numbers of all the line segments and ventilation shafts in this zone. No segment or ventilation shaft can be located in more than one zone. The order in which the identification numbers are entered is not significant. 1. ≤ N ≤ 999. Error Type 44, 95, 96, 97, 98, 114, 168, 191, 195 N must be any valid line segment or ventilation shaft identification number

FORM 11B - ENVIRONMENTAL CONTROL ZONES

Sheet ________ of ________
Made by: ________________
Checked by: ______________
Date: ___________________

Zone Data

Identification Numbers of Line Segments and Ventilation Shafts in Zone

1									10	
11									20	
21									30	
31									40	
41									50	
51									60	
61									70	
71									80	
										☒

etc.

FORM 12 - PRINT CONTROL DATA

TEMPERATURE TABULATION INCREMENT	The number entered here determines the increments for which the variations from design temperature are printed within the summary. To illustrate, if it is summer and the design temperature is 80°F, the user might enter +10. The summary would then print the percentage of time the air temperature goes above 60, 70, 80, 90, 100, and 110°F for each subsegment of each controlled zone. Conversely, if it is winter and the design temperature is 80°F, the user might enter -10. The summary would then print the percentage of time the air temperature goes below 50, 60, 70, 80, 90, and 100°F. $-10. \leq X \leq 10.$ °F	Error Type 130
NUMBER OF PRINT GROUPS	Enter the total number of print groups which are to be specified. $1. \leq N \leq 25.$	Error Type 79
NUMBER OF INTERVALS	Enter the number of equally spaced time intervals in this print group. After each interval a detailed or abbreviated print will be made. This number cannot be zero. An entry of -1. indicates there is one interval in this group, but printout should be bypassed. $0. \leq N \leq 1,000.$ or -1.	Error Type 80
INTERVAL LENGTH	Enter the length of time in each of the print intervals for this print group. $0.1 \leq N \leq 3600.$ sec	Error Type 81
NUMBER OF ABBREVIATED PRINTS PER DETAIL PRINT	This entry describes the ratio of abbreviated prints to detailed prints. $0. \leq N \leq$ Number of print intervals in this group.	Error Type 82
SUMMARY OPTION	The user may choose from the following options at the end of each print group: 0 - No summaries - only the detailed or abbreviated prints will be performed. 1 - Initialize - this resets the summary totals, and a new summary begins at this time. 2 - Summary - this prints a summary starting from the most recent initialization. 3 - Summary and Initialize - this performs options 2 and 1 (in that order). 4 - Summary, Environmental Estimate and Initialize - this performs option 2, then prints an environmental control estimate, and then performs option 1.	Error Type 83, 246 , 259
NUMBER OF CYCLES PER AERODYNAMIC EVALUATION NUMBER OF CYCLES PER THERMODYNAMIC EVALUATION	These numbers are integer multiples of the time increment per cycle and determine when a complete aerodynamic and thermodynamic evaluation for the system is to be performed. For example, if the user has entered 10. for the time increment per cycle, and enters a 1. here, a complete aerodynamic or thermodynamic evaluation will be performed every (1) x (0.1 sec)= 0.1 sec. If a zero is entered in the first print group, zero must be entered in all print groups. If a non-zero value is entered in the first print group, a non-zero value must be entered in all print groups. If the summary option in the previous print group is zero, but is non-zero in any other group, or the summary option in the previous print group is 2, the number of cycles per evaluation must be the same as in the previous print group. $0. \leq N \leq 100.$	Error Type 147, 228, 229, 148

FORM 12 - PRINT AND CYCLE CONTROL DATA

Sheet ________ of ________
Made by: ________
Checked by: ________
Date: ________

Temperature Tabulation Increment

Summer (+)
Winter (-)
1 ☐☐☐☐☐☐☒ 6

Number of Print Groups 11 ☐☐☐☐☐☐☒ 16

Group Number	Number of Intervals	Interval Length (sec)	Number of Abbreviated Prints per Detail Print	Summary Option	Number of Cycles per Aerodynamic Evaluation	Number of Cycles per Thermodynamic Evaluation
1	1 ☐☐☐☐☐☐ 6	11 ☐☐☐☐☐☐ 16	21 ☐☐☐☐☐☐ 26	31 ☐☐☐☐☐☐ 36	41 ☐☐☐☐☐☐ 46	51 ☐☐☐☐☐☐☒ 56
2	1 ☐☐☐☐☐☐ 6	11 ☐☐☐☐☐☐ 16	51 ☐☐☐☐☐☐ 26	31 ☐☐☐☐☐☐ 36	41 ☐☐☐☐☐☐ 46	51 ☐☐☐☐☐☐☒ 56
3	1 ☐☐☐☐☐☐ 6	11 ☐☐☐☐☐☐ 16	21 ☐☐☐☐☐☐ 26	31 ☐☐☐☐☐☐ 36	41 ☐☐☐☐☐☐ 46	51 ☐☐☐☐☐☐☒ 56
4	1 ☐☐☐☐☐☐ 6	11 ☐☐☐☐☐☐ 16	21 ☐☐☐☐☐☐ 26	31 ☐☐☐☐☐☐ 36	41 ☐☐☐☐☐☐ 46	51 ☐☐☐☐☐☐☒ 56
5	1 ☐☐☐☐☐☐ 6	11 ☐☐☐☐☐☐ 16	21 ☐☐☐☐☐☐ 26	31 ☐☐☐☐☐☐ 36	41 ☐☐☐☐☐☐ 46	51 ☐☐☐☐☐☐☒ 56
	etc.	etc.	etc.	etc.	etc.	etc.

FORM 13 - PROGRAM CONTROL DATA

TIME INCREMENT PER CYCLE	This is the basic time interval over which the location, speed, and acceleration of all the trains in the system is calculated. The aerodynamic, thermodynamic, and complete train evaluation calculations are performed at user specified integer multiples of this basic calculation time interval. This number is entered in 100ths (1/100) of a second. For example, if the user enters 10.0 (equivalent to 10/100 of a second), the location, speed, and acceleration of all trains will be calculated every tenth of a second. 1. ≤ N (equivalent to: 0.01 sec ≤ X)	Error Type 113
MAXIMUM SIMULATION TIME	Enter the maximum time for which the simulation is to be performed. 0. ≤ N ≤ Time of last print-out	Error Type 84. 113
NUMBER OF CYCLES PER COMPLETE TRAIN EVALUATION	This number is an integer multiple of the time increment per cycle and determines when a) new trains are to be dispatched into the system; b) trains that have traveled beyond the last track section on their route are to be removed; and c) checks for upcoming train speed restrictions to be made and whether or not braking is necessary. For example, if the user has entered 10.0 for the time increment per cycle and enters a 5.0 for this entry, a complete train evaluation will be performed every (5) x (0.10 sec) = 0.5 second. 1. ≤ N ≤ 100.	Error Type 146

The following is entered only if the Fire Simulation Option on Form 1G is 1

NUMBER OF THERMODYNAMIC CYCLES PER WALL TEMPERATURE EVALUATION	This number is an integer multiple of the number of cycles per thermodynamic evaluation entered on Form 12, and determines the frequency of wall temperature calculations for each subsegment of a segment which is designated as a fire segment on Form 3A. For example if the user has entered 10.0 for the time increment per cycle, 2.0 for the number of cycles per thermodynamic evaluation and 5.0 for this entry, the wall temperature calculations in the prescribed subsegments will be performed every (0.10 sec) x (2.0) x (5.0) = 1 second. N ≥ 0.	Error Type 261

FORM 13 - PROGRAM CONTROL DATA

Sheet ________ of ________
Made by: ____________________
Checked by: ____________________
Date: ____________________

	1 – 10
Time Increment per Cycle (1/100th of sec)	☐☐☐☐☐☐☐☐☐☐

	11 – 20
Maximum Simulation Time (sec)	☐☐☐☐☐☐☐☐☐☐

	21 – 30
Number of Cycles per Complete Train Evaluation	☐☐☐☐☐☐☐☐☐☐

	31 – 40
Number of Thermodynamic Cycles per Wall Temperature Evaluation (Applicable during fire simulations only)	☐☐☐☐☐☐☐☐☐☐☒

13. INPUT ERROR MESSAGES

The SES program has a built-in warning system to alert the user to any questionable or erroneous input data. Most of the error messages are very specific and warn the user that a particular input item is not within generally accepted limits. (When the input involves new or unknown subway design criteria, the generally accepted limits are based upon reasonable estimates.) In addition to the error messages that result from an input item being beyond its generally accepted limits, there are various error messages that result from either the user's carelessness or failure to arrange the system in the proper manner. All of the error messages fall under two general types. The first type is called a "fatal error message," and the second type is called a "non-fatal error message." The discussion of these two types of error messages as well as a brief description of each non-self-explanatory error message is given below.

13.1 The Fatal Error Message

The fatal error message occurs when the user has entered data that results in the program exceeding its storage limits for that particular data or when data entered has no meaning. When the program encounters a fatal error, the simulation is immediately terminated. The fatal error message will first identify the fatal error and then inform the user that "THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE. SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT."

Exceeding the Storage Limits. The SES program has finite limitations on the size of system it can simulate. This limitation is due to the actual physical limitations of the computer being used. All computers have finite limitations on their memory storage capacities, and this in turn places finite limitations upon all programs (referred to in the SES as "array sizes"). Each SES input item uses an assigned portion of the computer's memory storage. The proportion of memory storage for each input item has been carefully allotted so that the size of the system that can be simulated has been maximized. Therefore it is obvious that if the size of an input item exceeds its allotted storage capacity, the user must be notified of the mistake and the simulation must be terminated immediately. As stated previously, the fatal error message was created exactly for this purpose.

Meaningless or Conflicting Data. The fatal error message also occurs when conflicting or meaningless data is placed into the SES. This is often caused by specific input items that are completely incongruous with one another. One example of this incongruity would be when the user states there are N line sections and (N-2) line segments. The number of line segments must always be greater than or equal to the number of line sections. Other fatal error messages are the result of meaningless input. One example of this is when the user states there are four subsegments in a segment, and then proceeds to describe a steady-state heat source within this segment between subsegment 1 and subsegment 6.

Obviously, the program finds the description of a steady-state heat source in subsegment 5 and 6 to be meaningless.

13.2 The Non-Fatal Error Message

The non-fatal error simply tells the user that an input item is not within its generally accepted limits. A non-fatal error may or may not immediately terminate the simulation, depending upon whether this error causes the number of allowable input errors to be exceeded. The number of allowable input errors allows the user to choose the number of non-fatal errors the program can tolerate before it terminates the simulation. The user may allow for up to N non-fatal errors by setting the number of allowable input errors to +N. As soon as the program encounters error number N+1 it will immediately terminate the simulation. If the user wishes the program to terminate immediately upon discovering the first error, the number of allowable input errors should be set equal to zero. This is a very important option as it allows the user to simulate unusual geometries or design conditions that are not within their generally accepted limits. The unusual design conditions will cause one or more non-fatal errors, but the simulation will not terminate due to the fact the user has allowed for them by means of the number of allowable input errors. An example of the use of this is as follows: The user wishes to simulate the operation of a very long train consisting of 24 cars. There will be an error message saying "THE NUMBER OF CARS IN THIS SUBWAY TRAIN IS LESS THAN 1 OR GREATER THAN 20". The user is aware of the fact the program is simulating what is generally considered to be an extremely long train, and therefore allows this "error" by setting the number of allowable input errors to +1.0. The program will then allow this non-fatal error, and will finish the simulation assuming no further non-fatal or fatal errors are found. The program will immediately terminate the simulation if another non-fatal error is found, as the number of allowable input errors was set equal to +1.0.

13.3 Input Verification

The SES program verifies all the input data in order to determine whether or not it should proceed with the simulation of the given system. This process is referred to as "input verification". The input verification is done for every SES simulation. As explained in Sections 13.1 and 13.2, if the input contains no fatal errors and has a number of non-fatal errors that is less than or equal to the number of allowable input errors, the simulation will proceed as intended.

The First Attempt to Simulate A Given System. When the user finally has gathered all the input data and is attempting the first simulation, it is likely that there will be errors in the input data. Until a fair amount of experience using the SES program has been gained, a user should expect errors in the gathering and preparation of the data.

The SES program allows the user to run an input verification without running a simulation. This enables the user to determine the errors in the data before actually running a simulation in which a considerable amount of money may be wasted due to an unknown error that renders the whole simulation useless. The user must set the number of allowable input errors equal to -1.0 on Input Form 1C to have the SES perform only the input verification.

Setting the Number of Allowable Input Errors to -1.0. When the user sets the number of allowable input errors to -1.0, the SES will verify the input data and print an error message for all non-fatal errors found in the data until a fatal error is reached. The total number of non-fatal errors found in the input data is printed at the very end of the input verification. If fatal-error is found in the data, the input verification will terminate immediately. This procedure allows the user to correct all fatal errors and unintentional non-fatal errors. After performing the necessary number of input verifications to correct all unintentional errors, the user will be ready to perform a simulation of the system. The user must set the number of allowable input errors equal to the number of intentional non-fatal errors. If there is no intentional errors in the simulation, the user must set the number of allowable input errors equal to zero.

Performing a Simulation. After setting the number of allowable input errors equal to the number of intentional non-fatal errors, the user is ready to perform a simulation. If any of the input data is changed subsequent to the final input verification, the simulation may terminate due to an unforeseen error caused by the changes in the input data. Therefore the user should always perform a final input verification after all the changes to the input data have been made. When the simulation is finally performed, the user will receive both an input verification and the results of the simulation.

13.4 Error Messages

Many of the error messages are self-explanatory. Only the non-self-explanatory error messages will be discussed in this section. The discussion of each non-self-explanatory error message contains a clarification of the type of error created and the cause of the error. In addition, the method needed to correct the error is outlined. When the corrective method involves increasing an array size limit, both the general descriptive name and the program variable name of the array size limit is provided.

```
*ERROR* TYPE    1              ********************************************************************************
                THE TOTAL NUMBER OF LINE SEGMENTS ENTERED IS LESS THAN 1 OR GREATER THAN  620.
                THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 1 is a fatal error that is caused either by exceeding the program array size limit for the total number of line segments (variable name: LMLSEG), or by having fewer than 1 segment, as all systems must contain at least one segment. The former can be corrected by increasing the array size (see Programmer's Manual) and/or combining adjacent segments that are similar to each other within each section until the total number of segments in the system is within the array size limit. In addition, the portion of the system being simulated can be reduced in order to decrease the total number of segments to a number within the array size limit (see Section 5.2).

```
*ERROR* TYPE    2              ********************************************************************************
                THE NUMBER OF VENTILATION SHAFTS ENTERED IS LESS THAN 0 OR GREATER THAN  406.
                THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 2 is a fatal error that is caused either by exceeding the program array size limit for the total number of ventilation shafts (variable name: LMVSEG), OR by having a negative number of ventilation shafts. The former can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the portion of the system being simulated until the number of ventilation shafts is within the array size limit (see Section 5.2).

```
*ERROR* TYPE    3              ********************************************************************************
                THE NUMBER OF TRACK SECTIONS ENTERED IS LESS THAN 0 OR GREATER THAN  619.
                THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 3 is a fatal error that is caused either by exceeding the program array size limit for the total number of track sections (variable name: LMTSRT), or by having fewer than one track section. The former can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the number of track sections. The number of track sections may be reduced by combining two adjacent very similar track sections into one track section. In addition, the portion of the system being simulated can be reduced until the number of track sections is within the array size limits (see Section 5.2). There must always be at least one track section if trains are to be operating within the system.

```
*ERROR* TYPE    4              ********************************************************************************
                THE AVERAGE PATRON WEIGHT IS LESS THAN 50 OR GREATER THAN 200 LBS.


*ERROR* TYPE    5              ********************************************************************************
                THE AMBIENT BAROMETRIC PRESSURE ENTERED IS LESS THAN 20.00 OR GREATER THAN 32.00 IN. HG.


*ERROR* TYPE    6              ********************************************************************************
                THE SOURCE TYPE SHOULD BE 1 OR 2.
```

```
*ERROR* TYPE   7                     ********************************************************************************
               THE DRY-BULB TEMPERATURE ENTERED IS LESS THAN -50.0 OR GREATER THAN 140.0 DEG. F.
```

```
*ERROR* TYPE   8                     ********************************************************************************
               THE WET-BULB TEMPERATURE ENTERED IS LESS THAN -50.0 OR GREATER THAN THE DRY-BULB TEMPERATURE.
```

```
*ERROR* TYPE   9                     ********************************************************************************
               THE TOTAL NUMBER OF PASSENGERS ON THIS TRAIN IS LESS THAN ZERO.
```

This non-fatal error occurs when the number of people leaving the train at a stop is greater than the number of people already onboard prior to the stop. In addition, the number of people onboard the train at the scheduling origin must be a non-negative number.

```
*ERROR* TYPE  10                     ********************************************************************************
               AN INVALID TYPE OF LINE SEGMENT HAS BEEN ENTERED.
```

This non-fatal error occurs when the line segment type has not been entered as either type 1 (tunnel segment), types 2 - 4 (station segments), or types 5 - 16 (special tunnel segments).

```
*ERROR* TYPE  11                     ********************************************************************************
               THE FAN STOPPING/WINDMILLING OPTION HAS NOT BEEN ENTERED AS EITHER 1(SIMULATION TERMINATION)
                                                                               OR 2(FAN SHUTDOWN ONLY).
               THE DEFAULT VALUE OF 1(SIMULATION TERMINATION) WILL BE USED.
```

```
*ERROR* TYPE  12                     ********************************************************************************
               THE LOCATION OF THE FORWARD END OF THIS TRACK SECTION IS LESS THAN 0 OR GREATER THAN 1,000,000 FEET.
```

```
*ERROR* TYPE  13                     ********************************************************************************
               THE LENGTH OF THIS TRACK SECTION IS LESS THAN 10 FT.
```

```
*ERROR* TYPE  14                     ********************************************************************************
               THE RADIUS OF CURVATURE OF THIS TRACK SECTION IS LESS THAN 75 FT.
```

```
*ERROR* TYPE  15                     ********************************************************************************
               THE GRADE OF THIS TRACK SECTION IS STEEPER THAN 10 PERCENT.
```

```
*ERROR* TYPE  16                     ********************************************************************************
               THE MAXIMUM ALLOWABLE TRAIN VELOCITY IN THIS TRACK SECTION IS LESS THAN
               1 OR GREATER THAN 250 MPH.
```

```
*ERROR* TYPE  17                    ********************************************************************************
               THE TRAIN PERFORMANCE OPTION HAS BEEN ENTERED INCORRECTLY-
               IT SHOULD BE 0 (BYPASS)
                            1 (IMPLICIT)
                            2 (EXPLICIT WITH TRAIN HEAT REJECTION COMPUTED)
                            3 (EXPLICIT WITH TRAIN HEAT REJECTION INPUT).
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE  18                    ********************************************************************************
               THE INITIAL LOCATION OF THE ABOVE TRAIN IS LESS THAN THAT OF THE SCHEDULING ORIGIN FOR ITS ROUTE.
```

This non-fatal error occurs when a train is initialized at a location less than the scheduling origin for trains along the same route. All trains must be within the normal operating route which is bounded by the scheduling origin and the end of the last track section.

```
*ERROR* TYPE  19                    ********************************************************************************
               THE LENGTH OF THIS LINE SEGMENT IS LESS THAN 10 FEET
               OR GREATER THAN 100,000 FEET.


*ERROR* TYPE  20                    ********************************************************************************
               THE AREA OF THIS LINE SEGMENT IS LESS THAN 75 OR GREATER THAN 10,000 SQ FT.


*ERROR* TYPE  21                    ********************************************************************************
               THE PERIMETER OF THIS LINE SEGMENT IS LESS THAN 30 OR GREATER THAN 1,000 FT.


*ERROR* TYPE  22                    ********************************************************************************
               THE WEIGHTED AVERAGE ROUGHNESS LENGTH FOR THIS LINE SEGMENT IS LESS THAN 0.0 OR GREATER THAN 2.0.
```

This non-fatal error occurs when the weighted average of all the roughness lengths associated with the perimeters of the segment is less than 0.0 or greater than 2.0 feet. Roughness lengths cannot be negative. Certain portions of a subway system may contain large uniformly spaced protrusions that approach a length of 2.0 feet, but the percent of a system's perimeter that contains such a roughness length should be extremely small. Therefore, the weighted average roughness length should not be above 2.0 feet.

```
*ERROR* TYPE  23                    ********************************************************************************
               THE WALL SURFACE TEMPERATURE IS LESS THAN 0 OR GREATER THAN 130 DEG. F.


*ERROR* TYPE  24                    ********************************************************************************
               THE INITIAL AIR DRY-BULB TEMPERATURE IS LESS THAN 0 OR GREATER THAN 130 DEG F.


*ERROR* TYPE  25                    ********************************************************************************
               THE INITIAL AIR WET-BULB TEMPERATURE IS LESS THAN 0 OR GREATER THAN THE DRY-BULB TEMPERATURE.


*ERROR* TYPE  26                    ********************************************************************************
               THE DESIGN DRY-BULB TEMPERATURE IS LESS THAN 40 OR GREATER THAN 100 DEG F.
```

```
*ERROR* TYPE  27              ********************************************************************************
                THE DESIGN WET-BULB TEMPERATURE IS LESS THAN 40 OR
                GREATER THAN THE DESIGN DRY-BULB TEMPERATURE.
```

```
*ERROR* TYPE  28              ********************************************************************************
                THE VALUE ENTERED FOR THIS HEAD LOSS COEFFICIENT IS LESS THAN 0 OR GREATER THAN 1000.
```

```
*ERROR* TYPE  29              ********************************************************************************
                THE NUMBER OF SUBSEGMENTS IN THIS LINE SEGMENT IS LESS THAN 1 OR GREATER THAN 1200.
                THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 29 is a fatal error that is caused either by exceeding the program array size limit for the total number of line subsegments (variable name: LMLSS), or by having less than 1 subsegment in the line segment. The former can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the number of subsegments within the line segment until the number of line subsegments is within the array size limit. The lengths of most subsegments can be increased, especially in tunnel segments where temperature fluctuations are not as great or as significant as in stations, without greatly affecting the accuracy of the results. Increasing the length of the subsegments in a line segment will decrease the total number of subsegments within the line segment. There must always be at least 1 line subsegment per line segment.

```
*ERROR* TYPE  30              ********************************************************************************
                THE TOTAL NUMBER OF LINE SUBSEGMENTS HAS EXCEEDED 1200.
                THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 30 is a fatal error that is caused by exceeding the program array size limit for line subsegments (variable name: LMLSS). This error can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the total number of line subsegments in the system until the total number of line subsegments is within array size limits. The length of most subsegments can be increased, especially in tunnel segments where temperature fluctuations are not as great or as significant as in stations, without greatly affecting the accuracy of the results. Increasing the length of various line subsegments will decrease the total number of line subsegments within the system. In addition, the user may reduce the portion of system that is to be simulated until the total number of line segments is within the array size limits (see Section 5.2).

```
*ERROR* TYPE  31              ********************************************************************************
                AN IMPROPER SUBSEGMENT NUMBER HAS BEEN ENTERED AS A LIMIT FOR A STEADY STATE HEATING OR COOLING SOURCE.
                THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 31 is a fatal error that is caused either by stating a steady-state heat source exists within a segment in one or more undefined or non-existent subsegments, or by describing the subsegments that bound the steady-state heat source in improper order. An example of this type is as follows: A steady-state heat source is distributed evenly over five subsegments in a particular segment containing 10 subsegments. If the user states this steady-state heat source exists from subsegment number 7 to subsegment number 11, an error type 31 will be received as there is no subsegment number 11. Similarly, if the user states the steady-state heat source starts in subsegment 8 and ends in subsegment 4, this error will be received as the bounding subsegments of the steady-state heat source have been entered in incorrect order. The subsegment number that marks the end of the steady-state heat source must be greater than or equal to the subsegment number that marks the beginning of the steady-state heat source. No subsegment number can ever be less than 1.

```
*ERROR* TYPE  32                      *************************************************************************************
               THE START OF SIMULATION PERIOD IS LESS THAN 0 OR GREATER THAN 24 HRS.  THE DEFAULT VALUE OF 17 HRS WILL BE USED.


*ERROR* TYPE  33                      *************************************************************************************
               THE DESIGN MONTH ENTERED IS LESS THAN 1 OR GREATER THAN 12.  THE DEFAULT VALUE OF 7 WILL BE USED.


*ERROR* TYPE  34                      *************************************************************************************
               THE HEAT SINK THERMAL CONDUCTIVITY ENTERED IS LESS THAN 0.005 OR GREATER THAN 2.0 BTU/HR-FT-DEG. F.


*ERROR* TYPE  35                      *************************************************************************************
               THE HEAT SINK THERMAL DIFFUSIVITY ENTERED IS LESS THAN 0.005 OR GREATER THAN 1.0 SQ FT/HR.


*ERROR* TYPE  36                      *************************************************************************************
               THE MINUTES PORTION OF THE DESIGN TIME IS GREATER THAN 59.  THE DEFAULT VALUE OF ZERO (0) WILL BE USED.


*ERROR* TYPE  37                      *************************************************************************************
               THE STACK HEIGHT OF THIS VENTILATION SHAFT IS LESS THAN -1000 OR GREATER THAN 1000 FEET.


*ERROR* TYPE  38                      *************************************************************************************
               THE AREA OF THIS VENTILATION SHAFT IS LESS THAN 3 OR GREATER THAN 3000 SQ FT.


*ERROR* TYPE  39                      *************************************************************************************
               THE PERIMETER OF THIS VENTILATION SHAFT IS LESS THAN 5 OR GREATER THAN 500 FEET.


*ERROR* TYPE  40                      *************************************************************************************
               THE LENGTH OF THIS VENTILATION SHAFT SEGMENT IS LESS THAN 0
               OR GREATER THAN 2000 FEET.


*ERROR* TYPE  41                      *************************************************************************************
               THE AVERAGE NUMBER OF LOOPS ADJACENT TO EACH LOOP IN THE SENSE OF SHARING ONE OR MORE SECTIONS HAS BEEN EXCEEDED.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 41 is a fatal error that is <u>not</u> caused by a user error. This error is due solely to the memory storage capacity limitations of the computer. This error may be corrected by increasing the LMLPK array size limit (see Programmer's Manual) and/or decreasing the portion of the system that is to be simulated (see Section 5.2).

```
*ERROR* TYPE  42                      *************************************************************************************
               THE NUMBER OF SUBSEGMENTS IN THIS VENTILATION SHAFT IS LESS THAN 1 OR GREATER THAN 1600.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 42 is a fatal error that is caused either by exceeding the program array size limit for the total number of ventilation shaft sub-segments (variable name: LMSS), or by having fewer than 1 subsegment in the ventilation shaft. The former can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the number of subsegments within the ventilation shaft until the number of ventilation shaft subsegments is within the array size limit. There must always be at least 1 subsegment in every ventilation shaft.

```
*ERROR* TYPE  43                    ********************************************************************************
          THE TOTAL NUMBER OF LINE AND VENT SHAFT SUBSEGMENTS IN THIS SYSTEM IS GREATER THAN 1600.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE  44                    ********************************************************************************
          A CONTROLLED ZONE ( TYPE 1 ) MUST NOT CONTAIN A VENTILATION SHAFT.


*ERROR* TYPE  45                    ********************************************************************************
          THE NUMBER OF DATA POINTS FOR THIS SPEED VS TIME PROFILE IS LESS THAN 2 OR GREATER THAN  100.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 45 is a fatal error that is caused either by exceeding the program array size limit for the total number of speed-time profile points (variable name: LMEXPD), or by having less than 2 speed-time data points. The former can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the number of speed-time profile points until the number of speed-time points is within the array size limit. One method of reducing the number of speed-time profile points without losing any accuracy is to reduce the number of speed-time data points during the times the train is moving at constant speed. Due to the fact the program interpolates linearly between data points, the only data required while the train is moving at constant speed is two successive speed-time entries, the first being at the point in time where the train begins moving at constant speed, and the second at the point in time where the train stops moving at constant speed. Any data between these two points is unessential and can be eliminated if deemed necessary. If train performance option number 3 is being used, the train heat rejection rate must also be a constant during this time for this method to be applicable. Additional reductions can be made within the portions of the speed-time profile where the train speed does not vary appreciably (less than 5 percent) by assuming the train is moving at constant speed and reducing the number of data points by the method outlined above. The accuracy of the speed-time profile will not be greatly affected by this procedure. As in the procedure described above, if train performance option number 3 is being used, the train heat rejection rates must also be approximately constant during this time for this method to be applicable. Finally, the portion of the system that is to be simulated can be reduced until the number of speed-time profile points is within the array size limits (see Section 5.2). The program interpolates linearly between the speed-time data points when train speed information is required during a simulation, and it is for this reason that at least two speed-time data points must be entered, as interpolation can only be performed when there are two or more points within a data set.

```
*ERROR* TYPE  46                     ********************************************************************************
          THE TIME DATA POINTS HAVE BEEN ENTERED OUT OF ORDER OR HAVE A TIME SPAN GREATER THAN 1 DAY.


*ERROR* TYPE  47                     ********************************************************************************
          A TRAIN SPEED LESS THAN 0 OR GREATER THAN 250 MPH HAS BEEN ENTERED.


*ERROR* TYPE  48                     ********************************************************************************
          THE NUMBER OF TRACK SECTIONS PLUS TWICE THE NUMBER OF SCHEDULED STOPS
          PLUS THE NUMBER OF LINE SEGMENTS THRU WHICH THE ROUTE PASSES PLUS 2 IS GREATER THAN 620
          OR THE NUMBER OF STOPS ENTERED IS NEGATIVE.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 48 is a fatal error that is caused by exceeding the array size limit for the total number of track sections (variable name: LMTSRT). The program internally creates two track sections for each stop along a route, and one track section for each segment through which the train passes in addition to the track sections entered by the user when describing the train route. In addition, the program internally creates up to two additional track sections depending on the geometry of the system described by the user. Therefore, the user might receive this error message if the number of track sections described externally exceeds the maximum number allowed, depending upon the number of scheduled stops made and the number of segments through which the train passed. This error can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the number of track sections. The number of track sections may be reduced by combining two adjacent very similar track sections into one track section. In addition, the number of track sections may be reduced by combining adjacent segments that are similar to each other within each section. Finally, the user may reduce the portion of the system being simulated until the total number of track sections is within the array size limits (see Section 5.2).

```
*ERROR* TYPE  49                     ********************************************************************************
          THE LOCATION OF THIS SCHEDULED STOP IS NOT WITHIN THE LIMITS OF THE TRACK SECTIONS.

*ERROR* TYPE  50                     ********************************************************************************
          THE DWELL TIME AT A SCHEDULED STOP IS GREATER THAN 900 SECONDS.


*ERROR* TYPE  51                     ********************************************************************************
          THE NUMBER OF CARS IN THIS SUBWAY TRAIN IS LESS THAN 1 OR GREATER THAN 20.


*ERROR* TYPE  52                     ********************************************************************************
          THE LENGTH OF THIS SUBWAY TRAIN IS LESS THAN 25 OR GREATER THAN 1,500 FT.


*ERROR* TYPE  53                     ********************************************************************************
          THE FRONTAL AREA OF THIS SUBWAY TRAIN IS LESS THAN 25 OR GREATER THAN 300 SQ FT.


*ERROR* TYPE  54                     ********************************************************************************
          THE DECELERATION RATE FOR THIS TRAIN IS LESS THAN 0.5 OR GREATER THAN 5.0 MPH/SEC.


*ERROR* TYPE  55                     ********************************************************************************
          THE SKIN FRICTION COEFFICIENT FOR THIS TRAIN IS LESS THAN 0.0001 OR GREATER THAN 0.20.


*ERROR* TYPE  56                     ********************************************************************************
          THE AVERAGE EMPTY CAR WEIGHT IS LESS THAN 5 OR GREATER THAN 150 TONS.
```

```
*ERROR* TYPE  57                    ********************************************************************************
               THE SENSIBLE HEAT REJECTION RATE PER CAR IS LESS THAN 0 OR GREATER THAN 1,000,000 BTU/HR.


*ERROR* TYPE  58                    ********************************************************************************
               THE LATENT HEAT REJECTION RATE PER CAR IS LESS THAN -50,000 OR GREATER THAN 200,000 BTU/HR.


*ERROR* TYPE  59                    ********************************************************************************
               THIS WHEEL DIAMETER IS LESS THAN 20 OR GREATER THAN 40 IN.


*ERROR* TYPE  60                    ********************************************************************************
               THIS GEAR RATIO IS LESS THAN 1 TO 1 OR GREATER THAN 20 TO 1.


*ERROR* TYPE  61                    ********************************************************************************
               TOTAL MOTOR RESISTANCES ENTERED ARE LESS THAN 0.001 OR GREATER THAN 3.0 OHMS.


*ERROR* TYPE  62                    ********************************************************************************
               THESE RESISTANCE VELOCITIES ARE LESS THAN 0 MPH, GREATER THAN 100 MPH, OR NOT ENTERED IN THE PROPER ORDER.
```

This non-fatal error message is basically self-explanatory. The second of the two resistance velocities entered in the input data must be greater than or equal to the first resistance velocity entered.

```
*ERROR* TYPE  63                    ********************************************************************************
               THE TUNNEL WALL THICKNESS IS LESS THAN 0 OR GREATER THAN 30 FEET.


*ERROR* TYPE  64                    ********************************************************************************
               THE NUMBER OF GROUPS OF TRAINS ENTERED IS LESS THAN 1 OR GREATER THAN  25.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE  65                    ********************************************************************************
               THE TRAIN TYPE ENTERED DOES NOT EXIST.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 65 is a fatal error that is caused by an error in the identification of the type of train that is to be traveling on a route. The program asks for the number of train types in the "General Data" section of the input. If 3 train types are stated in the General Data section, the user must refer to these 3 train types in the General Data section. The user must also refer to these 3 train types as type 1, type 2, and type 3 when describing the trains in the "Train Route Description" data section. Any other train type other than those mentioned will cause this error type.

```
*ERROR* TYPE  66                    ********************************************************************************
               THE NUMBER OF TRAINS IN THIS GROUP IS LESS THAN 1 OR GREATER THAN 1,000.


*ERROR* TYPE  67                    ********************************************************************************
               THE HEADWAY FOR THIS GROUP OF TRAINS IS NEGATIVE OR GREATER THAN 10,000 SECONDS.


*ERROR* TYPE  68                    ********************************************************************************
               A TOTAL PRESSURE RISE FOR THIS FAN IS LESS THAN -15. OR GREATER THAN 50.0 IN. W.G.
```

```
*ERROR* TYPE  69                    ********************************************************************************
          A VOLUME FLOW RATE FOR THIS FAN IS LESS THAN 0 OR GREATER THAN 2,000,000 CFM.
```

```
*ERROR* TYPE  70                    ********************************************************************************
          THIS PERIMETER IS INCONSISTENT WITH THE SPECIFIED AREA.
```

```
*ERROR* TYPE  71                    ********************************************************************************
          THE DIFFERENCE BETWEEN THE END OF THE LAST TRACK SECTION ON THIS ROUTE AND THE
          SUM OF THE SCHEDULING ORIGIN PLUS THE DISTANCE TRAVELED DURING THIS SPEED-TIME PROFILE
          IS GREATER THAN +50.0 FEET.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 71 is a fatal error that is caused by miscalculating the speed-time profile for a train when using train performance option number 2. When a speed-time profile is provided for a train, the user must make sure the train travels the <u>entire distance</u> along the route it is traveling. The program has a tolerance of 50 feet. Therefore, if the train travels to within 50 feet or less of the end of the last track section on its route, it will be within the tolerance of the program. This error message only pertains to trains that <u>fall short</u> of the end of the last track section on their route by more than 50 feet. The distance traveled during a speed-time profile may always be greater than the end of the last track section on their route by more than 50 feet. The distance traveled during a speed-time profile may always be greater than the end of the last track section for all trains on all routes.

```
*ERROR* TYPE  72                    ********************************************************************************
          THE NUMBER OF MOTORS PER CAR IN THIS TRAIN IS LESS THAN 1 OR GREATER THAN 10.
```

```
*ERROR* TYPE  73                    ********************************************************************************
          THE NUMBER OF NON-ZERO ITEMS IN THE GENERAL DATA IS INSUFFICIENT TO DESCRIBE ANY SIMULATION.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 73 is a fatal error that is caused by having no trains and no tunnel system. The SES may be run with trains and no tunnel system (such as when trains are running in free air), or with a tunnel system and no trains (such as when simulating the emergency ventilation capabilities of a system with fans), but no simulation may be run with no trains <u>and</u> no tunnel system.

```
*ERROR* TYPE  74                    ********************************************************************************
          THE MAXIMUM ACCELERATION RATE ALLOWED FOR THIS TRAIN IS LESS THAN 0.5 OR GREATER THAN 5.0 MPH/SEC.
```

```
*ERROR* TYPE  75                    ********************************************************************************
          THE DATA POINTS FOR THIS FAN CURVE ARE INCORRECT OR TOO CLOSE TO EACH OTHER.
```

This non-fatal error is caused by placing the fan curve data in the input in a manner that does not supply the program with four pairs of independent data points. This occurs when there is a duplication of a data point, or when two data points have been entered so close to one another that the program is unable to fit a cubic polynomial curve through all four points.

```
*ERROR* TYPE  76                    ***************************************************************************************
              THE OPERATING TIMES FOR THIS FAN ARE OUT OF ORDER.
```

```
*ERROR* TYPE  77                    ***************************************************************************************
              THE ACCELERATION RESISTANCE OF THE ROTATING PARTS OF THIS TRAIN IS LESS THAN 0.1 OR
              GREATER THAN 30.0 LBS PER TON/(MPH/SEC).
```

```
*ERROR* TYPE  78                    ***************************************************************************************
              THE PERIMETER OF THIS TRAIN IS LESS THAN 20.0 OR GREATER THAN 200.0 FEET.
```

```
*ERROR* TYPE  79                    ***************************************************************************************
              THE NUMBER OF PRINT GROUPS IS LESS THAN 1 OR GREATER THAN  25.
              THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
              SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
              ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
              PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE  80                    ***************************************************************************************
              THE NUMBER OF PRINT INTERVALS IN THIS PRINT GROUP IS LESS THAN -1, GREATER THAN 1000, OR EQUAL TO 0.
```

This non-fatal error is basically self-explanatory. If the user wishes to have one print interval in a print group, but <u>does not wish to have a printout</u> at the end of this print interval, then a -1.0 must be entered for the number of print intervals. There can <u>never</u> be 0.0 print intervals in a print group.

```
*ERROR* TYPE  81                    ***************************************************************************************
              THE PRINT INTERVAL FOR THIS PRINT GROUP IS LESS THAN 0.1 OR GREATER THAN 3600.0 SECONDS.
```

```
*ERROR* TYPE  82                    ***************************************************************************************
              THE NUMBER OF ABBREVIATED PRINTS PER DETAIL PRINT IS LESS THAN ZERO OR
              GREATER THAN THE NUMBER OF PRINT INTERVALS IN THIS PRINT GROUP.
```

```
*ERROR* TYPE  83                    ***************************************************************************************
              THE SUMMARY OPTION FOR THIS PRINT GROUP IS LESS THAN 0 OR GREATER THAN 4.
```

```
*ERROR* TYPE  84                    ***************************************************************************************
              THE MAXIMUM SIMULATION TIME IS GREATER THAN THE TIME AT WHICH THE LAST PRINT-OUT WILL OCCUR.
```

```
*ERROR* TYPE  85                    ***************************************************************************************
              THE FITTED FAN CURVE HAS UNLIMITED TOTAL PRESSURE GAINS FOR FLOW IN ITS NORMAL OPERATING DIRECTION.
```

This non-fatal error is usually caused either by having the fan curve data points too narrowly spaced or by having too large an upper flow rate limit. The fan curve input data should be re-checked against the actual fan curve.

```
*ERROR* TYPE  86                    ***************************************************************************************
              THE DATA POINTS FOR THIS TRACTIVE EFFORT VS. TRAIN SPEED CURVE ARE INCORRECT
              OR TOO CLOSE TO EACH OTHER.
```

This non-fatal error is caused by placing the tractive effort vs. train speed in the input in a manner that does not supply the program with four pairs of independent data points. This occurs when there is a duplication of a data point, or when two data points have been entered so close to one another that the program is unable to make a proper curve fit through all four points.

```
*ERROR* TYPE  87                    ********************************************************************************
              THE DATA POINTS FOR THIS TRAIN MOTOR CURRENT VS. TRACTIVE EFFORT CURVE
              ARE INCORRECT OR TOO CLOSE TO EACH OTHER.
```

This non-fatal error is caused by placing the motor current vs. tractive effort data in the input in a manner that does not supply the program with four pairs of independent data points. This occurs when there is a duplication of a data point, or when two data points have been entered so close to one another that the program is unable to make a proper curve fit through all four points.

```
*ERROR* TYPE  88                    ********************************************************************************
              THE FIRST COEFFICIENT OF TRAIN MECHANICAL RESISTANCE IS LESS THAN 0.5 OR GREATER THAN 50.0 LBS/TON.


*ERROR* TYPE  89                    ********************************************************************************
              THE THIRD COEFFICIENT OF TRAIN MECHANICAL RESISTANCE IS LESS THAN 0.001 OR
               GREATER THAN 1.000 LBS/(TON-MPH).


*ERROR* TYPE  90                    ********************************************************************************
              THE POWER INPUT TO THE ACCELERATION RESISTOR GRIDS IS LESS THAN 0 OR
               GREATER THEN 20,000 KILOWATTS PER TRAIN.


*ERROR* TYPE  91                    ********************************************************************************
              THE POWER INPUT TO THE BRAKING RESISTOR GRIDS IS LESS THAN 0 OR GREATER THAN 20,000 KILOWATTS PER TRAIN.


*ERROR* TYPE  92                    ********************************************************************************
              POWER CANNOT BE INPUT TO BOTH THE ACCELERATION AND BRAKING RESISTOR GRIDS AT THE SAME TIME.


*ERROR* TYPE  93                    ********************************************************************************
              THE NUMBER OF TRACK SECTIONS MUST BE 0 WHEN TRAIN PERFORMANCE OPTION 3 IS CHOSEN.


*ERROR* TYPE  94                    ********************************************************************************
              THE HUMIDITY DISPLAY OPTION HAS BEEN ENTERED INCORRECTLY-
              IT SHOULD BE 1 (HUMIDITY RATIO), 2 (WET-BULB TEMPERATURES), OR 3 (RELATIVE HUMIDITY).
              THE DEFAULT VALUE OF 1 (HUMIDITY RATIO) WILL BE USED.


*ERROR* TYPE  95                    ********************************************************************************
              THERE IS NO LINE SEGMENT OR VENTILATION SHAFT IN THIS SYSTEM WITH THIS IDENTIFICATION NUMBER.


*ERROR* TYPE  96                    ********************************************************************************
              THE ABOVE SEGMENT HAS BEEN PLACED IN TWO DIFFERENT ZONES.


*ERROR* TYPE  97                    ********************************************************************************
              THE ABOVE NODE IS ADJACENT TO TWO DIFFERENT TYPE 2 ZONES.
              THESE TWO ZONES SHOULD BE COMBINED INTO ONE ZONE.


*ERROR* TYPE  98                    ********************************************************************************
              THE ABOVE LINE SEGMENT OR VENTILATION SHAFT HAS NOT BEEN INCLUDED IN ANY OF THE ZONES.


*ERROR* TYPE  99                    ********************************************************************************
              THE SECOND MECHANICAL RESISTANCE COEFFICIENT IS LESS THAN 0.1 OR GREATER THAN 500.0 LBS.


*ERROR* TYPE 100                    ********************************************************************************
              THE NUMBER OF ZONES IS LESS THAN 0 OR GREATER THAN  75.
              THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
              SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
              ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
              PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 101                     *********************************************************************************
               THE TOTAL WEIGHT OF THE ACCELERATION RESISTOR GRIDS PER CAR IS LESS THAN 0 OR GREATER THAN 2,000 LBS.


*ERROR* TYPE 102                     *********************************************************************************
               THE TOTAL WEIGHT OF THE DECELERATION RESISTOR GRIDS PER CAR IS LESS THAN 0 OR GREATER THAN 2,000 LBS.


*ERROR* TYPE 103                     *********************************************************************************
               THE EFFECTIVE DIAMETER OF THIS ACCELERATION RESISTOR GRID ELEMENT IS LESS THAN 0 OR GREATER THAN 24.0 IN.


*ERROR* TYPE 104                     *********************************************************************************
               THE EFFECTIVE DIAMETER OF THIS DECELERATION RESISTOR GRID ELEMENT IS LESS THAN 0 OR GREATER THAN 24.0 IN.


*ERROR* TYPE 105                     *********************************************************************************
               THE ACCELERATION RESISTOR GRID EFFECTIVE CONVECTION SURFACE AREA IS LESS THAN 0 OR
               GREATER THAN 500 SQUARE FEET.


*ERROR* TYPE 106                     *********************************************************************************
               THE DECELERATION RESISTOR GRID EFFECTIVE CONVECTION SURFACE AREA IS LESS THAN 0 OR
               GREATER THAN 500 SQUARE FEET.


*ERROR* TYPE 107                     *********************************************************************************
               THE ACCELERATION RESISTOR GRID EFFECTIVE RADIATION SURFACE AREA IS LESS THAN 0 OR
               GREATER THAN 500 SQUARE FEET.


*ERROR* TYPE 108                     *********************************************************************************
               THE DECELERATION RESISTOR GRID EFFECTIVE RADIATION SURFACE AREA IS LESS THAN 0 OR
               GREATER THAN 500 SQUARE FEET.


*ERROR* TYPE 109                     *********************************************************************************
               THE EMISSIVITY OF THE ACCELERATION RESISTOR GRID ELEMENTS IS LESS THAN 0 OR GREATER THAN 1.0.


*ERROR* TYPE 110                     *********************************************************************************
               THE EMISSIVITY OF THE DECELERATION RESISTOR GRID ELEMENTS IS LESS THAN 0 OR GREATER THAN 1.0.


*ERROR* TYPE 111                     *********************************************************************************
               THE SPECIFIC HEAT OF THE ACCELERATION RESISTOR GRID ELEMENT
               IS LESS THAN 0 OR GREATER THAN 1.0 BTU/(LB-DEG. F.).


*ERROR* TYPE 112                     *********************************************************************************
               THE SPECIFIC HEAT OF THE DECELERATION RESISTOR GRID ELEMENT
               IS LESS THAN 0 OR GREATER THAN 1.0 BTU/(LB-DEG. F.).


*ERROR* TYPE 113                     *********************************************************************************
               THE TIME INCREMENT PER CYCLE OR THE MAXIMUM SIMULATION TIME HAS BEEN ENTERED AS ZERO, OR NEGATIVE.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 114                     *********************************************************************************
               THE ABOVE NODE HAS NOT BEEN INCLUDED IN ANY OF THE ZONES IN THE SYSTEM.


*ERROR* TYPE 115                     *********************************************************************************
               THE FRONT OF TRAIN DRAG COEFFICIENT IS LESS THAN 0.0 OR GREATER THAN 1.5.


*ERROR* TYPE 116                     *********************************************************************************
               THE NUMBER OF POWERED CARS IN THIS TRAIN IS LESS THAN 1
               OR GREATER THAN THE TOTAL NUMBER OF CARS.


*ERROR* TYPE 117                     *********************************************************************************
               THE SUPPLY VOLTAGE IS LESS THAN 100 VOLTS OR GREATER THAN 1,500 VOLTS.
```

```
*ERROR* TYPE 118                    **********************************************************************************
               THE SPEED V1 IS LESS THAN 10 OR GREATER THAN 100 MPH.


*ERROR* TYPE 119                    **********************************************************************************
               THE SPEED V2 IS LESS THAN V1 OR GREATER THAN 250 MPH.


*ERROR* TYPE 120                    **********************************************************************************
               THE TRAIN SCHEDULING ORIGIN IS LESS THAN ZERO OR GREATER THAN 1,000,000.0 FEET.


*ERROR* TYPE 121                    **********************************************************************************
               THE NUMBER OF PERSONS ENTERING OR LEAVING THE TRAIN AT THIS STATION
               IS GREATER THAN 4000.


*ERROR* TYPE 122                    **********************************************************************************
               THE DISTANCE FROM THE ROUTE ORIGIN TO THE ENTRANCE PORTAL IS LESS THAN ZERO
               OR GREATER THAN THE LENGTH OF THE ENTIRE ROUTE.


*ERROR* TYPE 124                    **********************************************************************************
               THIS SECTION HAS NOT BEEN DEFINED.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

This non-fatal error is caused by stating a train travels through a section that has not been previously defined in the System Geometry portion of the input data. <u>Every</u> section in the system <u>must</u> be defined in the System Geometry portion of the input data, and every section must <u>always</u> be referred to by its section identification number.

```
*ERROR* TYPE 125                    **********************************************************************************
               THE TRAIN ROUTE DOES NOT EXTEND INTO ALL THE SECTIONS OR SEGMENTS WHICH WERE SPECIFIED.
               THE ROUTE DOES NOT PASS THROUGH THE FOLLOWING SECTIONS OR SEGMENTS -
```

This non-fatal error occurs when the total length of all the track sections on a route is less than the sum of the distance from the route origin to the first portal plus the total length of all the line sections through which the route is designed to pass. This error message lists the line sections the user has described as having trains passing through them, but for which there is no track section and therefore no train route.

```
*ERROR* TYPE 126                    **********************************************************************************
               THE ABOVE OPTION SHOULD BE EITHER ZERO (0), ONE (1), OR TWO (2).
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 127                    **********************************************************************************
               THE NUMBER OF SECTIONS IS LESS THAN 1 OR GREATER THAN 900.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.

*ERROR* TYPE 128                    **********************************************************************************
               THE NUMBER OF NODES IS LESS THAN 2 OR GREATER THAN ONE MORE THAN THE NUMBER OF SECTIONS.


*ERROR* TYPE 129                    **********************************************************************************
               THE NUMBER OF BRANCHED JUNCTIONS IS LESS THAN 0 OR GREATER THAN THE NUMBER OF NODES.
```

```
*ERROR* TYPE 130                    ********************************************************************************
               THE TEMPERATURE TABULATION INCREMENT IS EITHER LESS THAN -10.0 OR GREATER THAN 10.0 DEG F.


*ERROR* TYPE 131                    ********************************************************************************
               THE DISTANCE BETWEEN THE INSIDE WALL SURFACES OF ADJACENT TUNNELS
               IS LESS THAN 0 OR GREATER THAN 100 FEET.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 132                    ********************************************************************************
               THE NUMBER OF UNSTEADY HEAT LOADS IS LESS THAN 0 OR GREATER THAN 50.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 133                    ********************************************************************************
               THE NUMBER OF FAN TYPES IS LESS THAN 0 OR GREATER THAN 75.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 134                    ********************************************************************************
               THE NUMBER OF TRAIN ROUTES MUST BE ZERO (0) IF THE TRAIN PERFORMANCE OPTION IS ZERO.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 135                    ********************************************************************************
               THE NUMBER OF TRAIN ROUTES IS LESS THAN 0 OR GREATER THAN 20.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 136                    ********************************************************************************
               THE NUMBER OF TRAIN TYPES MUST BE ZERO (0) IF THE TRAIN PERFORMANCE OPTION IS ZERO.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 137                    ********************************************************************************
               THE NUMBER OF TRAIN TYPES IS LESS THAN 0 OR GREATER THAN 16.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 138                    ********************************************************************************
               THIS SEGMENT HAS NOT BEEN DEFINED.
```

This non-fatal error is caused by stating an unsteady heat source exists in a segment that was not previously described in the Line Segment Data portion of the input data. Every line segment must be described in the Line Segment Data portion of the input data. Line segments must always be referred to by their segment identification number.

```
*ERROR* TYPE 139                    ********************************************************************************
               THE SUBSEGMENT NUMBER IS LESS THAN 1 OR GREATER THAN THE NUMBER OF SUBSEGMENTS IN THIS SEGMENT.


*ERROR* TYPE 140                    ********************************************************************************
               THE TIME THAT THE FIRE/UNSTEADY HEAT SOURCE BECOMES INACTIVE IS BEFORE THE TIME THAT THIS HEAT
SOURCE BECOMES ACTIVE.
```

```
*ERROR* TYPE 141                     **********************************************************************************
               THE NUMBER OF TRAINS IN OPERATION IS LESS THAN ZERO OR GREATER THAN 75.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 142                     **********************************************************************************
               THE ROUTE OF THE ABOVE TRAIN HAS NOT BEEN DEFINED FOR THIS SIMULATION.
```

This non-fatal error only pertains to initialized trains. The program requires the user to supply the route number when initializing a train, and the number supplied must be one of the route numbers specified in the General Data portion of the input data. Each route specified in the General Data portion of the input must be described in the Train Route Description portion of the input data, and must always be referred to by its route identification number.

```
*ERROR* TYPE 143                     **********************************************************************************
               THE TYPE OF THE ABOVE TRAIN HAS NOT BEEN DEFINED FOR THIS SIMULATION.
```

This non-fatal error only pertains to initialized trains. The program requires the user to supply the train type when initializing a train, and the train type identification number supplied must be one of the train type identification numbers specified in the General Data portion of the input data. Each train specified in the General Data portion of the input must be described in the Train Data portion of the input data, and must always be referred to by its train type identification number.

```
*ERROR* TYPE 144                     **********************************************************************************
               THE LOCATION OF THE ABOVE TRAIN IS NOT WITHIN THE LIMITS DEFINED FOR THIS ROUTE.


*ERROR* TYPE 145                     **********************************************************************************
               THE TRAIN SPEED IS LESS THAN ZERO OR GREATER THAN 250 MPH.


*ERROR* TYPE 146                     **********************************************************************************
               THE NUMBER OF CYCLES PER COMPLETE TRAIN EVALUATION IS LESS THAN 1 OR GREATER THAN 100.


*ERROR* TYPE 147                     **********************************************************************************
               THE NUMBER OF CYCLES PER AERODYNAMIC EVALUATION IS LESS THAN 0 OR GREATER THAN 100.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 148                     **********************************************************************************
               THE NUMBER OF CYCLES PER THERMODYNAMIC EVALUATION IS LESS THAN 0 OR GREATER THAN 100.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 149                     **********************************************************************************
               THIS IDENTIFICATION NUMBER IS LESS THAN 1 OR GREATER THAN 999.


*ERROR* TYPE 150                     **********************************************************************************
               AN IMPROPER SUBSEGMENT NUMBER HAS BEEN ENTERED.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 150 is a fatal error that is caused by incorrectly stating the positioning within a line segment of an initial air or wall surface temperature. The wall surface temperatures and initial air temperatures must be specified for each subsegment within each line segment. If there are N subsegments in a line segment, the first subsegment is always identified as subsegment number 1, and the last subsegment is always identified as subsegment number N. No subsegment number can be less than 1.0 or greater than the number of subsegments within the line segment.

```
*ERROR* TYPE 151                 ********************************************************************************
          A PERCENTAGE MUST RANGE FROM ZERO TO 100 PERCENT.


*ERROR* TYPE 152                 ********************************************************************************
          THE ABOVE OPTION SHOULD BE EITHER ZERO (0), ONE (1), TWO (2), THREE (3), FOUR (4), OR FIVE (5).
          THE DEFAULT VALUE OF ZERO (0) WILL BE USED.


*ERROR* TYPE 153                 ********************************************************************************
          THE SECTION IDENTIFICATION NUMBER IS LESS THAN 1 OR GREATER THAN 999.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 154                 ********************************************************************************
          THE NODE IDENTIFICATION NUMBER IS LESS THAN 1 OR GREATER THAN 999.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 155                 ********************************************************************************
          THIS SECTION BEGINS AND ENDS AT THE SAME NODE.


*ERROR* TYPE 156                 ********************************************************************************
          THIS SECTION IDENTIFICATION NUMBER HAS BEEN USED PREVIOUSLY.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 157                 ********************************************************************************
          MORE THAN 5 SECTIONS ARE CONNECTED TO THIS NODE.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 158                 ********************************************************************************
          THE NUMBER OF NODES THAT WERE DESCRIBED IN THE GEOMETRY DATA IS NOT EQUAL
          TO THE NUMBER SPECIFIED FOR THIS SYSTEM.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 158 is a fatal error that is caused by an inconsistency between the total number of nodes specified in the General Data portion of the input data and the number of nodes defined while describing the system geometry in the System Geometry portion of the input data. If N nodes have been specified in the General Data portion of the input, the sum of all the nodes defined while describing the beginning and end of each section in the System Geometry portion of the input data must be equal to N. Each node is always referred to by its node identification number, and no two nodes may possess the same identification number.

```
*ERROR* TYPE 159                 *******************************************************************************
          THE DEEP SINK TEMPERATURE IS LESS THAN 0 OR GREATER THAN 100 DEG F.
```

```
*ERROR* TYPE 160                 *******************************************************************************
          THE NUMBER OF SEGMENTS IN THIS SECTION IS LESS THAN 1 OR
          GREATER THAN THE NUMBER OF SEGMENTS IN THE SYSTEM.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 161                 *******************************************************************************
          THE NUMBER OF LINE SEGMENTS IN THIS SYSTEM IS NOT EQUAL TO THE NUMBER SPECIFIED FOR THIS SYSTEM.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 161 is a fatal error that is caused by an inconsistency between the total number of line segments specified in the General Data portion of the input data and the total number of line segments described in the Line Segment Data portion of the input data. If N line segments have been specified in the General Data portion of the input, the sum of all the line segments described in the Line Segment Data portion of the input data <u>must be equal</u> to N. Each line segment is <u>always</u> referred to by its segment identification number, and no two segments may possess the same identification number.

```
*ERROR* TYPE 162                 *******************************************************************************
          THIS SEGMENT OR VENTILATION SHAFT IDENTIFICATION NUMBER HAS BEEN USED PREVIOUSLY.
```

```
*ERROR* TYPE 163                 *******************************************************************************
          THE SUM OF THE CFM ENTRIES FOR THIS FAN IS ZERO OR NEGATIVE.
```

```
*ERROR* TYPE 164                 *******************************************************************************
          THE ABOVE TWO SECTIONS ARE NOT CONNECTED AT A COMMON NODE.
```

This non-fatal error is due to the user incorrectly specifying the sections through which a train route passes. If two sections are adjacent to one another they <u>must</u> have a common node at their common boundary. Trains may <u>only</u> pass from one line section to another if the two sections are adjacent to one another. Therefore, each successive line section in a train route must be adjacent to the previous line section and must have a common node at the common boundary with the previous line section.

```
*ERROR* TYPE 165                 *******************************************************************************
          THIS NODE HAS NOT BEEN DEFINED IN THE SYSTEM GEOMETRY DATA.
```

This non-fatal error is due to the user incorrectly defining the nodes in the System Geometry portion of the input data. The user defines the nodes when specifying them as beginning and ending points for the sections in the System Geometry portion of the input data. Every section and every node in the system <u>must</u> be defined in the System Geometry portion of the input data, and must always be referred to by their respective identification numbers. This error message results when the user attempts to describe a node in the Node Data portion of the input data that was not defined in the System Geometry portion of the input data.

```
*ERROR* TYPE 166                    ********************************************************************************
                 THIS NODE IS NOT A PORTAL OR AN OPENING TO THE ATMOSPHERE.
```

```
*ERROR* TYPE 167                    ********************************************************************************
                 AN INVALID TYPE OF VENTILATION SHAFT HAS BEEN ENTERED.
```

This non-fatal error occurs when the ventilation shaft type has not been entered as either type 1.0 (ventilation shaft or blast shaft that may or may not contain a fan) or type 2.0 (stairway or escalator).

```
*ERROR* TYPE 168                    ********************************************************************************
                 THE ARRAY SIZE LIMIT OF THE DYNAMIC THERMAL RESPONSE MATRIX (DTRM) HAS BEEN EXCEEDED.
                 THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                 SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                 ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                 PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 168 is a fatal error that is caused by exceeding the Dynamic Thermal Response Matrix (DTRM) array size limit (Variable name: LMEQRM). This array size limit is exceeded when the number of subsegments (both line and vent) plus the number of thermal sub-nodes within a single uncontrolled zone is greater than the value of LMEQRM (see Appendix A). This error can be corrected by increasing the array size limit (see Programmer's Manual) and/or decreasing the number of subsegments within the zone until the total number of subsegments is within the DTRM array size limit. In addition, the ventilation shafts within this uncontrolled zone may be made into separate, type 3 (non-inertial) zones (see section 5.9). The total number of subsegments plus thermal sub-nodes in the zone that originally exceeded the DTRM array size limit would then be reduced by the sum of the number of subsegments within the ventilation shafts that were made into type 3 zones plus one thermal sub-node per ventilation shaft. Finally, the portion of the system being simulated can be reduced until the total number of elements in the DTRM matrix is within array size limits (see section 5.2).

```
*ERROR* TYPE 169                    ********************************************************************************
                 THE DESIGN MAXIMUM OUTFLOW AIR VELOCITY AT THE GRATE IS LESS THAN ZERO OR GREATER THAN
                 6000 FPM.
```

```
*ERROR* TYPE 170                    ********************************************************************************
                 AN INVALID FAN TYPE HAS BEEN ENTERED.
```

This non-fatal error occurs when the user has incorrectly specified the fan type. If the user has stated there are N fan types in the General Data portion of the input data, only a fan type whose identification number is between 1 and N may be specified. If the number of fan types entered in the General Data portion of the input data is greater than zero, a fan type <u>must be entered for every ventilation shaft in the system</u>. When the system contains N fan types (N being greater than zero), the user must enter a <u>zero</u> for the fan type for all ventilation shafts that <u>do not have a fan</u>.

```
*ERROR* TYPE 171                    ********************************************************************************
                 A STAIRWAY SEGMENT CANNOT CONTAIN A FAN.
```

```
*ERROR* TYPE 172                    ********************************************************************************
               A VENTILATION SHAFT MUST CONTAIN AT LEAST ONE SEGMENT.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 173                    ********************************************************************************
               THE VENTILATION SHAFT STACK HEIGHT IS GREATER THAN THE SUM OF THE SEGMENT LENGTHS.
```

```
*ERROR* TYPE 174                    ********************************************************************************
               THE INITIAL AIRFLOW ENTERED IS LESS THAN -10,000,000 CFM OR GREATER THAN +10,000,000 CFM.
```

```
*ERROR* TYPE 175                    ********************************************************************************
               THE INITIAL AIRFLOWS AT A NODE VIOLATE CONTINUITY (I.E. THEIR ALGEBRAIC SUM IS NON-ZERO).
```

```
*ERROR* TYPE 176                    ********************************************************************************
               THE FAN RUN-UP TIME IS LESS THAN 0. OR GREATER THAN 300.0 SECONDS.
```

```
*ERROR* TYPE 177                    ********************************************************************************
               AN IMPROPER AERODYNAMIC TYPE HAS BEEN ENTERED FOR THE ABOVE NODE.
```

This non-fatal error is due to the user improperly entering the node aerodynamic type when describing a node in the Node Data portion of the input data. The node aerodynamic type must be either 0, 1, 2, 3, 4, 5, or 7. All nodes fit into these seven aerodynamic types and no other aerodynamic type may be used.

```
*ERROR* TYPE 178                    ********************************************************************************
               AN IMPROPER THERMODYNAMIC TYPE HAS BEEN ENTERED FOR THE ABOVE NODE.
```

This non-fatal error is due to the user improperly entering the node thermodynamic type when describing a node in the Node Data portion of the input data. The node thermodynamic type must be entered as type 1.0 (mixing node), type 2.0 (non-mixing node), or type 3.0 (temperature/humidity boundary condition). All nodes fit into these three thermodynamic types and no other thermodynamic type may be used.

```
*ERROR* TYPE 179                    ********************************************************************************
               THE NUMBER OF THERMAL SUB-NODES IN THIS SYSTEM HAS EXCEEDED 600.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 179 is a fatal error that is caused by exceeding the program array size limit for thermal sub-nodes (variable name: LMTHND). This error can be corrected by increasing the array size (see Programmer's Manual) and/or decreasing the portion of the system that is to be simulated (see section 5.2) until the total number of thermal sub-nodes is within array size limits. Each type 1 and type 3 thermodynamic node consists of <u>one</u> thermal sub-node, and each type 2 thermodynamic node consists of <u>three</u> thermal sub-nodes.

```
*ERROR* TYPE 180                *********************************************************************************
              TRAIN ROUTES MAY NOT PASS THROUGH VENT SHAFTS.
              THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
              SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
              ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
              PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 181                *********************************************************************************
              THIS SECTION IS NOT CONNECTED TO THIS NODE.
              THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
              SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
              ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
              PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 181 is a fatal error that is caused by the user incorrectly specifying one of the sections connected to a thermal sub-node when describing a thermodynamic type 2 node in the Node Data portion of the input data. All sections must always be referred to by their individual section identification numbers. Check the System Geometry input data - either the node at the beginning or the node at the end of the section in question should be the node being described in the Node Data portion of the input.

```
*ERROR* TYPE 182                *********************************************************************************
              THE NUMBER OF SECTIONS ATTACHED TO THIS NODE IS INCONSISTENT WITH
              THE SYSTEM GEOMETRY DATA.
              THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
              SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
              ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
              PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 182 is a fatal error that is caused by the user incorrectly describing the sections that are attached to a type 2 thermodynamic node. This error will occur when the total number of sections connected to the type 2 thermodynamic node being described is either less than or greater than the number of sections that have been defined as being connected to this node in the System Geometry data. Check the System Geometry data against the Node Data. Every node and every section must always be referred to by their respective identification numbers.

```
*ERROR* TYPE 183                *********************************************************************************
              THE ABOVE NODE HAS NOT BEEN DESCRIBED IN THE NODE DATA.
              THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
              SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
              ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
              PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 183 is a fatal error that is caused by the user failing to describe within the Node Data portion of the input a node that has been previously defined in the System Geometry portion of the input. If a node has been defined in the System Geometry portion of the input data, it must be defined in the System Geometry portion of the input data, and must always be referred to by their respective identification numbers.

```
*ERROR* TYPE 184                *********************************************************************************
              A MIXING NODE MUST HAVE TWO OR MORE SECTIONS CONNECTED TO IT.
```

```
*ERROR* TYPE 185                *********************************************************************************
              THE ZONE TYPE MUST BE EITHER 1, 2, OR 3.
```

```
*ERROR* TYPE 186                 *********************************************************************************
                  THE ALLOWABLE NUMBER OF SIMULATION ERRORS IS LESS THAN 0 OR GREATER THAN 50.
                  THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                  SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                  ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                  PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 187                 *********************************************************************************
                  THE AIR DENSITY GIVEN WITH THE FAN PERFORMANCE CURVE DATA POINTS IS EITHER LESS THAN 0.040 OR
                  GREATER THAN 0.085 LBS/CU FT.
```

```
*ERROR* TYPE 188                 *********************************************************************************
                  THE NUMBER OF ELEMENTS IN THE AERODYNAMIC 'DQ/DT' MATRIX IS GREATER THAN THE PROGRAM CAPACITY.
                  THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                  SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                  ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                  PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 188 is a fatal error that is not caused by a user error. This error is due solely to the memory storage capacity limitations of the computer. This error may be corrected by increasing the LMBLP array size limit (see Programmer's Manual) and/or decreasing the portion of the system that is to be simulated (see section 5.2).

```
*ERROR* TYPE 189                 *********************************************************************************
                  A SYSTEM WHICH CONTAINS TWO OR MORE INDEPENDENT NETWORKS HAS BEEN ENTERED ('FRAGMENTED NETWORK').
                  THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                  SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                  ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                  PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 189 is a fatal error that is caused either by the user incorrectly defining the geometry of the system or by attempting to simulate two distinct independent systems within a single simulation. Every section in a simulation must somehow be connected to every other section within the system via a path that passes only through other sections within the system. The program internally checks the system geometry data to determine whether or not all the sections are directly connected to one another. This error occurs when the program discovers a certain number of sections cannot be reached from a particular node via the other sections within the system. The error message lists first the node and then the sections which cannot be reached from this node via the other sections within the system. Check the schematic diagram of the system to make certain that all the system geometry data was entered correctly. Two independent systems may never be simulated in the same simulation - they must be simulated separately.

```
*ERROR* TYPE 190                 *********************************************************************************
                  THE TOTAL LENGTH OF THIS VENTILATION SHAFT IS LESS THAN 10 OR GREATER THAN 2000 FEET.
```

This non-fatal error occurs when the sum of the lengths of all the segments in this ventilation shaft are less than 10 or greater than 1000 feet. It is very strongly recommended that the user does not bypass the 10-foot minimum by allowing for a smaller than 10-foot vent shaft via the Number of Allowable Input Errors in Form 1C (see Chapter 12). This cautionary note is due to the fact that very short ventilation shafts may cause stability problems within the thermodynamic subprogram.

```
*ERROR* TYPE 191                  ********************************************************************************
               A NON-INERTIAL (TYPE 3) ZONE IS NOT CONNECTED TO AN UNCONTROLLED (TYPE 2) ZONE.
```

```
*ERROR* TYPE 192                  ********************************************************************************
               THE AMPLITUDE OF THE ANNUAL TEMPERATURE FLUCTUATION IS LESS THAN 0 OR GREATER THAN 50 DEG F.
```

```
*ERROR* TYPE 193                  ********************************************************************************
               THE FAN LOWER FLOW LIMIT (POINT OF MOTOR BREAKDOWN TORQUE OR STOPPING) ENTERED IS EITHER LESS THAN
               -100,000 CFM OR GREATER THAN 0 CFM.
```

```
*ERROR* TYPE 194                  ********************************************************************************
               THE FAN UPPER FLOW LIMIT (POINT OF WINDMILLING) IS EITHER LESS THAN 1000 CFM OR GREATER THAN 2,000,000 CFM.
```

```
*ERROR* TYPE 195                  ********************************************************************************
               A NON-INERTIA VENT SHAFT ZONE (TYPE 3) MUST NOT CONTAIN A LINE SEGMENT.
```

```
*ERROR* TYPE 196                  ********************************************************************************
               A SECTION HAS BEEN ENTERED THAT IS ISOLATED FROM ALL OTHER SECTIONS IN THE NETWORK.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 196 is a fatal error that is caused either by the user incorrectly defining the geometry of the system or by attempting to simulate two distinct independent systems within a single simulation. Every section in a simulation must somehow be connected to every other section within the system via a path that passes only through other sections within the system. The program internally checks the system geometry data to determine whether or not all the sections are directly connected to one another. This error occurs when the program discovers that one particular section has been entered that cannot be reached via a path through any of the other sections in the system. The error message lists the section that is isolated from the rest of the system. Check the schematic diagram of the system to make certain that all the system geometry data was entered correctly. Two independent systems may never be simulated in the same simulation - they must be simulated separately.

```
*ERROR* TYPE 197                  ********************************************************************************
               A NETWORK HAVING ONLY ONE OPENING TO THE ATMOSPHERE HAS BEEN DEFINED.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES  PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 197 is a fatal error that is caused either by the user attempting to simulate a system that has only one external opening to the atmosphere or by an error in the system geometry definitions. Although a system that has only one opening to the atmosphere is possible, the SES program cannot simulate such a system. If the system being simulated does possess more than one opening to the atmosphere, check the System Geometry data against the schematic diagram for any inconsistencies or errors.

```
*ERROR* TYPE 198                  ********************************************************************************
               A THERMODYNAMIC TYPE 2 (NON-MIXING) NODE MUST BE AT A 4 OR 5 BRANCH NODE ONLY.
```

```
*ERROR* TYPE 199                    ********************************************************************************
               THE NUMBER OF LOOPS DEFINED BY THE GEOMETRY IS GREATER THAN 500.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

Error type 199 is a fatal error that is not caused by a user error. This error is due solely to the memory storage capacity limitations of the computer. This error may be corrected by increasing the LMNLOP array size limit (see Programmer's Manual) and/or decreasing the portion of the system that is to be simulated (see section 5.2). As a general rule, the number of loops in a system is equal to the number of sections minus the number of internal nodes (nodes at portals and tops of vent shafts are external nodes).

```
*ERROR* TYPE 200                    ********************************************************************************
               THE AVERAGE NUMBER OF SECTIONS ALLOWED PER LOOP HAS BEEN EXCEEDED.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 201                    ********************************************************************************
               THE DRAG COEFFICIENT WEIGHTED TOTAL TRUCK AREA IS NEGATIVE OR GREATER THAN 500 SQ FT.
```

```
*ERROR* TYPE 202                    ********************************************************************************
               THE NUMBER OF LOOPS PASSING THROUGH BRANCHED JUNCTIONS PLUS THE NUMBER OF TRAINS THAT MAY PASS THROUGH
               BRANCHED JUNCTIONS IS TOO GREAT.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 203                    ********************************************************************************
               AN IMPROPER SECTION HAS BEEN LINKED TO THIS BRANCHED JUNCTION.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 204                    ********************************************************************************
               THE NUMBER OF LINE SEGMENTS AND VENTILATION SHAFTS IN THIS ENVIRONMENTAL CONTROL ZONE
               IS LESS THAN ZERO OR GREATER THAN THE NUMBER OF LINE SEGMENTS AND VENTILATION SHAFTS
               IN THE ENTIRE SYSTEM.
               THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
               SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
               ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
               PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.
```

```
*ERROR* TYPE 205                    ********************************************************************************
               THE JUNCTION ANGLE FOR THIS JUNCTION IS NOT 10, 20, OR 30 DEGREES.
```

```
*ERROR* TYPE 206                    ********************************************************************************
               THE ASPECT RATIO OF THIS CROSSOVER JUNCTION IS LESS THAN 0.1 OR GREATER THAN 50.0.
```

```
*ERROR* TYPE 207                    ********************************************************************************
               THE ASPECT RATIO OF THIS JUNCTION IS LESS THAN 0.1 OR GREATER THAN 30.0.
```

```
*ERROR* TYPE 208                    ********************************************************************************
               THE DATA POINTS FOR THIS LINE CURRENT VS. TRAIN SPEED CURVE ARE INCORRECT
                OR TOO CLOSE TO EACH OTHER.
```

```
*ERROR* TYPE 209                    ********************************************************************************
               A NUMBER OTHER THAN 1.0 OR 2.0 HAS BEEN ENTERED FOR THE TRAIN CONTROLLER OPTION.
```

```
*ERROR* TYPE 210                   ********************************************************************************
          THE SPEED U1 IS LESS THAN 0 OR GREATER THAN 100 MPH.


*ERROR* TYPE 211                   ********************************************************************************
          THE MINIMUM ALLOWABLE TRAIN VELOCITY DURING COASTING ON THIS ROUTE IS
          LESS THAN 0 OR GREATER THAN 250 MPH.


*ERROR* TYPE 212                   ********************************************************************************
          A NUMBER OTHER THAN 1 OR 0 HAS BEEN ENTERED FOR THE COASTING PARAMETER.


*ERROR* TYPE 213                   ********************************************************************************
          COASTING IS PERMITTED FOR TRAIN PERFORMANCE OPTION 1 (IMPLICIT) ONLY.


*ERROR* TYPE 214                   ********************************************************************************
          THE NUMBER OF COEFFICIENTS REQUIRED BY THE AERODYNAMIC JUNCTION EQUATIONS
          HAS EXCEEDED THE NUMBER THE PROGRAM MAY STORE.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 215                   ********************************************************************************
          THE COASTING OPTION FOR THIS ROUTE HAS NOT BEEN ENTERED AS 0 (MAINTAIN MINIMUM SPEED) OR
          1 (ACCELERATE FROM MINIMUM SPEED).  ZERO (0) IS THE DEFAULT VALUE.


*ERROR* TYPE 216                   ********************************************************************************
          THE NUMBER OF IMPULSE FAN TYPES IS LESS THAN 0 OR GREATER THAN 6.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 217                   ********************************************************************************
          THE INITIALIZATION FILE WRITING AND READING OPTION IS LESS THAN 0 OR GREATER THAN 5.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 218                   ********************************************************************************
          THE IMPULSE FAN VOLUME FLOW RATE IS LESS THAN 0 OR GREATER THAN 1,000,000 CFM.


*ERROR* TYPE 219                   ********************************************************************************
          THE IMPULSE FAN PRESSURE EFFICIENCY IS LESS THAN 0.1 OR GREATER THAN 1.0.


*ERROR* TYPE 220                   ********************************************************************************
          THE IMPULSE FAN NOZZLE DISCHARGE VELOCITY IS LESS THAN -10000 FPM OR GREATER THAN 10000 FPM.


*ERROR* TYPE 221                   ********************************************************************************
          THE IMPULSE FAN OPERATING TIME IS LESS THAN 0 OR GREATER THAN 10000 SECONDS.


*ERROR* TYPE 222                   ********************************************************************************
          THE SENSIBLE OR LATENT HEAT REJECTION PER PATRON IS LESS THAN -100 OR GREATER THAN 1000 BTU/HR.


*ERROR* TYPE 223                   ********************************************************************************
          THE INITIALIZATION FILE READING OPTION IN THE PRESENT SIMULATION IS INCONSISTENT WITH THE INITIALIZATION FILE
          WRITING OPTION USED IN GENERATING THE INITIALIZING FILE.

*ERROR* TYPE 224                   ********************************************************************************
          THE NUMBER OF SECTIONS TO BE INITIALIZED IS INCONSISTENT WITH THE TOTAL NUMBER OF SECTIONS IN THE SYSTEM.


*ERROR* TYPE 225                   ********************************************************************************
          THE NUMBER OF LINE SUBSEGMENTS TO BE INITIALIZED IS INCONSISTENT WITH THE NUMBER OF LINE SUBSEGMENTS IN THE
          SYSTEM.
```

```
*ERROR* TYPE 226                ********************************************************************************
          THE NUMBER OF VENT SUBSEGMENTS TO BE INITIALIZED IS INCONSISTENT WITH THE NUMBER OF LINE SUBSEGMENTS IN THE
          SYSTEM.


*ERROR* TYPE 227                ********************************************************************************
          THE ABOVE SECTION-SEGMENT-SUBSEGMENT NUMBER IS INCORRECT.


*ERROR* TYPE 228                ********************************************************************************
          THE NUMBER OF CYCLES PER AERODYNAMIC EVALUATION OR PER THERMODYNAMIC EVALUATION ARE NOT ALLOWED TO CHANGE
          WHEN SUMMARY OPTION IS 0 (WITH A SUMMARY PRINTED AT OTHER TIMES DURING THE SIMULATION) OR 2.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 229                ********************************************************************************
          THE NUMBER OF CYCLES PER AERODYNAMIC OR PER THERMODYNAMIC EVALUATION IN THE PRINT GROUPS SHOULD BE -
                        0, IF THE VALUE IN THE FIRST PRINT GROUP IS 0
                    NOT 0, IF THE VALUE IN THE FIRST PRINT GROUP IS NOT 0.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 230                ********************************************************************************
          A NUMBER OTHER THAN 1 OR 2 HAS BEEN ENTERED FOR THE FLYWHEEL SIMULATION OPTION.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 231                ********************************************************************************
          THE FLYWHEEL SIMULATION OPTION IS PERMITTED WITH TRAIN PERFORMANCE OPTION 1 (IMPLICIT) ONLY.
          THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
          SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
          ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
          PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 232                ********************************************************************************
          THE POLAR MOMENT OF INERTIA OF THE FLYWHEEL IS LESS THAN 50 OR GREATER THAN 4000 LBS-FT SQUARED.


*ERROR* TYPE 233                ********************************************************************************
          THE NUMBER OF FLYWHEELS PER POWERED CAR IS LESS THAN 1 OR GREATER THAN 4.


*ERROR* TYPE 234                ********************************************************************************
          THE MINIMUM ALLOWABLE ROTATIONAL SPEED OF THE FLYWHEEL IS LESS THAN 0 OR GREATER THAN 20000 RPM.


*ERROR* TYPE 235                ********************************************************************************
          THE MAXIMUM ALLOWABLE ROTATIONAL SPEED OF THE FLYWHEEL IS LESS THAN THE MINIMUM VALUE SPECIFIED,
          OR GREATER THAN 30000 RPM.


*ERROR* TYPE 236                ********************************************************************************
          THE INITIAL ROTATIONAL SPEED OF THE FLYWHEEL IS NOT WITHIN THE RANGE SPECIFIED ABOVE.


*ERROR* TYPE 237                ********************************************************************************
          THE OVERALL EFFICIENCY OF POWER CONVERSION FOR THE FLYWHEEL IS LESS THAN 0 OR GREATER THAN 100 PERCENT.


*ERROR* TYPE 238                ********************************************************************************
          THE TERMINAL MOTOR VOLTAGE IS LESS THAN 100 OR GREATER THAN 1000 VOLTS/MOTOR.


*ERROR* TYPE 239                ********************************************************************************
          THE COEFFICIENT FOR THE FLYWHEEL LOSS FUNCTION IS NEGATIVE.


*ERROR* TYPE 240                ********************************************************************************
          THE EXPONENT IS LESS THAN 0 OR GREATER THAN 3.
```

```
*ERROR* TYPE 241                    ********************************************************************************
                 THE POWER CONSUMPTION BY VEHICLE AUXILIARY SYSTEMS FOR EMPTY CAR IS LESS THAN 0.0 OR GREATER THAN 100.0 KW.


*ERROR* TYPE 242                    ********************************************************************************
                 THE POWER CONSUMPTION BY VEHICLE AUXILIARY SYSTEMS PER PASSENGER IS LESS THAN -2.0 OR GREATER THAN 5.0 KW.


*ERROR* TYPE 243                    ********************************************************************************
                 THE ENERGY SECTOR NUMBER IS LESS THAN 0 OR GREATER THAN 50.
                 THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                 SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                 ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                 PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 244                    ********************************************************************************
                 THE HEAT REJECTION AND POWER CONSUMPTION PER PASSENGER MUST BE ZERO WHEN THE TRAIN PERFORMANCE OPTION IS 2 OR 3.
                 AS A DEFAULT THESE VALUES HAVE BEEN SET TO ZERO.


*ERROR* TYPE 245                    ********************************************************************************
                 THE CENTRAL ANGLE OF THE ABOVE CURVE IS GREATER THAN 180 DEGREES.


*ERROR* TYPE 246                    ********************************************************************************
                 THE ABOVE SUMMARY OPTION IS 4 WHILE THE ENVIRONMENTAL CONTROL LOAD EVALUATION OPTION IS 0.
                 THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                 SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                 ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                 PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 247                    ********************************************************************************
                 THE FIRE SIMULATION OPTION IS NEITHER ZERO (0) NOR ONE (1).
                 THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                 SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                 ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                 PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 248                    ********************************************************************************
                 THERE IS NO 'FIRE SEGMENT' IN THE SYSTEM WHILE A FIRE IS BEING SIMULATED.
                 THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                 SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                 ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                 PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 249                    ********************************************************************************
                 THE EFFECTIVE FLAME TEMPERATURE OF THE FIRE SOURCE IS LESS THAN 500.0 OR GREATER THAN 2000.0 DEG F.


*ERROR* TYPE 250                    ********************************************************************************
                 THE EFFECTIVE AREA OF THE FIRE FOR RADIATION IS LESS THAN 0. OR GREATER THAN THE SURFACE AREA OF THE SUBSEGMENT.


*ERROR* TYPE 251                    ********************************************************************************
                 THE TYPE OF LINE SEGMENT IS LESS THAN 8 OR GREATER THAN THE NUMBER OF IMPULSE FANS PLUS 8.


*ERROR* TYPE 252                    ********************************************************************************
                 THE FIRE SEGMENT TYPE IS NEITHER ZERO (0) NOR ONE (1).


*ERROR* TYPE 253                    ********************************************************************************
                 THE TEMPERATURE/HUMIDITY SIMULATION OPTION IS ZERO WHILE A FIRE IS BEING SIMULATED.
                 THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                 SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                 ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                 PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 254                    ********************************************************************************
                 ONE OR MORE OF THE ABOVE TRAIN VELOCITY POINTS ARE NEGATIVE, OUT OF ORDER OR TOO CLOSE TOGETHER.


*ERROR* TYPE 255                    ********************************************************************************
                 THE ABSOLUTE VALUE OF THE LINE SEGMENT STACK HEIGHT IS GREATER THAN THE LINE SEGMENT LENGTH.
```

```
*ERROR* TYPE 256                    *************************************************************************************
                  AN IMPULSE FAN LINE SEGMENT TYPE HAS BEEN ENTERED FOR WHICH NO IMPULSE FAN TYPE HAS BEEN DEFINED.


*ERROR* TYPE 257                    *************************************************************************************
                  THE NUMBER OF FIRES/UNSTEADY HEAT LOADS IS ZERO, WHILE A FIRE IS BEING SIMULATED.


*ERROR* TYPE 258                    *************************************************************************************
                  THE ABOVE TRAIN COASTING INDICATOR IS NEITHER ZERO (0) NOR ONE (1).


*ERROR* TYPE 259                    *************************************************************************************
                  AN ENVIRONMENTAL CONTROL LOAD EVALUATION (SUMMARY OPTION 4) MAY NOT BE MADE AT ANYTIME DURING A
                  FIRE SIMULATION (FIRE OPTION 1).
                  THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                  SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                  ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                  PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 260                    *************************************************************************************
                  THE ABOVE TWO FIRE/UNSTEADY HEAT SOURCES ARE IN ONE LINE SUBSEGMENT AND THEIR ACTIVE TIMES
                  ARE OVERLAPPED.  THIS WILL RESULT IN INCORRECT CALCULATION OF THROTTLING EFFECTS.


*ERROR* TYPE 261                    *************************************************************************************
                  THE NUMBER OF THERMODYNAMIC CYCLES PER WALL TEMPERATURE EVALUATION IS LESS THAN ZERO.
                  THIS FATAL ERROR PREVENTS FURTHER INTERPRETATION OF THIS SYSTEM INPUT FILE.
                  SOME FATAL ERRORS MAY BE CORRECTED BY EITHER CHANGING THE NUMBER OF ITEMS INPUT OR CHANGING THE PROGRAM
                  ARRAY SIZES. PLEASE SEE DISCUSSIONS IN BOTH THE 'ERROR MESSAGES' PORTION OF THE USER'S MANUAL AND THE
                  PORTION OF THE PROGRAMMER'S GUIDE IN THE PROGRAMMER'S MANUAL DEALING WITH ARRAY SIZE ADJUSTMENT.


*ERROR* TYPE 262                    *************************************************************************************
                  THE EFFECTIVE EMISSIVITY OF THE COMBUSTION PRODUCTS IS LESS THAN ZERO OR GREATER THAN 1.0.
```

14. SIMULATION ERROR MESSAGES

A simulation error is an error that cannot be detected during input verification because the conditions that cause the error exist only after the simulation has started. The program prints both the simulation error message and a detail print at the moment in time the simulation error occurs. The detail print is given as an aid to the user in determining the factors that caused the simulation error. The user must specify the number of simulation errors to be allowed during any given simulation. If the user wishes to allow +N simulation errors, +N must be entered for the number of "Allowable Simulation Errors" in the General Data portion of the input data. The program uses the number of Allowable Simulation Errors in exactly the same manner as the number of Allowable Input Errors is used during input verification (see section 13.2). If +N is entered for the number of allowable simulation errors, the simulation will terminate after discovering (N+1) simulation errors.

Regardless of the number of allowable simulation errors entered in the general data, if an "irrecoverable simulation error" occurs, the simulation is immediately terminated. The program uses the "irrecoverable error" in exactly the same manner as the "fatal error" issued during input verification (see section 13.1). The irrecoverable simulation error is an error that renders a simulation useless under any and all circumstances. The factors that caused the irrecoverable simulation error must be corrected and the simulation must be performed again after incorporating these corrections. When the program discovers an irrecoverable simulation error it prints both the simulation error message and a detail print at the moment in time the irrecoverable simulation error occurs. There is virtually no difference between the irrecoverable simulation error and simulation error except for the fact the irrecoverable simulation error immediately terminates a simulation while the simulation error only terminates a simulation if it causes the number of simulation errors to exceed the allowable number of simulation errors. It is strongly recommended that the user specifiy no more than 10 allowable simulation errors.

Under certain circumstances, a simulation error will not be extremely detrimental to a simulation, and there will be no need to re-run the simulation. One example of such a circumstance is at the start of a simulation. If a simulation error occurs at the very beginning of a simulation due to transient start-up conditions, but never occurs again during the remainder of the simulation, there is no need to re-run the simulation if it was not important to obtain accurate information on the status of the system at the very beginning of the simulation. This only holds true if the results from the remainder of the simulation appear normal after the first few seconds. It is up to the user to determine whether or not a simulation error has rendered the simulation useless. Therefore, it is important that the user analyze the results of the simulation very carefully after receiving a simulation error. The user should find the source of the error and correct it — a user can be completely sure of the validity of the results only after the simulation has been performed free of simulation errors.

The discussion of each simulation error contains a clarification of the error created and the cause of the error. In addition, the method needed to correct the error is outlined. As a general rule, all simulation errors must be corrected if one wishes to consider the results completely valid.

```
SIMULATION *ERROR* TYPE   1          ********************************************************************************
          ATTEMPT TO EXCEED THE MAXIMUM NUMBER OF SIMULTANEOUS OPERATING TRAINS.
          THE CURRENT TRAIN WILL NOT BE PLACED INTO OPERATION.
```

This error is caused by having too many trains operating within the systems at one time. The maximum number of trains that can operate at any one time is governed by the value of the variable LMTRAN. This error can be corrected by any one or combination of the following methods:

1. Increase the array size limit for the number of operational trains at any given point in time (variable name: LMTRAN).
2. Increase the train headways in order to increase the spacing between the trains. Increasing the spacing between trains will decrease the number of trains in the system at any given time.
3. Reduce the portion of the system that is to be simulated. Reducing the size of the system will reduce the total number of trains within the system at any given time.
4. If the user is simulating a tunnel system with adjoining outside tracks, any travel not essential to the simulation along the outside tracks can be eliminated.
5. If the user is simulating a tunnel system with adjoining outside tracks and is only interested in the results of the simulation for the tunnel portion of the system, all stops outside the tunnel system can be eliminated. In addition, all travel outside the tunnel system that is not essential to the simulation can be eliminated.

It is important to note that trains "disappear" from the simulation as soon as they reach the forward end of the last track section in the system. If explicit train performance is used, the trains disappear from the system as soon as they have traveled the total distance involved in the speed-time profile supplied by the user. Therefore, reducing the unessential track sections in a system will decrease the amount of time trains will need to reach the end of their track route. Increasing the rate at which trains are taken out of the simulation increases the rate at which trains may be introduced into the simulation.

```
SIMULATION *ERROR* TYPE   2          ********************************************************************************
          DIVISION BY ZERO.     TIME =      .00
```

The purpose of this error message is simply to notify the user that somewhere within the program division by zero has taken place. This error can be the result of either an input error or a program error. The error message informs the user of the exact time in which this division by zero occurred. The user must determine where in the program the division by zero occurred and whether or not it rendered the simulation useless. It is suggested that the user obtain assistance from a programmer when correcting such an error.

```
SIMULATION *ERROR* TYPE   3          ********************************************************************************
          EXPONENT OVERFLOW.    TIME =      .00
```

The purpose of this error message is simply to notify the user that somewhere within the program an exponent has exceeded the maximum value allowed for the type of computer being used. The error message informs the user of the exact time in which this exponent overflow occurred. The user must determine where in the program the exponent overflow occurred and whether or not it rendered the simulation useless. It is suggested that the user obtain assistance from a programmer when correcting such an error.

```
SIMULATION *ERROR* TYPE   4          *******************************************************************************
          MORE THAN 8 TRAINS ARE IN THE ABOVE SEGMENT.
          THE ABOVE TRAIN WILL BE TEMPORARILY CONSIDERED TO BE OUTSIDE THE TUNNEL SYSTEM.
```

This error occurs when more than 8 trains are in one particular segment at any given time. The 8 trains do not have to be totally within the segment - if any portion of the front or rear of the train is within the segment, the train is considered to be within the segment. This error message informs the user as to which segment attempted to have more than 8 trains and at what time this error occurred. Every train that attempts to enter this segment beyond the first 8 trains is temporarily considered to be running on tracks outside of the tunnel system. As soon as a train leaves the tunnel segment, a train that has been temporarily considered outside the tunnel system is returned to the tunnel segment. It is important to note that trains that are temporarily placed outside of the tunnel system operate “alongside” the tunnel in the same manner as they would if they had remained within the tunnel system.

This error can be corrected by dividing the segment into as many different segments as is necessary to prevent this error from re-occurring. As a general rule, there is a much smaller probability of 9 or more trains entering a short segment than there is for a long segment. The headways between trains can also be modified so that more than 8 trains will never enter any of the segments at any one time.

```
SIMULATION *ERROR* TYPE   5          *******************************************************************************
          THERMODYNAMIC VELOCITY-TIME STABILITY CRITERIA HAS BEEN EXCEEDED.
```

This error is due to an incompatibility between the air velocity within a subsegment, the length of the subsegment, and the “number of cycles per thermodynamic cycle” data entered by the user in Input Form 12. The thermodynamic velocity - time stability criteria is exceeded when the air within a subsegment travels a distance greater than the length of the subsegment during one thermodynamic cycle. These stability criteria can be exceeded by both the bulk and the annual airflows. The “bulk” airflow rate is the total rate of volumetric flow through a segment over a given length of time. The “annular” airflow rate is the rate of flow in the region between the sides of a train and the walls of the tunnel segment through which the train is passing. When this error is caused by the bulk airflow within a subsegment, the program prints three sets of numbers in addition to the error message. These three sets of numbers are as follows:

1. Line segment identification number (section - segment).
2. Air Velocity in the subsegment (ft/sec) x thermodynamic time cycle (sec) =

Distance the air traveled during one thermodynamic cycle (ft).

3. Maximum distance the air would be able to travel before exceeding the velocity - time stability criteria (ft).

The situation can be corrected from these three sets of numbers. The user can increase the length of the subsegment and/or decrease the time increment between thermodynamic cycles. If the corrections are done properly, the product of the air velocity in the subsegment and the thermodynamic time cycle should be less than the length of the subsegment.

When this error is caused by the annular airflow within a subsegment, the program prints three sets of numbers in addition to the error message. These three sets of numbers are as follows:

1. Line segment identification number (section - segment).
2. Airflow rate in the subsegment (cfs) x thermodynamic time cycle (sec) = Volume of air that passed through the subsegement during one thermodynamic cycle (ft^3).
3. The net volume of the subsegment (ft^3). This volume is the volume of the subsegment minus the volume of the train occupying the subsegment. The situation can be corrected from these three sets of numbers. The user can increase the length of the subsegment (thereby increasing its volume) and/or decrease the time increment between thermodynamic cycles. If the corrections are done properly, the product of the airflow rate in the subsegment and the thermodynamic time cycle should be less than the net volume of the subsegment.

```
SIMULATION *ERROR* TYPE   6          ********************************************************************************
          THE FAN IN THE ABOVE VENTILATION SHAFT HAS EXCEEDED EITHER ITS UPPER OR LOWER FLOW LIMIT.
```

This error is due to a fan attempting to exceed either its maximum or its minimum volume flow rate. The user supplies the program with the maximum and minimum volume flow rates for each fan type. In addition, the user chooses whether or not the simulation should continue after a fan encounters a stopping/windmilling condition through use of the fan stopping/windmilling option in the General Data portion of the input data. If the user chose fan stopping/windmilling option 1, the program will first print the error message identifying the fan causing the error and then terminate the simulation. If the user chose fan stopping/windmilling option 2, the program will first print this error message identifying the fan causing the error and then turn off this fan without terminating the simulation.

The user may correct this error by one or a combination of the following methods:

1. Change the fan curve in a manner that would eliminate excessive positive or negative volume flow rates.
2. Increase the fan operating upper flow limit and/or decrease the fan operating lower flow limit.
3. Decrease the time increment between aerodynamic cycles.
4. If the fan is exceeding its flow limits at the beginning of the simulation, the fan start-up time should be increased.

5. If the fan is exceeding its flow limits at the beginning of the simulation, initial airflows can be used to reduce the sudden impact of the fan upon the system airflow. These initial flows do not have to be very accurate - the purpose of putting in initial flows is simply to reduce the initial impact of the fan when it starts-up in a system with absolutely still air.

```
SIMULATION *ERROR* TYPE   7          ********************************************************************************

               THE COEFFICIENT MATRIX FOR THE SET OF AERODYNAMIC EQUATIONS IS NOT POSITIVE DEFINITE.
               THIS IS CAUSED BY:
                 1. THE TOTAL TRAIN CROSS SECTION AREA OVERLAPPING THE TUNNEL CROSS SECTION AREA(BLOCKAGE
                    RATIO GREATER THAN OR EQUAL TO ONE) OR
                 2. THE TIME INTERVAL USED FOR THE INTEGRATION OF THE AERODYNAMIC EQUATIONS IS TOO LARGE.

               THIS SIMULATION IS TERMINATED BECAUSE THE NUMBER OF ALLOWABLE SIMULATION ERRORS
               OR AN IRRECOVERABLE ERROR HAS BEEN ENCOUNTERED
```

This simulation error is an irrecoverable simulation error. Two distinct independent conditions can cause this error type. The first of these two conditions is when a train whose cross-sectional area is greater than the cross-sectional area of the tunnel enters the system. The second condition is when the methods used to solve the aerodynamic flow equations go awry and breakdown. This breakdown of the methods of solution is due to the user entering an aerodynamic time cycle that is too long for the conditions that exist in the system being simulated. The former can be corrected by checking the input data for both the line segments and the train descriptions.

The cross-sectional area of a train can never be greater than the cross-sectional area of the tunnel in which it is traveling. The latter can be corrected by decreasing the time increment between aerodynamic cycles by whatever amount is necessary to correct the error. This method of correction can in general only be performed by an iterative trial and error process.

```
SIMULATION *ERROR* TYPE   8          ********************************************************************************
          THE NUMBER OF ITERATIONS REQUIRED FOR THE HEAT SINK ANALYSIS TO CONVERGE FOR THE ZONE BELOW HAS EXCEEDED 50.
          THE HEAT SINK ANALYSIS FOR THE ZONE BELOW PROVIDES THE RESULTS OF THE 51ST ITERATION.
          TO ENABLE THE HEAT SINK ANALYSIS TO PROPERLY CONVERGE, DO THE FOLLOWING:
               RE-RUN THE PROGRAM AND RE-SET THE INITIAL WALL TEMPERATURES IN THE ZONE BELOW TO THE WALL
               TEMPERATURE VALUES PRINTED IN THIS 51ST ITERATION OF THE HEAT SINK ANALYSIS.


SIMULATION *ERROR* TYPE  11          ********************************************************************************
          ILL-CONDITIONED OR SINGULAR DYNAMIC HUMIDITY RESPONSE MATRIX


SIMULATION *ERROR* TYPE  12          ********************************************************************************
          ILL-CONDITIONED OR SINGULAR DYNAMIC THERMAL RESPONSE MATRIX
```

Either of the above two simulation errors occurs when the program is unable to solve the Dynamic Humidity Response Matrix (DHRM) or the Dynamic Temperature Response Matrix (DTRM) respectively. The inability to solve one of these matrices is usually caused by a particular combination of system geometry, train location, fan performance, and other data. This error can usually be corrected by slightly modifying the system geometry or train delay or headway times. Recurrence of this error may indicate an error in the program.

15. SES VALIDATION

15.1 Scale Model Tests

Prior to, during, and after the development of the SES computer program, scale model tests were done to confirm the accuracy of the SES mathematical models and their components. Below are short descriptions of the tests made. The references listed at the end of this chapter are for those who wish to understand in detail the tests done, their accuracy and limitations, etc.

15.1.1 Pre-SES

Prior to the development of the SES, dimensionless analyses and scale model testing were done by others to develop certain basic aerodynamic and thermodynamic relationships. Among those developed were the dimensionless relationships between the friction factor, the relative roughness and the Reynolds Number; the Nusselt Number and the Reynolds Number for smooth-wall tunnels; the friction factor correction to the Nusselt Number; the correction to the Nusselt Number caused by ribbed tunnels, etc. The references for these works are contained in the SES Programmers Manual or embedded in the SES program FORTRAN source code as Comment lines.

15.1.2 SES

The Single Track Subway Environment Simulation (ST-SES) computer program was a forerunner of the SES. For the circumstance of a single track tunnel with ventilation shafts to the atmosphere and unidirectional trains, the aerodynamic and thermodynamic models of the two computer programs are quite similar, the major difference being how Reynolds Number influences were modeled. A 300-foot long, 1/16 scale model having moving trains with blockage ratios of 0.35, 0.55 and 0.75 was constructed and transient air velocity measurements were taken. These measurements were then compared to the predictions of the ST-SES. The comparisons were acceptable; however, the data suggested that adding Reynolds Number effects to the SES would improve scale model comparisons. The test facility is described in Reference 1. Reference 2 documents the work.

The ST-SES and the SES can simulate the effect of combining and diverging airflows at 'T', angled and 'Y' junctions. The theory behind these junctions and the scale model tests that determined the coefficients required by their equations are presented in Reference 3. The test facility is described in Reference 1.

Prior to the completion of the SES thermodynamic subprogram, comparisons were made between the predictions of the SES aerodynamic model and scale model tests. A 300-foot long, 1/16 scale test facility having trains moving in both directions was constructed. A removable center partition allowed double- track, double-track porous center wall and single-track tests. Comparisons were made between measured transient air velocities and the predictions of the SES computer program. The differences were often less than five percent. The test facility is described in References 1 and 4. Reference 5 documents the comparison.

15.1.3 Bureau of Mines - 1979

Mine fires and tunnel fires have similarities. The airflow is essentially one dimensional. Escape is difficult and the ventilation system must be able to move the smoke and hot gases in one direction (i.e., to prevent 'backlayering') while allowing the people to evacuate in the other direction. The minimum air velocity required to control the direction of smoke movement is known as the "critical velocity". During the 1970s, the US Bureau of Mines did fundamental work in this area and concluded that Froude Number modeling provided insight to the phenomena just as it does for building corridor fires. A scale-model test program followed and its results indicated that to be able to avoid backlayering, the fire site Froude Number had to be kept below a range value from 4.5 to 6.7. This result was then used as a constant in the PB-derived critical velocity equations. These tests are documented in Reference 6 and the critical velocity calibration is documented in Reference 17.

15.2 Full-Scale Tests

During and after the development of the SES computer program, full-scale tests were carried out to confirm its validity and to suggest areas where improvements could be made. Below are short descriptions of the tests made. The references listed at the end of this chapter are for those who wish to understand in detail the tests done, their accuracy and limitations, etc. It should be noted that none of these would have occurred without the extreme cooperation with the owners and operators mentioned.

15.2.1 PATH Resistor Grid Tests - 1971

The kinetic energy of train movement has to become zero when a train stops. This occurs by 1) an exchange with mechanical potential energy as the train goes up or downhill, 2) conversion to heat as a result of aerodynamic drag and rolling resistance, 3) conversion to electrical potential energy by regeneration into the traction power supply system, 4) conversion to heat as a result of the application of the train's friction brakes and 5) conversion to heat through the trains braking resistor grids. Because of their mass, the resistor grids can carry train heat from one stop to another and create a spatial heat distribution in addition to the temporal distribution that occurs with each stop. Prior to these tests there was no quantitative data on resistor grid heat release. Peak operating temperatures had been confirmed by 'meltdowns', but the actual pattern of grid heat release and temperature increase and decrease was not known. The Port Authority Trans-Hudson subway (aka the "PATH Tubes") is owned and operated by Port Authority of New York and New Jersey and was selected as a test site because of its range of train speeds, etc. The results were used to calibrate and confirm the SES resistor grid model. References 7 and 8 document this work. The Berkeley Hills Tunnels tests, Reference 9, confirmed that the calibrated resistor grid model was appropriate for projects other than PATH.

15.2.2 Berkeley Hills Tunnels - 1973

The Berkeley Hills Tunnels are 16,855-foot long, twin-bore, single-track rail-transit tunnels under the Berkeley Hills east of Oakland. These tunnels are owned and operated by the San Francisco Bay Area Rapid Transit (BART) System. The tunnel length was sufficient to study both steady-state and transient air velocities. Air temperatures, air velocities, air pressures, and resistor grid temperatures were measured in one tunnel for train speeds up to 70 miles per hour. Comparisons were made between these measurements and the predictions of the ST-SES. The air pressure and velocity measurements were often within 5 percent of prediction with the air temperature measurements being within about 10 percent of prediction. Reference 9 documents the work.

15.2.3 Toronto Heat Sink - 1974

The heat transfer to and from the station and tunnel walls has a significant effect on the station and tunnel air temperatures. As a result, a heat sink subprogram was included in the SES. This subprogram estimates the station and tunnel wall temperatures to a sufficient level of accuracy such that their overall effect on system air temperatures is properly accounted for. The assumptions behind the subprogram needed confirmation. As a result, a series of air velocity and air and wall surface temperature measurements were made in the tunnels between Christie and Bathurst Stations in the Toronto Subway, which is owned and operated by the Toronto Transit Commission. These measurements were compared with the predictions of the SES computer program. The results showed that the SES heat conduction model predicts the wall surface temperature with sufficient accuracy to provide an adequate estimate of the heat exchange between the walls and air for the purpose of subway environment analysis. Reference 10 documents the work.

15.2.4 Montreal SES Validation - 1975

The Montreal Metro was opened in 1967 just prior to the World's Fair (EXPO). The Metro has single-bore two-track tunnels and is owned and operated by the Montreal Urban Community Transit Commission. The environmental control concept includes mid-tunnel ventilation shafts with fans and vent shafts adjacent to some stations for air velocity control. The purpose of the Montreal Metro full-scale field validation tests was to directly validate the SES program for use as a design tool and thus confirm its viability on a 'system' level rather than a 'component' level. Station and tunnel air velocities, air temperatures, wall temperatures and train speeds as a function of location and time were field measured and compared with the predictions of the SES. The comparisons were quite favorable. It was concluded: 1) that the SES accurately predicted the airflows, the air temperatures and humidities, train performance and vent shaft performance in an operating subway and 2) that the SES could be used as a design tool for predicting the environment within a given subway system with a high level of confidence. Reference 11 documents the work.

15.2.5 Toronto Underplatform Exhaust Tests - 1976

Underplatform exhaust (UPE) systems take advantage of the fact that the major source of subway heat is the train. The release of this heat to the subway air occurs for the most part beneath the car through convection from the propulsion/braking systems, air-conditioning compressor-condenser units and train ancillaries. In concept, the UPE system captures some of this heat from beneath a train while it is in a station. Prior to these tests, the percentage of the heat extracted as a function of the UPE airflow rate was not known and as a result UPE capacities were selected by either intuition and heuristic calculations. It was therefore decided to build a full-size mock-up of a UPE system in the Toronto Transit Commission's Bay Station and to perform tests with varying UPE inlet port locations and airflows. Reference 1 presents the application of this work. Reference 12 documents the test work done and its evolution to application.

15.2.6 Washington Metro - 1982

The Montreal tests described above did not include the effects of underplatform exhaust (UPE) systems, trains having speeds greater than 50 mph and twin-bore, single-track tunnels on station air velocities and temperatures. Since most of the newer systems being designed and built in the USA at that time included these features, it was deemed appropriate that a second series of validation tests at the 'systems' level be made. The Washington Metro was selected because it was the only operating subway that had all these features. Station and tunnel air velocities, air and wall temperatures, resistor grid temperatures and train speeds as a function of location and time were field measured and compared with the predictions of the SES. The resistor grid temperatures and the computed UPE efficiencies correlated with the SES; however, the temperatures, air-wall heat transfer coefficients and low air velocities in the high-domed stations did not. After a thorough review it was determined that the uniqueness of the high-domed stations was more the issue than the SES program itself. It was therefore decided not to recommend any changes to the SES program or the Subway Environmental Design Handbook as a result of the project. Reference 13 documents this work.

15.2.7 Mount Lebanon Tunnels - 1987

The Mount Lebanon Tunnels are 2900-foot long, twin-bore, single-track rail transit tunnels under Mount Lebanon south of Pittsburgh, owned and operated by the Port Authority of Allegheny County. It was the first rapid transit tunnel built in the USA using the New Austrian Tunneling Method (NATM). The twin bores are connected with tunnel-to-tunnel crosspassages having doors at the third points along the tunnel length. The tunnel emergency ventilation system concept is longitudinal airflow caused by the injection of high-velocity air through nozzles at the portals. During the ventilation system commissioning, the as-built tunnel cross sections were measured. The revised data was input to the SES and the design simulations were repeated for different numbers of trains in the tunnel and different combinations of the crosspassages being opened or closed. The emergency ventilation airflows predicted by the SES were then compared with those field measured. The differences were often less than five percent with the greatest difference being about 15 percent for the circumstance of all crosspassages open and airflow induced in both tunnels. Reference 14 documents the work.

15.2.8 Toronto - 1990

Following the emergency ventilation system upgrade program and in preparation for refining the fan operation procedures, field tests were performed in the Toronto subway at selected locations, such that sufficient data could be gathered to establish confidence in the computer models as representations of the tunnel networks and fan capabilities. The tests were conducted at night during November, December, and January. Each test consisted of a series of air velocity measurements at multiple locations in the incident area. Measurement locations were selected so that a flow balance could be checked. A 450-foot train was positioned in the tunnel or station. After the airflow reached a steady-state condition, initial measurements were taken at the ambient conditions, followed by the operation of one or more fans in the mode thought best to ventilate the incident location for a 'worst-case' evacuation. Data sheets with airflow measurements for each location and conditions were completed during each test and were submitted as part of the field test report. Representative locations were modeled and the airflows predicted by the SES program were compared with field test measurements. In all cases the airflow pattern predicted by the SES matched the airflow pattern derived from the field test results. Reference 15 documents the test plan and results.

15.2.9 Mount Shaughnessy Tunnel - 1991

The Mount Shaughnessy Tunnel is a 6100-foot long, single-bore single-track rail tunnel in the Canadian Rockies owned and operated by Canadian-Pacific Rail. It is actually shorter than many of the freight trains that pass through it. Its normal operations concept utilizes transient airflow phenomena to cool the diesel-engine trains as they pass through the tunnel. Comparisons were made between the transient airflows and air temperatures predicted by the SES and transient airflow and air temperature measurements taken in the tunnel. The differences between the two sets of numbers were 15 percent or less, thus confirming the use of the SES computer program as the tunnel design tool. Reference 16 documents the work.

15.2.10 Memorial Tunnel Fire Ventilation Test Program (MTFVTP) - 1995

The Memorial Tunnel is a 2800-foot single-bore two-lane road tunnel built in 1953 as part of the West Virginia Turnpike, near Charleston, West Virginia and removed from service in 1987 when it was replaced by a four-lane highway. 98 full scale tests were performed for fire heat release rates of 10, 20, 50 and 100 megawatts (34.1, 68.2, 170.5 and 341.0 million Btus per hour). Approximately 15 of the MTFVTP tests determined the longitudinal air velocity required to control the direction of spread of smoke and hot gases from a fire (aka critical velocity). The MTFVTP results strongly supported the SES methodology (Froude Number modeling) for the design of longitudinally-ventilated rail tunnels. They indicated that, depending on the fire heat release rate, the SES methodology over-predicted the critical velocity between 4 and 20 percent. References 17 and 18 document the work. The graphs presented in Reference 17 supersede those in Reference 18.

REFERENCES

1. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., Deleuw, Cather & Company and Kaiser Engineers, "Subway Environmental Design Handbook, Part I, Principles and Applications," Second Edition, NTIS No. 254-788, Transit Development Corporation, Urban Mass Transportation Administration, March 1976.
2. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., Deleuw, Cather & Company and Kaiser Engineers, "A Comparison of the ST-SES and the SAT," Technical Report No. UMTA-DC-MTD-7-72-21, Transit Development Corporation, Washington, D.C., March 1973.
3. Developmental Sciences, Inc., "Vent and Station Test (VST) Facility - Special and Complex Vent Shaft Testing," Technical Report No. UMTA-DC-06-0010-73-4, Transit Development Corporation, Washington, D.C., December 1973.
4. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., Deleuw Cather & Company and Kaiser Engineers, "A Comparison of the SES with the SAT," Technical Report No. UMTA-DC-0010-73-5, Transit Development Corporation, Washington, D.C., February 1974.
5. Developmental Sciences, Inc., "Double Track Porosity Testing," Technical Report No. UMTA-DC-06-0010-75-4, Transit Development Corporation, Washington, D.C., November 1975.
6. C.K. Lee, R.F. Chaiken, and J.M. Singer, "Interaction Between Duct Fires and Ventilation Flow: An Experimental Study," Combustion Science and Technology, Volume 20, 1979.
7. General Electric Company, Inc., "Transit Car Braking Grid Temperature and Air Flow Tests," performed for the Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade and Douglas, Inc., Deleuw, Cather & Company and Kaiser Engineers, September 1972.
8. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., DeLeuw Cather & Company and Kaiser Engineers, "Thermal Behavior of Transit Vehicle Resistor Grids," Technical Report No. UMTA-DC-MTD-7-72-6, Transit Development Corporation, Washington, D.C., January 1973.
9. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., DeLeuw, Cather & Company and Kaiser Engineers, "Aerodynamic and Thermodynamic Validation Tests in Berkeley Hills Tunnel," Technical Report No. UMTA-DC-06-0010-73-1, Transit Development Corporation, Washington, D.C., June 1973.
10. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., DeLeuw, Cather & Company and Kaiser Engineers, "SES Heat Conduction Validation," Technical Report No. UMTA-DC-06-0010-73-8, Transit Development Corporation, Washington, D.C., January 1974.

11. Associated Engineers, A Joint Venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., DeLeuw, Cather & Company and Kaiser Engineers, "Comparisons of Computer Model Predictions and Field Measurements of Subway Environment in the Montreal Metro," Technical Report No. UMTA-DC-06-0010-75-3, Transit Development Corporation, Washington, D.C., August 1975.
12. Associated Engineers, A Joint Venture of Parsons Brinckerhoff, Quade & Douglas, Inc., Deleuw, Cather & Company and Kaiser Engineers, "Underplatform Exhaust Tests in the Toronto Subway," Technical Report No. UMTA-DC-06-0010-75-5, Transit Development Corporation, Washington, D.C., December 1975.
13. Deleuw, Cather & Company, "Subway Environment Simulation Program and Subway Environmental Design Handbook Validation Through Field Testing," in four volumes, Report No. UMTA-DC-06-0267-86-4, prepared for the Washington Metropolitan Area Transit Authority and the USDOT's Urban Mass Transportation Administration, February 1983.
14. W.D. Kennedy and S.J. Patel, "The Mount Lebanon Tunnel Ventilation System," Sixth International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels, Durham, England, September 1988, Cranfield, England: British Hydromechanics Research Association (BHRA) Fluid Engineering 1988 (reprinted in June 1989 Tunnels and Tunnelling).
15. Henry J. Kaiser Company (Canada), Ltd., "In-house Test and Computer Simulation of Subway Ventilation System for the Toronto Transit Commission," Contract G35-6, Toronto Transit Commission, March 1990.
16. S.S. Levy and D.P. Elpidorou, "Ventilation of the Mount Shaughnessy Tunnel," Seventh International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels, September 1991, Cranfield, England: British Hydromechanics Research Group (BHRG) Fluid Engineering, 1991.
17. W.D. Kennedy, "The Influence of the Memorial Tunnel Fire Tests on Transit Tunnel Fire Emergency Ventilation Analysis," Presented at the American Public Transit Association's 1997 Rapid Transit Conference Seminar on Ventilation of Transit Tunnels and Underground Stations, Washington, 7-11 June 1997, available from Parsons Brinckerhoff, One Penn Plaza, New York City, NY 10119.
18. Bechtel/Parsons Brinckerhoff, "Memorial Tunnel Fire Ventilation Test Program, Comprehensive Test Report," prepared for the Massachusetts Highway Department, November 1995.

16. SAMPLE CALCULATIONS

This chapter presents the methodology for developing the SES input data for a sample system. The system consists of a simple one-station subway with adjoining tunnels at both ends of the station. The station has a mezzanine with two stairways connecting the platform and the mezzanine, and one stairway connecting the mezzanine with the street. The adjoining tunnels at the west end of the station (see Figure 16.1) are single-track tunnels with one-way traffic. The tunnel adjoining the east end of the station is a double-track tunnel with two-way traffic. Each of the two single-track tunnels has a ventilating shaft halfway between the west end of the station and the portals at the west end of the system. The ventilation shaft on the incoming single-track tunnel (route 1) forms a "T"-junction with the tunnel, and the ventilation shaft on the outgoing single-track tunnel (route 2) forms an "angled" junction with the tunnel. There is a ventilation shaft with an exhaust fan 500 feet beyond the east end of the station in the double-track tunnel. This fan shaft forms a "T"-junction with the double-track tunnel.

There are five track sections of various grades and speed restrictions. These track sections are shown in Figure 16.1.

A "dummy" node has been placed at the east end of the station (node 9) to allow for a future addition of a stairway at that end of the station.

Obtaining the Input Data

The methods used to obtain most of the input data for the system are given below. The calculations for the tunnel velocity head loss coefficients due to changes in the tunnel area are shown in Figure 16.3. It was assumed that all the losses are either square-edge abrupt contraction or square-edge abrupt expansion losses.

The calculations for the velocity head loss coefficient between the station platform area and the mezzanine are shown in Figure 16.4. It is assumed that the mezzanine area and platform area are both plenums. The loss coefficient between the platform and mezzanine is then simply a square-edge orifice loss between two plenums. The user must estimate the free area of a stairway opening based on the average number of patrons occupying the stairway at any given time and the amount of the total free area these patrons obstruct.

Figures 16.5 through 16.7 provide sketches of the vent shafts in the system. The head loss coefficients are calculated for both inflow and outflow in each segment of each vent shaft. The loss coefficients for inflow in a vent shaft segment are often different from the loss coefficients for outflow in the same segment. This difference in loss coefficients for inflow and outflow is shown in Figure 16.6 at the boundary between segment 1 and segment 2.

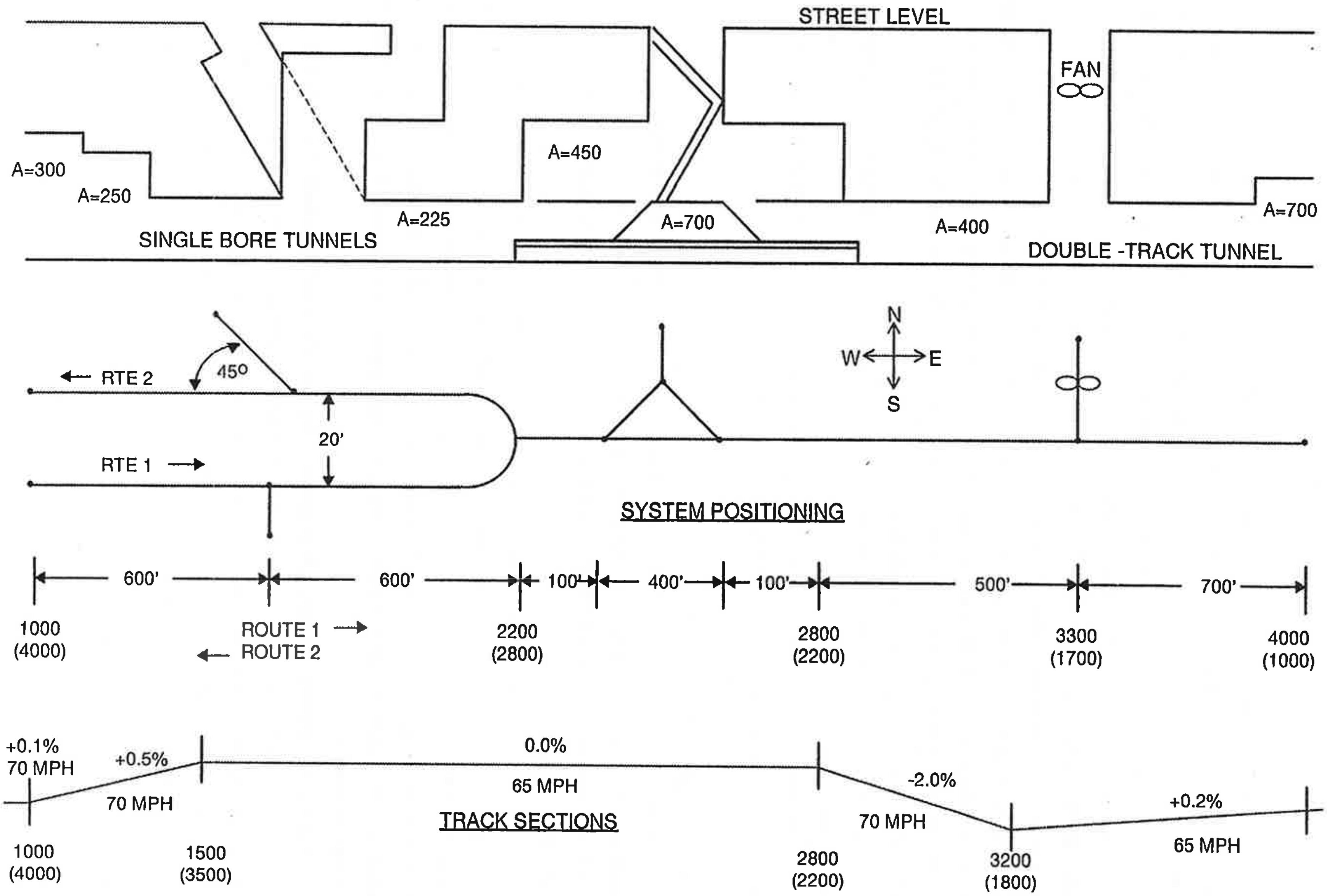


Figure 16.1 Sample Problem System

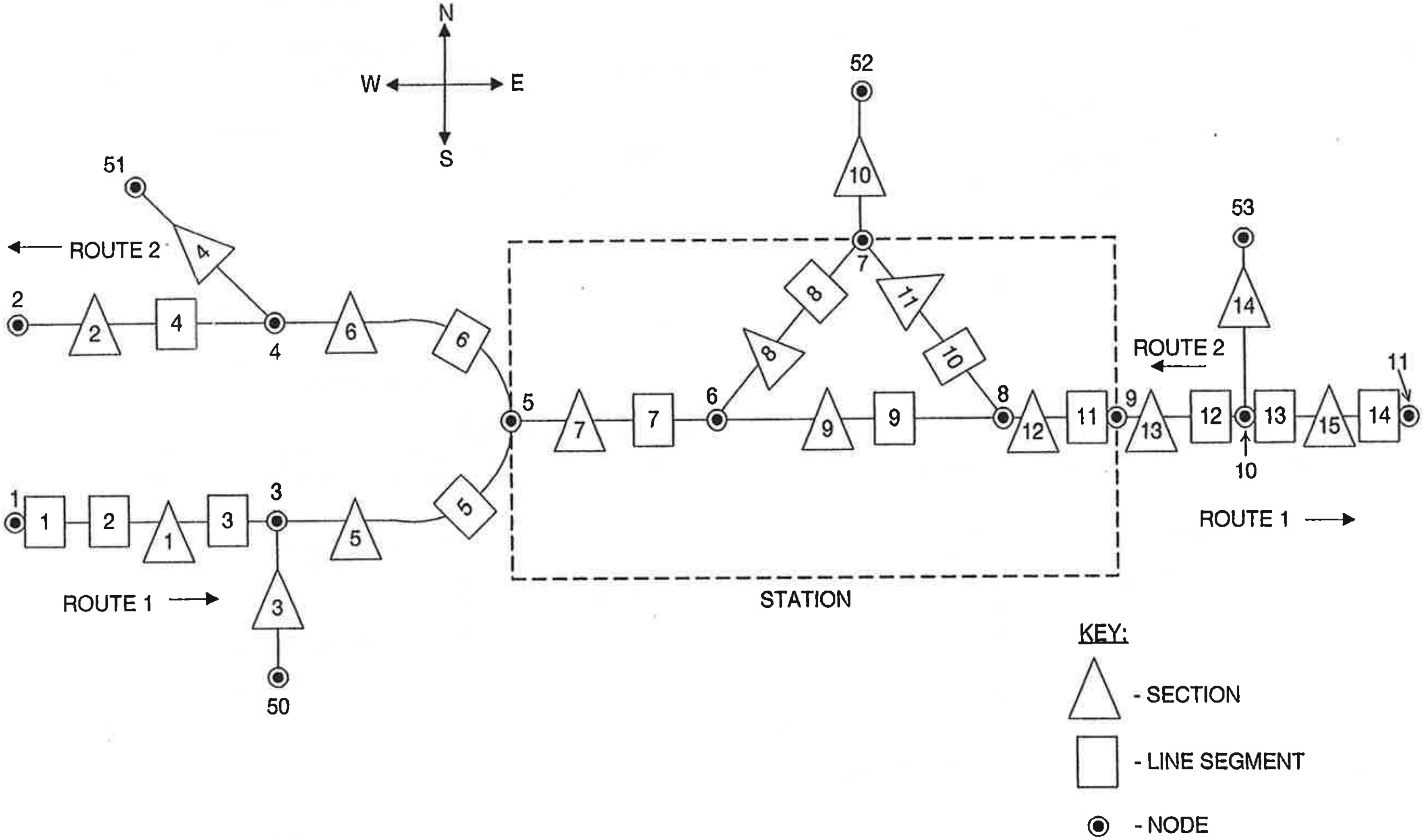


Figure 16.2 Sample Problem Schematic Diagram

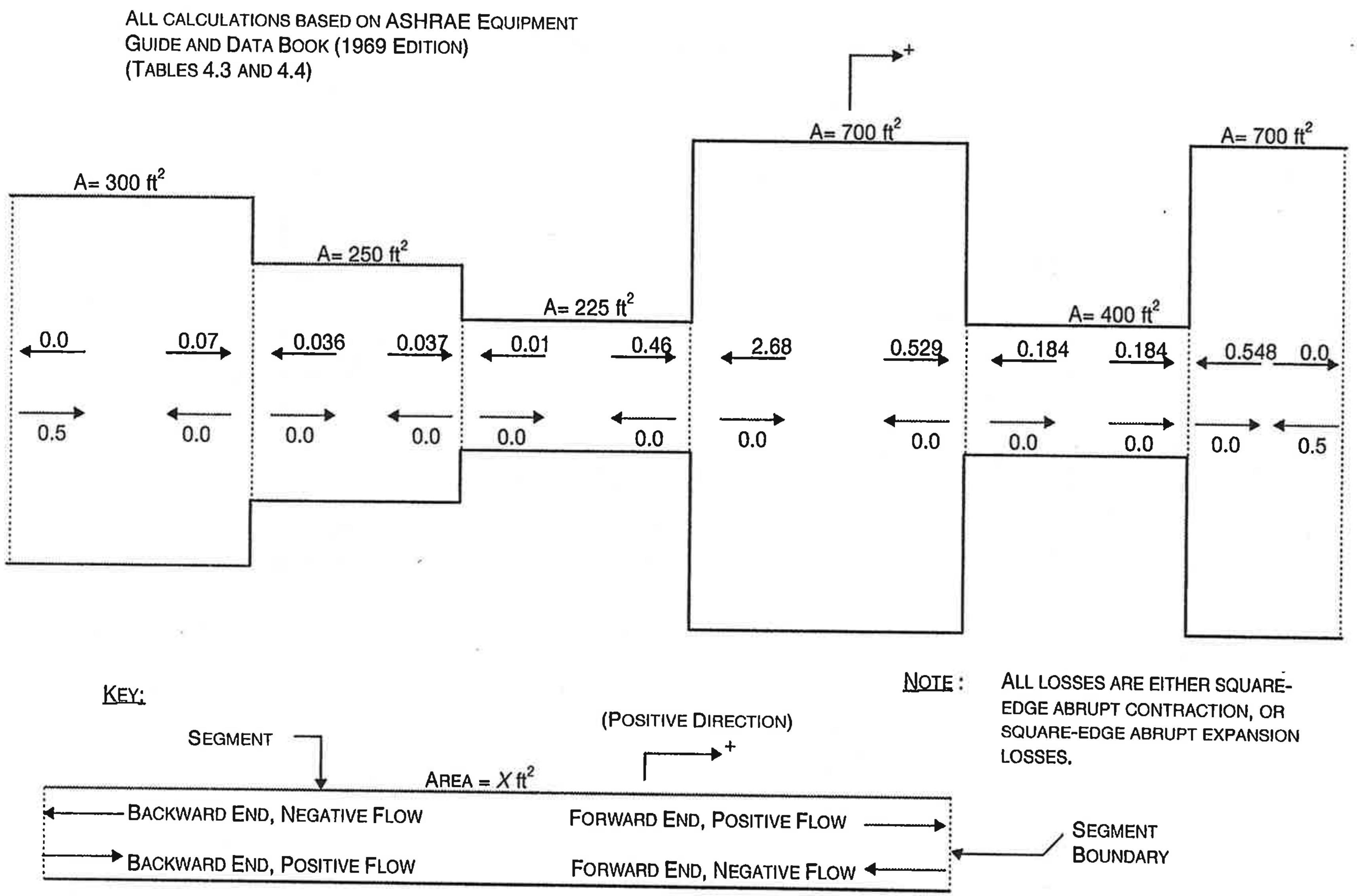
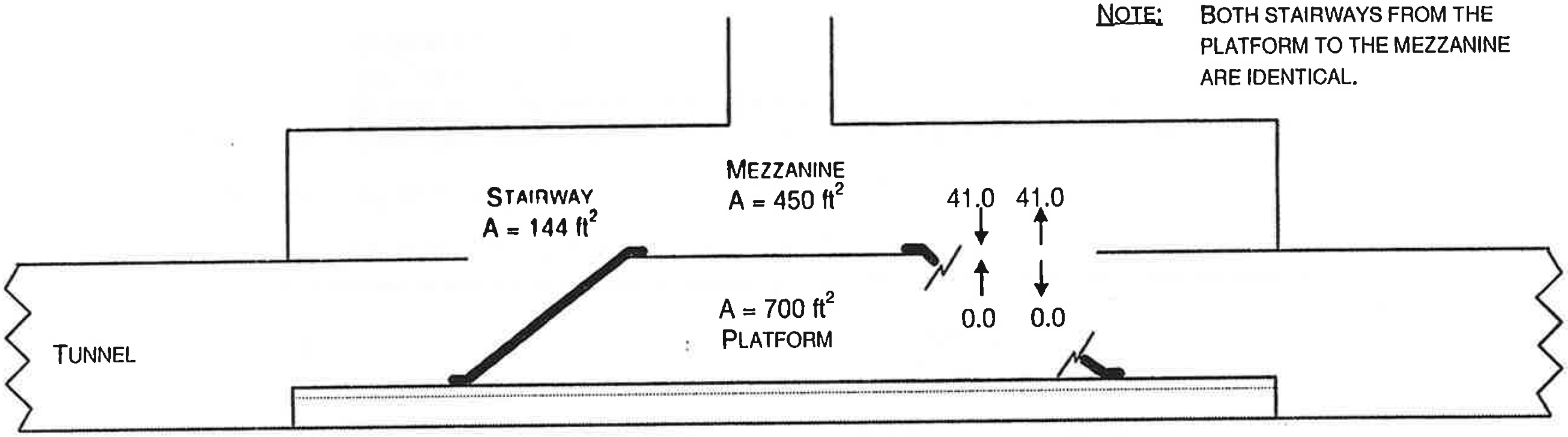


Fig. 16.3 Tunnel Segment Head Loss



<u>NOTE:</u> BOTH STAIRWAYS FROM THE PLATFORM TO THE MEZZANINE ARE IDENTICAL.

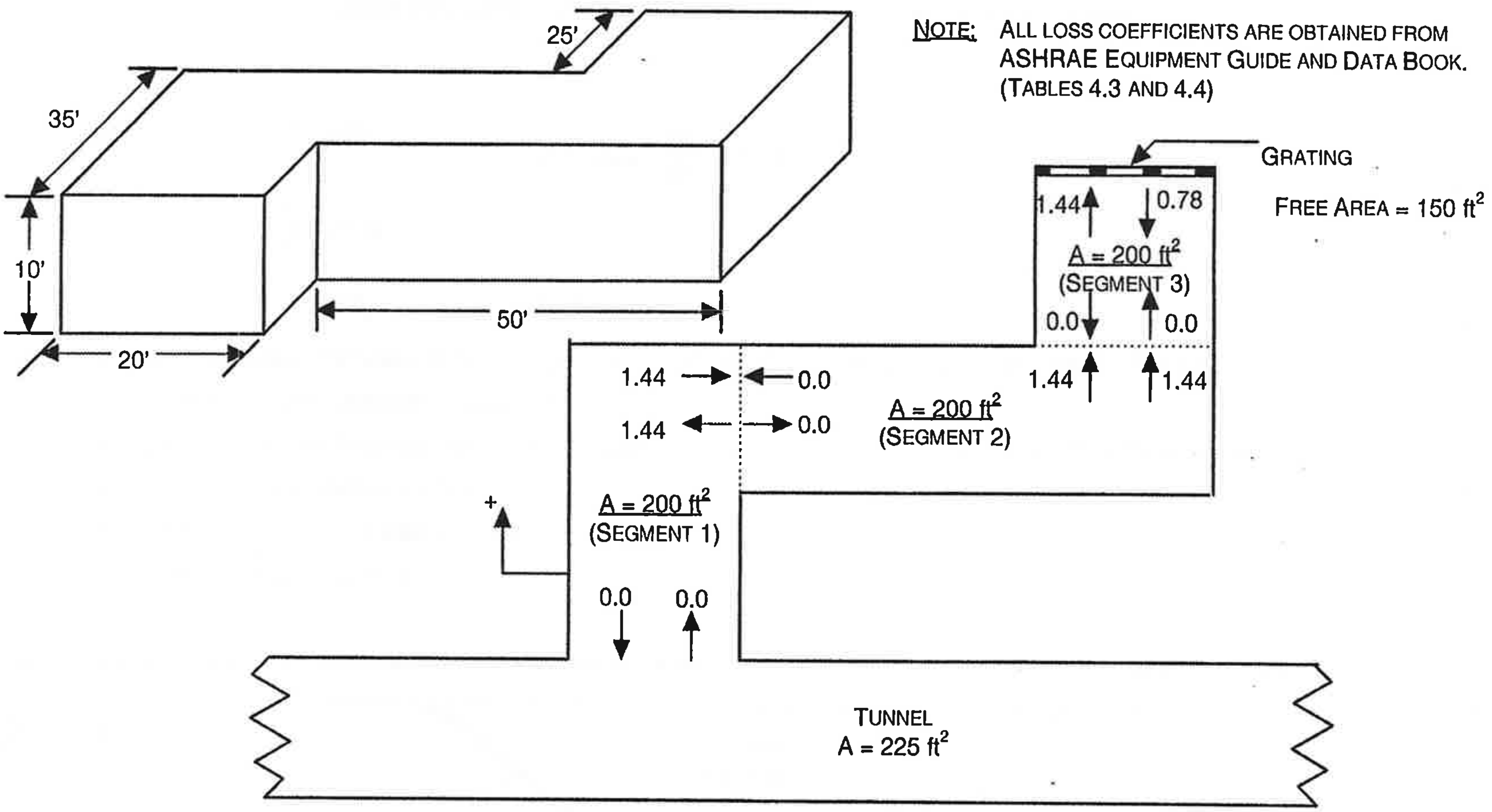
1. STAIRWAY IS 12' x 12' = 144 ft^2
2. PEOPLE BLOCK APPROX. 33% OF AREA.
3. FREE AREA OF STAIRWAY = $A_o = 96\ ft^2$
4. CONSIDER THE HEAD LOSS BETWEEN THE PLATFORM AND THE MEZZANINE AS TWO PLENUMS WITH A SQUARE-EDGE ORIFICE (STAIRWAY OPENING) IN BETWEEN.
5. FROM ASHRAE EQUIPMENT GUIDE AND DATA BOOK: SQUARE-EDGE ORIFICE ENTRANCE LOSS (TABLES 4.3 AND 4.4)

$A_o = 96\ ft^2$ $\qquad A_2 = 450\ ft^2$

$$\frac{A_o}{A_2} = 0.213$$

$$C_o = 1.867 \qquad C_2 = (1.867)\left[\frac{450^2}{96^2}\right] = 41.0$$

Figure 16.4 Head Loss Between Platform Area and Mezzanine through Stairway



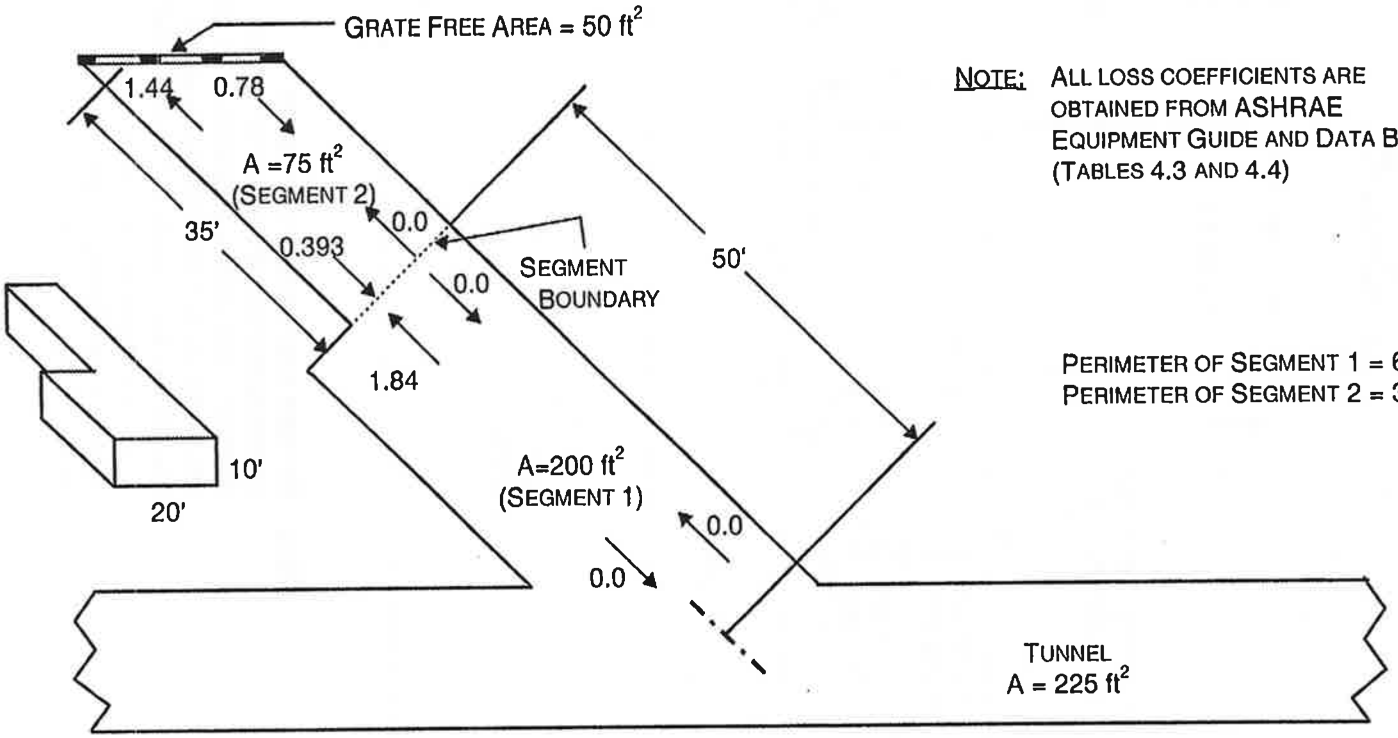
NOTE: ALL LOSS COEFFICIENTS ARE OBTAINED FROM ASHRAE EQUIPMENT GUIDE AND DATA BOOK. (TABLES 4.3 AND 4.4)

SEGMENT #1. 90° MITER TURN, RECTANGULAR SECTION : C = 1.44

SEGMENT #2. 90° MITER TURN, RECTANGULAR SECTION: C = 1.44

SEGMENT #3. GRATE FREE AREA = 150ft^2 : TOTAL PRESSURE LOSS THROUGH GRATING = 0.0275 in. w.g.
@1000 fpm ∴K THROUGH GRATING = 0.44 FOR BOTH INFLOW AND OUTFLOW
EXIT LOSS = 1.00
ENTRANCE LOSS = 0.34

Figure 16.5 Vent Shaft Head Loss Calculations For A Vent At 1600 ft - Route 1



NOTE: ALL LOSS COEFFICIENTS ARE OBTAINED FROM ASHRAE EQUIPMENT GUIDE AND DATA BOOK. (TABLES 4.3 AND 4.4)

PERIMETER OF SEGMENT 1 = 60 ft
PERIMETER OF SEGMENT 2 = 35 ft

SEGMENT #1: ABRUPT CONTRACTION:
(FORWARD END, POSITIVE FLOW) $A_2 / A_1 = 0.375$

$$C_1 = 0.259\left(\frac{200}{75}\right)^2 = 1.84$$

$C_2 = 0.259$

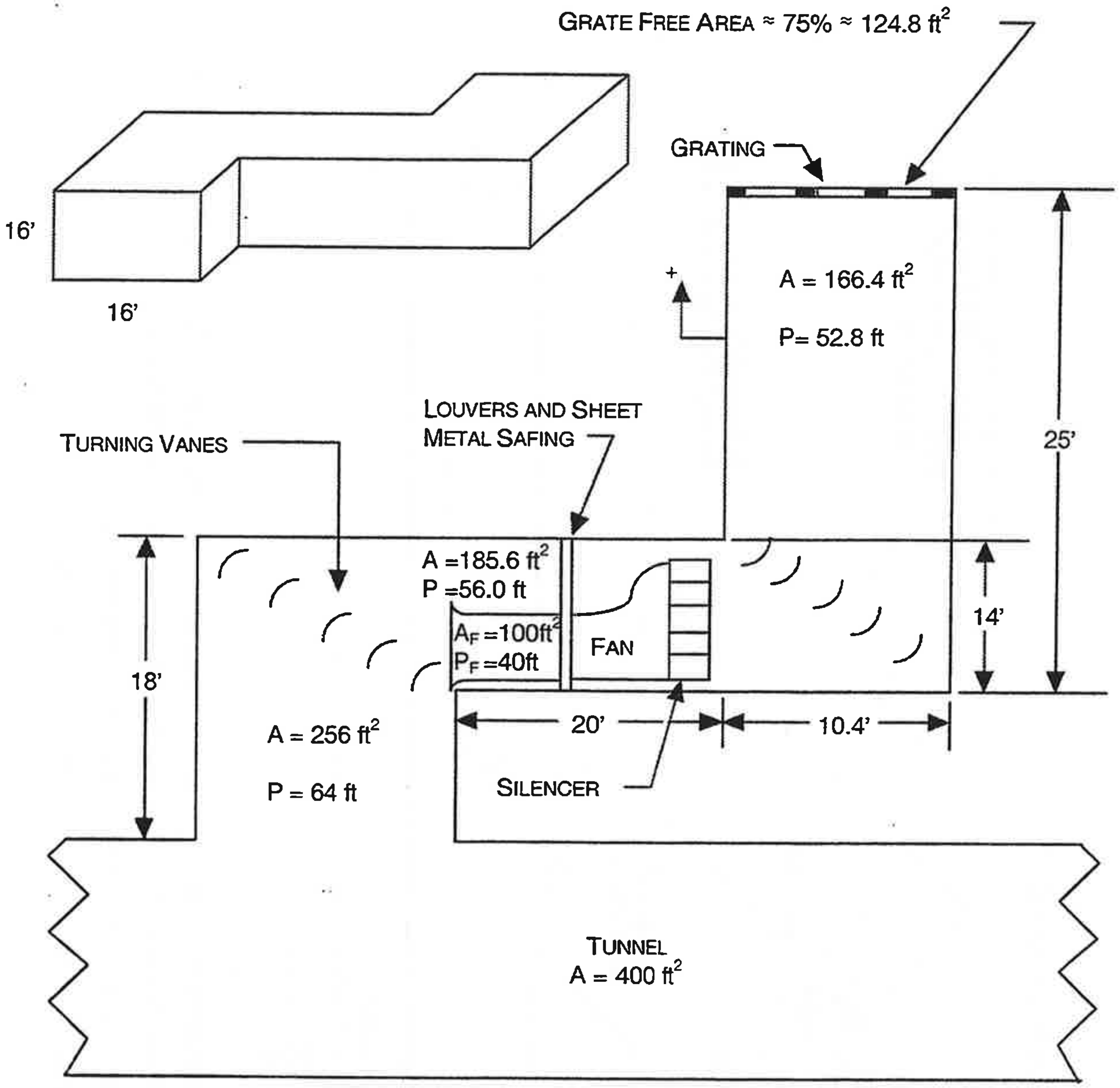
SEGMENT #2: a. ABRUPT EXPANSION (BACKWARD END, NEGATIVE FLOW): $A_1/A_2 = 0.375$ $C_1 = 0.393$

b. LOSS THROUGH GRATING: TOTAL PRESSURE LOSS THROUGH GRATING = 0.0275 in. w.g.

@ 1,000 fpm $\therefore$ K THROUGH GRATING = 0.44 FOR BOTH DIRECTIONS

EXIT LOSS = 1.00 ENTRANCE LOSS = 0.34

Figure 16.6 Vent Shaft Head Loss Calculations For A Vent At 1600 ft - Route 2



Key:

A = AREA OF SEGMENT

P = PERIMETER OF SEGMENT

A_F = AREA OF FAN INTAKE

P_F = PERIMETER OF FAN INTAKE

NOTE: BECAUSE THIS FAN SHAFT OPERATES CONTINUOUSLY IN THE EXHAUST (POSITIVE) DIRECTION, THE LOSS COEFFICIENTS FOR THE INFLOW (NEGATIVE) DIRECTION ARE NEVER UTILIZED AND MAY THEREFORE BE SET EQUAL TO THE COEFFICIENTS CALCULATED FOR POSITIVE FLOW TO AVOID UNNECESSARY CALCULATIONS.

Figure 16.7 Sketch of Tunnel Exhaust Fan Shaft 500 ft East of the Station

1. FROM ASHRAE EQUIPMENT GUIDE AND DATA BOOK (TABLES 3.3 AND 3.4):

SEGMENT 1: $A = 256\ \text{ft}^2$ $P = 64\ \text{ft}$

FORWARD END:

a. Turning loss through turning vanes (Positive and Negative)
Consider this as a miter with turning vanes $\therefore \underline{C \approx 0.225}$

b. Abrupt contraction: $A_1 = 256\ \text{ft}^2$ $A_2 = 100\ \text{ft}^2$ $A_2/A_1 = 0.391$
$C_2 = 0.253$ $C_1 = 0.253(256/100)^2 = \underline{1.658}$

$$\boxed{\Sigma_{\text{SEGMENT 1}} = 1.88}$$

SEGMENT 2: $A = 100\ \text{ft}^2$ $P = 40\ \text{ft}$

FORWARD END:

a. Loss through silencer - depends on type of silencer installed.
Loss through silencer ≈ 0.15 in. w.g. @ 2250 fpm.
Reference this loss to fan area and fan volume flowrate:
AREA = $100\ \text{ft}^2$ CFM = 120,000 CFM

$$0.15 = \Delta P = \frac{K\rho V^2}{2g} = (0.075)\left(\frac{120{,}00}{100\times 60}\right)^2 \frac{K}{32.2\times 5.202\times 2} \Rightarrow \underline{K{=}1.675}$$

b. Turning loss through turning vanes - consider this a miter turn with turning vanes: $\therefore \underline{C \approx 0.225}$

c. Abrupt Expansion: $A_1 = 100\ \text{ft}^2$ $A_2 = 166.4\ \text{ft}^2$ $A_1/A_2 = 0.601$ $C_1 = 0.16$

$$\boxed{\Sigma_{\text{SEGMENT 2}} = 2.06}$$

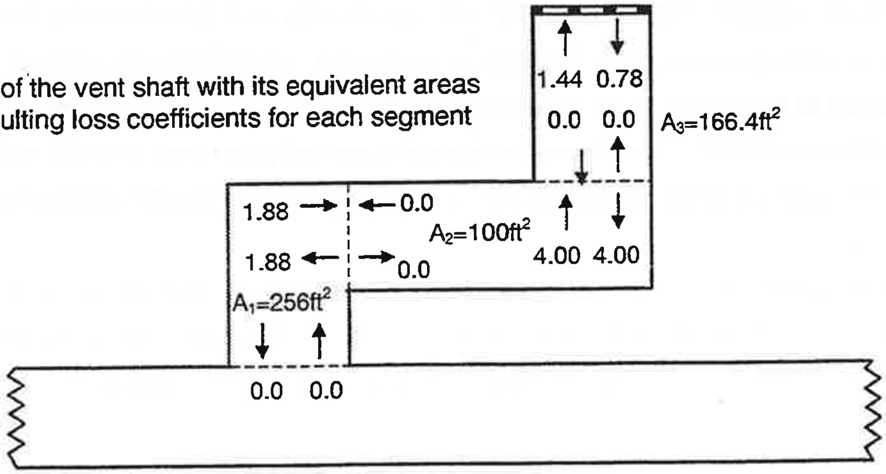
SEGMENT 3 : $A = 166.4\ \text{ft}^2$ $P = 52.8\ \text{ft}$

Loss through grating: Grate free area = $124.8\ \text{ft}^2$
Total pressure loss through grating = 0.0275 in. w.g. @ 1,000 fpm
∴ Loss Coefficient = 0.44 for both inflow and outflow

EXIT LOSS = 1.00 ENTRANCE LOSS = 0.34

$$\boxed{\Sigma_{\text{SEGMENT 3 OUT}} = 1.44 \qquad \Sigma_{\text{SEGMENT 3 IN}} = 0.78}$$

Sketch of the vent shaft with its equivalent areas and resulting loss coefficients for each segment



Calculation of Loss Coefficients in Exhaust Vent Shaft 500ft East of the Station

The exhaust fan shaft located in the double-track tunnel at the east end of the system is shown in Figure 16.7. The loss coefficients were in certain instances only calculated for the outflow (exhaust) direction of flow as this fan runs continuously in the outflow direction for the entire simulation (Fan Stopping/Windmilling Option 1.0). Therefore, certain loss coefficients for the inflow direction were set equal to the loss coefficients for the outflow direction to avoid unnecessary calculations (a good approximation). This procedure is only valid if the Fan Stopping/Windmilling Option is 1.0. If the Fan Stopping/Windmilling Option is 2.0, the fan may possibly shut off and the simulation continue. When a fan shuts off within a vent shaft, both inflow and outflow will generally occur within the shaft as the fan is no longer forcing air to flow in one direction. Therefore, the loss coefficients for both inflow and outflow must be calculated for a fan shaft if the Fan Stopping/Windmilling Option is 2.0.

Figure 16.8 provides the fan curve for the exhaust fan mentioned above. The program requires the user to enter four points along this curve. These four points are spaced fairly evenly, with one of the points being where the volume flow rate is zero, and another of the points being where the total pressure rise across the fan is practically zero. The upper flow limit was set at 220,000 cfm to allow for a slight degree of windmilling when a train passes beneath the vent shaft. The lower flow limit was set at zero as it is intended for the fan to always operate in the outflow (exhaust) direction. The simulation will terminate if the fan volume flow rate attempts to fall below zero cfm.

The junction at node 4 (see Figure 16.2) is a 45-degree angled junction. The SES program only allows the user to enter an angle of either 10, 20, or 30 degrees for junction angles. Therefore, when the junction angle is greater than 30 degrees, the user must choose whether to enter the junction as a 30-degree angled junction or as a 90-degree "T" junction. In this case, the 45-degree angled junction at node 4 more closely resembles a 30-degree angled junction than a 90-degree "T" junction, and was therefore entered as a 30-degree angled junction. The aerodynamic node types at the remaining junctions are basically self-evident and need no further explanation.

Figure 16.9 provides the tractive effort, motor current, and external resistance curve data used in the train performance subprogram. These three curves are interrelated to one another and must be entered in a specific manner. The tractive effort and current data must be entered for the same train speeds. The user must also remember that there is a constant internal resistance that is added to the external resistance of the motors in the program calculations. This internal resistance is the third resistance entered on Form 9I. This internal resistance is not included in the external resistance curve, but must be taken into account when calculating the train heat rejection in kilowatts/train when using Train Performance Option 3.

Figure 16.2 provides a schematic diagram of the base system. The schematic diagram is an extremely helpful aid when entering the system geometry in the input data. The vent shaft identification numbers have been arbitrarily set equal to the vent shaft section identification numbers plus 100.

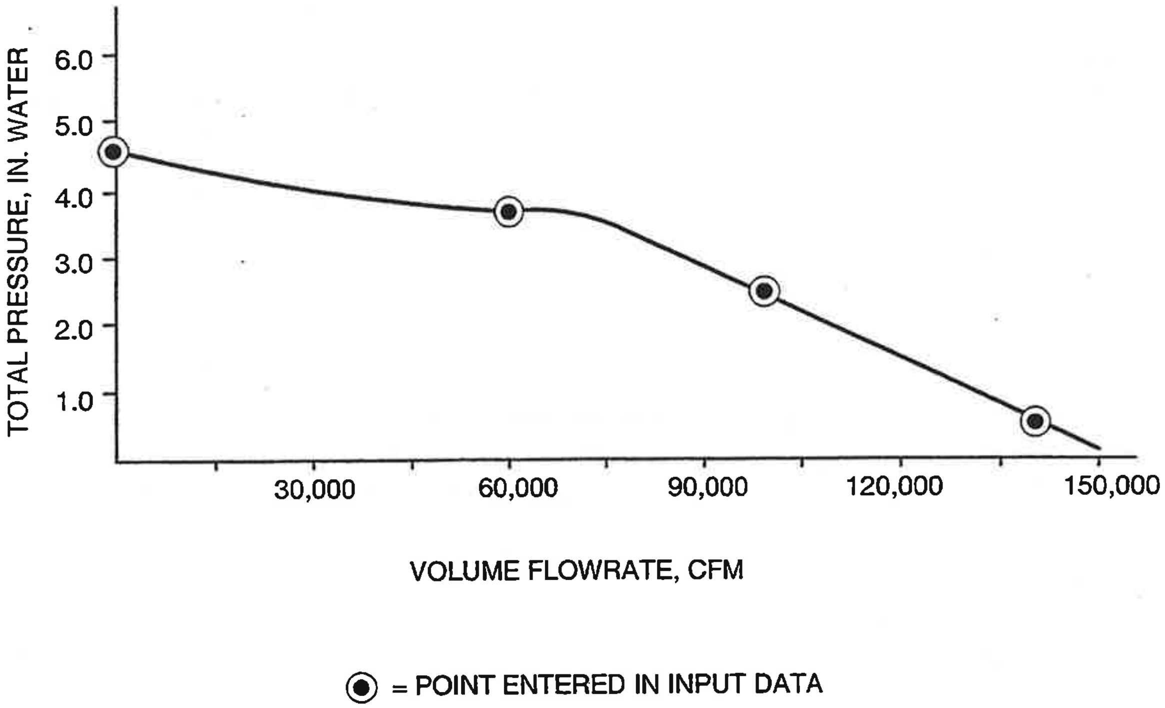


Figure 16.8 Sample Problem #1 - Fan Performance Curve For The Tunnel Exhaust Fan

The aerodynamic type of each node is as follows:

Node No.	Aerodynamic Type
1	0 - straight-through junction or portal
2	0 - straight-through junction or portal
3	3 - "T" junction
4	4 - angled junction
5	5 - "Y" junction
6	7 - zero static pressure change junction
7	3 - "T" junction
8	7 - zero static pressure change junction
9	7 - zero static pressure change junction
10	3 - "T" junction
11	0 - straight-through junction or portal
50	0 - straight-through junction or portal
51	0 - straight-through junction or portal
52	0 - straight-through junction or portal
53	0 - straight-through junction or portal

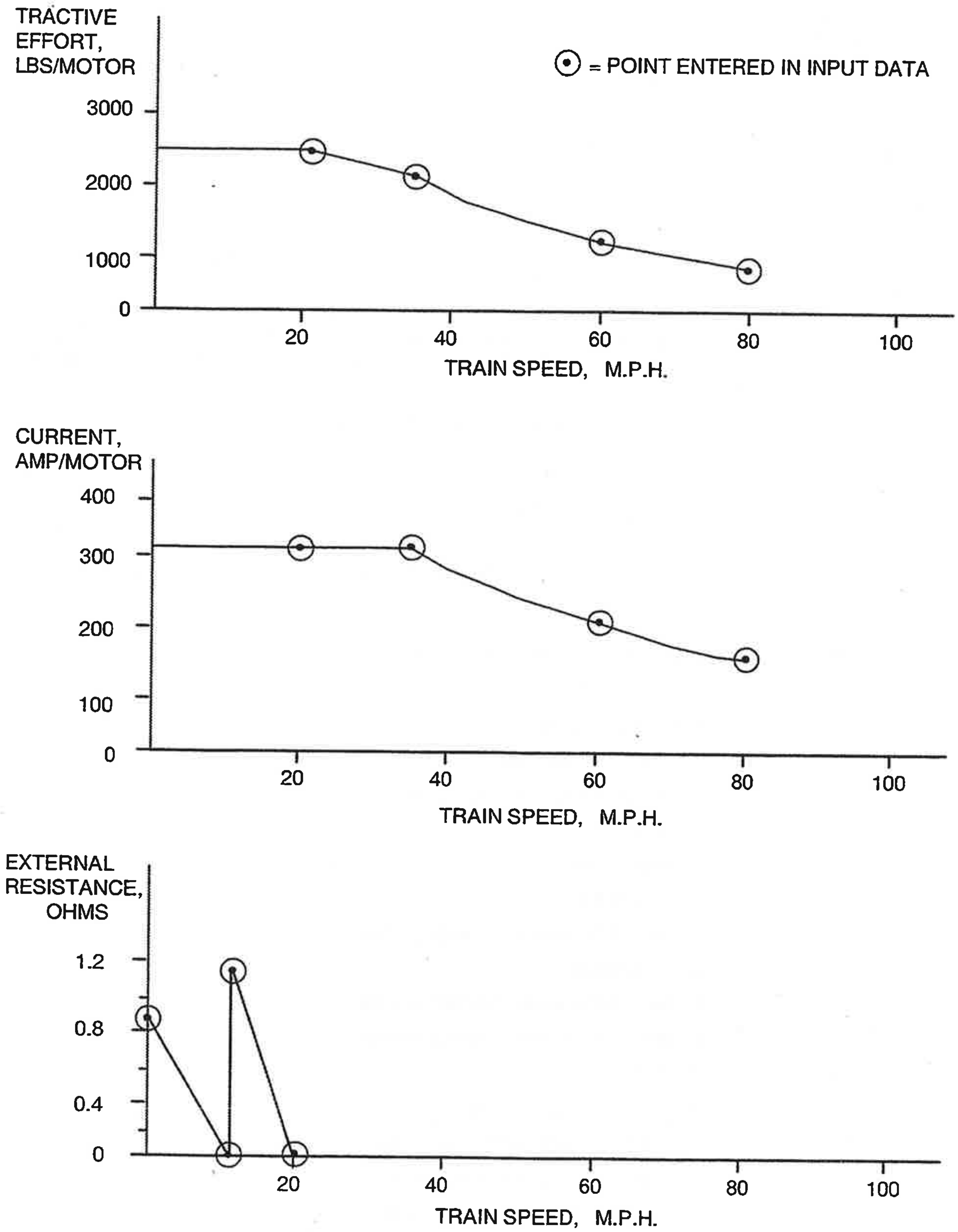


Figure 16.9 Train Propulsion Motor Performance Curves

1. TUNNEL LIGHTING: 7.0 Btu/hr/ft of Tunnel

2. THIRD RAIL LOSSES: $q_{3R} = \dfrac{0.65(KE + q_D + q_M + q_m + q_{SR})^2 R}{N t_a V_o^2}$

KE = 11.1 x 10^{-6} x $W_e N n U^2$

Train Length = 560 ft

N = 40 trains per hour

n = 8 cars per train

V_o = 1,000 volts

W_e = 35 tons

U = 60 mph = 5280 ft/min

KE = 11.1 x 10^{-6} x 35 tons x 8 cars/train x 40 trains/hour x $(5280)^2$ ft^2/min^2

KE = 3,465,842.7 Btu/hr

ASSUME AVERAGE ACCELERATION RATE FROM 0 TO 60 MPH IS 1.5 MPH/SEC.

DISTANCE REQUIRED FOR TRAIN TO ACCELERATE TO MAXIMUM SPEED:

$$S = \tfrac{1}{2} a t_a^2 \qquad t_a = \frac{60 mph}{1.5 mph/\sec} = 40 \sec$$

$$S = (0.5)(1.5)\frac{mi}{hr \cdot \sec} \times (40)^2 \sec^2 \times (5280)\frac{ft}{mi} \times \frac{hr}{(3600)\sec} \qquad \Rightarrow S = 1760 ft$$

R = (12 + 15) milliohms/mile = 27 milliohms/mile

$$q_{3R} = \frac{0.65(3,465,842.7 + q_D + q_M + q_m + q_{SR})^2(27)}{(40)(40)(1000)^2}$$

$$F_D = 4.3 \times 10^{-6}(100)(0.075)(4)(2640)^2 = 899\ lb$$

$$q_D = \frac{(899)(1760)(40)}{778} = 81{,}349\ Btu/hr$$

$$F_M = 1.3 + \frac{116}{W_e} + (5.1 \times 10^{-4})\overline{U}$$

$$F_M = 1.3 + \frac{116}{35} + (5.1 \times 10^{-4})(2640) = 5.96\ lb/ton$$

$$q_M = \frac{F_M d_a W_e N n}{778}$$

$$q_M = \frac{(5.96)(1760)(35)(8)(40)}{778} = 151{,}007.1\ Btu/hr$$

$$q_{STEP1} = KE_{STEP1} + q_{M STEP2}$$

$$q_{M STEP1} = KE_{STEP1}\frac{1 - E_m}{E_m}$$

The steady-state heat source calculations are given for both the tunnels and the station in Appendix D. The tunnel lighting is a constant 7.0 Btu/hr/ft of tunnel. This number is simply a function of the number and power of the lights within the tunnels.

Third rail losses are also considered to be steady-state heat sources if they are averaged over the entire simulation, but they exist only in the line segments where trains are providing substantial amounts of power to their propulsion systems. This is due to the fact that trains draw relatively little power from the third rail when braking or maintaining speed on level trackway. Power is always being drawn from the third rail to provide power for train lighting, air conditioning and auxiliaries, but the third rail losses involved are very small in comparison to the losses that occur when a train is accelerating or maintaining speed against a large grade. Therefore, the user must determine where in the system trains will be drawing substantial amounts of power from the third rail to provide power to the trains' propulsion systems. It is only in these line segments that third rail losses are to be entered as steady-state heat sources.

It was determined that trains on route 1 (west to east) only draw substantial amounts of power when they accelerate from the station after making their scheduled stop in the station. The trains on route 1 accelerate to speed outside the tunnel system and enter the system at speed. Therefore, while the trains on route 1 approach the station within the tunnel, the only power being drawn from the third rail is for the purpose of overcoming air drag to maintain speed and to power the train's lights, air conditioners and auxiliaries.

Similarly, it was determined that the trains on route 2 (east to west) only draw substantial amounts of power when they accelerate from the station, as they also enter the tunnel system at speed and require relatively little power while approaching the station within the tunnel system.

Therefore, each tunnel segment has a steady-state heat source entitled "Third Rail Loss, Tunnel Lighting". This number includes the rate of heat release from both tunnel lighting and third rail losses — if the segment is one in which no third rail losses occur, the steady-state heat source rate is equal to the rate of heat release from tunnel lighting only.

The initial conditions within the sample system were set equal to the outside ambient conditions as no data on the initial conditions within the system were provided. Therefore, the initial wall surface temperatures throughout the entire system were generally set equal to the outside ambient air dry-bulb temperature. As explained in section 5.3 (Initial Conditions), the initial wall surface temperatures for the line segments within controlled zones were set equal to one degree F less than the design dry-bulb air temperature for the controlled zone. The initial dry-bulb and wet-bulb air temperatures throughout the system were set equal to the outside ambient dry-bulb and wet-bulb temperatures respectively.

The physical data for the train is not included as this information is very straight-forward and is most often supplied by the manufacturer. The actual train motor data entered is slightly different from the manufacturer's motor data supplied. As a result, the user may notice that the program adjusted the tractive effort curve data supplied in Form 9F based on the adjusted vehicle data supplied in Form 9E. Many times, actual vehicle data corresponds to manufacturer's data and no adjustment will be necessary.

APPENDIX A

SES PROGRAM ARRAY SIZE LIMITS

This appendix contains a list of the limitations to the size of the system that can be simulated using the SES program. Only systems that do not exceed any of these limits may be simulated. Instructions for changing these array size limits appear in the SES Programmer's Manual.

These program limitations fall into two categories: limits to the number of physical or conceptual components in the system, and numerical limits which are imposed by the computation procedure. For a given system the number of items in the first category, physical or conceptual components, can be determined from inspection of the system. However, for a system the number of items in the second category of numerical limits cannot be easily determined or calculated by the user. In most systems of typical configuration these limits would pose no problem to the user. However, if one is exceeded, an error message will be printed and the user must either simplify the system being simulated or expand the program capacity. The column entitled "variable name" contains the FORTRAN variable of the array size limit within the SES program. These variables are also discussed in the Programmer's Manual.

Limits on Physical or Conceptual Components

Variable Name	Value	Explanation
LMCLST	75	The maximum number of environmental control zones in system (sum of controlled, uncontrolled zones and non-inertial zones).
LMCRPT	12	The maximum number of inflection points (critical points) in the wall heat flux function.
LMEQRM	1350	The maximum number of equations in the Dynamic Thermal Response Matrix. This matrix must be generated to perform the heat sink analysis of each uncontrolled zone. One equation is formed for each subsegment and each thermodynamic subnode in the zone.
LMEXPD	101	The maximum number of explicit train performance speed-time profile points on any single route cannot exceed LMEXPD-1.
LMFNTP	75	The maximum number of fan types.
LMLSEG	620	The maximum number of line segments.
LMLSS	1200	The maximum number of line subsegments.
LMNODE	600	The maximum number of nodes in the system.
LMNODX	999	The upper limit of the range of allowable node identification numbers.
LMPRGP	25	The maximum number of print groups.
LMSCND	5	The maximum number of sections attached to a node.

Variable Name	Value	Explanation
LMSCTX	999	The upper limit of the range of allowable section identification numbers.
LMSECT	900	The maximum number of sections (sum of line sections and ventilation shaft sections).
LMSS	1600	The maximum number of subsegments (sum of line subsegments and ventilation shaft subsegments).
LMSSTN	2200	The maximum number of subsegments plus thermodynamic nodes. (Always equal to LMSS plus LMTHND).
LMSTR	50	The maximum number of energy sectors in a simulation.
LMTHND	600	The maximum number of thermodynamic subnodes. Each node of thermodynamic type 1 or 3 is composed of one subnode, and each thermodynamic type 2 node is composed of 3 subnodes.
LMTRAN	75	The maximum number of simultaneous operating trains.
LMTRGP	25	The maximum number of train dispatcher groups for each route.
LMTRRT	20	The maximum number of train routes.
LMTRSG	8	The maximum number of trains which may be simultaneously located in a segment.
LMTRTP	16	The maximum number of train types.
LMTSRT	620	The maximum number of track sections in a route.
LMUL	50	The maximum number of unsteady heat loads.
LMVSEG	406	The maximum number of ventilation shaft sections.
—	6	The maximum number of impulse fan types.

Numerical Limits Imposed by Computation Procedure

Variable Name	Value	Explanation
LMBLP	20000	The maximum number of elements in the aerodynamic "dQ/dT" matrix.
LMCOND	800	The maximum number of coefficients for the aerodynamic node equations.
LMLPK	2220	The maximum number of entries in array LPK. This array contains the loops that a given loop is adjacent to in the sense of sharing one or more sections. Loops I and J are adjacent to each other if they pass through the same section or sections.
LMLPLK	2700	The maximum value of the summation over all the loops of the number of sections each loop passes through. (Dimension of arrays LOOP and LPLK.)
LMNLOP	500	The maximum number of flow loops in the system.
LMTBL2	20000	The maximum number of loops passing through branched junctions plus the number of trains that may pass through branched junctions.

APPENDIX B

TABLES FOR DETERMINING TUNNEL WALL ROUGHNESS LENGTH

Table A

Darcy-Weisbach Friction Factor (F) as a Function of Relative Roughness (E/D) for Fully Developed Turbulent Flow

E/D	0.00000	0.00010	0.00020	0.00030	0.00040	0.00050	0.00060	0.00070	0.00080	0.00090
F	0.00550	0.01231	0.01408	0.01533	0.01632	0.01715	0.1788	0.01854	0.01913	0.01968

E/D	E/D+.000	E/D+.001	E/D+.002	E/D+.003	E/D+.004	E/D+.005	E/D+.006	E/D+.007	E/D+.008	E/D+.009
0.00	0.00550	0.02019	0.02403	0.02675	0.02894	0.03082	0.03248	0.03398	0.03537	0.03667
0.01	0.03789	0.03906	0.04017	0.04125	0.04229	0.04329	0.04427	0.04523	0.04617	0.04708
0.02	0.04799	0.04887	0.04975	0.05061	0.05146	0.05231	0.05314	0.05397	0.05479	0.05560
0.03	0.05641	0.05721	0.05801	0.05880	0.05959	0.06037	0.06115	0.06193	0.06270	0.06347
0.04	0.06424	0.06500	0.06576	0.06652	0.06728	0.06803	0.06879	0.06954	0.07029	0.07103
0.05	0.07178	0.07252	0.07327	0.07401	0.07475	0.07548	0.07622	0.07696	0.07769	0.07843
0.06	0.07916	0.07989	0.08062	0.08135	0.08208	0.08280	0.08353	0.08425	0.08498	0.08570
0.07	0.08642	0.08715	0.08787	0.08859	0.08931	0.09002	0.09074	0.09146	0.09217	0.09289
0.08	0.09360	0.09432	0.09503	0.09574	0.09645	0.09717	0.09788	0.09859	0.09929	0.10000
0.09	0.10071	0.10142	0.10212	0.10283	0.10353	0.10424	0.10494	0.10564	0.10635	0.10705
0.10	0.10775									

Table B

Darcy-Weisbach Friction Factors

Relative Roughness	Reynolds Number								
	5,000	10,000	50,000	100,000	500,000	1,000,000	5,000,000	10,000,000	50,000,000
0.00000	0.03766	0.03103	0.02043	0.01735	0.01243	0.01100	0.00872	0.00805	0.00699
0.00010	0.03777	0.03119	0.02089	0.01806	0.01416	0.01334	0.01254	0.01243	0. 01234
0.00020	0.03787	0.03135	0.02132	0.01869	0.01538	0.01478	0.01423	0.01416	0.01410
0.00030	0.03797	0.03151	0.02173	0.01927	0.01636	0.01587	0.01544	0.01538	0.01534
0.00040	0.03807	0.03166	0.02212	0.01981	0.01719	0.01677	0.01641	0.01636	0.01633
0.00050	0.03817	0.03181	0.02250	0.02031	0.01792	0.01755	0.01723	0.01719	0.01716
0.00060	0.03826	0.03197	0.02285	0.02077	0.01857	0.01823	0.01795	0.01792	0.01789
0.00070	0.03836	0.03212	0.02320	0.02121	0.01916	0.01886	0.01860	0.01857	0.01854
0.00080	0.03846	0.03226	0.02353	0.02163	0.01970	0.01942	0.01919	0.01916	0.01914
0.00090	0.03856	0.03241	0.02385	0.02203	0.02021	0.01995	0.01973	0.01971	0.01968
0.00100	0.03865	0.03256	0.02416	0.02241	0.02068	0.02044	0.02024	0.02021	0.02019
0.00200	0.03960	0.03394	0.02682	0.02552	0.02435	0.02419	0.02406	0.02405	0.02404
0.00300	0.04050	0.03522	0.02897	0.02792	0.02700	0.02688	0.02678	0.02677	0.02676
0.00400	0.04137	0.03641	0.03081	0.02991	0.02914	0.02904	0.02896	0.02895	0.02895
0.00500	0.04222	0.03753	0.03244	0.03165	0.03099	0.03090	0.03083	0.03083	0.03082
0.00600	0.04304	0.03860	0.03392	0.03322	0.03263	0.03255	0.03249	0.03248	0.03248
0.00700	0.04384	0.03963	0.03529	0.03465	0.03412	0.03405	0.03400	0.03399	0.03398
0.00800	0.04463	0.04061	0.03657	0.03598	0.03549	0.03543	0.03538	0.03538	0.03537
0.00900	0.04541	0.04157	0.03777	0.03723	0.03678	0.03673	0.03668	0.03667	0.03667
0.01000	0.04617	0.04249	0.03892	0.03841	0.03800	0.03795	0.03790	0.03790	0.03789
0.01100	0.04692	0.04340	0.04002	0.03954	0.03916	0.03911	0.03907	0.03906	0.03906
0.01200	0.04766	0.04428	0.04107	0.04063	0.04027	0.04022	0.04018	0.04018	0.04018
0.01300	0.04840	0.04515	0.04210	0.04168	0.04133	0.04129	0.04126	0.04125	0.04125
0.01400	0.04913	0.04600	0.04309	0.04269	0.04237	0.04233	0.04229	0.04229	0.04229
0.01500	0.04985	0.04683	0.04405	0.04368	0.04337	0.04333	0.04330	0.04330	0.04329
0.01600	0.05057	0.04766	0.04500	0.04464	0.04435	0.04431	0.04428	0.04428	0.04427
0.01700	0.05129	0.04847	0.04592	0.04558	0.04530	0.04526	0.04524	0.04523	0.04523
0.01800	0.05200	0.04928	0.04683	0.04650	0.04623	0.04620	0.04617	0.04617	0.04617
0.01900	0.05270	0.05007	0.04772	0.04740	0.04715	0.04712	0.04709	0.04709	0.04708
0.02000	0.05341	0.05086	0.04859	0.04829	0.04805	0.04802	0.04799	0.04799	0.04799
0.02100	0.05411	0.05164	0.04946	0.04917	0.04893	0.04890	0.04888	0.04888	0.04887
0.02200	0.05481	0.05242	0.05031	0.05003	0.04981	0.04978	0.04975	0.04975	0.04975
0.02300	0.05551	0.05319	0.05115	0.05088	0.05067	0.05064	0.05062	0.05061	0.05061
0.02400	0.05621	0.05395	0.05198	0.05173	0.05152	0.05149	0.05147	0.05147	0.05147
0.02500	0.05690	0.05471	0.05281	0.05256	0.05236	0.05233	0.05231	0.05231	0.05231
0.02600	0.05760	0.05547	0.05363	0.05339	0.05319	0.05317	0.05315	0.05315	0.05314
0.02700	0.05829	0.05622	0.05444	0.05420	0.05402	0.05399	0.05397	0.05397	0.05397
0.02800	0.05899	0.05697	0.05524	0.05502	0.05484	0.05481	0.05479	0.05479	0.05479
0.02900	0.05968	0.05772	0.05604	0.05582	0.05565	0.05562	0.05561	0.05560	0.05560
0.03000	0.06037	0.05847	0.05683	0.05662	0.05645	0.05643	0.05641	0.05641	0.05641

Table B (Continued)

Darcy-Weisbach Friction Factors

Relative Roughness	Reynolds Number								
	5,000	10,000	50,000	100,000	500,000	1,000,000	5,000,000	10,000,000	50,000,000
0.03100	0.06107	0.05921	0.05762	0.05742	0.05725	0.05723	0.05722	0.05721	0.05721
0.03200	0.06176	0.05995	0.05841	0.05821	0.05805	0.05803	0.05601	0.05801	0.05801
0.03300	0.06245	0.06068	0.05919	0.05899	0.05884	0.05882	0.05880	0.05880	0.05880
0.03400	0.06314	0.06142	0.05996	0.05978	0.05963	0.05961	0.05959	0.05959	0.05959
0.03500	0.06383	0.06215	0.06074	0.06055	0.06041	0.06039	0.06037	0.06037	0.06037
0.03600	0.06452	0.06289	0.06151	0.06133	0.06119	0.06177	0.06115	0.06115	0.06115
0.03700	0.06521	0.06362	0.06227	0.06210	0.06196	0.06194	0.06193	0.06193	0.06193
0.03800	0.06591	0.06435	0.06304	0.06287	0.06273	0.06272	0.06270	0.06270	0.06270
0.03900	0.06660	0.06507	0.06380	0.06363	0.06350	0.06349	0.06347	0.06347	0.06347
0.04000	0.06729	0.06580	0.06456	0.06440	0.06427	0.06425	0.06424	0.06424	0.06424
0.04100	0.06798	0.06653	0.06531	0.06516	0.06503	0.06502	0.06500	0.06500	0.06500
0.04200	0.06867	0.06725	0.06607	0.06591	0.06579	0.06578	0.06577	0.06576	0.06576
0.04300	0.06937	0.06798	0.06682	0.06667	0.06655	0.06654	0.06652	0.06652	0.06652
0.04400	0.07006	0.06870	0.06757	0.06742	0.06731	0.06729	0.06728	0.06728	0.06728
0.04500	0.07075	0.06942	0.06832	0.06817	0.06806	0.06805	0.06804	0.06803	0.06803
0.04600	0.07144	0.07014	0.06906	0.06892	0.06881	0.06880	0.06879	0.06879	0.06879
0.04700	0.07213	0.07086	0.06981	0.06967	0.06956	0.06955	0.06954	0.06954	0.06954
0.04800	0.07283	0.07158	0.07055	0.07042	0.07031	0.07030	0.07029	0.07029	0.07029
0.04900	0.07352	0.07230	0.07129	0.07116	0.07106	0.07105	0.07104	0.07103	0.07103
0.05000	0.07421	0.07302	0.07203	0.07190	0.07180	0.07179	0.07178	0.07178	0.07178
0.05500	0.07768	0.07660	0.07571	0.07560	0.07551	0.07550	0.07549	0.07549	0.07548
0.06000	0.08115	0.08017	0.07936	0.07926	0.07918	0.07917	0.07916	0.07916	0.07916
0.06500	0.08462	0.08372	0.08299	0.08290	0.08282	0.08281	0.08280	0.08280	0.08280
0.07000	0.08808	0.08726	0.08659	0.08651	0.08644	0.08643	0.08643	0.08643	0.08642
0.07500	0.09155	0.09079	0.09018	0.09010	0.09004	0.09003	0.09003	0.09002	0.09002
0.08000	0.09501	0.09431	0.09375	0.09368	0.09362	0.09361	0.09361	0.09360	0.09360
0.08500	0.09847	0.09782	0.09730	0.09723	0.09718	0.09717	0.09717	0.09717	0.09717
0.09000	0.10192	0.10132	0.10083	0.10077	0.10072	0.10072	0.10071	0.10071	0.10071
0.09500	0.10536	0.10480	0.10435	0.10429	0.10425	0.10424	0.10424	0.10424	0.10424
0.10000	0.10880	0.10828	0.10786	0.10780	0.10776	0.10776	0.10775	0.10775	0.10775
0.15000	0.14269	0.14240	0.14216	0.14213	0.14211	0.14210	0.14210	0.14210	0.14210
0.20000	0.17563	0.17544	0.17529	0.17527	0.17525	0.17525	0.17525	0.17525	0.17525
0.25000	0.20768	0.20754	0.20743	0.20742	0.20741	0.20741	0.20741	0.20741	0.20741
0.30000	0.23892	0.23882	0.23874	0.23873	0.23872	0.23872	0.23872	0.23872	0.23872
0.35000	0.26948	0.26940	0.26933	0.26933	0.26932	0.26932	0.26932	0.26932	0.26932

Table C

Relative Roughness (E/D) as a Function of Darcy-Weisbach Friction Factor (F) for Fully Developed Turbulent Flow

F	F+.000	F+.001	F+.002	F+.003	F+.004	F+.005	F+.006	F+.007	F+.008	F+.009
0.00							0.00001	0.00001	0.00000	0.00001
0.01	0.00003	0.00005	0.00009	0.00013	0.00019	0.00027	0.00037	0.00048	0.00062	0.00078
0.02	0.00096	0.00117	0.00142	0.00169	0.00199	0.00233	0.00270	0.00310	0.00355	0.00403
0.03	0.00455	0.00511	0.00570	0.00634	0.00701	0.00773	0.00848	0.00927	0.01009	0.01095
0.04	0.01184	0.01277	0.01372	0.01471	0.01572	0.01676	0.01782	0.01891	0.02002	0.02114
0.05	0.02229	0.02345	0.02463	0.02583	0.02704	0.02826	0.02949	0.03074	0.03199	0.03325
0.06	0.03453	0.03581	0.03709	0.03839	0.03969	0.04100	0.04231	0.04363	0.04496	0.04628
0.07	0.04762	0.04896	0.05030	0.05164	0.05299	0.05434	0.05570	0.05706	0.05842	0.05978
0.08	0.06115	0.06252	0.06390	0.06527	0.06665	0.06803	0.06941	0.07080	0.07219	0.07357
0.09	0.07497	0.07636	0.07776	0.07915	0.08055	0.08196	0.08336	0.08477	0.08617	0.08758
0.10	0.08900									

APPENDIX C

OUTSIDE AMBIENT CONDITIONS

Table 1 gives the "Normal Summer Design Conditions," "Maximum Summer Design Conditions," "Normal Winter Design Conditions," "Average Summer Daily Temperature Range" and various other design criteria for various locations.

The "Normal Summer Design Conditions" are the simultaneously occurring dry-bulb and wet-bulb temperatures which can be expected to be exceeded a few times a year for brief periods.

The "Average Summer Daily Temperature Range" is the average difference between the highest and lowest dry-bulb temperatures during a typical design period day.

The "Maximum Summer Design Conditions" are the simultaneous peak dry-bulb temperatures that occur during the peak summer month. The maximum summer design conditions can be expected to be exceeded no more than 3 hours in a normal summer.

The "Normal Winter Design Conditions" are the dry-bulb temperature that the user can expect the temperature to go below a few times a year and the annual degree days for the particular location. The annual degree days are equivalent to the "sum of all the days in the year on which the daily mean temperature falls below 65°F db times the number of degrees between 65°F db and the daily mean temperature."

The user should note that the time of day when the peak air temperatures within a subway system occur is often different from the time of day the peak outside ambient temperatures occur. Due to the thermal inertia of a subway system, the peak system temperatures in July will usually occur around 5:00 P.M. even though the outside ambient temperatures peak at approximately 3:00 P.M. Therefore, in order to simulate a subway system for the peak summer design conditions, the user should simulate the system for 5:00 P.M. in July, and use the peak summer 3:00 P.M. July ambient temperatures corrected to July at 5:00 P.M. The methods used to obtain approximate corrections to the design conditions listed in Table 1 are described below.

Table 2 gives the approximate corrections that are to be made to obtain dry-bulb and wet-bulb temperatures from 8 A.M. to 12 P.M. based on the average daily range.

Table 3 gives the approximate corrections that are to be made to the dry-bulb and wet-bulb temperatures from March to November based on the yearly range in the dry-bulb temperature (summer normal design dry-bulb temperature minus the winter normal design dry-bulb temperature).

<u>Example 6.1</u> An example of the use of these tables is as follows:

Given: A comfort application in New York City.

Find: The approximate dry-bulb and wet-bulb temperatures at 6 00 P.M. in July.

Solution:

Normal design conditions for New York in July at 3:00 P.M. are 95°F db, 75°F wb (Table 1). Daily range in New York City is 14°F db.

Yearly range in New York City = 95°F db.

Correction for time of day (6 P.M.) from Table 2:

Dry bulb = -2°F

Wet-bulb = -1°F

Correction for time of year (July) from Table 3:

Dry-bulb = 0°F

Wet-bulb = 0°F

Design conditions at 6 P.M. in July in New York City (approximate):

Dry-bulb = 95 - 2 - 0 = 93°F

Wet-bulb = 75 - 1 - 0 = 74°F

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Latitude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
ALABAMA													
Anniston	95	78	117.5	19				5	2806			733	34
Birmingham	95	78	117.5	19	99			10	2611	5.0 S	8.0 N	694	34
Mobile	95	80	131	12	95	82	155.6	15	1566	9.0 SW	9.9 N	10	31
Montgomery	95	78	117.5	15				10	2071		7.5 NW	293	32
ARIZONA													
Flagstaff	90	65	81	26	90			-10	7242		7.7 SW	6894	35
Phoenix	105	76	94	30	113	78	126.9	25	1441	5.0 W	5.4 E	1108	33
Tucson	105	72	77	30				25		5.0 W	5.2 NW	2376	32
Winslow	100	70	85					-10				4853	35
Yuma	110	78	93	30				30	1036		6.7 N	146	33
ARKANSAS													
Fort Smith	95	76	104.5	16	103			10	3226	7.0 E	8.3 E	448	35
Little Rock	95	78	117.5	16	103	83	145.5	5	3009	6.0 NW	8.3 NW	324	35
CALIFORNIA													
Bakersfield	105	70	54	25				25				499	35
El Centro	110	78	94									43	33
Eureka	90	65	52					30	4758	7.0 N	7.3	132	41
Fresno	105	74	76	35	110	75	95.9	25	2403	8.0 NW	5.4 NW	287	37
Laguna Beach				9	82	70	103.0					10	34
Long Beach	90	70	78	14								47	34
Los Angeles	90	70	78	14	94			35	1391	6.0 SW	6.4 NE	261	34
Oakland	85	65	60	17	94	68	99.3	30				17	38
Montague								0				2635	42
Pasadena	95	70	70										34
Red Bluff	100	70	62									305	40
Sacramento	100	72	73	18				30	2680		7.2 SE	116	39
San Bernadino	105	72	65										34
San Diego	85	68	75	10	88	74	78.4	35	1596	7.0 W	6.3 NW	26	33
San Francisco	85	65	60	17				35	3137	12.0 W	7.5 N	17	38
San Jose	91	70	76.5					25	2823			100	37
Williams				40	110	80	74.4					86	39
COLORADO													
Denver	95	64	60	25	99	68	89.4	-10	5839	7.0 S	7.5 S	5221	40
Durango	95	65	70									6553	37
Fort Collins								-30					41
Grand Junction	95	65	62	24	102	68	86.2	-15	5613	6.0 SE	4.4 NW	4587	39
Pueblo	95	65	63	25				-20	5558		7.9 NW	4770	38
CONNECTICUT													
Bridgeport	95	75	99	14				0				9	41
Hartford	93	75	102	16	94	82		0	6113	7.0 S	8.7 NW	58	42
New Haven	95	75	99	14	95			0	5880	7.0 S	9.4 N	23	41
Waterbury								-15					42
DELAWARE													
Wilmington	95	78	117.5	15				0		10.0 SW	NW	134	40
DIST. OF COLUMBIA													
Washington	95	78	117.5	18	99	84	155.6	0	4561	5.0 S	7.8 NW	72	39
FLORIDA													
Apalachicola	95	80	131					25	1252	5.0 SW	8.4	23	30
Jacksonville	95	78	117.5	17	99	82	150.5	25	1185	8.0 SW	9.0 NE	18	30
Key West	98	78	112.5					45	59	9.0 SE	10.6 NE	23	25
Miami	91	79	131	12	92	81	150.5	35	185	7.0 SE	10.1 E	11	26
Pensacola	95	78	117.5	12				20	1281		10.9 N	408	31
Tampa	95	78	117.5	14	95			30	671	6.0 NE	8.6 NE	25	28
Tallahassee								25	1463		N	68	30

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.

† Corresponds to peak dewpoint temperature, corrected for altitude.

Reproduced by permission of Carrier Corporation.

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER (Cont.)

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Lati-tude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
GEORGIA													
Atlanta	95	76	109.5	18	101	82	150.5	10	2985	7.0 NW	11.7 NW	975	34
Augusta	98	76	100	18				10	2306		6.5 NW	195	34
Brunswick	95	78	117.5										31
Columbus	98	75	100										33
Macon	95	78	117.5	18				15	2338	5.0 S	6.7 NW	408	33
Savannah	95	78	117.5	17	99			20	1635	8.0 SW	9.5 NW	42	32
IDAHO													
Boise	95	65	54.5	31	109	71	92.6	-10	5678	5.0 NW	9.1 SE	2705	44
Lewiston	95	65	44	28				5	5109		4.1 E	763	46
Pocatello	95	65	61	28	100			-5	6741		8.9 SE	4468	43
Twin Falls								-10			W		42
ILLINOIS													
Cairo	98	78	112.5					0	3957		9.8	319	37
Chicago	95	75	99	19	104	80	140.6	-10	6282	10.0	12.0 SW	594	42
Danville								-5		NE	NW		40
Moline	96	76	103	22	103	83	155.6	-10				594	41
Peoria	96	76	103	20	100			-10	6004		8.3 S	602	41
Springfield	98	77	106	20				-10	5446	8.0 S	11.9 NW	603	40
INDIANA													
Evansville	95	78	117.5	19	102	82	150.5	0	4410	7.0 SW	9.7 S	388	38
Fort Wayne	95	75	99	20	100			-10	6232	8.0 SW	10.4 SW	777	41
Indianapolis	95	76	104.5	18	99			-10	5458	9.0 SW	11.3 S	715	40
South Bend								-5			SW	773	42
Terre Haute	95	78	124									1146	40
IOWA													
Cedar Rapids								-5					
Davenport	95	78	117.5	18				-15	6252		10.5 NW	648	42
Des Moines	95	78	123	18	102			-15	6375	6.0 SW	10.1 NW	800	42
Dubuque	95	78	117.5					-20	6820		7.1	740	43
Fort Dodge								-20					42
Keokuk	95	78	117.5					-10	5663		8.2 SW	637	41
Sioux City	95	78	124	19	102			-20	6905	10.0 S	11.5 NW	1111	43
Waterloo								-15					43
KANSAS													
Concordia	95	78	125	20				-10	5425		7.7 S	1425	39
Dodge City	95	78	132	21	106			-10	5069		10.6	2522	38
Salina					111			-15			NW	1226	39
Topeka	100	78	109.5	19				-10	5075	10.0 S	9.2 S	991	39
Wichita	100	75	98	21	110	79	126.9	-10	4644	11.0 S	12.4 S	1300	38
KENTUCKY													
Lexington								0	4792		13.3 SW	989	38
Louisville	95	78	117.5	22	99			0	4417	7.0 SW	9.8 SW	459	38
LOUISIANA													
Alexandria								20			N	89	32
New Orleans	95	80	131	13	95	83	161.2	20	1203	6.0 SW	8.6 N	9	30
Shreveport	100	78	109.5	15	102	83	150.5	20	2132	5.0 S	8.8 SE	197	33
MAINE													
Augusta	90	73	95	13								362	45
Bangor	90	73	95	13									45
Bar Harbor								-15			NW		44
Belfast								-5					44
Eastport	90	70	78	13				-10	8445	7.0 S	12.6 W	100	45
Millinocket								-15					46
Presque Isle									9644		NW		47
Portland	90	73	95	13	93			-5	7377	7.0 S	10.4 NW	47	44
Rumford								-20					44

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.
† Corresponds to peak dewpoint temperature, corrected for altitude.

Reproduced by permission of Carrier Corporation.

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER (Cont.)

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Latitude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
MARYLAND													
Baltimore	95	78	117.5	18	99			0	4487	6.0 SW	8.2 NW	14	39
Cambridge								5			NW		39
Cumberland	95	75	99	18									39
Frederick								-5			NW		40
Frostburg								-5			W		40
Salisbury								10			NW		40
MASSACHUSETTS													
Amherst								-10			NW		42
Boston	92	75	104	13	96	78	135.9	0	5936	9.0 SW	12.4 W	14	42
Fall River								-10					42
Fitchburg	93	75	102	17				-10	6743	W	NW	402	43
Lowell								-15					43
Nantucket	95	75	99					0			14.8	45	41
New Bedford								0					42
Plymouth								-5			W		42
Springfield	93	75	102	17				-10		9.0 SW		199	42
Worcester	93	75	102	17				0				625	42
MICHIGAN													
Alpena	95	75	99					-10	8278		11.0 SW	615	45
Big Rapids								-15			NW		43
Detroit	95	75	99	19	101	79	135.9	-10	6560	10.0	12.0 SW	619	42
Escanaba								-15	8777	SW	9.5 NW		46
Flint	95	75	99	20				-10			W	766	43
Grand Rapids	95	75	99	20	98			-10	6702	W	12.1	638	43
Kalamazoo								-5		8.0 W	NW		42
Lansing	95	75	104	20				-10	7149		W	861	43
Ludington								-10	7458		9.8 SW		44
Marquette	93	73	90	20	96			-10	8745		11.9 W	652	47
Saginaw	95	75	99								10.6	601	43
Sault Ste Marie								-20	9307		NW	724	47
											8.9 SE		
MINNESOTA													
Alexandria								-25			NW		
Duluth	93	73	96	19				-25	9723	13.4	13.4 SW	1128	47
Minneapolis	95	75	103	17	102			-20	7966	SW	11.3	839	45
St. Cloud								-25		10.0 S	NW		46
St. Paul	95	75	99	17	103	79	131.1	-20	7975	8.0 SE	9.5 NW	719	45
MISSISSIPPI													
Jackson				21	103	83	155.6	15		5.0 SW	7.7 SE	316	32
Meridian	95	79	124	21				10	2330	4.0 SW	6.3 N	410	32
Vicksburg	95	78	117.5	21	96			10	2069	6.0 SW	8.3	226	32
MISSOURI													
Columbia	100	78	109.5	19				-10	5070		8.9 SW	739	39
Kansas City	100	76	106.5	19	109	79	135.9	-10	4962	9.0 S	10.3	741	39
Kirksville				19	108	82	150.5			SW	NW	969	40
St. Louis	95	78	117.5	20	108	81	135.9	0	4596	9.0 S		465	39
St. Joseph								-10	5596		11.8 S	817	40
Springfield				18	98	79	135.9	-10	4569	8.0 S	9.3 NW	1301	37
											10.9 SE		
MONTANA													
Billings	90	66	70	20	104			-25	7213		12.4 W	3119	46
Butte								-20			NW	5538	46
Great Falls								-20			SW	3667	48
Havre	95	70	82	20				-30	8416	7.0 E	9.4 SW	2498	49
Helena	95	67	71	20	97	70	77.4	-20	7930	7.0 SW	7.4 SW	4090	47
Kalispell	95	65	56					-20	8032		5.2	3004	48
Miles City				20				-35	7591		5.5 S	2609	47
Missoula	95	66	49	20				-20	7604		E	3205	47

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.

† Corresponds to peak dewpoint temperature, corrected for altitude.

Reproduced by permission of Carrier Corporation.

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER (Cont.)

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Latitude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
NEBRASKA													
Grand Island								-20				1856	41
Lincoln	95	78	124	20	106			-10	5980	9.0 S	10.6 S	1180	41
Norfolk								-15		NW	NW		42
North Platte	95	78	135	26	104	76	74.4	-20	6384	6.0 S	7.9 NW	2805	41
Omaha	95	78	123	20	108	80	131.1	-10	6095	8.0 S	9.7 NW	978	41
Valentine	95	78	135	20				-25	7197		9.2	2627	43
York								-10			NW		
NEVADA													
Las Vegas	115	75	76	40				20			S	1882	36
Reno	95	65	62	41	102	66	66.9	-5	5621	7.0 SW	6.0 W	4493	40
Tonopah								5	5812		9.9 SE	5421	38
Winnemucca	95	65	62	40				-15	6357	7.0 SW	8.1 NE	4293	42
NEW HAMPSHIRE													
Berlin								-25					45
Concord	90	73	95	14				-15	7400	5.0 NW	6.2 NW	289	43
Keene								-20			NW		43
Manchester	90	73	95	14	92							171	43
Portsmouth	90	73	95	14									43
NEW JERSEY													
Atlantic City	95	78	117.5	14				5	5015	13.0 SW	15.8	8	39
Bloomfield	95	75	99	14							NW	125	41
Camden				14	102	82	145.5	0		10.0 SW		30	40
East Orange	95	75	99	14								173	41
Jersey City	95	75	99					0					41
Newark	95	75	99	14	99	81	140.6	0	5500	13.0 SW	NW	10	41
Paterson	95	75	99	14	95					13.0 SW	17.1	10	41
Sandy Hook								0	5369		NW		41
Trenton	95	78	117.5	14	96			0	5256	9.0 SW		56	40
											16.1		
											10.9		
											NW		
NEW MEXICO													
Albuquerque	95	70	94.5	26	98	68	95.9	0	4517	8.0 SW	7.3 N	5101	35
Roswell	95	70	87	25				-10	3578	6.0 S	7.1 S	3643	32
Santa Fe	90	65	80	30	90			0	6123	6.0 SE	7.1 NE	7000	36
NEW YORK													
Albany	93	75	102	18	97	78	131.1	-10	6648	7.0 S	10.5 S	19	43
Binghampton	95	75	103.5					-10	6818		6.8 NW	915	42
Buffalo	93	73	90	18	93	77	126.9	-5	6925	12.0 SW	17.1 W	604	43
Canton	90	73	95					-25	8305	8.0	10.5	458	43
Cortland								-10			NW		43
Glens Falls								-15			W		43
Ithaca								-15	6914		11.3		42
Jamestown								-10			NW		42
Lake Placid								-20			SW		44
New York City	95	75	99	14	100	81	145.5	0	5280	13.0 S	W	10	41
Ogdensburg								-20			16.8		45
Oneonta								-15			NW		43
Oswego	93	73	90					-10	7186		SW	363	43
Rochester	95	75	102	18	95			-5	6772	8.0 SW	SW	543	43
Schenectady	93	75	102	18							12.1 S	235	43
Syracuse	93	75	102	18	96			-10	6599	9.0 S	9.6 W	400	43
Watertown								-15					44
											11.2 S		
											SW		
NORTH CAROLINA													
Asheville	93	75	114.5	19	93			0	4236	6.0 NW	9.5 NW	2192	36
Charlotte	95	78	117.5	16				10	3224	5.0 SW	7.3 SW	809	35
Greensboro	95	78	123.5	15				10	3849		7.9 SW	896	37
Raleigh	95	78	117.5	15	98	82	155.6	10	3275	6.0 SW	7.9 SW	345	36
Wilmington	95	78	117.5	15	95	81	150.5	15	2420	7.0 SW	9.4 SW	6	34

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.

† Corresponds to peak dewpoint temperature, corrected for altitude.

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER (Cont.)

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Latitude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
NORTH DAKOTA													
Bismarck	95	73	95.9	19	103			-30	8937	9.0 NW	9.1 NW	1670	47
Devils Lake	95	70	77					-30	10104		10.1 W	1481	48
Fargo	95	75	104.5	19				-25			10.9	900	47
Grand Forks								-25	9871		NW	832	48
Williston	95	73	96.5					-35	9301	8.0 SE	NW 8.6 W	1919	48
OHIO													
Akron	95	75	99	19				-5				104	41
Cincinnati	95	78	117.5	22	106	81	145.5	0	4990	7.0 SW	8.5 SW	553	39
Cleveland	95	75	99	19	101	79	135.9	0	6144	11.0 S	14.7 SW	651	42
Columbus	95	76	104.5	23	95			-10	5506	9.0 SW	11.6 SW	724	40
Dayton	95	78	123	23	99			0	5412	8.0 SW	11.1 SW	900	40
Lima								-5					41
Sandusky	95	75	99					0	6095		11.0	608	42
Toledo	95	75	99	19	99			-10	6269	10.0 SW	12.1 SW	589	42
Youngstown	95	75	99	19								1186	41
OKLAHOMA													
Ardmore								10			N	762	34
Bartlesville								-10			N		37
Oklahoma City	101	77	108	21	104			0	3670	10.0 S	11.5 S	1254	35
Tulsa	101	77	101.5		106	79	104.6	0		10.0 S	N	804	36
OREGON													
Baker	90	66	71	19				-5	7197		5.6 SE	3501	44
Eugene	90	68	67	19				-15				366	44
Medford	95	70	76	19								1428	42
Pendleton								-15			W	1494	46
Portland	90	68	67	19	99	70	103.0	10	4353	6.0 NW	7.3 S	30	46
Rosenburg	90	66	57	19						4.0 N		523	42
Wamic								0			W		45
PENNSYLVANIA													
Altoona	95	75	99	14				-5				1469	40
Bethlehem								-5					41
Erie	93	75	102	18				-5	6363	9.0 S	13.6 SW	670	42
Harrisburg	95	75	99	14				0	5412		7.6 NW	339	40
New Castle								0			NW		41
Oil City	95	75	99	18									42
Philadelphia	95	78	117.5	14	97			0	4739	10.0 SW	11.0	26	40
Pittsburgh	95	75	105	14	98	79	126.9	0	5430	9.0 SW	NW	1248	40
Reading	95	75	99					0	5232		11.6 W	311	40
Scranton	95	75	99	14	95			-5	6218	6.0 SW	9.0	746	41
Warren								-15			7.6 SW		41
Williamsport								-5			NW NW	525	42
RHODE ISLAND													
Block Island	95	75	99						5897		20.6	46	41
Newport	93	75	102	14							NW		41
Providence	93	75	102	14				0	5984	10.0 NW	12.1 NW	8	42
SOUTH CAROLINA													
Charleston	95	78	117.5	17	98	82	155.6	15	1866	10.0 SW	10.5 SW	9	33
Columbia	95	75	99	17				10	2488		8.0 SW	401	34
Greensville	95	76	104.5	17				10	3059	7.0 NE	8.4	982	35
SOUTH DAKOTA													
Huron	95	75	106	19	106	76	1269	-20	7940	10.0 SE	10.7	1282	44
Rapid City	95	70	85	22	103	71	95.9	-20	7197	7.0 W	NW	3231	44
Sioux Falls	95	75	99	20				-20			8.0 W NW	1427	43

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.

† Corresponds to peak dewpoint temperature, corrected for altitude.

Reproduced by permission of Carrier Corporation.

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER (Cont.)

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Latitude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
TENNESSEE													
Chattanooga	95	76	104.5	18	98			10	3238	6.0 SW	7.7 NW	689	35
Johnson City								0			W		36
Knoxville	95	75	103.5	17	100	79	135.9	0	3658	6.0 SW	7.2 SW	921	36
Memphis	95	78	117.5	18	103	83	155.6	0	3090	7.0 SW	9.3 W	271	35
Nashville	95	78	117.5	17	98			0	3613	8.0 W	9.8 NW	485	36
TEXAS													
Abilene	100	74	93					15	2573	9.0 S	10.1 S	1748	32
Amarillo	100	72	91.6	22	101	75	110.4	-10	4196	11.0 S	12.1 SW	3657	35
Austin	100	78	109.6	19				20	1676		8.3 N	625	31
Brownsville	95	80	131	20	96	80	150.5	30	628	9.0 SE	10.4 SE	35	26
Corpus Christi	95	80	131					20	965	13.0 SE	11.0 SE	21	28
Dallas	100	78	109.5	21	105	80	135.9	0	2367	8.0 S	10.6 NW	460	33
Del Rio	100	78	115					15	1501	10.0 SE	8.0 SE	1020	29
El Paso	100	69	73	23	101	72	106.6	10	2532	9.0 E	9.0 NW	3720	32
Fort Worth	100	78	109.5	21				10	2355	10.0	10.5 NW	708	33
Galveston	95	80	131	14				20	1174	9.0 S	11.2 SE	6	29
Houston	95	80	131	14	100	81	150.5	20	1315	8.0 S	10.5 SE	52	30
Palestine	100	78	109.5					15	2068		8.0	555	32
Port Arthur	95	79	124					20	1532		10.7	64	30
San Antonio	100	78	109.5	19	102	83	166.4	20	1435	7.0 SE	8.3 NE	646	29
UTAH													
Modena	95	65	66	25	97	66	80.3	-15	6598	11.0 SW	9.0	5479	38
Logan								-15					42
Ogden								-10			S	4446	42
Salt Lake City	95	65	61	25	102	68	89.4	-10	5650	7.0 S	7.8 SE	4222	42
VERMONT													
Bennington								-10					43
Burlington	90	73	95	17	91			-10	8051	8.0 S	11.6 S	308	44
Rutland	90	73	95	17				-20					43
VIRGINIA													
Cape Henry	95	78	117.5					10	3538		14.0	24	37
Lynchburg	95	75	99	16	99			5	4068		8.1	386	37
Norfolk	95	78	117.5	16	95			15	3364	11.0 S	12.1 N	11	37
Richmond	95	78	117.5	16	98			15	3922	6.0 SW	8.1 SW	162	38
Roanoke	95	76	111.5	16				0	4075		8.2 W	1194	38
WASHINGON													
North Head	85	65	60					20	5367		16.1	199	
Seattle	85	65	60	17	86	70	99.3	15	4815	7.0 N	9.8 SE	14	48
Spokane	93	65	54.5	28	106	68	71.9	-15	6318	7.0 SW	6.2 SW	1879	48
Tacoma	85	64	55.5	17				15	5039		8.0	279	47
Tatooch Island								15	5857		18.9	110	48
Walla Walla	95	65	47.5	28	105			-10	4910		5.4 S	952	48
Wenatchee	90	65	52	20									48
Yakima	95	65	48	20				5	5585		4.1	1160	47
WEST VIRGINA													
Bluefield	95	75	99	16									37
Charleston	95	75	99	16	102			0		4.0 SW	W	603	38
Elkins								-10	5800		6.2 W	2006	39
Huntington	95	76	104.5	16				-5			W		38
Martinsburg								-5				540	39
Parkersburg	95	75	99	16	98			-10	4928	4.0 SE	7.2 SW	615	39
Wheeling	95	75	99	14				-5					40

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.

† Corresponds to peak dewpoint temperature, corrected for altitude.

Reproduced by permission of Carrier Corporation.

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER (Cont.)

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Latitude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
WISCONSIN													
Ashland								-20			SW		42
Eau Claire								-20			NW	885	45
Green Bay	95	75	99	14	99	79	131.1	-20	7931	8.0 S	10.5	589	45
La Crosse	95	75	99	17	100	83	161.2	-25	7421	6.0 S	SW	673	44
Madison	95	75	103.5	18	96			-15	7405	8.0 SW	9.3 S	938	43
Milwaukee	95	75	99	14	99			-15	7079	9.0 SW	10.1 NW 12.1 W	619	43
WYOMING													
Casper								-20			SW	5321	43
Cheyenne	95	65	68.5	28				-15	7536	9.0 S	13.3	6139	42
Lander	95	65	66	28				-18	8243	5.0 SW	NW	5448	44
Sheridan					102			-30	7239	5.0 NW	3.9 4.9 NW	3773	45
CANADA **PROVINCE AND CITY**													
ALBERTA													
Calgary	90	66	71					-29	9520	9.7	10.1	3540	51
Edmonton	90	68	77					-33	10320	8.9	7.6	2219	54
Grand Prairie								-39			7.9	2190	55
Lethbridge								-32	8650		15.0	3018	50
McMurray								-42				1216	57
Medicine Hat	90	65						-35	8650	9.1	9.0	2365	50
BRITISH COLUMBIA													
Estevan Piont								17			9.9	20	49
Fort Nelson								-38			3.7	1230	59
Penticton								-6				1121	50
Prince George								-32	9500		7.2	2218	54
Pince Rupert								8	6910		8.0	170	54
Vancouver	80	67	78					11	5230		7.7	22	49
Victoria								15	5410		12.3	228	48
MANITOBA													
Brandon								-32	10930			1200	50
Churchill								-42	16810		14.7	115	59
The Pas								-39			6.4	894	54
Winnipeg	90	71	83.5					-29	10630	11.5	12.0	786	50
NEW BRUNSWICK													
Campbellton								-11				42	48
Fredericton	90	75	107					-6	8830		9.2	164	46
Moncton								-8	8700		14.9	248	46
Saint John								-3	8380	7.9	13.8	119	45
NEWFOUNDLAND													
Corner Brook								-1	9210			40	49
Gander								-3	9440		17.2	482	49
Goose Bay								-26	12140		10.3	144	53
Saint Johns								1	8780		19.3	463	48
NORTHWEST TERRITORIES													
Aklavik								-46	17870			30	68
Fort Norman								-42	16020			300	65
Probisher								-47				68	
Resolute								-42			9.2	56	
Yellowknife								-47				682	62

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.

† Corresponds to peak dewpoint temperature, corrected for altitude.

Reproduced by permission of Carrier Corporation.

TABLE 1 – OUTDOOR DESIGN CONDITIONS - SUMMER AND WINTER (Cont.)

STATE AND CITY	NORMAL DESIGN COND. - SUMMER July at 3:00 PM			AVG. DAILY RANGE	MAXIMUM DESIGN COND-SUMMER July at 3:00 PM			NORMAL DESIGN COND. WINTER		WIND DATA Avg. Velocity and Prevailing Direction		Elevation Above Sea Level (ft)	Latitude (deg)
	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content* (gr/lb of dry air)	Dry-Bulb (F)	Dry-Bulb (F)	Wet-Bulb (F)	Moisture Content† (gr/lb of dry air)	Dry-Bulb (F)	Annual Degree Days	Summer	Winter		
NOVA SCOTIA													
Halifax	90	75	107					4	7570	6.6	9.6	83	45
Sydney								1	8220	9.9	13.1	197	46
Yarmouth								7	7520		13.5	136	44
ONTARIO													
Fort Williams								-24	10350	8.4	9.6	644	48
Hamilton								0	6890			303	43
Kapuskasing								-30	11790		10.0	752	49
Kingston								-11	7810		10.8	340	44
Kitchener								-3	7380			1100	43
London								-1			11.9	912	43
North Bay								-20		9.6	11.3	1210	46
Ottawa	90	75	107					-15	8830	8.9	11.1	339	45
Peterborough								-11				648	44
Sioux Lookout								-33			8.5	1227	50
Sudbury								-17				837	47
Timmins								-26				1100	48
Toronto	93	75	102					0	7020	8.1	14.1	379	43
Windsor								3			12.3	637	42
Sault Ste. Marie	93	75	102									635	47
PRINCE EDWARD ISLAND													
Charlottetown								-3	8380	8.7	11.3	74	46
QUEBEC													
Arvida								-19	10440		8.2	375	
Knob Lake								-40				1605	55
Mont Joli								-11			13.3	150	48
Montreal	90	75	107					-9	8130	9.9	12.3	187	46
Port Harrison								-39			13.4	66	58
Quebec City	90	75	107					-12	9070	9.0	12.4	296	47
Seven Islands								-20				190	50
Sherbrooke								-12	8610		8.2	620	45
Three Rivers								-13				50	46
SASKATCHEWAN													
Prince Albert								-41	11430		4.9	1414	53
Regina								-34	10770	12.4	12.1	1884	50
Saskatoon	90	71	92.5					-37	10960	10.7	9.7	1645	52
Swift Current	90	70	81					-33	9660		14.6	2677	50
YUKON TERRITORY													
Dawson													
Whitehorse								-56	15040			1062	64
								-43			8.7	2289	61

* Corresponds to dry-bulb and wet-bulb temperatures listed, and is corrected for altitude of city.

† Corresponds to peak dewpoint temperature, corrected for altitude.

Reproduced by permission of Carrier Corporation.

TABLE 2 – CORRECTIONS IN OUTDOOR DESIGN TEMPERATURES FOR TIME OF DAY

(For Cooling Load Estimates)

DAILY RANGE OF TEMPERATURE(F)*	DRY OR WET BULB	SUN TIME									
		AM			PM						
		8	10	12	2	3	4	6	8	10	12
10	Dry-Bulb	-9	-7	-5	-1	0	-1	-2	-5	-8	-9
	Wet-Bulb	-2	-2	-1	0	0	0	-1	-1	-2	-2
15	Dry-Bulb	-12	-9	-5	-1	0	-1	-2	-6	-10	-14
	Wet-Bulb	-3	-2	-1	0	0	0	-1	-1	-3	-4
20	Dry-Bulb	-14	-10	-5	-1	0	-1	-3	-7	-11	-16
	Wet-Bulb	-4	-3	-1	0	0	0	-1	-2	-3	-4
25	Dry-Bulb	-16	-10	-5	-1	0	-1	-3	-8	-13	-18
	Wet-Bulb	-4	-3	-1	0	0	0	-1	-2	-3	-5
30	Dry-Bulb	-18	-12	-6	-1	0	-1	-4	-10	-15	-21
	Wet-Bulb	-5	-3	-1	0	0	0	-1	-3	-4	-6
35	Dry-Bulb	-21	-14	-7	-1	0	-1	-6	-12	-18	-24
	Wet-Bulb	-6	-4	-2	0	0	0	-1	-3	-5	-7
40	Dry-Bulb	-24	-16	-8	-1	0	-1	-7	-14	-21	-28
	Wet-Bulb	-7	-4	-2	0	0	0	-2	-4	-6	-9
45	Dry-Bulb	-26	-17	-8	-2	0	-2	-8	-15	-24	-31
	Wet-Bulb	-7	-5	-2	0	0	-1	-2	-4	-8	-10

* The daily range of dry-bulb temperature is the difference between the highest and lowest dry-bulb temperature during a 24-hour period on a typical design day. (See Table 1 for the value of day range for a particular city).

TABLE 3 – CORRECTIONS IN OUTDOOR DESIGN CONDITIONS FOR TIME OF YEAR

(For Cooling Load Estimates)

YEARLY RANGE OF TEMPERATURE(F)*	DRY OR WET BULB	TIME OF YEAR								
		March	April	May	June	July	August	Sept.	Oct.	Nov.
120	Dry-Bulb	-39	-22	-11	-4	0	0	-9	-24	-44
	Wet-Bulb	-23	-12	-5	-2	0	0	-4	-13	-27
115	Dry-Bulb	-33	-22	-11	-4	0	0	-8	-20	-36
	Wet-Bulb	-18	-11	-5	-2	0	0	-4	-10	-21
110	Dry-Bulb	-30	-20	-11	-4	0	0	-6	-17	-31
	Wet-Bulb	-15	-10	-5	-2	0	0	-3	-8	-16
105	Dry-Bulb	-30	-20	-11	-4	0	0	-6	-17	-29
	Wet-Bulb	-15	-10	-5	-2	0	0	-3	-8	-14
100	Dry-Bulb	-29	-19	-10	-3	0	0	-6	-16	-27
	Wet-Bulb	-14	-10	-5	-2	0	0	-3	-8	-14
95	Dry-Bulb	-29	-19	-10	-3	0	0	-6	-16	-27
	Wet-Bulb	-14	-10	-5	-2	0	0	-3	-8	-14
90	Dry-Bulb	-29	-19	-10	-3	0	0	-6	-16	-26
	Wet-Bulb	-14	-10	-5	-2	0	0	-3	-8	-14
85	Dry-Bulb	-29	-19	-9	-3	0	0	-5	-16	-25
	Wet-Bulb	-14	-10	-5	-2	0	0	-3	-8	-14
80	Dry-Bulb	-24	-16	-8	-3	0	0	-4	-12	-20
	Wet-Bulb	-13	-9	-4	-2	0	0	-2	-6	-11
75	Dry-Bulb	-14	-9	-4	-1	0	0	-3	-7	-15
	Wet-Bulb	-7	-5	-2	0	0	0	-2	-4	-8
70	Dry-Bulb	-13	-9	-4	-1	0	0	-2	-7	-14
	Wet-Bulb	-6	-4	-2	0	0	0	-1	-4	-6
65	Dry-Bulb	-11	-8	-4	-1	0	0	-2	-6	-12
	Wet-Bulb	-6	-4	-2	0	0	0	-1	-3	-6
60	Dry-Bulb	-9	-7	-3	-1	0	0	-2	-5	-10
	Wet-Bulb	-4	-3	-2	0	0	0	-1	-3	-5
55	Dry-Bulb	-6	-5	-3	-1	0	0	-2	-4	-8
	Wet-Bulb	-3	-3	-2	0	0	0	-1	-2	-4
50	Dry-Bulb	-3	-4	-3	-1	0	0	-2	-4	-7
	Wet-Bulb	-3	-2	-1	0	0	0	-1	-2	-3

*Yearly range of temperature is the difference between summer and winter normal design dry-bulb temperatures (Table 1).

APPENDIX D

STEADY-STATE HEAT SOURCE COMPUTATION PROCEDURES

The following are recommended procedures for computing the values of steady-state heat sources in the tunnels and stations of a subway system.

1. Tunnel lighting

$$q_{TL} = 3.41\ W_L L$$

where q_{TL} = the tunnel lighting heat rate, Btu/hr
W_L = the tunnel lighting, watts per linear ft
L = length of tunnel, ft

2. Third rail losses. These losses only occur where trains accelerate to maximum speed (such as in a station and the tunnels adjoining the station where trains accelerate away from the station after making their scheduled stop), or where trains maintain or increase speed against a large grade. These losses may be calculated as follows:

$$q_{3R} = \frac{0.65(KE + q_D + q_M + q_m + q_{SR})^2 R}{N\, t_a\, V_O^2}$$

where q_{3R} = the third rail losses during acceleration, Btu/hr
KE = kinetic energy of the trains at maximum speed, Btu/hr
q_D = heat gain due to aerodynamic drag, Btu/hr
q_M = heat gain due to mechanical resistance, Btu/hr
q_m = heat gain due to traction motor losses, Btu/hr
q_{SR} = starting resistor losses, Btu/hr
R = combined contact and running rail resistance, milliohms
N = number of trains passing through the segment per hour
t_a = time to accelerate to maximum speed, sec
V_O = third rail voltage, volts

The resistance of the power distribution circuit is the sum of the third rail resistance and the resistance of the running rails which form the return path for the current. Typical values for the third rail and running rail are:

Third rail: 12 milliohms per mile
Running rail (in parallel):15 milliohms per mile

The equations used to calculate the kinetic energy of the trains and the various losses in the electrical circuits of the trains are given below. A more detailed description of the methods used to calculate the third rail losses is given in Volume I of the Subway Environmental Design Handbook.

The kinetic energy of the trains is calculated as follows:

$$KE = 11.1 \times 10^{-6} W_e NnU^2$$

where KE = the kinetic energy of the trains at maximum speed in system, Btu/hr
W_e = equivalent weight of single car including passengers and rotational inertia, tons
n = number of cars per train
N = number of trains per hour
U = the maximum train speed, fpm

The loss due to aerodynamic drag is calculated as follows:

$$F_D = 4.3 \times 10^{-6} a\rho C_D \overline{U}^2$$

where F_D = the aerodynamic drag force, lb
ρ = the density of air, lb/ft^3
C_D = aerodynamic drag coefficient, dimensionless
$\overline{U}$ = the average train velocity, fpm
a = frontal area of train, ft^2

$$q_D = \frac{F_D d_a N}{778}$$

where q_D = subway heat gain due to aerodynamic drag, Btu/hr
d_a = distance to accelerate to maximum speed, ft
N = number of trains per hour

Since the drag term is usually small in comparison to the other heat releases, a C_D value of 4.0 will suffice for most conditions.

The heat loss due to mechanical resistance is calculated as follows:

$$F_M = 1.3 + \frac{116}{W} + (5.1 \, x \, 10^{-4})\overline{U}$$

where F_M = mechanical resistance force of single car, lb/ton
W = weight of single car including passengers, tons
$\overline{U}$ = average train speed, fpm

$$q_M = \frac{F_M \, d_a \, WNn}{778}$$

where q_M = subway heat gain due to mechanical resistance, Btu/hr
F_M = mechanical resistance force of single car, lb/ton
d_a = distance to accelerate to maximum speed, ft
W = weight of single car including passengers, tons
n = number of cars per train
N = number of trains per hour

The calculations of the starting resistor heat loss can be simplified so that values can be obtained without detailed knowledge of motor characteristics such as the curves for tractive effort and motor current that the electrical engineer must work with. For the purpose of estimating the heat dissipated during the first step transition, the following equation may be used:

$$q_{step\ 1} = KE_{step\ 1} + q_{M\ step\ 1}$$

where KE = kinetic energy, Btu/hr
q_M = subway heat gain due to mechanical resistance, Btu/hr

and where the speed at which the kinetic energy is computed is the transition speed between the first step and the second step. Typical transition speeds are given in Figure D.1.

$$q_{M\ step\ 1} = KE_{step\ 1} \frac{1 - \varepsilon_m}{\varepsilon_m}$$

where ε_m = motor efficiency

Train resistance losses are negligible and can be ignored in computing the motor losses.

The circuitry is such that the heat released by the resistor grids during the second step is about equal to that released in the first step.

$$q_{step1} = q_{step\,2}$$

Hence:

$$q_{SR} = 2q_{step1}$$

where q_{SR} = starting resistor losses, Btu/hr
q_{step1} = starting resistor losses for first step of cam-controlled series-parallel connection, Btu/hr

Motor efficiency may be assumed as 90 percent if specific data are not available. The heat release from the motors is computed as follows:

$$q_m = (KE + q_D + q_M + q_{SR})\left(\frac{1-\varepsilon_m}{\varepsilon_m}\right)$$

where q_m = subway heat gain due to traction motor losses, Btu/hr
KE = kinetic energy of trains at maximum speed, Btu/hr
q_D = subway heat gain due to aerodynamic drag, Btu/hr
q_M = subway heat gain due to mechanical resistance, Btu/hr
q_{SR} = subway heat gain due to starting resistor losses, Btu/hr
ε_m = traction motor efficiency, dimensionless

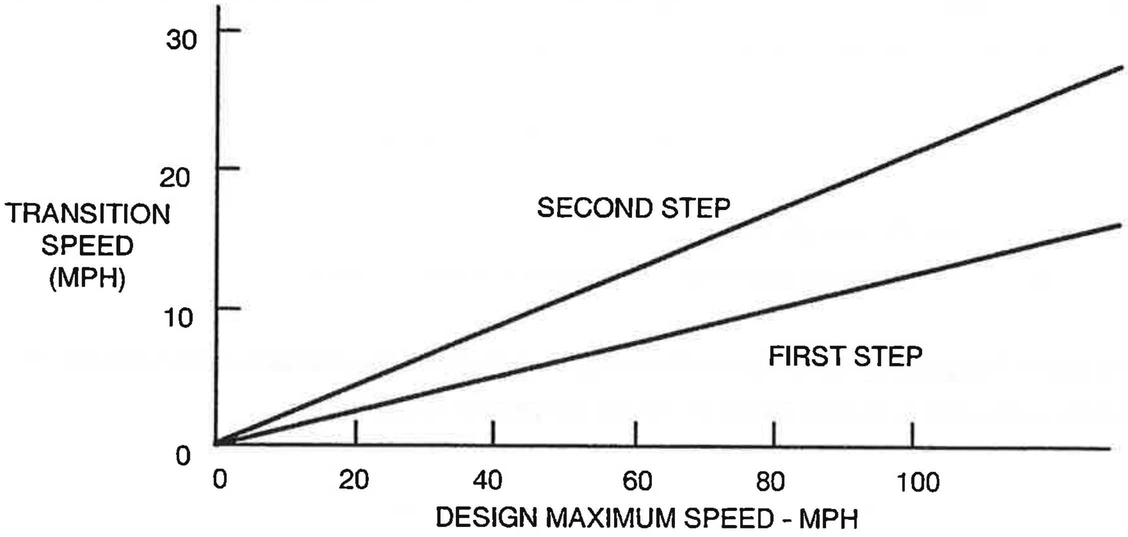


Figure D.1 Transition Speeds - Cam-Controlled Rapid Transit Motors

3. Station lighting. These calculations depend upon the amount of lighting in the station and the size of the station. The heat gain from station lighting can be calculated as follows:

$$q_{SL} = 3.412\ W_{SF} A_s$$

where q_{SL} = the heat from station lighting, Btu/hr

W_{SF} = the station lighting, watts/ft^2

A_s = the area of the station, ft^2

4. Passenger heat. The passenger heat consists of both sensible and latent heat. The amounts of sensible and latent heat depend upon the station temperature, and the degree of activity of the passengers can be calculated as follows:

For sensible heat:

$$q_{PS} = N_P t_{av} q_{SEN}$$

where q_{PS} = the sensible heat from passengers, Btu/hr

N_P = the number of passengers through station during the peak hour, passengers/hr

t_{av} = the average time each passenger is in the station including walk to or from the street, hr

q_{SEN} = the sensible passenger heat, Btu/hr

For latent heat:

$$q_{PL} = N_P t_{av} q_{LAT}$$

where q_{PL} = the latent heat from passengers, Btu/hr

q_{LAT} = the latent passenger heat, Btu/hr

5. Display lighting. The heat from display lighting can be calculated as follows:

$$q_{DL} = 3.412\ W_{SF} A_{AS}$$

where q_{DL} = the heat from display lighting, Btu/hr

W_{SF} = the display lighting, watt/ft^2

A_{AS} = the total area used for advertising space

6. Escalators. The heat from escalators can be calculated as follows:

$$q_E = 2{,}545\ W_E\ L_F$$

where q_E = the heat from the escalators, Btu/hr
W_E = the maximum hp rating of the escalator, horsepower
L_F = the average load factor for the escalator

7. Fare Collection Equipment. The heat from fare collection can be calculated as follows:

$$q_{FC} = 3.412\ W_{FC}$$

where q_{FC} = the heat from fare collection equipment, Btu/hr
W_{FC} = the power expended by the fare collection equipment, watts

8. Train Indicators. The heat from train indicators (annunciators) may be calculated as follows:

$$q_{TI} = 3.412\ N_S\ W_{TI}$$

where q_{TI} = the heat from the train indicator, Btu/hr
N_S = the number of signs
W_{TI} = the power expended by a sign unit, watts

9. Mezzanine Concessions. The heat from mezzanine businesses can be calculated as follows:

$$q_{MB} = 3.412\ N_B\ W_{MB}$$

where q_{MB} = the heat from the mezzanine business, Btu/hr
N_B = the number of businesses
W_{MB} = the power expended by each business, watts

10. Mechanical Equipment. The heat added or removed by equipment depends upon the capacity of the equipment. The capacity must be entered in Btu/hr. (One ton of refrigeration is equivalent to 12,000 Btu/hr.)

APPENDIX E

METHODS FOR CALCULATING HEAT REJECTION FROM A SUBWAY CAR

Notes

- All values are calculated on a per-car basis.
- Final values for steady-state heat rejection are calculated.
- Final values for power consumption are calculated in kW.
- Heat release from braking and acceleration grids, and power consumption from acceleration are not considered in this section, as they are handled separately by the program.

I. Steady-State Heat Rejection

The program requires that steady-state heat rejection be divided into two parts.

1) Heat rejection from an empty car
2) Heat rejection from passengers and auxiliaries per patron

These two divisions must be divided again into their sensible and latent components.
The method outlined below first calculates heat rejection from an empty car, and then calculates heat rejection from passengers and auxiliaries per patron using the following formula[*]:

$$Q_p = \frac{(Q_{LC} - Q_{EC})}{N_{PFL}}$$

where Q_p = Heat rejection from passengers and auxiliaries per patron, Btu/hr
Q_{LC} = Heat rejection from a fully loaded car, Btu/hr
Q_{EC} = Heat rejection from an empty car, Btu/hr
N_{PFL} = Number of people aboard a fully loaded car

As explained in Section 8.2 the program calculates instantaneous heat rejection using the formula:

$$Q_{C_O} = Q_{EC} + (N_P \, x \, Q_P)$$

---

[*] Note: List of abbreviations given on page E-18

where Q_{C_O} = Heat rejection from a car at time T_o

N_P = Number of people aboard car at time T_o

1) Heat Rejection from an Empty Car

Referring to Figure E.1.

$$Q_{EC} = Q_{EA} + Q_{AC_E} - Q_{TL} - Q_{OA}$$

where Q_{EA} = Heat rejection from external auxiliaries, Btu/hr

Q_{AC_E} = Heat rejection from train air conditioning, Btu/hr (For an empty car)

Q_{TL} = Heat absorbed by train from tunnel transmission load, Btu/hr

Q_{OA} = Heat absorbed by train from outside (i.e. Tunnel) air, Btu/hr

a) Heat Rejection from External Auxiliaries (Q_{EA})

External auxiliaries include such equipment as air compressors for friction braking, motor-alternators and other train equipment which release heat directly to the tunnel and not into the car.

For equipment rated in HP

$$Q_{EA} = P_{EHP} \times \left(\frac{C_D}{100}\right) \times 2{,}545.0\ \text{Btu / hr} - \text{hp}$$

For equipment rated in KW

$$Q_{EA} = P_{EKW} \times \left(\frac{C_D}{100}\right) \times 3{,}415.0\ \text{Btu / hr} - \text{kW}$$

Where: P_{EHP} = Power rating in hp

P_{EKW} = Power rating in kW

C_D = Duty cycle or percent of time equipment is operated

For the sample car being evaluated in this section we will assume an external auxiliary load of 10 kW operating 100% of the time.

$$Q_{EA} = 10\ \text{kW}\left(\frac{100}{100}\right) 3415.0\ \text{Btu / hr} - \text{kW} = 34{,}150\ \text{Btu / hr}$$

b) Heat Rejection from Train Air Conditioning (Q_{AC_E})

(For an empty Car)

Heat rejection from train air conditioning may be defined as follows:

$$Q_{AC_E} = Q_L + W$$

where Q_L = Heat Removed from the car, Btu/hr

W = Heat produced from the work done by the compressor and condenser, Btu/hr

These two parts are related to each other by the following equation:

$$COP = Q_L / W$$

where COP = coefficient of performance

The COP is a description of an air conditioner's efficiency. The higher the COP, the more efficiently the air conditioner is operating.

In general, an air conditioner operates most efficiently when it is working at, or near, its design capacity. When half loaded or partially loaded, its efficiency and therefore its COP are decreased. Typical values of COP range from 1.0 to 4.0. The COP for both full load and partial load conditions should be available from the manufacturer.

In our case the same COP will be used for full load (a fully loaded car) and partial load (an empty car). The COP is assumed to be 2.2.

We will next calculate the heat removed from the car (Q_L) and then solve the above equation for W using Q_T and COP.

(Note: The following is for the case of an empty car)

The Heat Removed from the Car may be defined by the equation:

$$Q_L = Q_T + Q_{AIR} + Q_{IA}$$

where Q_L = Heat removed from the car, Btu/hr

Q_T = Heat due to transmission through car from tunnel, Btu/hr

Q_{AIR} = Heat due to intake of outside (tunnel) air, Btu/hr

Q_{IA} = Heat due to internal auxiliaries (lighting, evaporator fans, etc.), Btu/hr

Heat Due to Transmission (Q_T)

$$Q_T = A_S \times U \, \Delta T$$

where A_S = Surface area of car, ft^2

U = Transmission coefficient, Btu/hr-ft^2

ΔT = Difference in temperature between tunnel air and car interior, °F

(For more information see Subway Environmental Design Handbook Pgs. 4-60 to 4-64)

In our case the car is constructed of two types of materials:

	A_s	U
Glass	480	0.99
Car Wall	1471	0.58

and at design conditions, the car temperature will be maintained at 20°F below tunnel temperature.

$$\therefore \quad Q_T = (480 \text{ ft}^2 \times 0.99 \text{ Btu/hr-ft-°F} \times 20\text{°F})$$
$$+ (1471 \text{ ft}^2 \times 0.58 \text{ Btu/hr-ft}^2\text{-°F} \times 20\text{°F})$$
$$= 26{,}568 \text{ Btu/hr}$$

Heat Due to Intake of Tunnel Air (Q_{AIR})

$$Q_{AIR} = \Delta H \times CFM \times \rho \times 60 \text{ min/hr} \times POA/100$$

where ΔH = Difference in enthalpy between tunnel air and car interior, Btu/lbm

CFM= Volume airflow rate of car air supply, ft^3/min

ρ = Density of air, lbm/ft^3

POA= Percent of tunnel air used in car air conditioning system

Note: The sensible heat component of this item is rejected to the tunnel via the condenser coil; the latent heat component is rejected to the tunnel via the evaporation of the condensate from the air conditioner's evaporator coils.

In our case the tunnel air is taken to be 95°F DB, 78°F WB = 41.9 Btu/lbm and the car design point is taken to be 75°F DB, 64°F WB = 29.6 Btu/lbm.

ΔH = 41.9 - 29.6 = 12.3 Btu/lbm
CFM = 3500 ft^3/min
ρ = 0.0711 lbm/ft^3
Q_{AIR} = 12.3 Btu/lbm x 3500 ft^3/min x 0.0711 lbm/ft^3 x 60 min/hr x 25/100
= 45,913 Btu/hr

Heat Due to Internal Auxiliaries (Q_{IA})

$$Q_{IA} = P_{EHP} \text{ x } 2,545.0 \text{ Btu/hr-hp (For equipment rated in hp)}$$

or

$$Q_{IA} = P_{EKW} \text{ x } 3,415.0 \text{ Btu/hr-kW (For equipment rated in kW)}$$

where P_{EHP} = Power rating in hp
P_{EKW} = Power rating in kW

If lighting is given per square foot;

$$Q_{IA} \text{ (Lighting)} = L_{SF} \text{ x } A_F \text{ x } 3,415.0 \text{ Btu/hr-kW}$$

where L_{SF} = lighting in kW/ft^2
A_F = Floor area of car, ft^2

In our case internal auxiliaries include lighting at 1.6 W/ft and 2 evaporator fans at 1 hp each, floor area of vehicle equals 642.5 ft^2.

Q_{IA} = 1.6 W/ft^2 x 1 kW/1000W x 642.5 ft^2 x 3,415.0 Btu/hr-kW
+ (2 x 1 hp x 2,545.0 Btu/hr-hp)
= 8,601 Btu/hr

Now we calculate the heat removed from the car by adding

$$Q_T + Q_{AIR} + Q_{IA} = Q_L$$
$$Q_L = 81,081 \text{ Btu/hr}$$

and using the formula $COP = Q_L / W$
For a COP of 2.2
Gives us:

$$W = Q_L / COP = 81{,}081 \text{ Btu/hr} / 2.2 = 36{,}855 \text{ Btu/hr}$$

We can now calculate

$$Q_{AC_E} = Q_L + W = 117{,}936 \text{ Btu / hr}$$

c). <u>Heat Absorbed by Train From Tunnel Transmission Load</u> (Q_{TL})

This has already been done in the above section under Air Conditioning Heat Rejection (Page E-4).

$$Q_{TL} = Q_T = \text{Heat Due to Transmission}$$

In our case Q_{TL} = 26,568 Btu/hr

d). <u>Heat Absorbed by Train From Outside (i.e. tunnel) Air</u> (Q_{OA})

This was also done in the above section under Air Conditioning Heat Rejection (Page E-5).

$$Q_{OA} = Q_{AIR} = \text{Heat Due to Intake of Tunnel Air}$$

Note: The above equality is based on the assumption that the heat removed from tunnel air is rejected back into the tunnel and the moisture removed is evaporated back into the tunnel. In some designs the moisture may drip from the car and be removed by the drainage system, in that case the above equality will not hold, and the net effect will be that the car will produce a latent cooling load (by removing moisture that is not returned) on the tunnel.

In our case we assume all latent heat removed will be returned to the system by evaporation.

$$\therefore \qquad Q_{OA} = 45{,}913 \text{ Btu/hr}$$

We now go back to our original equation and calculate heat rejection for an empty car (Page E-2)

$$Q_{EC} = Q_{EA} + Q_{AC_E} - Q_{TL} - Q_{OA}$$

In our case

Q_{EA} = 34,150 Btu/hr
Q_{AC_E} = 117,936
Q_{TL} = 26,568
Q_{OA} = 45,913
and Q_{EC} = 79, 605 Btu/hr

Also in our case, only Q_{OA} (the outside air heat absorbed) has a latent component, and this is canceled out by the moisture evaporated from the coils back into the tunnel. Therefore Q_{OA} is only a sensible heat load. The latent heat rejection for the empty car is equal to zero.

2). Heat Rejection From Passengers and Auxiliaries Per Patron (Q_p)

This will be calculated using the formula:

$$Q_P = \frac{(Q_{LC} - Q_{EC})}{N_{PFL}}$$

As explained on Page E-1.

As we have already calculated the heat rejection for an empty car (Q_{EC}) and the number of people aboard a fully loaded car (N_{PFL}) is available from either the car manufacturer or the system design study, we need only calculate the heat rejection from a fully loaded car Q_{LC} in order to solve the above equation for Q_P (heat rejection from passengers and auxiliaries per patron.)

a). Heat Rejection From a Fully Loaded Car (Q_{LC})

Referring to Figure E.1.

$$Q_{LC} = Q_{EA} + Q_{AC_L} - Q_{TL} - Q_{OA}$$

This formula is similar to the one on Page E-2, with the exception that Q_{AC_E} has been replaced by Q_{AC_L}. As all the other variables have been calculated previously, we need only calculate Q_{AC_L} in order to solve the above equation for Q_{LC}.

i). Heat Rejection From Train Air Conditioning $\left(Q_{AC_L}\right)$

As explained on Page E-3, this may be defined as follows:

$$Q_{AC_L} = Q_L + W$$

Where Q_L and W are related by the equation

$$COP = Q_L / W$$

(See Pages E-3, for the explanation of COP)

Again, as on Pages E-3 to E-6 we will first calculate Q_L and then use COP to solve for W.

(Note: The following is for the case of a fully loaded car)

Heat removed from the car (Q_L) may be defined by the following equation

$$Q_L = Q_T + Q_{AIR} + Q_{IA} + Q_{PL}$$

where Q_T = Heat due to transmission through car from tunnel, Btu/hr
Q_{IA} = Heat due to internal auxiliaries (lighting, evaporator fans etc.), Btu/hr
Q_{AIR} = Heat due to intake of outside air, Btu/hr
Q_{PT} = Heat due to people load, Btu/hr

The values for Q_T, Q_{AIR}, and Q_{IA} are the same as calculated on Pages E-4 to E-5 above. Therefore only Q_{PL} need be calculated to solve this equation. For a detailed description on how to determine the heat given off by subway patrons, refer to Pages 4-57 to 4-60 of the Subway Environmental Design Handbook.

In our case

Q_T = 26,568 Btu/hr
Q_{AIR} = 45,913 Btu/hr
Q_{IA} = 8,601 Btu/hr

and Q_{PL} is calculated as follows:

The Ratio of seated to standing passengers = 1.27 , and the number of passengers aboard a fully loaded car (N_{PFL}) equals 108.

∴ 60 Seated and 48 Standing

Assuming the average passenger has walked 3 mph for 3 minutes prior to boarding a train, his/her heat release upon entering will be:

Seated: 5/6 (700) + 1/6 (400) = 650 Btu/hr
Standing: 5/6 (700) + 1/6 (450) = 658 Btu/hr

Assuming an average ride of 8 minutes.

Seated: 3/4 (650 + 400) 1/2 + 1/4 (400) = 494 Btu/hr
Standing: 3/4 (658 + 450) 1/2 + 1/4 (450) = 528 Btu/hr

Assuming car temperature of 75°F DB
The heat release per passenger is:
Sensible: Seated = 0.55 (494) = 271.7 Btu/hr
Standing = 0.61 (528) = 322.1 Btu/hr

Latent: Seated = 0.45 (494) = 222.3 Btu/hr
Standing = 0.39 (528) = 205.9 Btu/hr

or on a per car basis:

Sensible = 60 (271.7) + 48 (322.1) = 31,763 Btu/hr
Latent = 60 (222.3) + 48 (205.9) = <u>23,221</u>
Total = 54,984 Btu/hr

Now solving for Q_L

$$Q_L = Q_T + Q_{AIR} + Q_{IA} + Q_{PL} = 136{,}066 \text{ Btu/hr}$$

and using the formula

$$COP = Q_L / W$$

For a COP of 2.2, $W = Q_L / COP = 136{,}066 \text{ BTU/HR} / 2.2 = 61{,}848 \text{ Btu/hr}$

We can now calculate Q_{AC_L}

$$Q_{AC_L} = Q_L + W = 197{,}914 \text{ Btu/hr}$$

Now we calculate Q_{LC} using the formula on Page E-7.

$$Q_{LC} = Q_{EA} + Q_{AC_L} - Q_{TL} - Q_{OA}$$

in our case

Q_{EA} = 34,150 Btu/hr

Q_{AC_L} = 197,914

Q_{TL} = 26,568

Q_{OA} = 45,913

and Q_{LC} = 159,583 Btu/hr

As in the case of the empty car the latent component of the outside air Q_{OA} is canceled out by Q_{AIR} (see note on Page E-7). The only other latent component is Q_{PL} (People Load) which is contained in Q_{AC}. Therefore separating Q_{LC} into its sensible and latent components.

Total Load = Q_{LC}	= 159,583 Btu/hr
- Latent Component (see Pg. E-9)	= <u>23,221</u>
= Sensible Component	= 136,362 Btu/hr

We will now calculate Q_P (heat rejection from passengers and auxiliaries per patron) according to the equation on Page E-1.

$$Q_p = \frac{(Q_{LC} - Q_{EC})}{N_{PFL}}$$

This must be done twice, once for the sensible component and once for the latent component.

In our case

$$Q_P\ (SENSIBLE) = \frac{(136,362\ -\ 79,605)}{108} = 526$$

$$Q_P\ (LATENT) = \frac{(23,221\ -\ 0)}{108} = 215$$

Figure E.2 shows a completed form 9C for this case.

II. Power Consumption

As was the case with steady-state heat rejection, the program requires that power consumption be divided into two parts:

1) Power consumption by auxiliary systems for an empty car (P_{EC})
2) Power consumption by auxiliary systems per patron (P_P)

The method outlined below first calculates P_{EC} and then calculates P_P using the following formula:

$$\dot{P}_P = \frac{(P_{LC} - P_{EC})}{N_{PFL}}$$

where P_{LC} = Power consumption for a fully loaded car, kW
N_{PFL} = Number of people aboard a fully loaded car

This is similar to the formula on page E-1.

1). Power Consumption By Auxiliary Systems for an Empty Car (P_{EC})

$$P_{EC} = P_{EA} + P_{AC_E} + P_{IA}$$

where P_{EA} = Power consumption by external auxiliaries, kW
P_{AC_E} = Power consumption by air conditioning equipment, kW
P_{IA} = Power consumption by internal auxiliaries, kW

All these values are quickly determined by using their heat rejection value and the conversion

1 kW = 3,415.0 Btu/hr

∴	$P_{EA} = Q_{EA}/3{,}415.0$	(See page E-2)
	$P_{AC_E} = {}^{*}W/3{,}415.0$	(See page E-6)
	$P_{IA} = Q_{IA}/3{,}415.0$	(See page E-5)

* W and not Q_{AC_E} must be used, as W is the only component of the air conditioning system that consumes power. Also W for an empty, not a loaded car, must be used.

For our case:

$$\begin{aligned} P_{EA} &= 34{,}150.0/3{,}415.0 = 10\text{ kW} \\ P_{AC_E} &= 36{,}855.0/3{,}415.0 = 10.8\text{ kW} \\ P_{IA} &= 8{,}601.0/3{,}415.0 = \underline{2.5\text{ kW}} \\ P_{EC} &= \qquad\qquad\qquad\quad 23.3\text{ kW} \end{aligned}$$

2). Power Consumption by Auxiliary Systems Per Patron (P_P)

This will be calculated using

$$P_P = \frac{(P_{LC} - P_{EC})}{N_{PFL}}$$

As explained on Page E-11.

As we have already calculated P_{EC} above, and we are given N_{PFL} (see Page E-9) we need only calculate P_{LC} in order to solve this equation for P_P.

a) Power Consumption by Auxiliary Systems for a Fully Loaded Car (P_{LC})

$$P_{LC} = P_{EA} + P_{AC_L} + P_{IA}$$

This formula is similar to the one on Page E-11 with the exception that P_{AC_E} has been replaced by P_{AC_L}.

As all the other variables have been calculated we need only calculate P_{AC_L} in order to solve for P_{LC}.

$P_{AC_L} = {}^*W/3{,}415.0$ (See page E-10)

* W and not Q_{AC_L} must be used, as W is the only component of the air conditioning system that consumes power. Also W for a fully loaded, not an empty car, must be used.

For our case:

$$P_{AC_L} = 61{,}848.0/3{,}415.0 = 18.1\text{ kW}$$

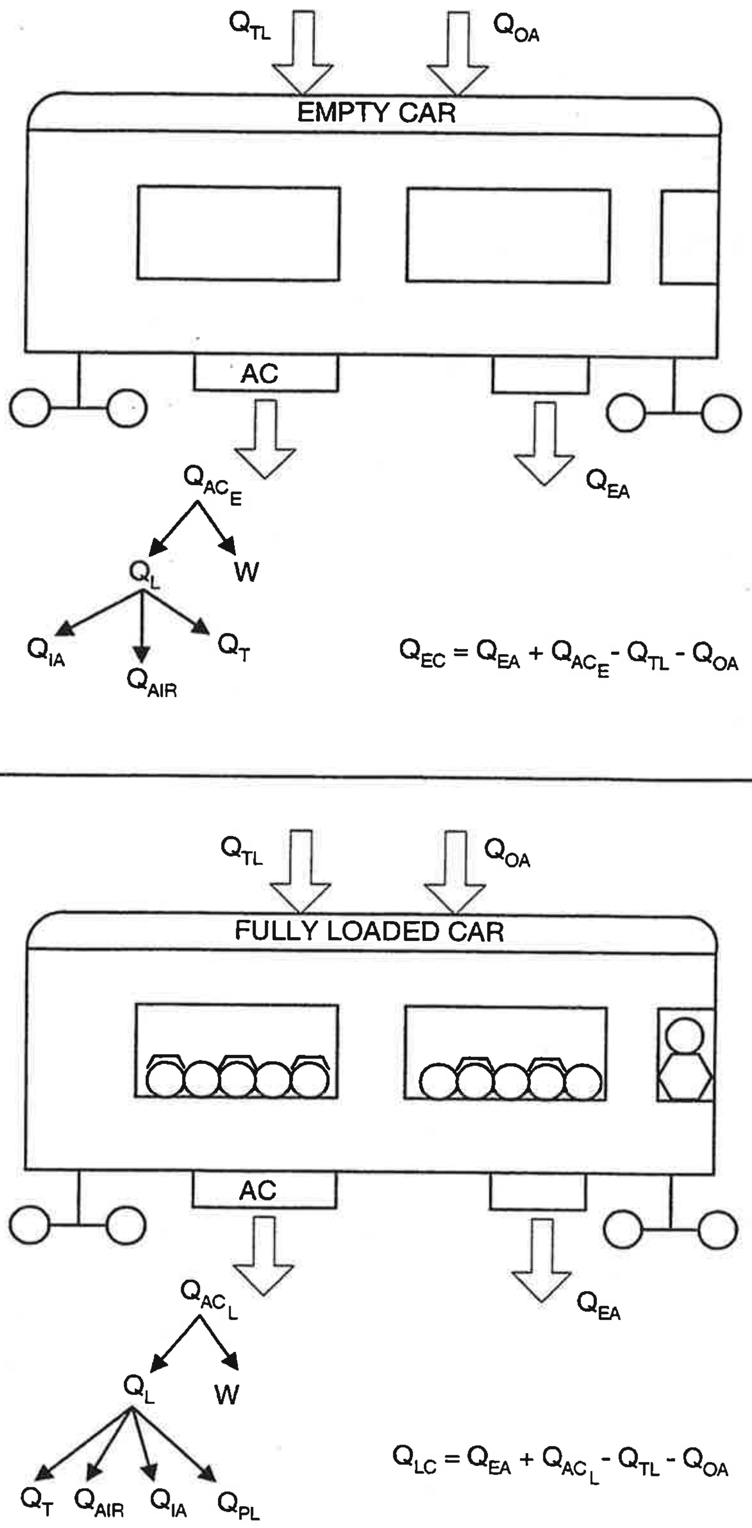
and

$$
\begin{aligned}
P_{EA} &= 10 \text{ kW} \\
P_{AC_L} &= 18.1 \text{ kW} \\
P_{IA} &= \underline{2.5 \text{ kW}} \\
P_{LC} &= 30.6 \text{ kW}
\end{aligned}
$$

Now going back to the equation on Page E-12

$$P_P = \frac{(P_{LC} - P_{EC})}{N_{FPL}}$$

$$= \frac{(30.6 - 23.3)}{108} = 0.0676 \text{ kW per patron}$$



$$Q_{EC} = Q_{EA} + Q_{AC_E} - Q_{TL} - Q_{OA}$$

$$Q_{LC} = Q_{EA} + Q_{AC_L} - Q_{TL} - Q_{OA}$$

Figure E.1

FORM 9C - TRAIN DATA

Sheet ________ of ________
Made by: ____________
Checked by: ____________
Date: ____________

Sensible Heat Rejection from Auxiliary Systems for an Empty Car excluding Propulsion System (Btu/hr per car)	1 – 10	79605.0
Latent Heat Rejection from Auxiliary Systems for an Empty Car excluding Propulsion System (Btu/hr per car)	11 – 20	0.0
Sensible Heat Rejection from Passengers and Auxiliary Systems per Patron in Car (Btu/hr per patron) (Does not apply if Train Performance Option is 2 or 3)	21 – 30	526.0
Latent Heat Rejection from Passengers and Auxiliary Systems per Patron in Car (Btu/hr per patron) (Does not apply if Train Performance Option is 2 or 3)	31 – 40	215.0
Power Consumption by Auxiliary Systems for an Empty Car (kW per car)	41 – 50	23.3
Power Consumption by Auxiliary Systems per Patron in Car (kW per patron) (Does not apply if Train Performance Option is 2 or 3)	51 – 60	0.0676 ☒

Figure E.2

Major Equations Used in this Appendix

I. Steady-State Heat Rejection

1) Heat rejection from an empty car

$$Q_{EC} = Q_{EA} + Q_{AC_E} - Q_{TL} - Q_{OA}$$

$$Q_{EA} = P_{EHP} \times \left(\frac{C_D}{100}\right) \times 2{,}545.0$$

$$Q_{EA} = P_{EKW} \times \left(\frac{C_D}{100}\right) \times 3{,}415.0$$

$$Q_{AC_E} = {}^*Q_L + {}^*W$$

$$COP = {}^*Q_L \,/\, {}^*W$$

$${}^*Q_L = Q_T + Q_{AIR} + Q_{IA}$$

$$Q_T = A_S \times U \times \Delta T$$

$$Q_{AIR} = \Delta H \times CFM \times \rho \times 60 \;\; POA/100$$

$$Q_{IA} = P_{EHP} \times 2{,}545.0$$

$$Q_{IA} = P_{EKW} \times 3{,}415.0$$

$$Q_{IA\,(Lighting)} = L_{SF} \times A_F \times 3{,}415.0$$

$$Q_{TL} = Q_T = A_S \times U \times \Delta T$$

$$Q_{OA} = Q_{AIR} = \Delta H \times CFM \times \rho \times 60 \;\; POA/100$$

2) Heat rejection from passengers and auxiliaries per patron

$$Q_P = \frac{(Q_{LC} - Q_{EC})}{N_{PFL}}$$

$$Q_{LC} = Q_{EA} + Q_{AC_L} - Q_{TL} - Q_{OA}$$

$$Q_{AC_L} = {}^{**}Q_L + {}^{**}W$$

$$COP = {}^{**}Q_L / {}^{**}W$$

$$^{**}Q_L = Q_T + Q_{AIR} + Q_{IA} + Q_{PL}$$

II. Power Consumption

1) Power Consumption by auxiliary systems for an empty car

$$P_{EC} = P_{EA} + P_{AC_E} + P_{IA}$$

$$P_{EA} = Q_{EA} / 3{,}415.0$$

$$P_{AC_E} = {}^{*}W / 3{,}415.0$$

$$P_{IA} = Q_{IA} / 3{,}415.0$$

2) Power Consumption by auxiliary per patron

$$P_P = \frac{(P_{LC} - P_{EC})}{N_{PFL}}$$

$$P_{LC} = P_{EA} + P_{AC_L} + P_{IA}$$

$$P_{AC_L} = {}^{**}W / 3{,}415.0$$

Notes: * refers to an empty car; ** refers to a fully loaded car.

Abbreviations Used in this Appendix

A_F = Floor area of car (ft^2)
A_S = Surface area of car (ft^2)
Btu/hr = British thermal units per hour
C_D = Duty cycle, or percent of time equipment is operated
CFM = Volume airflow rate of car air supply (ft^3/hr)
COP = Coefficient of performance
hp = Horsepower
kW = Kilowatts
L_{SF} = Lighting per square foot (kW/ft^2)
N_P = Number of people aboard car at time T_o
N_{PFL} = Number of people aboard fully loaded car
P_{AC_E} = Power consumption by air conditioning equipment for an empty car (kW)
P_{AC_L} = Power consumption by air conditioning equipment for a fully loaded car (kW)
P_{EA} = Power consumption by external auxiliaries (kW)
P_{EC} = Power consumption by auxiliary systems for an empty car (kW)
P_{EHP} = Power rating in Horsepower
P_{EKW} = Power rating in Kilowatts
P_{IA} = Power consumption by internal auxiliaries (kW)
P_{LC} = Power consumption by auxiliary systems for a fully loaded car (kW)
P_P = Power consumption by auxiliary systems per patron (kW)
POA = Percent of tunnel air used in car air conditioning system
Q_{AC_E} = Heat rejection from train air conditioning for an empty loaded car (Btu/hr)
Q_{AC_L} = Heat rejection from train air conditioning for an fully loaded car (Btu/hr)
Q_{AIR} = Heat due to intake of outside (i.e. tunnel) air (Btu/hr)
Q_{C_o} = Heat rejection from a car at time T_o (Btu/hr)
Q_{EA} = Heat rejection from external auxiliaries (Btu/hr)
Q_{EC} = Heat rejection from an empty car (Btu/hr)
Q_{IA} = Heat due to internal auxiliaries (Btu/hr)
Q_L = Heat removed from the car by the air conditioning (Btu/hr)

Q_{LC} = Heat rejection from a fully loaded car (Btu/hr)

Q_{OA} = Heat absorbed by train from outside (Btu/hr)

Q_P = Heat release from passengers and auxiliaries per patron (Btu/hr)

Q_{PL} = Heat due to people load (Btu/hr)

Q_T = Heat due to transmission through car from tunnel (Btu/hr)

Q_{TL} = Heat absorbed by train from tunnel transmission load (Btu/hr)

U = Transmission coefficient (Btu/hr-ft^2-°F)

W = Heat produced by work done by air conditioning compressor and condenser (Btu/hr)

ΔH = Difference in enthalpy between tunnel air and car interior (Btu/lbm)

ΔT = Difference in temperature between tunnel air and car interior (°F)

ρ = Density of air (lbm/ft^3)

APPENDIX F

RESISTOR GRID TEMPERATURE INITIALIZATION

The temperature and heat release profile of a train's deceleration resistor grids are dependent upon several variables. The grid mass, for example, will have a large bearing on the number of station stops required to approach a state of thermal equilibrium. A low mass grid, with less capacity for heat storage, will in general heat to this condition after fewer stops than a high mass grid. Also, the low mass grid will experience greater fluctuations in temperature and heat release rate than the higher mass grid.

The kinetic energy of the train will have a significant effect on the equilibrium temperature range ultimately attained by the deceleration resistor grids. When the grids are operating in a state of thermal equilibrium, the kinetic energy dissipated during braking represents the upper limit to the heat release over a travel-dwell cycle. Since this heat release is roughly in direct proportion to the grid temperature, lighter trains or lower top speeds mean a lower range for the grid temperature cycle.

Similarly, the length of time required for one travel-dwell cycle has a bearing on the equilibrium temperature range apart from the maximum speed of the train. The longer the cycle, the lower the average heat release rate that is required to dissipate the kinetic energy of the train and hence, the lower range of grid equilibrium temperature.

The following expression will enable the user to estimate the average temperature of the deceleration grid when it is operating at thermal equilibrium.

$$T_{G,E} = \frac{41.22\, N_{cars}\, MV^2}{\bar{t}\, N_{pcars} \left(A_c + A_R\right)} + T_{air}$$

$T_{G,E}$ = Grid temperature at thermal equilibrium,°F
M = Average empty car weight, tons
V = Average maximum train speed attained between stops, mph
N_{cars} = Total number of cars per train
N_{pcars} = Number of powered cars per train
A_C = Effective surface area of grid for convection, ft^2
A_R = Effective surface area of grid for radiation, ft^2
$\bar{t}$ = Average dwell plus travel time between stops, seconds
T_{air} = Average tunnel air temperature, °F

A second expression is presented which enables the user to approximate station to station cascading of deceleration grid average temperature. By utilizing this expression in an iterative manner, the user can estimate the average temperature of the deceleration grid as a function of the number of stops the train has made and the temperature of the grid prior to making the first stop. If a sufficient number of iterations are performed, the resulting temperature will correspond to the temperature of the grid when it is operating at thermal equilibrium.

$$T_{G,n+1} = \frac{0.103\left(\frac{N_{cars}}{N_{pcars}}\right)MV^2 + 1.5\,M_{DG}C_pT_{G,n} + 0.0025(A_C + A_R)T_{air}\ t}{1.5\,M_{DG}C_P + 0.0025(A_C + A_R)t}$$

where

$T_{G,n+1}$ = Average deceleration grid temperature after n+1 train stops, °F

$T_{G,n}$ = Average deceleration grid temperature after n train stops, °F

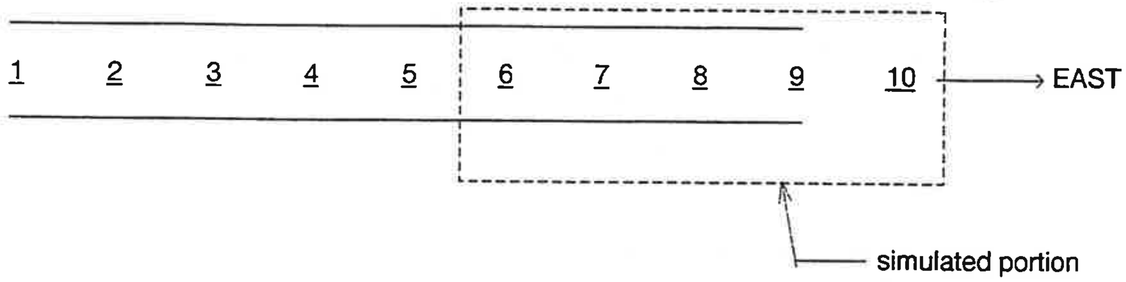
M_{DG} = Deceleration grid weight, lbs

C_p = Specific heat of grid material Btu/lb -°F

t = Dwell plus travel time between stops n and n+1.

To illustrate how these expressions are to be employed, consider the following example.

A portion of a given single-tunnel ten-station system is to be simulated. The portion begins between the fifth and sixth station and extends into the system to the east portal.



Prior to entering the actual system from the west portal, the trains were located in an outdoor storage area where the train resistor grids have cooled down to ambient temperature. The user is required to estimate the deceleration grid temperature prior to the train braking into the sixth station, since this is the approximate location where the simulation of the eastbound trains begin.

The values of the parameter appearing in the expressions should be taken directly from the program input data with the exception of V, t and T_{air}. The values of these parameters must be estimated or computed. For the purpose of illustration, let us assume the following values for the parameters:

M = 30 tons
V = 50 mph
N_{cars} = 6
N_{pcars} = 6
A_C = 30 ft^2
A_R = 25 ft^2
M_{DG} = 350 lbs
C_p = 0.1 Btu/lb-°F
T_{air} = 80°F
t = 100 seconds

By inserting these values in the latter expression with the deceleration grid temperature set initially to ambient temperature and then repeating the procedure six times with the resulting grid temperatures, the initial grid temperature to be used in the simulation can be estimated. The results of the above procedure are shown below.

n (Number of train stops)	T_n (Average grid temperature prior to stop)	T_{n+1} (Average grid temperature after stop)
0	80	197
1	197	289
2	289	362
3	362	420
4	420	466
5	466	502

The grid temperature at thermal equilibrium is computed as 642°F.

In many SES conceptual studies, train operations data beyond the limits of the subway may not be known in sufficient detail to permit a reasonable assessment of the history of resistor grid excitation beyond the locations where trains are dispatched for the SES simulation. In such instances, it is recommended that the deceleration resistor grid be initialized at the temperature corresponding to thermal equilibrium behavior within the simulated portion of the system. The estimated initial temperature in this case can be checked by examining a sequence of detailed or abbreviated print results. If the peak resistor temperature of a train increases at successive stops with the simulated system, the estimated temperature was below the equilibrium value.

The heat rejection from the acceleration grids of a cam-controlled vehicle propulsion system is only a small fraction of the deceleration resistor value. As a rule of thumb, the acceleration resistor grids should be initialized between 150 and 250°F. Again, as a check the SES output should be consulted.

APPENDIX G

SOIL PROPERTIES

Studies with the SES Heat Sink Subprogram have indicated a low sensitivity to soil thermal property variations within the normally encountered range of values. This is fortuitous, since non-homogeneity and an-isotropy of local soil composition renders a precise determination of soil thermal properties impossible. Even case sample tests along a proposed subway route would not provide totally reliable data, since soil composition and moisture content can vary markedly over a short distance. To quote the Handbook of Physical Constants, "Even for relatively well defined substances, measurements by qualified investigators show startling discrepancies; some of them are due to real differences between different samples of what is nominally the same material, but some must be attributed to experimental error."

Broad descriptive categories of rock and soil types are appropriate for use in the SES. Composite tables taken from different sources on the thermal properties of soil are given on the following page:

I. Soil

Type	Moisture Content (% dry weight)	Conductivity* (Btu/hr-°F-ft)	Diffusivity** (ft^2/hr)
Sand	.2	0.16	0.01
	30	0.95	0.03
Crushed Feldspar	4	0.63	0.03
Crushed Granite	4	0.63	0.03
Crushed Trap Rock	4	0.50	0.03
Sandy Loam	4	0.54	0.02
	10	0.83	0.025
Fine Sandy Loam	.3	0.19	0.01
	27	1.33	0.03
Loamy Sand	0	0.11	0.01
	5	0.29	0.015
Sandy Clay Loam	0	0.09	0.01
Loam	0	0.09	0.01
	13	0.14	0.02
	25	0.24	0.025
Silt Loam	10	0.75	0.025
	20	0.83	0.03
Silty Clay Loam	10	0.75	0.025
	20	0.79	0.03
Clay	1.4	0.14	0.01
	67	0.87	0.04
Muck Soil	4	0.08	0.01
	67	0.21	0.04

*Data taken from:

- S.P. Clark, Jr. (Ed.), Handbook of Physical Constants, The Geological Society of America, New York, New York, Memoir 97, 1966.
- ASHRAE Handbook of Fundamentals (1972)

**These values represent extrapolated estimates based primarily on water content. The basis for extrapolation was derived from a review of:

- Kusuda, T. and Achenbach, P., Earth Temperature and Thermal Diffusivity at Selected Stations in the United States, ASHRAE Transactions, V.71, pt. 1, pp. 61-75, 1965.

- Kreith, F., Principles of Heat Transfer, International Textbook Co., Scranton, Pa., 1964
- Perry, J.H. (Ed.), Chemical Engineers' Handbook, McGraw-Hill Book Co., Inc., New York, 4th Edition, 1963.
- ASHRAE Handbook of Fundamentals (1972)

As is made clear in these references, thermal properties are strongly dependent on such factors as grain size and shape, density, and moisture content. The stated thermal property values are therefore to be considered as rough estimates.

II. Rock

Type	Conductivity* (Btu/hr-ft-°F)	Diffusivity** (ft^2/hr)
Granite	1.51	0.046
Granite Gneis	1.52	0.046
Quartzite	3.60	0.11
Quartzitic Sandstone	3.23	0.098
Slate	1.26	0.037

*Data from Handbook of Physical Constants.

**Based on a specific heat of 0.20 Btu/lb-°F.

III. Concrete*

Type	Conductivity* (Btu/hr-ft-°F)	Diffusivity** (ft^2/hr)
Stone	0.54	0.019
10% Moisture	0.70	0.025

*From Kreith's Principles of Heat Transfer.

APPENDIX H

FIRE STUDIES - LITERATURE SEARCH
SUMMARY OF FINDINGS

INTRODUCTION

A survey of the available literature on the subject of tunnel fires has been made. The purpose of this survey was three-fold:

1. To assess the state-of-the-art in the mathematical modeling of tunnel and mine fires.
2. To identify any existing data on full-scale and model tunnel fire tests.
3. To catalogue descriptions of major subway fires which have occurred.

On the basis of the material and information assembled during this task, the decision whether to adopt an existing fire model; develop a simplified model; or improve the present method of using the SES computer program, was made.

The results of items 1 and 2, are presented in the form of an annotated bibliography. Item 3 consist of a listing of known subway fire incidents with a brief description of the circumstances involving each case.

1.1 Souces of Information

The sources of information used during the literature search included the standard printed indexes of technical information as well as a number of existing computerized information retrieval services. The period covered by the search varied according to the data base used, but generally the period from 1970 through 1978 was covered. However, information as recent as late 1979 has been obtained. More specifically, the following sources of information were used:

(i) <u>Computerized Searches</u>:

- (a) The Engineering Index Monthly (COMPENDEX) (1970 - 1978).
- (b) The National Technical Information Service (NTIS) (1965 - 1978).
- (c) The Smithsonian Science Information Exchange (SSIE Current Research) (1976 - 1978).
- (d) Information Service in Mechanical Engineering (ISMEC) (1973 - 1978).
- (e) New York Times Index (1973 - 1978).

(ii) Printed Indexes:

  (a) The Engineering Index Monthly.
  (b) Fire Research Abstracts and Reviews.
  (c) Energy Research Abstracts.

(iii) Libraries:

  (a) Engineering Societies Library (ESL).
  (b) New York Public Library.

(iv) Miscellaneous Sources:

  (a) Accident/Incident Data Bases of Federal Government Agencies (e.g. Federal Railroad Administration (FRA), National Transporation Satety Board (NTSB), U.S. Fire Administration).
  (b) Index compiled by the British Hydromechanics Research Association (BHRA) on tunnel ventilation.
  (c) Work on current fire safety efforts done by the Volpe National Transportation Systems Center (VNTSC) staff.
  (d) Reports on Montreal Metro fires obtained from the Montreal Urban Community Transit Commission (MUCTC).
  (e) Material received from Kaiser Engineers.
  (f) Newspapers and in-house data.

1.1.1 Keywords

The keywords used varied according to the information sources scanned. The more comprehensive indexes were searched using wider ranging keywords. For the various computerized searches, the keywords used were: "SUBWAY FIRE," "TUNNEL FIRE," "FIRE MODEL," "TUNNEL FIRE TEST," "TUNNEL FIRE MODEL," "DUCT FIRE," "DUCT FIRE MODEL," "CORRIDOR FIRE MODEL," "MINE FIRE MODEL," "UNDERGROUND FIRE," "TUNNEL FIRE RESEARCH," "TUNNEL SMOKE FLOW," "BUOYANT STRATIFIED LAYER," "VEHICLE BURNING TESTS," "VEHICLE COMBUST...". The manual searches also used the following keywords: "SMOKE," "SMOKE ABATEMENT," "FIRE," "FLAME RESEARCH," "FLAMMABLE MATERIALS," "VENTILATION," "COMBUSTION," "MINE VENTILATION," "MINE FIRES," "TUNNEL".

1.2 Summary of Results

A review of the material gathered yielded the following:

1.2.1 State-of-the-Art in Mathematical Modeling of Fires

The tunnel (mine) ventilation computer programs found (Ref. 17, 28, 29, 49, 67, 77) are the one-dimensional, steady-state, slug-flow type which treat the effects of a fire as an additional buoyant force exerted over the entire cross-section of the tunnel or mine gallery. Reference 28 is a comprehensive study of the effects of fires on mine ventilation systems. This work which was sponsored by the U.S. Bureau of Mines (USBM) surveys the various approaches used for analyzing the effects of mine fires and develops some very useful relationships for computing the buoyant and throttling (increased pressure losses) effects of a fire. This work appears to be the foundation for a mine ventilation computer program (Ref. 29) with the ability to simulate the pressure disturbances caused by an underground fire. According to the author (Ref. 29), this computer program is based on the so-called "Michigan Technological Program" which in turn is based on a ventilation network program developed in West Germany around 1965. This program (a one-dimensional incompressible, steady-state model) uses the Hardy Cross iteration method to solve for the airflow distribution in the mine (or tunnel) network. A transient conduction model is used to compute the convection heat losses to the passage walls. The "time dependent" changes in airflows throughout the network are approximated by solving a succession of steady-state conditions.

A phenomenon characteristic of tunnel fires is the formation of a hot buoyant layer of gases along the crown of the tunnel. In the absence of forced ventilation, this hot layer flows equally in both directions (for approximately level tunnels) away from the source of the fire, while the freah air supporting combustion flows beneath and toward the fire. Small-scale and large-scale tests (Ref. 12, 13, 14, 20, 34, 41, 47, 53, 59, 77) have shown that even in the presence of forced ventilation, this hot layer can flow against the ventilating air stream (a phenomenon called "backlayering") if the magnitude of the fresh air velocity is not sufficiently high. The magnitude of the "critical" air velocity to prevent backlayering depends on such factors as: the heat release rate of the fire, the tunnel dimensions, and the tunnel grade. The only reference found which attempts to mathematically model the stratified layered flow caused by a tunnel fire is the paper by Hwang and Chaiken (Ref. 39) of the U.S. Bureau of Mines. The mathematical formulation of their model is similar to that used by Bakke and Leach (Ref. 5) to described methane layers. This type of model lends itself to a parametric study and is well suited for studying the general behavior of a hot gas layer with the goal of developing a criterion for preventing backlayering (or reverse flow). This model appears very promising in terms of understanding the mechanics of a buoyant gas layer and the effects of changes in variables such as ventilating air velocity, tunnel grade, etc. However, the work is on-going and only partial results have been reported (Ref. 47).

There are some two-dimensional, finite difference models (Ref. 15, 16, 42, 43) which attempt to simulate the recirculating airflows and temperatures resulting from a fire in a corridor or a room connected to a corridor. These models are too detailed and not suited for simulating subway tunnel fires. Any attempt to model a fire in a tunnel longer than a few diameters would most likely prove too costly to use.

References 33, 34, 36 and 55 present a number of equations and empirical correlations which can be used to estimate the spread rate and depth of smoke layers produced by fires in unventilated tunnels. This information would be useful in evaluating the hazards of a tunnel fire. The authors conjecture that a ventilating air velocity of equal magnitude (but opposite direction) to the rate of smoke advance predicted by their equations would prevent backlayering. However, recent test results (Ref. 47, 48) indicate that this would be a conservatively high estimate.

There is a large body of information on the modeling of fires in compartments or enclosures (Ref. 22, 25, 63, 78, 82). These models range in sophistication from a set of algebraic equations to computer models with the ability to simulate heat transfer (radiation and convection) and mass transfer phenomena as well as smoke and combustion processes to some extent (e.g., Ref. 22). These models could be useful for modeling fires in the interior of a subway vehicle.

1.2.2 Full-Scale and Model Tunnel Fire Tests

The only tests identified are:

1.2.2.1 U.S. Bureau of Mines Tests (Ref. 12, 13, 40, 46, 47, 48)

- The Bureau of Mines has been conducting a number of full-scale and model tunnel tests. These tests are primarily concerned with investigating the spread of fire in fuel-lined passages (coal and wood lined), a common situation in mines. As a by-product of this-work, the Bureau of Mines is also studying the effects of a mine fire on the ventilation system such as the throttling of the airflow, the conditions leading to reverse flow (backlayering), and more importantly, they have developed a criterion to prevent reverse flow.

1.2.2.2 Offenegg Tests (Ref. 54)

- Large-scale fire experiments were performed in 1965 in the Offenegg railway tunnel near Weesen. The tests were carried out by the Swiss Commission for Safety Precautions in Road Tunnels. These tests were primarily concerned with determining the tunnel conditions resulting from large liquid fires. Eleven tests were carried out with either 100, 500 or 1000 liters of gasoline. There were tests with and without sprinklers, with longitudinal, semitransverse and no mechanical ventilation.

1.2.2.3 Glassow Tunnel Tests (Ref. 34, 36, 55)

- These tests are useful for illustrating smoke layering and as supporting evidence for the simplified equations for the rate of smoke advance given by Heselden and Hinkley (Ref. 33, 36).

1.2.2.4 Tests Reported by Eisner & Smith (Ref. 20)

- Results presented include: the layer temperature variation with distance from the fire; ventilation air velocity; and the distance over which back-layering occurred.

1.2.2.5 Tunnel Fire Tests (Austria) (Ref. 24)

- In 1975 a series of full-scale tests were performed in the disused Zwenbertunnel in Austria. The paper summarizing these tests contains a number of temperature vs. distance for various tests. This data may be useful in establishing an effective heat transfer coefficient (convection and radiation) between the hot gases and the tunnel walls.

1.2.2.6 Tunnel Fire Tests (Japan)

- In 1973 and 1975, the Japanese carried out 1:3 scale and full-scale tests, respectively, in connection with the new ventilation system of the Amikske Tunnel. The paper (Ref. 41) summarizing these tests presents the resulting smoke flow patterns for a few tests. Back-layering against a ventilation velocity of 315 fpm resulted in two of the cases illustrated.

A series of train-burning tests were conducted by the Japanese National Railway (JNR) from 1972 through 1974 (Ref. 70, 72). These tests were concerned with determining whether a train with a car on fire could continue moving through a tunnel (and above ground) without endangering the rest of the train. These tests also investigated the effect of using different materials in the vehicle interior on the intensity of the fires produced. These tests were well instrumented and produced much useful information concerning the conditions within a burning vehicle (temperature, combustion gases, etc.).

1.2.2.7 Memorial Tunnel Fire Ventilation Test Program (MTFVTP) (Ref. 84, 85)

The Memorial Tunnel is a 2800-foot single-bore two-lane road tunnel built in 1953 as part of the West Virginia Turnpike, near Charleston, West Virginia and removed from service in 1987 when it was replaced by a four-lane highway. 98 full scale tests were performed for fire heat release rates of 10, 20, 50 and 100 megawatts (34.1, 68.2, 170.5 and 341.0 million Btus per hour). Approximately 15 of the MTFVTP tests determined the longitudinal air velocity required to control the direction of spread of smoke and hot gases from a fire (aka critical velocity). The MTFVTP results strongly supported the SES methodology (Froude Number modeling) for the design of longitudinally-ventilated rail tunnels. They indicated that, depending on the fire heat release rate, the SES methodology over-predicted the critical velocity between 4 and 20 percent.

1.2.3 Major Subway Fires

The descriptions of the various fire incidents listed have been taken directly from the references cited. Where possible the descriptions have been condensed, principally by omitting extraneous material. No attempt has been made to corroborate the accuracy of the descriptions particularly when the sole source of information is a newspaper account of the incident. Note, the number of fire incidents reported for each transit system is not intended to reflect (and does not reflect) the frequency of fires in that system. Rather, these fire incidents were either well publicized in newspapers, or reports describing these incidents were available. The subway fires identified to date are the following:

1.2.3.1 Transit System: Bay Area Rapid Transit (BART), San Francisco, California.

1. Fire Incident (Ref.): Nov. 18, 1974, 8:58 AM - Train No. 379, Car No. 618.
   Classification: Undercar; mechanical equipment caused.
   Fire Description: Automatic train control continuously applied the brakes of car 618, resulted in overheating of the brakes, ignited leaking brake fluid and the wooden insulation blocks at the 3rd rail pick-up shoe.

   Heat and flames at the brake shoe ignited undercar wiring, etc., causing the train to stop. The fire burned a hole in the floor igniting seats in the immediate area.

   The operator of a train passing in opposite direction noticed the smoke and sparks and notified Central Control who notified the operator of train 379. The passengers were transferred to another train which had been dispatched on the adjacent track.

   The fire department arrived at 9:10 and extinguished the fire before it had spread beyond the first seats and the walls near the hole burned in the floor.
   Extent of Property Damage: The seats and walls of the car were repairable. The brake pads, disks, hydraulic and pneumatic liner, electrical wiring, air bellows, evaporator box and air conditioning ducts were destroyed.

2. Fire Incident (Ref.): Nov. 17, 1976, 3:45 EM - Train No. 369, Car No. 120.
   Classification: car interior; arson
   Fire Description: An arsonist ignited a crumpled newspaper on seat of car 120 (last car of nine car train), as train left 19th Street Station at 3:45 PM.

   The newspaper burned through the neoprene seat cover and ignited the polyurethane foam cushion. The fire spread to the reinforced fiberglass ceiling. The heat radiated ignited the nearby seats, rug, and floor insulation. The flammable gases released by the burning plastics flashed-over.

   The train operator, having been informed of this fire by the passengers, drove the train to the next above ground station to de-train passengers and allow the fire department to deal with the fire.

   Extent of Property Damage: The interior of the car (excluding the attendants compartment and last 8 seats) was destroyed. The exterior and undercar were not damaged. The estimated repair cost was $100,000.

3. Fire Incident (Ref.): August 5, 1977, 4:45 AM - Car No. 178.
   Classification: Undercar; electrical equipment caused.
   Fire Description: A metallic object lodged near the line switchbox short-circuited the starting resistor causing "...a temperature rise of 1200°F, igniting the car floor above". The heat from the resistor (approximately 1 ft. away from floor) pyrolyzed the

polyurethane/aluminum sheet sandwich floor. The aluminum sheet melted and ruptured, releasing flammable gases, which entered the passenger compartment and ignited the fiberglass reinforced walls and ceiling and polyurethane seat cushions.

Station personnel and the train operator heard a loud bang (at approx. 4:56 AM) from the floor rupture. Heavy black and gray smoke and (orange) flames were coming from under the car. Passengers de-trained at the Daly City Station. The burning car was decoupled and the rest of the train was moved.

Extent of Property Damage: The interior of the car was totally destroyed. Undercar equipment was also damaged (two evaporator boxes, wiring, switch boxes, hydraulic and air liner, relays, resistor grid, and motor control box). The damage was estimated at $200,000.

4. Fire Incident (Ref. newspaper): June 30, 1978, 11:15 AM -

Classification: car interior; arson suspected.

Fire Description: The fire broke out in a seat (made of polyurethane) of the third car of a 6 car train as the train approached Pleasant Hill Station. Three persons (none was suspected of starting the fire) were in the car when it caught fire. Two of the witnesses told officials they saw a cigarette left on a newspaper. The fire was extinguished in 39 minutes by 17 fire fighters.

Extent of Property Damage: Damage was mainly confined to one seat and smoke damage throughout the car. However, firemen chopped through the floor and ceiling to ensure the fire had not spread through the insulation. Damage was estimated at $50,000.

5. Fire Incident (Ref. newspapers): Oct. 27, 1978, approx. 5:00 PM

Classification: car interior; arson.

Fire Description: A fire broke out in the rear car of a seven-car train as it travelled between the Coliseum and Lake Merritt stations. The fire started in the three rear seats (polyurethane) on the left side of the car. There were only two passengers in the car. A moment after the train arrived at Lake Merritt Station, the heat blew out two car windows. Service was interrupted for about 30 minutes as firemen extinguished the fire.

Extent of Property Damage: Preliminary estimates of damage were set at $100,000.

6. Fire incident (Ref.): Jan. 17, 1979, 6:06 PM, Train No. 117

Classification: undercar; electrical equipment caused.

Fire Description: Train No. 117 (a 7-car train) speeded through the Trans-Bay Tube toward San Francisco at perhaps 70 mph, as it approached an area of the third rail assembly which had been damaged by another train (No. 363) about 90 minutes earlier. The third rail shoe assembly of the fifth car was snagged (probably when it struck the line switch cover from train No. 363) and became loose. The assembly - shoe, bracket and cable leading into the car - struck the underside of the car triggering a series of electrical explosions.

The third rail assembly and attached wires carrying 1000 V dc current struck the 100 psi air suspension equalization tanks causing arcing and fire and blew a hole in the tank. The air bags located above the collector shoes burned and the stainless steel plates between the air bags and car floor melted. Their contact with the aluminum car body caused it to burn and a hole above the plate to develop. The hole exposed the polyurethane core (of the floor) and the interior of the car to extreme heat and fire. The interior floor covering pads and carpet over the hole and adjacent area then caught fire. Fire progressed through the interiors of the 5th and 6th cars burning the carpet, seats, walls and ceiling liners.

Due to a number of coordination problems at Central Control, firemen did not begin fighting the blaze until about 9:40 PM. The fire was declared under control at 1:30 AM (Jan. 18) about 7 hours after the fire began. Forty passengers and two BART employees were evacuated from the burning train via a train on the adjacent tunnel. Tragically, one fireman died of smoke inhalation and cyanide poisoning when his oxygen supply was exhausted.

Extent of Property Damage: The first three cars of train #117 sustained extensive interior smoke damage. The fourth car had extensive smoke and fire damage. The fifth car was destroyed by fire and smoke and there was evidence of heavy undercar electrical arcing. A hole about 12 inches in diameter had been burned through the floor above the collector shoe assembly. The sixth car was destroyed by fire and smoke and a hole was also burned through the car floor. The seventh car was also destroyed by fire and smoke.

Damage was also incurred by sections of the 3rd rail near the site of the fire. The concrete ceiling of the tunnel was covered with black soot and was damaged by heat. The ceiling concrete above the coupled ends of the fifth and sixth cars had spelled sufficiently to expose the steel reinforcements. Also, about 20 feet of steel handrail on the tunnel walkway was warped and about 800 feet of overhead radio and train control cables were also destroyed. Property damage was estimated to be $2,450,000.

7. Fire Incident (Ref. newspaper): Dec. 12, 1979, 12:38 AM - Car No. 511.
Classification: Undertermined but preliminary inspection indicated arson.
Fire Description: The fire broke out while the 10 car train was underground between the 12th Street Station and the elevated Oakland West Station. Flames poured through the doors between the 3rd and 2nd cars causing some damage. Minutes later when the train pulled into the station and the 15 passengers were ordered off, flames shot upward from the third car. The fire started at the front of the third car under a seat next to an air duct

made of a highly flammable material. The seat was directly above an evaporator box containing heating and cooling components. A three-foot hole was burned under the seat and a 10-foot hole in the ceiling directly above. It was believed that if the exhaust system had been operating, flames and heat could have been sucked through the duct in the evaporator box.

The Oakland Fire Department responded quickly and had the flames under control within 15 minutes.

Extent of Property Damage: The third car where the fire started was virtually destroyed and the second car (car 528) was also damaged. Preliminary estimates of the damage range from $900,000 to over $1 million.

8. (Ref.): In addition to the incidents listed above, there was also 27 fire or smoke incidents on subway cars of the BART system during the period from March 1975 through November 1976. "...All but three of these incidents occurred below the car floor and did not penetrate into the passenger compartment. The remaining three cases involved interior car fires that produced only minor damage, primarily because the fires were detected at an early stage of development and quickly extinguished. The third was an aborted arson attempt to ignite a seat cushion with a pile of matches."

1.2.3.2 Transit System: Massachusetts Bay Transportation Authority (MBTA)

1. Fire Incident (Ref.): July 2, 1975, 9:08 AM

Classification: Exterior; electrical

Fire Description: At approximately 9:00 am on July 2, 1975 an eastbound train was approaching the Kenmore Square station. When the train was about 400 feet from the station, an electrical malfunction occurred in the last car, and the train stopped. After some confusion, this car was disconnected from the overhead power line and pulled into the station by the rest of the train. (Usually three cars make up a train.) The electrical malfunction left a smokey haze in this area of the tunnel. The next train, which had stopped because of the haze, received a signal to proceed to the station. As that train proceeded forward it struck the 600-volt overhead line, which apparently had broken or weakened during the electrical malfunction and was at that time dangling about four feet above the track. The dangling line was still energized since power is fed from both directions of the line. When the front of the lead car hit the wire, the wire arced, then jumped up in the air, and landed on top of the lead car as the train came to a halt. The cable coming into contact with the roof of the grounded lead car arced a large hole approximately 18 inches wide through the roof and the arcing ignited the sound-deadening insulation. This occurred at approximately 9:08 am. The crew immediately started to evacuate the train. It was estimated that there were almost 400 people in the three cars. Apparently, at this point, some confusion arose as to who called the Fire Department because Boston Fire Alarm did not receive a call until 9:31 am, more than 20 minutes after fire had started. Since the fire was near Boston's border with the town of Brookline, both Jurisdictions' Fire Departments sent apparatus. They were met not only by a hot, smokey fire, but also found some riders still groping their way through the smoke to the station.

Fire fighters were sent in from the Kenmore Square station and the two tunnel entrances to check for and evacuate lost passengers. The location of the train required that all fire fighting be done from the Kenmore Square station. Therefore, after search and rescue was completed, all apparatus that had not been originally assigned to Kenmore Square station was moved to it. Since there were no standpipes in the tunnel or in the station, hose lines were stretched from the street, down into the station, and from there into the tunnel. This long hose line operation under hot, smokey conditions made it necessary for relief crews to be sent in early and often. After the fire was extinguished, the train was pulled out of the tunnel and was searched for hot spots.

Extent of Property Damage: The lead car was completely burned and the second car received extensive damage to the forward upper portions. Signal cable in about 200 feet of the tunnel had to be replaced. The fire fortunately developed fairly slowly, which gave riders a chance to escape before the situation became too dangerous. The seats in the cars, which were of fiberglass reinforced plastic, all burned. The fire spread slowly because of the arrangement and type of fuels involved. The fire was ignited at the top of the car, and this slowed the burning.

* Vehicle Description: The street cars involved were purchased in 1951; they were "Pullman Standard GE Picture Window Cars." The interior surface of the exterior steel shell of the car was covered with a sound-deadening material that resembled automobile undercoating. The interior surfaces of the car consisted of a hard fiberboard material similar to kitchen counter tops. The seats were of fiberglass reinforced plastic, and the floor tile was vinyl asbestos. Most of the windows were glass; however, some were plastic.

1.2.3.3 Transit System: Montreal Urban Community Transit Commission (MUCTC)

1. Fire Incident (Ref.): Jan. 23, 1974, 8:00 AM Train No.16.

Classification: Undercar;

Fire Description: Train No. 16 was traveling southbound on line 2 carrying approximately 1,000 passengers shortly before 8:00 AM. Soon after arriving at Beaubien Station the front left tire of the second vehicle developed a flat. The motorman did not realize what had happened until arriving at Rosement Station.

A supervisor was dispatched to the scene. On his arrival, the supervisor made the train advance partially into the tunnel to inspect the punctured tire. The flat fire did not appear dangerous to him so he decided to have the train proceed to the next station (Laurier) and evacuate the passengers.

Soon after leaving Rosemont, some reinforcing wires from the damaged tire touched the guiderail causing arcing and sufficient heat to ignite the tire. The train came to a halt approximately 1,000 feet south of Rosemont. The supervisor and motorman attempted to use a fire extinguisher but had no success. At 8:00 AM, the supervisor contacted Central Control requesting Fire Department assistance and a power cut.

Passenger evacuation began promptly after the power cut and was completed approximately 15 minutes later. Passengers were evacuated in both directions via Rosemont and Laurier Stations.

The train was immobilized in the tunnel between the south end of Rosemont and St. Gregoire fan shaft which is approximately 1,160 feet south of the station. At approximately 8:00 AM, either the supervisor or motorman had requested that the fans at St. Gregoire and Bellechase (approximately 400 feet north of Rosemont) be activated - the first in supply and the second in exhaust. This produced a longitudinal flow towards Rosemont station threatening the passengers evacuating in that direction. At 8:05 AM, the rotation of the two fans was reversed producing a southerly airflow. This had the effect of reversing the movement of smoke and extracting it via the St. Gregoire fan shaft. According to witnesses, Rosemont Station was kept reasonably clear of smoke for the entire evacuation period (i.e. till 8:20 AM.) In the ensuing 10 minutes, the fire grew very rapidly such that by 8:30 AM the convection currents created by the the heat liberated had overpowered the ventilation system which resulted in vast quantities of smoke escaping from Rosemont Station.

(Note: Proceeding northward (towards Rosemont) from the lead car of the burning train, the tunnel grade rises at a 0.5% grade for approximately 400 feet and then at a 6.0% grade resulting in a change in elevation of about 30 feet.)

The Fire Department arrived at Rosemont at 8:15 AM, but did not have time to install their hoses because of the increasing quantity of smoke between 8:20 and 8:30 AM.

At 8:24 AM, conditions were so unbearable and uncontrollable that the firemen gave up the idea of advancing into the tunnel through Rosemont and decided to approach from Laurier Station. If was after 9:00 AM when the firemen were able to start combating the fire.

At 9:00 AM, all the fans south of the burning train (except the fan at St. Gregoire which failed by this time) were turned on in supply mode to increase the natural convection towards Rosemont. This was done with the intention of reducing the temperature in the vicinity of the fire thus helping the firemen in their task. It was observed that the increased airflow did not have the effect of intensifying the flames. Rather, it is believed that the resulting drop in temperature minimized damage to the tunnel and Rosemont station and prevented the fire from spreading to the train stopped in Rosemont Station. This train whose lead car remained in the hot air stream coming from the burning train, sustained only slight damage to the first car.

The fire was extinguished at 11:00 AM, after having consumed the last car.

Extent of Property Damage: All nine cars of train No. 16 suffered heavy fire damage. Only the bogies and certain undercar components were salvageable. The load-bearing and guide tires contributed little to the fire. The heat of the fire superficially damaged concrete lining in the tunnel which spelled in certain places.

All the cables for lighting, ventilation, communications, signalling, tele transmission, and pumping were located in trays bolted to the tunnel sidewalls approximately 7 feet above the invert. All these cables stretching from the head of the train to the south end of Rosemont Station (approximately 1000 feet) were destroyed and had to be replaced.

The intense heat caused the guide rails to expand breaking their support insulators. The running rails were slightly damaged in several stretches, but only a few sections of this rail had to be replaced.

Rosemont Station suffered smoke damage and had to be completely cleaned ard repainted. Cost estimates of the damage were in the neighborhood of $1,000,000.

2. Fire Incident (Newspaper): Dec. 9, 1971

Classification: Collision

Fire Description: A moving train smashed into a number of parked cars in the stub section north of the Henri-Bourassa Station. The train derailed and the short-circuit ignited a fire. The trapped motorman died in the ensuing fire.

The fire which lasted more than 24 hours, forced the closing of the Henri Bourassa and Sauve Stations, the two northern most on the line, for nearly a month.

Extent of Property Damage: Twenty-four cars were burned. The total damage was estimated at more than $5,000,000.

1.2.3.4 Transit System: Lisbon Metro, (Portugal)

1. Fire Incident (Ref.): May 25, 1976, 5:35 pm

Classification: undercar (?); electrical equipment caused

Fire Description: As a four car train enroute from Alameda Station was entering Arrois Station the crew of the train were alerted by the passengers that smoke was rising from the floor of the rear car.

The crew of the train evacuated the passengers of the rear car and having ascertained that the smoke was coming from a hatch at floor level, they opened it. Using portable fire extinguishers (CO_2), they discharged the extinguishers on the traction motor and its neighboring equipment.

The center of the fire apparently having been put out, the other cars were evacuated as a precautionary measure. They intended to bring the train to the nearest inspection terminal (Alvalede) to a special section of the track contiguous to the station. When the train was rolling at a reduced speed, the employees heard a detonation similar to an explosion and saw high flames erupted in the interior of the car, rapidly enveloping the car and the neighboring conductor's cabin.

The crew abandoned the train immediately to look for help at the closest station (Arroios). They intended to obtain some fire extinguishers and to request the intervention of the Municipal Fire Department.

When they returned to the train, it was no longer possible to approach the car where the fire broke out and all attempts to uncouple the car were in vain.

Note that the motorized car where the fire took place was completedly enveloped by flames in 2 to 3 minutes, and the heat which was being emitted and the smoke coming from the burning of the interior linings made it impossible to approach the car to do anything.

The Municipal Firemen rushed as soon as called, but they were delayed by traffic jams in the streets. They arrived at Alameda station 30 minutes after the fire broke out. At that point it was impossible to enter the tunnel because of the density of the smoke and the intensity of the heat. This station is situated 1640 feet from the site of the accident, but the natural convection currents resulting from the heat emitted by the fire and the incline of the tunnel were such that Alameda station was severely affected.

As soon as the firemen decided that it was impossible to fight the fire from Alameda Station, they went to the adjacent station (Arrolos) and succeeded in approaching the train without too much difficulty. They had to use portable means of lighting because all the electrical cables, signal cables, and telecommunication cables along the tunnel suspended by clamps or by metal guides were found to be out of working order.

In Lisbon's metro stations, there are water inlets for washing. When the firemen tried to use them, they found that the pressure in the pipes was insufficient to fight the fire in an efficient manner and they had to use the fire hydrants on the street.

The minutes lost because of all these problems could never be regained. Full fire-fighting efforts began only at 6:55 p.m., when the train was already the victim of the flames. The firemen's efforts were practically limited to putting out the hot cinders and refreshing the air near the train.

The fire broke out in one of the traction motors. The cause has not been precisely determined; however, there is some speculation that the increased dust levels in the tunnel caused by an intensive program of grinding the tracks may have been a contributing factor (by possibly short-circuiting electrical circuits).

Extent of Property Damage: The four vehicles were completely destroyed above the floor line, while almost all the undercar equipment was salvageable. All the tunnel electrical cables had to be replaced for a distance of 390 feet. It was found that the cables were completely burned only for a distance 246 feet which corresponds to the length of the train. All the tunnel lights (located along the crown of the tunnel) were detroyed for a distance of 1640 feet. The Acrylic diffusers of the lights at Alameda Station were deformed by the heat. Damage to the concrete structure of the ceiling and walls of the tunnels was light. A number of track ties were partially burned. The paint in Alameda Station was damaged by smoke. Also, a fan located in the tunnel above the area of the fire was damaged. The total damages amounted to $1,200,000.

1.2.3.5 Transit System: Sabadell, Spain

1. Fire Incident (Ref. Newspaper): April 8, 1980

Classification: undercar (?); electrical (?)

Fire Description: At least five people were killed and more were feared dead in a fire that engulfed a train in a tunnel northwest of Barcelona.

Railroad authorities said the fire was apparently started by a short circuit as the train went through a tunnel between the Apeadero and Rambla stations in the city of Sabadell. Several passengers and some fireman were taken to hospitals with smoke inhalation and other injuries.

Extent of Property Damage: Not known.

1.2.3.6 Transit System: Southeastern Pennsylvania Transportation Authority (SEPTA).

1. Fire Incident (Ref.): Nov. 19, 1978, 12:48 AM - Car No. 861

Classification: Interior; electrical equipment.

Fire Description: The vehicle* (a 1960 subway car, part of a married pair) was parked inside the 69th Street shop over a pit in the repair area, energized by a "stringer rod" in a 3rd rail shoe. The fire originated in the operators cab in an electrical panel and burned undetected for an undetermined period. At approximately 12:30 AM, a foreman noticed smoke and upon investigating he saw flames billowing from car No. 861. The foreman immediately called the fire department. The fire company arrived about 8 minutes later and quickly brought the fire under control.

The fire spread laterally through car No. 861 and consumed the entire vehicle above the floor level. The intense heat buckled the stainless steel shell beyond repair. There was no visible damage to the trucks on the car.

The train line door area of the attached car (No. 862) was scorched by radiant heat and flame, but the interior of the vehicle was not damaged. Subsequent investigation revealed that the lighting circuit breaker and the motor generator circuit breaker were "on" while all other circuit breakers were "off" indicating that the fire started on the high voltage side of the light circuits, at the polarity reversing relay.

Damage to the building was confined to the skylights and smoke damage to walls and ceilings.

Extent of Property Damage: The estimated damage to the vehicle was $88,152. The structural damage was estimated to be $58,203.

* Vehicle Description: Car No. 861 was a 1960 subway car. Length: 55 feet; Height: 13 feet; Width: 9 feet; Weight: 46,670 pounds. The exterior was constructed of stainless steel with formica covered wall panels and ceiling, rubber floor matting and vinyl covered stuffed seats.

2. Fire Incident (Ref.): Sept. 6, 1979, 5:20 PM, Train No. 8, Car No. 149. Train consist: Cars #160, #149, #1, #155, #141.

Classification: Undercar; electrical equipment caused.

Fire Description: Train #8 approached Erie Station northbound (Express track #3), operating under block signal indications at a speed varying between 5 MPH and 20 MPH. A third rail cable ground occurred on the second car* (#149 front end) approximately 135 feet from the platform accompanied by explosions, arcing and flame. The heat from the fire ignited the lubrication in the manual door control under the passenger seat above current collection #2.

The motorman attempted to keep the train in motion after the explosion and fire. A supervisor on the platform signalled the motorman to continue into the platform. The emergency braking system, not initiated by the crew, stopped the train with two cars on the platform. The supervisor immediately reported the fire and ensuing panic of the passengers to the Train Dispatcher via the emergency call box on the platform at 5:20 PM, requesting third rail power off on all tracks, assistance from Fire and Police Departments. Third rail power was blocked out at 5:25 PM.

The motorman opened his cab door with the intention of opening the center door, but the passengers pushed him back through the cab and out the cab window onto the platform. The passengers climbed through the window after him. At this time passengers from car #160 and car #149 (first and second cars) were breaking and climbing through windows and doors on both sides of the train.

The conductor had been operating from the fourth car instead of the third car which prevented him from opening the doors on the two cars over the platform. Had he been operating from the third car he could have controlled the doors on the first two cars without opening doors over the track area.

Following the evacuation of the train, police and fire personnel attended and transported victims to various hospitals. Ninety-one persons were injured, though none of the injuries were serious.

The fire was extinguished quickly by the Fire Department and the platform cleared of smoke.

Extent of Property Damage: An inspection of train No. 8 showed that current collector No. 3 at the rear of car #149 (on and away from platform) had trolley cable damage. The insulating on the trolley cable, approximately 10 inches from the retaining block was broken and several strands of wire were beaded from apparent arcing. Damage at the front end of the car at current collector 92 included a melted beam bolt, and most of the beam back assembly. The wooden third rail beam was burned almost completely through over the remains of the shoe back. The trip hose, main reservoir, brake pipe and Westinghouse hoses were also damaged by fire. Inside the car the passenger emergency braking switch (at the center door) was found to have been activated. The vehicle damage was estimated at $15,000. An inspection of the track and platform area at Erie Station immediately following the incident revealed that one third rail insulator and bracket were damaged, and the wooden protection board charred.

Vehicle Description: A 1928 subway car manufactured by the J.G. Brill Co. Length: 67'-6"; Width: 9'-10"; Height: 12'-4"; Weight: 112,000 pounds. The car is of steel construction with a 3-inch cement floor and leather padded seats.

1. Fire Incident (Ref. newspaper): Sept. 16, 1979, 5:20 PM

Classification: Undercar; Electrical Equipment caused.

Fire Description: A northbound train was entering Erie Station on the Broad Street line when a power cable swung loose from the undercarriage of a car. The loose cable set off an electrical fire as the train came to a halt. Initially there was a loud explosion followed minutes later by a series of smaller "popping" sounds and bright flashes. The panicked passengers smashed windows and jumped out when the doors were not opened. Of the 900 passengers abroad the train, 178 suffered minor injuries.

Extent of Property Damage: Not known.

4. Fire Incident (Ref. Newspaper): Nov. 13, 1979, evening rush hour

Classification: Undercar; Electrical Equipment caused.

Fire Description: The fire broke out under the carriage of the single-car train on the Bryn Mawr line west of the 69th Street Terminal. The fire started after two small explosions, the first like an electrical spark and then a larger explosion. The lights on the train went out with the second explosion, and the car began filling with smoke.

Passengers had seen sparks (the first "explosion"?) as the train pulled away from the 69th Street Terminal. The train continued to move and a few blocks later, a bigger blast near the engineer sent smoke rushirg into the car.

Passengers left the above-ground car (some 60 feet above street level) through the back door as the driver urged them not to panic. A total of 58 persons were treated for various injuries including smoke inhalation, cuts and bruises suffered when they tried to escape. The fire was controlled by 5:30 PM.

Extent of Property Damage: Not known.

1.2.3.7 Transit System: Toronto Transit Commission (TTC)

1. Fire Incident (Ref.): Oct. 15, 1976, 1:55 AM - Train No.77, car No.5388. Train Consist: Cars Nos. 5493, 5492, 5391, 5390, 5389, 5388.

Classification: Car interior arson

Fire Description: At 1:47 AM, train No. 77 was entering Dufferin Station at the same time as train No. 57 (travelling westbound) was entering the station. The motorman of train No. 57 observed flames in the rear car (No. 5308) of train No. 77. The flames were up to the tops of seat backs. The motorman of train No. 57 contacted Transit Control and he continued transmission even as train No. 77 started to exit the station. Transit Control contacted train No. 77 at 1:51 AM as it started to leave Christie Street Station (the second station east of Dufferia). The motorman heard Transit Control over the radio and then one long "buzz" which means "stop immediately". The guard called the motorman on the intercom and indicated that a fire was out of control. All passengers were ordered off the train and out of the station. The motorman indicated to control the severity of the fire and then ran through the car making sure that all passengers were out. He got as far as the third car when the smoke got so heavy that he had to leave. When he got back on the platform the smoke was so thick and black that he could not see farther than about four feet.

The guard on the train indicated that when he learned of the fire from Transit Control, he looked back through the cars and saw flames. There was a little light colored smoke. He grabbed a fire extinguisher and went towards the fire. The flames were at the back of the last car (in the southwest corner) with very little smoke. He got within 15 feet from the actual flames. The flames were going up the walls and spreading across the ceiling and down the other side, inside the car. The lowest point of the flame was on the seats. He tried to get closer to use the fire extinguisher, when the window over the southwest corner seats popped out, and heavy black smoke filled the car in about 30 seconds. At this time the flames were coming out from inside the car; possibly through the window opening. The guard got down on the floor and crawled to the stairs.

A witness who was the only passenger on the second car from the front reported that upon learning of the problem on the train, he looked toward the rear and saw gray smoke. The smoke had reached the stairwell nearest him (located approximately at the rear of the fourth car) but he walked hurriedly to the stairs and started up, but the smoke was very heavy. He got to the landing half way up the stairs but had to return to the platform because of the heavy concentration of smoke at that level. When he returned to the platform the entire station was filled with smoke and the heat was intense. He made his way to the east end of the platform and down to tracks proceeding eastward to Bathurst Station.

Train No. 79 which had been following train No. 77 stopped about 1000 feet short of Christie Street Station. The motorman could see flames through the right side of the rear car directly ahead of him. There was no smoke at that time. In about a minute, heavy black smoke started to roll towards the train (Note: there is a 0.3% upgrade from east to west at this point); the motorman had the intention of going to the west end of the train and moving the train westerly, but before he had left his cab the smoke had reached the train.

The fire department arrived at Christie Station at about 1:58 AM, but found it impossible to reach the fire scene from the station entrances via the main stair because of the high temperatures. The firemen entered the system at Bathurst Station (approx. 1360 feet east of Christie Street Sta.) and walked through the tunnel toward the scene of the fire. It was estimated that some 15 minutes were required to carry hose through the tunnel, this meant that water could not be applied to the burning train until about 2:20 AM. At approximately 2:45 AM, the fans at Christie Street Station were switched on and the station was cleared of smoke. However, fire-fighting operations had been largely concluded at that time.

<u>Additional Observations:</u>

(i) The three rear cars were completely burned to the floor level and suffered structural collapse to the road bed. The fourth car from the rear (car No. 5391) showed evidence of fire attack through the roof panel, but fire-fighting operations protected the side and end panels and no damage to the car interior resulted.

(ii) Sharp stratification of heat levels explains the absense of damage to the undercar gear of the three burned cars. This equipment appeared reusable despite the collapse of the car sub-frames.

(iii) All of the doors along the south side of the train were open with the exception of the doors nearest the fire scene.

(iv) It appears that the destruction of one car was well advanced before the next car was attacked, and if it is assumed that each car burned for the same period of time, then approximately 10 to 15 minutes was the time taken for the destruction of each car.

(v) It appears that combustion air drawn from the tunnels at either end of the station, was reaching the fire through the row of columns (perforated dividing wall) separating the eastbound and westbound tracks. This would account for the relatively clean appearance of the north side of the station.

(vi) Heavy smoke damage occurred at the mezzanine and street levels indicating that smoke had vented via the south platform escalator and stairway, through the mezzaine level to grade. The escalator was located approximately midway along the rear car (No. 5388) and the stairway was located by the rear of the fourth car from the back of the train (No. 5390).

(vii) A number of tests on the car seats were conducted. Various ignition sources were used including cigarettes, lighting fluid, methyl alcohol and rolled newspaper. The results showed:

(a) A cigarette could initiate a seat fire, but a considerable length of time was required for the fire to break out making it unlikely that such a fire would go undetected.

(b) It would not be possible to create the fire observed on train No.77 using a flammable liquid.

(c) A newspaper-fueled fire burns through the polyvinyl chloride faced upholstering in approximately 2 minutes and a fully developed fire involving the rubber padding would ensue within 4 minutes.

(d) The major fuel present in the burned car was the styrene butadine rubber filling in the car seats.

Extent of Property Damage: The damage was estimated at $2,500,000.

* Vehicle Description: Length: 75 feet; Height: 12 feet; Width: 10-4n. The vehicle was a 1965 "light-weight" car manufactured by the Canadian Car Division of Hawker Siddeley Canada Ltd. The walls and roof of the vehicle consist of aluminum sheeting applied to aluminum framing members. The main structural members of the above floor section of the cars consist of heavy aluminum extrusions. The sub-floor consists of sheet steel to which is applied a heavy plywood deck topped with a rubber floor covering. The interior finish of the vehicle consists predominately of urea formaldehyde laminates applied to the walls and ceilings. Seating consists of a flame retardant-treated plywood base to which is applied foam rubber padding covered with - heavy polyvinylchloride-faced fabric.

2. Fire Incident (Newspaper): March 27, 1963

Classification: Undercar (?) electrical equipment

Fire Description: A six-car train was able to speed to the systems southern terminal (Union Station) where the passengers got off. After the passengers were led to safety, the train was moved to a storage track where firemen extinguished the flames.

Extent of Property Damage: Not known.

BIBLIOGRAPHY

(Note: The references marked by an asterisk (*) were reviewed and found to be very useful. The remaining references provided good background material).

1. Alpert, R.L., "Pressure Modeling of Fires Controlled by Radiation," Sixteenth Symposium (International) on Combustion, The Combustion Institute, pp. 1489-1500, 1976.

2. Atallah, Sami, "Pressure Rise Due to a Fire in an Enclosure," Fire Technology, Vol. 5, pp. 112-121, 1969.

3. Bakke, P., "Some Interim Notes on Methane Roof Layers," Safety in Mines Research Establishment, Research Report No. 164, Buxton, England, 1959.

*4. Bakke, P. and Leach, S.J., "Methane Roof Layers," Safety in Mines Research Establishment, Research Report No. 195, Buxton, England, 1960.

*5. Bakke, P. and Leach, S.J., "Turbulent Diffusion of a Buoyant Layer at a Wall," Appl. Sci. Res. (Section A), Vol. 15, pp. 95-136, 1964.

6. Baltaretu, R. et al, "Efficacy of Ventilating Air Current Reversal as means for fighting Underground Fires," Twelfth Int. Conf. of Mine Safety Research Establishment, Sept. 11-15, 1967, Paper 53, Dortmund, West Germany. (In French).

7. Benjamin, T.B., "Gravity Currents and Related Phenomena," J. Fluid Mech., Vol. 3t, n 2, pp. 209-248, 1968.

*8. Braun, E., "A Fire Hazard Evaluation of the Interior of WMATA Metrorail Cars," National Bureau of Standards Report No. NSBUR 75-971, December 1975, (NTIS-PB 249 776).

*9. Braun, E., "Fire Hazard Evaluation of BART Vehicles," National Bureau of Standards Report IR 78-1421, March 1978, (NTIS-PB 281-383).

10. Bystron, Henryk, "Stabilization of Directions of Flow and of Volumes of Ventilating Air During Small or Large Underground Fires," Przegl Gorn, Vol. 30 n 4, pp. 207-217, April 1974. (In Polish).

*11. Chaiken, Robert F. and Singer, Joseph M., "Experimental Coal Mine Fire Research," Archives of Thermodynamics and Combustion, Vol. 7, No. 4. 1976.

*12. Chaiken, Robert F., Singer, Joseph M., and Lee, Calvin R., "Model Coal Tunnel Fires in Ventilation Flow," U.S. Bureau of Mines Report of Investigations, RI 8355, 1979.

*13. Croce, P.A. et al, "A Full-Scale Investigation of the Fuel-Load Hazard of Timber Sets in Mines," Second Annual Report, No. RC 78-T-6, 1978, Factory Mutual Research Corporation, Norwood, Mass.

*14. DeRis, J., "Duct Fires," Combustion Science and Technology, Vol. 2 n 4, pp. 239-258, 1970.

15. Doria, M.L., "Fire and Smoke Spread in a Corridor : The Preheat Period Analysis, 2-D Parabollic Flows".

16. Doria, M.L., "A Numerical Model for the Prediction of Two Dimensional Unsteady Flows of Multicomponent Gases with Strong Buoyancy Effects and Recirculation".

17. Duepre, G. and Hoffan, P.J., "Calculation of a Ventilating Network under Consideration of the Compressibility," Glueckauf-Forschungsh, Vol. 35 n 3, pp. 95-102, June 1974. (In German).

18. Edwards, John C., Perlee, Henry E. and Chaiken, Robert F., "Cylindrical Duct Fire Spread," U.S. Bureau of Mines Report of Investigations RI 8258, 1977.

19. Edwards, John C., "Radiant Heating of Mine Bulkheads," U. S. Bureau of Mines RI 8356, 1979.

*20. Eisner, H.S. and Smith, .B., "Convection Effects from Underground Fires: The Backing of Smoke Against the Ventilation," Safety in Mines Research Establishment, Research Report No. 96, Buxton, England, 1954.

21. Ellison, T.H. and Turner, J.S., "Turbulent Entrainment in Stratified Flows," J. Fluid Mech. Vol. 6, pp. 423-448, 1959.

*22. Emmons, H.W., "Computer Fire Code III," Home Fire Project Technical Report No. 25, Jan. 1978.

*23. Felske, J.D. and Tien, C.L., "Calculation of the Emissivity of Luminous Flames, Combustion Science and Technology," Vol. 7, pp. 25-31, 1973.

*24. Fezlmayr, A.H., "Research in Austria on Tunnel Fire," BHRA, Second International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels, March 23-25, 1976, Paper J2, Cambridge, England.

*25. "Fire-Safe Structural Steel: A Design Guide," American Iron and Steel Insitute, First Edition, March 1979.

*26. Gosman, A.D. and Lockwood, F.C., "Incorporation of a Flux Model for Radiation into a Finite-Difference Procedure for Furnace Calculations," Fourteenth Symposium (International) on Combustion. The Combustion Institute, Pittsburgh, Pa., pp. 661-671, 1973.

27. Graves, K.W., "Development of a Computer Program for Modeling the Heat Effects on a Railroad Tank Car," NTIS: PB-241 365/6ST, 1975.

*28. Greuer, R.E., "Influence of Mine Fires on the Ventilation of Underground Mines," U.S. Bureau of Mines Open File Report 74-73, July 1973. (NTIS: PB 225-834).

*29. Greuer, R.E., "Study of Mine Fires. Part I. Computer Simulation of Ventilation Systems Under the Influence of Mine Fires," U.S. Bureau of Mines Ope File Report 115(1)-78, October 1977. (NTIS: PS 288 231/AS).

*30. Hadden, J.D. et al, "Ventilation to Control the Smoke from a Fireproof Structure," Mining Enforcement and Safety Administration, Informational Report No. 1054, 1977.

*31. Harmathy, T.Z., "A New Look at Compartment Fires - Part 1," Fire Technology, Vol. 7, pp. 196-217, 1971.

*32. Hawthorne, B.J., "Plastics in Railway Rolling Stock," Trans, J. Plastics Inst., pp. 73-76, Great Britain, Jan. 1967.

*33. Heselden, A.J.M., "Studies of Fire and Smoke Behaviour Relevant to Tunnels," BHRA, Second International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels, March 23-25, 1976, Paper J1, Cambridge, England.

*34. Heselden, A.J.M. and Hinkley, P.L., "Smoke Travel in Shopping Malls. Experiments in Cooperation with Glasgow Fire Brigade. Parts 1 and 2". Joint Fire Research Organization, Fire Research Notes 832 and 854, Fire Research Station, 1970.

35. Hilado, C.J., "Smoke from Cellular Polymers," Fire Technology, Vol. 5, No. 2, pp. 130-139, 1969.

*36. Hinkley, P.L., "The Flow of Hot Gases Along an Enclosed Shoping Mall. A Tentative Theory," Joint Fire Research Organization, Fire Research Note 807, Fire Research Station, March 1970.

*37. Hottel, Hoyt C. and Sarofim, A.F., "Radiative Heat Transfer," McGraw-Hill Book Co., New York. 1967.

38. Huggett, C., "Annual Conference on Fire Research," National Bureau of Standards, Report No. NBSIR 77-1308, 1977. (NTIS: PB 273-589).

*39. Hwang, C.C. and Chaiken, R.F. et al, "Reverse Stratified Flow in Duct Fires: A Two-Dimensional Approach," Sixteenth Symposium (International) on Combustion held at MIT, Cambridge, Mass., August 15-21, 1976. DD. 1385-1395.

*40. Hwang, C.C. and Chaiken, R.F. "Effect of Duct Fire on the Ventilation Air Velocity," U.S. Bureau of Mines Report of Investigations No. 8311, 1978.

*41. Kawamura, R. et at, "Study on a New Ventilation System to Effectively Eliminate Fire Smoke in a Tunnel," BHRA, Second International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels, March 23-25, 1976, Paper J3, Cambridge, England.

42. Ku, A.C. and Doria, M.L. et al. "Numerical Modeling of Unsteady Buoyant Flows Generated by Fire in a Corridor," Sixteenth Symposium (International) on Combustion held at MIT, Cambridge, Mass., August 15-21, pp. 1373-1384, 1976.

43. Ku, A.C. and Doria, M.L., "Some Predictive Results Obtained from the Numerical Model for the Computation of Unsteady Recirculating Flows," National Science Foundation Report No. NSF-RA-E-74-086, 1974. (NTIS: PB 252-960).

*44. Leach, S.J. and Barbers, L.P., "Experiments on Methane Roof Layers: Single Sources in Rough and Smooth Tunnels with Uphill ard Downhill Ventilation, with an Appendix on Experimental Techniques," Safety in Mines Research Establishment, Research Report No. 222, Buxton, England, 1964.

*45. Lee, Calvin K., "Estimates of Luminous Flame Radiation from Fires," Combustion and Flame. 124, pp. 239-294, 1975.

*46. Lee, Calvin K., Joseph M. Singer and Kenneth L. Cashdollar, "Smoke Characteristics of Tunnel Wood Fires," Fire and Materials, Vol. 2, No. 3, 1978.

*47. Lee, Calvin K., Joseph M. Singer and Robert F. Chaiken, "Influence of Passageway Fires on Ventilation Flows," Second International Mine Ventilation Congress, Reno, Nevada, Nov. 4-8, 1979.

*48. Lee, Calvin K., Robert F. Chaiken and Joseph M. Singer, "Interaction between Duct Fires and Ventilation Flow: An Experimental Study," Combustion Science and Technology, Vol. 20, pp. 59-72, 1979.

*49. Lessor, D.L., "Duct Gas Cooling Model," Battelle Pacific Northwest Laboratories, BNWL-B-319, 1974.

*50. Mass, W. and Sadee, C., "Reversal of Air Flow by a Fire," Geologic en Mijnbouw, 45, No. 4, pp 117-23, 1966.

51. National Academy of Sciences Report, "Fire Safety and Fire Hazards Related to Polymeric Materials in Cars of Washingtcn Metropolitan Area Transit Authority," 1975.

52. National Science Foundation, "Proceedings of NSF/RANN Conference on Fire Research 1975 Held at Cambridge, Massachusetts on 25-27, June 1975," NSF-RA-E-75-031, June 1975. (NTIS: PB 023-712).

*53. National Transportation Safety Board, "Safety Methodology in Rail Rapid Transit System Development," NTSB-RSS-73-1, August 1973. (NTIS: PB 223-1573).

*54. (Offenegg Tunnel), "Final Report of the Tests in the Offenegg Tunnel from May 17-31, 1965," Commission for Safety Measures in Road Tunnels. (Two Volumes - In German).

*55. Phillips, A.M., "Smoke Travel in Shopping Malls. Froude Number Correlation of Small and Large-Scale Data," Joint Fire Research Organization Memorandum 44, Fire Research Station, 1971.

*56. Rasbash, D.J., "Smoke and Toxic Products Produced at Fires," Trans. J. Plastics Inst., pp. 55-61, Great Britain, 1967.

*57. Roberts, A.F., "Some Aspects of Fire Behavior in Tunnels," Tunnels and Tunnelling, pp. 73-77, January 1973.

*58. Roberts, A.F., "Comments on 'Duct Fires' by J. de Ris," Combustion Science and Technology, Vol. 3, pp. 263-266, 1971.

*59. Roberts, A.F. "Fires in the Timber Lining of Roadways: A Comparison of Data from Reduced-Scale and Large-Scale Experiments," SMRE Research Report 263, 1970.

*60. Roberts, A.F. and Clough, G., "The Propagation of Fires in Passages Lined with Flammable Material," Combustion and Flame, Vol. 11, pp. 365-376, 1967.

*61. Roberts, A.F. and Clough, G., "Model Studies of Heat Transfer in Mine Fires," Safety in Mines Research Establishment, Research Report No. 247, Buxton, England, 1967.

*62. Roberts, A.F. and Kennedy, M., "Modeling of Mine Roadway Fires," Safety in Mines Research Establishment, Research Report No. 239, Buxton, England, 1965.

*63. Rockett, J.A., "Fire Induced Gas Flow in an Enclosure," Combustion Science and Technology, Vol. 12, n 4-5-6, pp. 165-175, 1976.

*64. Sato, Takashi and Matsumoto, Ryuichi, "Radiant Heat Transfer from Luminous Flames," International Development in Heat Transfer, Part IV, Sec. B, 804, 1962.

65. Seader, J.D. and Einhorn, I.N., "Some Physical, Chemical, Toxicological, and Physiological Aspects of Fire Smokes," Sixteenth Symposium (International) on Combustion held at MIT, Cambridge, Mass., August 15-21, 1976, pp. 1423-1445.

*66. Silcock, A. and Hinkley, P.L., "Fire at Wultrum Shopping Centre, Wolverhampton 14.12.70," Joint Fire Research Organization, Fire Research Note 878, Fire Research Station, 1971.

*67. Simode, Etienne, "Simulation of Thermal and Aerodynamic Effects of a Fire in a Complex Underground Ventilation Network," Second International Mine Ventilation Congress, Reno, Nevada, Nov. 8, 1979.

68. Smith, E.E., "Evaluation of the Fire Hazard of Duct Materials," Fire Technology, Vol. 9, n 3, pp. 157-170, Aug. 1973.

69. Smith, E.E., "Transit Vehicle Material Specification Using Release Rate Tests for Flammability and Smoke - Phase I Report," Prepared for Transit Development Corporation, Oct. 1976. (Available through NTIS).

*70. Takita, Teruo, "Research on Prevention of Train Fire," Rail International, Vol. 8, n 7-8, pp. 395-406, July-Aug. 1977.

71. Tamura, G.T., "Computer Analysis of Smoke Control with Building Air Handling Systems," ASHRAE Journal, pp. 46-54, Aug. 1972.

*72. Tanaka, Toshio, "A Solution to Train Fires," Japanese Railway Engineering, Vol. 16, n 1, p. 4-6, 1975.

*73. Tateishi, Shunichi, "Experiment on Automobile Fire in Actual Road Tunnel," Annual Report of Roads, Japan Road Association, pp. 4353, 1970.

*74. Taylor, P.B. and Foster, P.J., "The Total Emissivities of Luminous and Non-Luminous Flames," Int. J. Heat Mass Transfer, Vol. 17 pp. 1591-1605, 1974.

*75. Tewarson, A. and Pion, R.F., "A Laboratory-Scale Test Method for the Measurement of Flammability Parameters," Final Technical Report, Factory Mutual Research Corporation, Norwood, Mass. 1977.

*76. Tewarson, A. and Tamanimi, F., "Research and Development for a Laboratory-Scale Flammability Test Method for Cellular Plastics," Final Report, No. RC76-T64, Factory Mutual Research Corporation, Norwood, Mass., 1976.

*77. Thomas, P.H., "Movement of Smoke in Horizontal Corridors Against an Air Flow," The Institution of Fire Engineers Quarterly, Vol. 30, n 77, pp. 45-53, March 1970.

*78. Thomas, P.H. et al, "Fully-Developed Compartment Fires - Two Kinds of Behavior," Joint Fire Research Organization, Fire Research Technical Paper No. 18. 1967.

*79. Trutwin, W., "Estimation of the Natural Ventilating Pressure Caused by Fire," International Journal of Rock Mechanics and Mining Science, Vol. 9, pp. 25-36. 1972.

80. Tsuchiya, Y. and Sumi, Rikooo, "Smoke-Producing Characteristics of Materials," J. Fire and Flammability, Vol. 5, p. 64, January 1974.

81. Williams, F.A., "Mechanisms of Fire Spread," Sixteenth Symposium (International) on Combustion, The Combustion Institute, pp. 12811294, 1976.

82. Yang, K.T. and Chang, C., "UNDSAFE-I: A Computer Code for Buoyant Flow in an Enclosure," NTIS: PB 278/OST.

*83. Yuen, W.W. and Tien, C.L., "A Simple Calculation Scheme for the Luminous-Flame Emissivity," Sixteenth Symposium (International) on Combustion held at MIT, Cambridge, Mass., Aug. 15-21, 1976.

84. W.D. Kennedy, "The Influence of the Memorial Tunnel Fire Tests on Transit Tunnel Fire Emergency Ventilation Analysis," Presented at the American Public Transit Association's 1997 Rapid Transit Conference Seminar on Ventilation of Transit Tunnels and Underground Stations, Washington, 7-11 June 1997, available from Parsons Brinckerhoff, One Penn Plaza, New York City, NY 10119.

85. Bechtel/Parsons Brinckerhoff, "Memorial Tunnel Fire Ventilation Test Program, Comprehensive Test Report," prepared for the Massachusetts Highway Department, November 1995.

APPENDIX I

NEW FEATURES IN SES VERSION 4.0

A. Compiler Selection

Two compilers were selected: Lahey 90 Version 3.0 and Microsoft Powerstation Version 4.0 (now called DEC Powerstation). The DOS version was compiled with Lahey and the Lahey/Interacter Starter Kit (LISK). The Windows version was compiled with Microsoft.

All subroutines that perform compiler-specific functions such as processing command line arguments and file open statements were collected into two files: DOSUTIL.FOR (for Lahey) and WINUTIL.FOR (for Microsoft). Following is a brief description of each of the subroutines included in these files:

• INITIALSETTINGS	Initializes QUICKWIN (Microsoft only)
• GETARGU	Gets the name of the specified input file from the command line and opens the input file for reading and the temporary output file for writing.
• OPENRRST	Opens the read restart file.
• OPENWRST	Opens the write restart file.
• OPENPRNT	Determines the path of the printer control file (PRINTER.CTL) and opens the temporary output file for reading and the formatted output file for writing.
• SETSTATUS	Sets up the display status window.
• UPDSTATUS	Updates the status window.
• SUBCLASSINIT	Sets up the frame and child windows (Microsoft only)
• CLEARSCR	Closes down the Interacter screen handling system. Although this subroutine is only used for the Lahey version it is also included, for compatibility, with the Microsoft version (without any statements) since it is called from DSES.

Additional differences between the two versions are:

- Microsoft: Statement "USE MSFLIB" is required at the top of DSHARE.
- Lahey: Requires the include file INTERACT.

B. SES Input Manager

The SES Input Manager (SESIN) is a graphical user interface developed using Visual Basic Version 4.0. SESIN provides a modern, interactive, Windows-based interface for developing and editing ASCII format SES input data files and for initiating execution of SES simulations. SESIN permits the user to view and enter SES input data using menu driven dialog boxes with tables, list boxes and other standard Windows data entry features. Files prepared or edited with SESIN are fully compatible with files prepared by the traditional editor method.

SESIN can simultaneously run two simulations (one from the batch list and one single file) and also permit input file editing while the simulations are performed. SESIN was designed for a default screen size of 640x480, but some limited scalability was also provided. The window size may be changed, but the fonts do not scale as it was not possible to implement consistent font scaling within the time and budget constraints. For additional details see the SESIN User's and Programmer's Manuals.

C. Increase program memory (array sizes) and modify program to make future array size increases easier.

The PARAMETER statement was used for the definition of the array size limits. Changes were made in DSHARE, DSHRHS, HEATUC and subroutines DSES, FORCE1, and FORCEL, HOOKUP, OMEGA2, OMEGA5 and PINPNT.

Because array the MONTHS is included in COMMON, it was necessary to remove the corresponding DATA statement from DSES. Array MONTHS is assigned values at execution time in subroutine DSES.

The new array sizes are as follows:

LMBLP:	20000
LMCLST:	75
LMCRPT:	12
LMCOND:	800
LMEQRM:	1350
LMEXPD:	101
LMFNTP:	75
LMLPK:	2220
LMLPLK:	2700
LMLSEG:	620
LMLSS:	1200
LMNLOP:	500
LMNODE:	600
LMNODX:	999
LMPRGP:	25
LMSCND:	5
LMSCTX:	999
LMSECT:	900
LMSS:	1600
LMSSTN:	2200
LMSTR:	50
LMTBL2:	20000
LMTHND:	600
LMTRAN:	75
LMTRGP:	25
LMTRRT:	20
LMTRSG:	8
LMTRTP:	16
LMTSRT:	620
LMUL:	50
LMVSEG:	406

LMCRPT is a new array size limit variable (refer to Appendix A for more details).

Array size limit LMSCND should not be less than 5.

D. Subroutine name changes

- ERROR ===> EERROR
- MAX ===> MMAX
- MIN ===> MMIN
- DECKRD ===> RSTREAD
- DECKPH ===> RSTWRITE

E. Correct known problems

1. T-Junction

   The problem was not specific to the T-Junction (Type #3). It was also found with either a "dividing wall termination junction" (Type #2), or an "angled junction" (Type 3).

   It appears that small round-off errors in the order of 1.0E-06 in the prediction of the air velocities cause errors in the calculation of the pressure drop across junctions (variable DELP) that ultimately lead to non-symmetric flows.

   The problem was fixed by rounding-off the variable DELP to six decimal places.

2. Unbalanced flow when a fire was being simulated

   This problem has not been completely resolved. The problem also appears to be caused by round-off errors. By rounding-off variable the BUOYS to six decimal places the problem is partially resolved.

3. Single control zone

   When only one control zone was used, the design temperature conditions for the zone were set to zero. Subroutine INPUT was revised.

4. Single section datasets

   Correction made in subroutine HOOKUP.

5. Wetted wall surface area

   When the evaporation option was set to 0 (bypass), the wetted surface area was excluded from the area used for the heat sink analysis. Subroutine INPUT was revised. Unless the evaporation option is set to 2, the percent wetted wall surface area entered is ignored.

6. Fire model's calculation of the heat transfer to the wall .

   Corrections were made in HEATUC and subroutine HEATUP. The criterion used for detecting an inflection point (critical point) in the wall heat flux function was changed from 0.005 to 0.0001 and the number of critical points was changed from 7 to 12. A new array size limit variable was defined (LMCRPT) for the maximum number of critical points. LMCRPT is defined via a PARAMETER statement in HEATUC. Various local one-dimensional arrays were changed to two-dimensional. With these changes, future increases in the maximum number of critical points would be accomplished just by changing the value of LMCRPT in HEATUC.

F. FORTRAN 90 compliance

Changes were made to FORMAT and READ/WRITE statements to eliminate all Hollerith formats ("1H0", "1H+" and "1H ").

The following variables were changed to CHARACTER type:

- TNUMV(LMTRAN)*2
- ITNLSS(LMLSS,LMTRRT)*2
- NAMLS(LMLSEG)*36
- NAMVS(LMVSEG)*36
- MONTHS(12)*9

Complete compliance with FORTRAN 90 requires that all arithmetic IF, assigned GOTO and computed GOTO statements be changed and all DO loops be modified to end at either a CONTINUE or an ENDDO statement. Arithmetic IF and assigned/computed GOTO statements are obsolete.

Arithmetic IF and computed GOTO statements are extensively used throughout the program and was not possible to update them given the project schedule and budget constraints.

G. File Management Structure

1. The program was modified to take advantage of PC file management capabilities. The new subroutine GETARGU gets the input filename from the command line. Unless an extension is specified the default input file extensions of INP or SES are assumed. The filename portion of the output and write restart files is the same as that of the input file. The default file extensions are:

   - Output files: TMP (raw output file), PRN (formatted output file)
   - Restart files: RST

   All files are opened as shared read only.

2. Opening the read and write restart files for input/output is done through the appropriate subroutines. To use a read restart file the user can either enter the name of the file at the end of the input file or append the entire restart file at the end of the input file. In this way, compatibility with Version 3 input files is maintained.

   CAUTION: Opening an input file with an appended restart file using SESIN will result in a loss of the appended restart file.

3. Subroutine DSES was modified such that the program does not check for the beginning of another data set once the current data set is processed and also it does not require a blank line at the end of the data set. The meaning of variable NEW was modified as follows:

- 0: Initial value at the beginning of simulation.
- 1: Fatal error occurred.
- 2: Normal simulation termination.

H. Printing Enhancements

Subroutine PRNTCONV was created to convert the raw output file (*.TMP) to the formatted, printer-ready file (*.PRN). The subroutine checks for the existence of the printer control file (PRINTER.CTL) and if the file is found, is read and each line is written to the top of the formatted output file. If the post-processing is successful, the raw output file is erased.

Every page of the formatted output file includes a header and footer. The footer contains the SES version number (maximum of five characters), the system description (first title line) and the page number. The footer contains the name of the input file (maximum of 80 characters), and the date and time of the simulation.

The PRINTER.CTL file distributed with SES Version 4 contains the escape sequence for double-sided, compress font printing on a Hewlett Packard Laserjet 4Si printer. The PRINTER.CTL file is installed in the program directory and can be modified for other printer types provided the name is not changed.

During a detailed print, because of the page width limitation (132 columns), only the first 14 train routes are shown.

I. New Program Features

1. A display window was added which shows the name of the input file being used, the time the simulation started, the total simulation time and the simulation status.
2. It is no longer necessary to enter the date on Form 1A. The number of title lines was increased to 20, each 80-character long. As each line is read the program checks for valid numeric input in columns 1 through 30 and blanks in columns 31 through 80 which will indicate the beginning of Form 1B.
3. Entering the number of portals in Form 1D is no longer required. For compatibility with Version 3 input files, however, the READ and FORMAT statements in subroutine INPUT were not changed and subsequent items in Form 1D were not re-located. The calculation of variable NOSYS was also modified.
4. When a value of zero is entered for the direction of fan operation the fan will not be operated during the simulation regardless of the values entered for the time to switch the fan ON or OFF.
5. The program was revised to accept a negative value for the delay time in Form 10. When a negative value is entered, a message is printed indicating that the train is to remain in that

position for the remaining of the simulation and the delay time is set internally to constant IZAP ($=2^{31}-1$) which represents the program equivalent of infinity for integer variables. When the initialization file writing option is used, a value of -1.0 is written for the delay time.

J. Other Program Modifications

1. The maximum number of iterations for heat sink convergence was increased from 20 to 50.
2. The following errors were changed from fatal to non-fatal: 11, 32, 33, 36, 94, 159. With the exception of Error #159, when an invalid data is entered, an error message is printed and a default value is used.
3. Error #130 was revised. It is now associated with the temperature tabulation increment instead of the number of portals.
4. The upper limit on the head loss coefficient for line segments and vent shafts was increased from 300 to 1000.
5. Changed train speed limit from 150 to 250 mph.
6. Changed FORMAT statements associated with FORM 4 to include "Fire/Unsteady Heat Source" and revised the wording of Error #140.
7. Added a new variable EXITCODE to indicate to SESIN whether or not a simulation was successful. If a simulation failed, the EXITCODE indicates the last successful stage. All STOP statements were changes to CALL EXIT (EXITCODE).
8. The following EQUIVALENCE statement was removed from DSHARE:

   ```
   EQUIVALENCE (SQWLLS(1),THCNLS(1,1)),(SQRDLS(1),THDFLS(1,1))
   ```

9. All input format statements were changed from F10.2 to F10.0. Format statements were also modified to handle simulation times in excess of 10000 seconds. All FORMAT statements were collected either to the beginning or end of each subroutine.
10. Changed FORMAT statements for Errors #133, 135 and 137 from I2 to I3.
11. Changed the word "ILLEGAL" to "INVALID" in all error messages.
12. Changed one of the supplementary output options from "INTERNAL" to "EXTERNAL".
13. The source code was checked to assure that all array limits have sufficient comment lines to adequately describe all arrays.

K. Changes to program variables and constants

1. The following variables were eliminated: BLANK, BLANK2, DATE, DATEI, NPORTL, SLASH, SLASH1, SLASH2, SYSTEM and SYSTMI.

2. The names of the following variables were changed:
   - DKROPT ===> RSTROPT
   - DKPOPT ===> RSTWOPT
   - ICHAR ===> IICHAR
   - INDEX ===> IINDEX
   - MAX ===> MAXI
   - PUNCH ===> RST
   - SIGN ===> SIGNS
3. The following common variables were added:
   a. DATETIME is a Character*20 variable used to store the date and time of the simulation as obtained from the system clock. The format is: DD MMM YYY HH:MM:SS

   b. EXITCODE is an integer variable indicating the status of the simulation as follows:
      - 1 - 13: Processing input forms 1 through 13.
      - 14: Reading data initialization file.
      - 15: Begin detail print of initial conditions.
      - 16: Simulation has been terminated through an error from subroutine SIMLAT.
      - 17: Simulation has been terminated through an error from subroutine DTHTS2.
      - 18 - 98: Not used.
      - 99: Input verification has been completed successfully.
      - 100: Simulation has been completed successfully.
      - 101: Simulation has been terminated due to an error opening specified input file.
      - 102: Simulation has been terminated due to an error opening temporary output file for writing.
      - 103: Simulation has been terminated due to an error opening specified restart file for reading.
      - 104: Simulation has been terminated due to an error opening specified restart file for writing.
      - 105: Simulation has been terminated due to an error opening temporary output file for reading.
      - 106: Simulation has been terminated due to an error opening specified formatted output file for writing.

   c. FILENAME is a Character*254 variable used to store the file name portion of the input file, i.e., without the file extension.

d. FOOTER is a Character*122 variable used to store the page footer of the formatted output file. It contains the name of the input file (up to a maximum of 80 characters) and the simulation date and time.

e. HEADER is a Character*116 variable used to store the page header of the formatted output file. It contains the SES Version number (maximum of five characters), the system description (first title line) and page number.

f. IDOT is an integer variable used to store the length of the variable FILENAME, excluding trailing blanks.

g. INPFILE is a Character*254 variable used to store the complete name of the input file as provided by the user at the command line (DOS version) or passed to the program through SESIN (Windows version).

h. NEWPAGE is an integer variable used to control page breaks during abbreviated and detailed prints. Used to coordinate page breaks between subroutines PRINT and SIMLAT. A value of 1 indicates that a page break has been written whereas a value of 2 indicates that no page break has been written.

i. PRNTCTRL is a Character*254 variable used to store the path of the printer control file PRINTER.CTL.

j. RESTART is a Character*254 variable used to store the name of the initialization file. For compatibility with Version 3 input files, this variable is also used to store the first line of a restart file that has been appended to the end of the input file.

k. SYSTEMI is a Character*132 variable used to store the ID of the initialized data file.

l. TITLE is a Character*80 variable used to read title descriptions such as for line segments, vent shafts etc.

4. The following common constants were added:

   a. IZAP is the program equivalent of infinity for integer variables. Defined in DSES as (2^{31}-1).

   b. LMCRPT is the array size limit of the two-dimensional heat flux arrays used in subroutine HEATUP. It represents the maximum number of inflection points (critical points) in the wall surface heat flux function.

   c. RST is the FORTRAN logical number of the write/read restart file.

   d. SESVER is a Character*5 constant used to store the SES Version number. Currently defined in DSES as '4.00 '. Changes to the length of this character variable would necessitate modifications to the definitions of variable HEADER as well as FORMAT statements in subroutines INPUT and SETSTATUS.

   e. ZAP is the program equivalent of infinity for real variables. Defined in DSES as 1.0E20.

L. Documentation Updates

1. The entire SES User's Manual was word processed. New chapters were added do describe the SES Input Manager. The chapter on field validation was also updated.
2. Modified the documentation to reflect the actual allowable range for the vent shaft stack height which is -1000 to 1000 feet.
3. Modified the description of the number of branch junctions to reflect the actual usage of this variable; that is, if is set to zero, the junction subroutines are bypassed.

   NOTE: Since the SESIN automatically calculates the number of branched junctions setting this value to zero can not be done through SESIN.
4. The User's Manual was modified to indicate the convention used for placement of fans in vent shafts with more that one subsegment. When more than one subsegment is used the fan is placed in the first subsegment.
5. Revised the dictionary of variables (RECORD.TXT) to indicate how to compute the maximum number of train stops which depends on the number of track sections, and the number of sections through which the route passes.
6. The term "Unsteady Heat Source" was changed to "Fire/Unsteady Heat Source".
7. Eliminated the words "card", "deck" and "punch" and replaced the word "illegal" with "invalid".

M. System Requirements

1. DOS Version

   IBM compatible PC using DOS Version 5.0 or later or Windows 3.1x with a minimum of 8MB of RAM. The minimum required disk space is 2 MB (5 MB if the source code is also installed). Although not required, a high-speed Laserjet printer with duplex capability is recommended.
2. Windows Version

   Windows 95 or NT 3.51 or later with a minimum of 7 MB hard disk space (9 MB if the source code is installed). Printer requirements are the same as for the DOS version.

N. Installation

1. DOS
   a. Insert Disk #1 in Drive A: and at the DOS prompt type A:\INSTALL.
   b. Press Enter and follow the instructions on the screen.

2. Windows NT 3.51
    a. Insert Disk #1 in Drive A: and from the Windows Program Manager choose Run... from the File menu.
    b. In the Command Line box type, A:\SETUP.
    c. Click OK and follow the instructions on the screen.
3. Windows 95 or NT 4.0
    a. Insert Disk #1 in Drive A:
    b. Choose Run... from the Start menu.
    c. In the Open box, type, A:\SETUP.
    d. Click OK and follow the instructions on the screen.

O. Execution

1. DOS
    a. At the DOS prompt type SES4D followed by the filename e.g., SES4D INFERNO.INP
    b. Use the DOS PRINT command to print an input, output or restart file.
2. Windows

To run SESIN from NT 3.51 click on the SESIN icon in the SES program group. For Windows 95 or NT 4.0, click on *Start*, select the SES folder and then select SESIN. To run the SES program from SESIN, select *Run* from the menu on the Main screen and then select *Current File* or *Batch Mode*. For additional details see the SESIN documentation.

To run SES for a group of files, click on the SES Batch icon or select it from the Start menu. SESBatch permits the selection of one or more SES files and then runs them one at a time, keeping a log of the status of each run. For additional details see the SESIN documentation.

Printing of input files can be done through SESIN. Printing of output files can be done through the DOS PRINT command or through word-processing programs such as Notepad, Word or Word Perfect.

APPENDIX J

SUBWAY ENVIRONMENT SIMULATION
INPUT MANAGER VERSION 4.0

PROGRAMMER'S REFERENCE

SESIN Programmer's Reference

Subway Environment Simulation Input Manager

v4.0

Programmer's Reference

United States Department of Transportation
Federal Transit Agency
John A. Volpe National Transportation Systems Center
1997

SESIN Programmer's Reference

1. INTRODUCTION

SESIN, the Windows interface for the Subway Environment Simulation (SES) program, provides an interactive Graphical User Interface (GUI) based environment for entering and editing SES data. The SES program is used by subway ventilation engineers as part of the design and analysis of subway ventilation systems. This analysis provides airflows and temperatures during both normal operations and emergency ventilation of fires.

The SES input data includes a general description of environmental and operational conditions, the geometry of the subway system, the physical and operational characteristics of the trains, the train routes and schedules, the fan operation characteristics, and the heat loads. Both routine heat loads from trains and passengers and emergency heat loads from fires are included. The input also includes the simulation parameters and output requirements.

The engineer enters the initial data describing the system and subsequently modifies this data, creating additional files for different types of analysis, each with numerous scenarios. Much of the initial data entry and many of the modifications are quite repetitive. The SESIN program provides support for both the original data entry and the numerous modifications. It also provides assistance with file management and setting up runs using the input files.

2. SCOPE

This document provides limited programming documentation for SESIN as a supplement to the User's Manual. It describes some of the general principles and programming practices followed, the class modules and some of their key methods, and the forms and some of the techniques used in their implementation.

It does not provide detailed documentation of each variable and subroutine or function used in the program, nor of every control used on each form.

The User's Manual provides details regarding the data associated with each control and the user's interface with the forms.

3. GENERAL PRINCIPLES

The program was developed using the 32 bit version of Visual Basic 4.0 for Windows 95 and Windows NT. Only those controls provided with Visual Basic Professional Edition were used in the program. Third party controls were avoided to maintain the broadest possible source code compatibility. Object oriented principles were used to the extent that they are supported by Visual Basic. All SES input data items are encapsulated in objects and accessed through methods. Some collections have been made public for efficiency.

Objectives

- PROVIDE AN EASY TO USE GUI INTERFACE FOR SES INPUT.
- Simple initial data entry, reducing redundancy and typing errors.
- Simple modification of data files for different scenarios.
- Provide logical organization and presentation of data while maintaining the essential data structure previously defined for the SES program.
- Identify units and allowable range of values for all data items.
- Provide immediate value checking at the field level, but allow the user to enter invalid values as markers or for special circumstances.
- Permit saving and retrieving of partial (incomplete) files.
- Provide capability to copy sections, segments, routes, trains.
- Provide sufficient on-line help information to explain procedures and data fields.
- Provide automatic counting of sections, segments, vent shafts, fan types, heat sources, train types, train routes, etc., i.e. everything that needs to be counted.
- Use standard Windows conventions for screen layout and interface conventions.
- Provide "batch" processing (selection and execution of multiple SES files).

Forms and Classes

The program consists of class modules defining the data and methods for manipulating it and form modules to display and modify the data. (To avoid confusion between Visual Basic Forms and SES Input File Forms, the user documentation refers to VB forms as screens. In this document, forms generally refers to VB forms. Any reference to SES Input Forms will be qualified as such.) A few common procedures are included in separate code modules.

The class modules contain the definitions of all the SES input data. The modules are divided by data type much like the Forms in the definition of the SES input file in the SES documentation.

Data Validation and Updating

In order to provide the best combination of user assistance and flexibility, a prompt is displayed showing the range of allowable values currently permitted by the SES program for each data field as it gets the focus. If the data is modified, the new value is checked against the allowable limits as soon as the field loses focus. If the value is non-numeric or is outside the allowable range, a message box is displayed specifying the allowable range and permitting the user to go back and try again or to continue on. The check is only made if the field has been modified for two reasons: 1) it permits the user to go on to the next field if they decide not to correct the value; and 2) it prevents repetitious error messages when the focus passes through fields which have been deliberately left out of bounds.

Within tables, each field is checked against range limitations for the individual data item, but is not compared to other input values due to the difficulty in accessing values from a table.

As a general (but not unbreakable) rule, the data entered on a form is not updated in the object until the OK button is pressed or the next record is selected, depending on the type of data involved. If the Cancel button is pressed, the form is closed and the object data for the current record is not updated. One specific exception is on the Line and Vent Section forms where the data is updated field by field. This is done to avoid bookkeeping problems with the associated line segments and vent shafts.

The data file is never updated until the user specifically requests File/Save or selects Run/Current File. Whenever a field is modified, a change flag is set and, if the changes are not cancelled, a FileDirty flag is set to indicate changes have been made. When the file is saved, the FileDirty flag is cleared. When exiting the program or clearing the data for a new file, the FileDirty flag is checked and, if it is set, the user is asked if they want to save the changes. This flag is managed aggressively to err on the side of assuming changes have been made when they may not have been.

SESIN Class Association Diagram

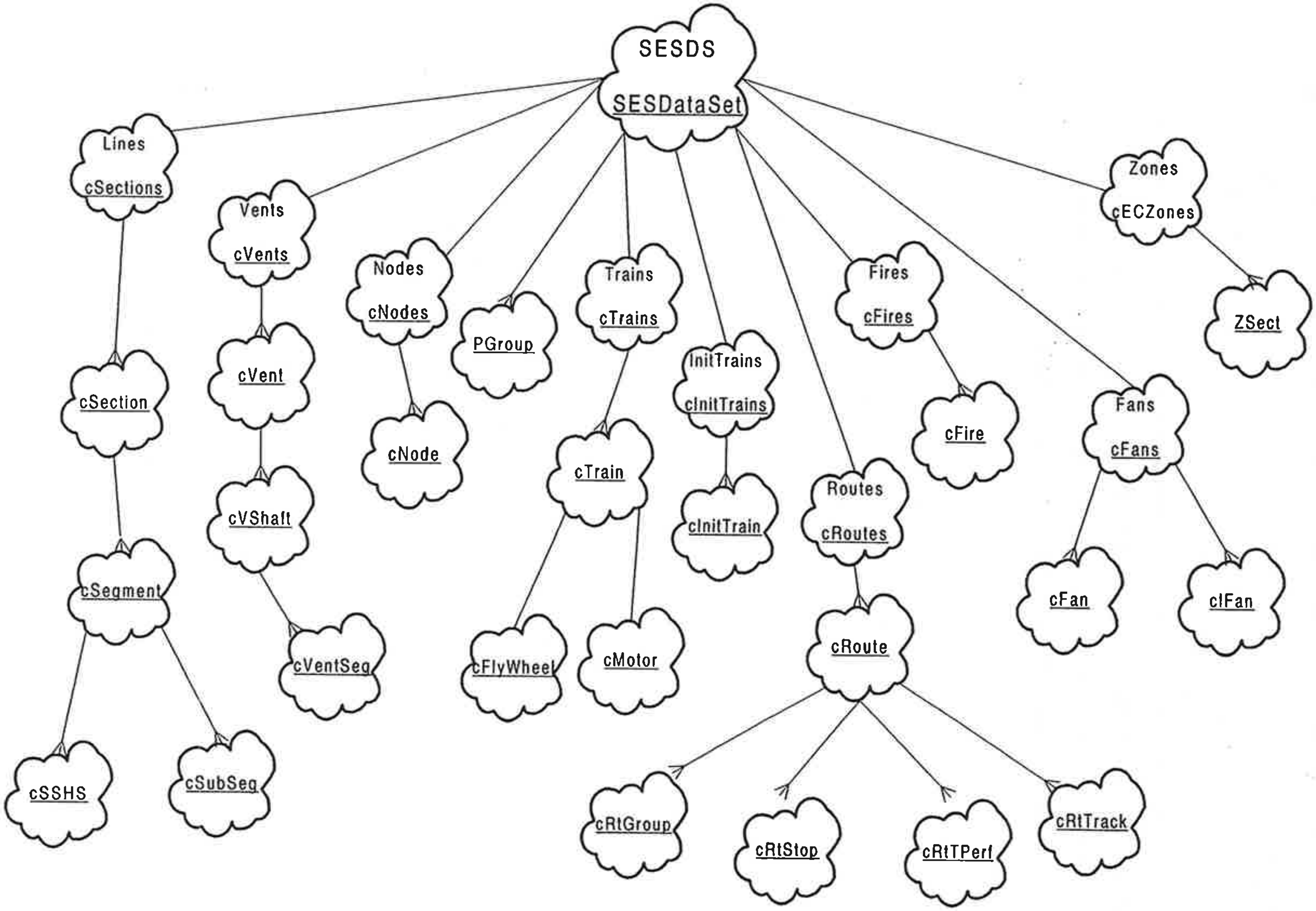


Figure 1 - Class Structure

4. CLASSES

The overall structure of the data classes is shown in Figure 1. In general, the Misc module contains a global object, SESDS, of the SESDataSet class which is accessible to the rest of the program. SESDS contains most of the individual data items from SES Input Forms 1, 12 and 13 and collection management classes for most of the other data.

In order to avoid the need for program modifications when SES array sizes are changed, nearly all the repetitive data is kept in collections rather than arrays. One exception is the print group objects which are kept in a 25-element array. Where objects are fairly simple, a simple collection is used, but most often, a separate collection management class is used to handle management of the individual objects.

SES Data is defined as properties of the appropriate classes and accessed through Get/Set/Let property methods or, in cases where numerous items are typically updated at the same time, through special Get/Set methods which handle numerous data items simultaneously. As described previously, data validation is done at the field level on the form and is, therefore, not repeated in the data access methods in the classes.

All class modules are described in this section. The properties in each class are primarily SES data items and are documented in the SES documentation and the field definitions of the SESIN User's Manual. These definitions are not repeated here. Only significant properties which are not SES data are described. All methods in each class are listed with brief descriptions where appropriate. Simple data access methods are not described.

Since Visual Basic does not support inheritance, some methods are common to many classes. These methods will be listed for each class but will only be described the first time they are encountered.

SES Data Set

The SES Data Set object (SESDS) has all the individual (unique) data fields as properties and has containers or container management objects for collections of other objects.

Properties:

Most of the Form 1 and Form 12 & 13 data are direct properties of the SESDS. In addition, the SESDS includes the following collection management objects:

Obect	Class	Description
Lines	cSections	Line Sections (Line sections containing their own segments)
Vents	cVents	Vent Sections (Vent section containing their own shafts)
Nodes	cNodes	Node description data
Fans	cFans	All Fans (Supply/Exhaust and Impulse)
Obect	Class	Description
Fires	cFires	Fires (Unsteady State Heat Sources) (Form 4)
ECZones	cECZones	Environmental Control Zones (Form 11)

Routes	cRoutes	Train Routes
Trains	cTrains	Train Descriptions
InitTrains	cInitTrains	Train Initialization Data (Form 10)

Methods:

Sub AddPGroup(pg As cPGroup)

Adds a Print control group (Form 12) to the array of groups in SESDS.

Sub ClrPGroup()

Deletes all Printer Control Groups

Public Function PGroup(i As Integer) As cPGroup

Return the i^th^ printer control group object. The array is private to SESDS.

Public Sub ReadFile

Reads a data file. The SES Form 1, 12 and 13 data is read directly by this routine. The Read*xxxx* routines in other collection objects are called to read other types of data. These routines typically create objects and call their ReadData routines to actual access of the file.

Each of the routines called uses On Error statements and the Err object to check for input errors and returns a flag to indicate success or failure. The SES Input Form number being read is stored in a publicly accessible property variable at the object level and is used for error reporting. If an input error is detected, the file is closed and a message box informs the user of the SES Input Form number where the error was detected. This may or may not be where the problem actually occured. It is typically where the program has gotten out of sync with the input file and is trying to read a text description as a number. The actual error may often have occurred some time earlier in the file.

Public Sub getCounts(nnls, nnlsec, nnvsec, nnnode, nnumul, nnfntyp, nniftyp, nntrrte, nntrtyp, nnclust, nntrain)

Gets the number of each type of data item. Used by the DataCounts form and by the WriteFile procedure.

Public Sub WriteFile()

Writes the data to the file. As with Read data, this method reads the Form 1, 12 and 13 data directly and calls the Write*xxxx* routines in the collection objects for the rest of the data.

Private Sub Class_Initialize()

Initializes the SESDataSet Class by setting initial data values and allocating the collections.

Private Sub Class_Terminate()

Performs cleanup by de-allocating all the collections and releasing their objects.

<u>cSections</u>

cSections is a special class to manage collections of Line Sections. It contains a collection to hold all the line sections in the data set and separate section objects to hold the current default values and the currently cut or copied section. It also contains the default buffer for segment data since this is the lowest level common to all segments. (The segment copy buffer is maintained by the segment form.)

Properties:

colSects - Collection to hold line sections.
DefaultSect - Section object to hold default values.
BufferSect - Section object to hold cut/copy values.
DefaultSeg - Segment object to hold default values.

Methods:

Public Function Add(ni As Integer) As cSection

Adds a selection to the collection at location *ni* (at the end if *ni* is zero) and calls Xcopy to copy the data from *BufferSect* into it. A reference to the section object is returned as the value of the function.

Public Sub Copy(isect As Integer)

Calls Xcopy to Copy the data from section *isect* into the copy buffer, *BufferSect.*

Public Sub SectList(gg As Grid)

Fills the grid control, *gg*, with the section numbers.

Public Sub SectShortList(LL As ListBox, rr As ListBox)

Fills the listbox control, *LL*, with a list of all the sections that are not in listbox *rr.*

Public Sub SetDefault(isect As Integer)

Calls Xcopy to Copy the data from section *isect* to *DefaultSect* as the new default section definition.

Public Sub Cut(isect As Integer)

Calls Xcopy to Copy the data from section *isect* into the copy buffer, *BufferSect.* Section *isect* is then deleted.

Public Function Delete(ni As Integer)

Deletes section *ni* from the collection. No copy is kept.

Public Function Paste(isect As Integer) As cSection

Creates a new section at position *isect* and calls Xcopy to copy the data from *BufferSect* into it. Returns a reference to the new object as the value of the function.

Public Function ReadSections(nn As Integer) As Boolean

Creates *nn* section objects, invoking the ReadData method of each to read the data from the file. Returns True if successful; False if an error occurs.

Public Function ReadSegments() As Boolean

Loops through all the sections, creating the specified number of segment objects for each one and invoking their ReadData methods to read the data from the file.

Public Function Section(sid) As cSection

Returns a reference to the sid^{th}section.

Public Sub SegCol(cc As Collection)

Loops through all the line sections to fill the collection, *cc*, with all the line segments in the correct sequence.

Public Sub SegList(gg As Grid, cc As Collection)

Similar to SegCol except that the Grid *gg* is filled with the Line and Segment Numbers.

Public Sub SegZList(cc As Collection)

Loads *cc* with environmental control zone segment, ZSect, objects for each segment.

Public Sub WriteSections()

Loops through all the sections writing the SES Form 2A data to the data file.

Private Sub Class_Initialize()

Initializes the default section, *DefaultSect*, and segment, *DefaultSeg*. Clears the copy buffer section.

Private Sub Class_Terminate()

Frees all collection members and deallocates the default and copy buffer objects.

<u>cSection</u>

cSection is the class definition for all of the section objects. Its properties consist of the data items for a single section, including a collection of one or more Line Segment objects.

Methods:

Public Sub DelSeg(ss As cSegment)

Finds segment *ss* in this section and deletes it.

Public Function InsertSeg(ss As cSegment, Bfore As Boolean) As cSegment

Inserts a copy of the default segment before or after segment *ss* depending on the value of *bfore*.

Public Function ReadSegs() As Boolean

Creates segment objects for each segment in the section and invokes the ReadData method of each segment to read the description from the data file.

Public Function AddSeg() As cSegment

Adds a new segment to the current section.

Public Sub ReadData()

Reads the Form 2A data for this section from the data file.

Public Sub WriteData()

Writes the Form 2A data for this section to the data file.

Public Sub WriteSegs()

Loops through each of the segments in the section and invokes the WriteData method of each.

Public Sub XCopy(ssrc As cSection)

Copies the data from ssrc, including all its segments.

Private Sub Class_Initialize()

Sets the number of segments to zero. Other data must be filled in by the routine which creates the object, either explicitly or by invoking Xcopy with a source section.

Private Sub Class_Terminate()

Deletes all segments.

cSegment

cSegment defines the SES Form 3 data for one line segment. Collections of cSegment objects are maintained by each section object.

Properties:

The cSegment properties include SES Form 3A, 3B and 3E data items and collections for subsegment and steady state heat load data. There is also a pointer to the owning section object.

colSubs	cSubSeg	Subsegment data (SES Form 3C). Contains one or more subsegment objects.
colSSHS	cSSHS	Steady state heat source data (SES Form 3D). May be empty.
Daddy	cSection	Reference to parent section object.

Methods:

Public Function AddSSHS() As cSSHS

Adds a steady state heat source and returns a reference to it as the value of the function.

Public Function AddSubSeg() As cSubSeg

Adds a subsegment and returns a reference to it as the value of the function.

Public Sub ClearSSHS()

Frees all steady state heat sources.

Public Sub ClearSubs()

Frees all subsegments

Public Sub SSHSList(gg As Grid)

Loads the grid control, *gg*, with steady state heat source data.

Public Sub SubList(gg As Grid)

Loads the grid, *gg*, with subsegment data.

Public Sub WriteData()

Writes SES Form 3 data to the data file.

Public Function SubSeg(ii As Integer) As cSubSeg

Returns a reference to subsegment ii.

Public Function SSHS(ii As Integer) As cSSHS

Returns a reference to steady state heat source ii.

Public Function ReadData() As Boolean

Reads SES Form 3 data from the data file.

Public Sub XCopy(ssrc As cSegment)

Private Sub Class_Initialize()

Sets default values and creates an initial subsegment.

Private Sub Class_Terminate()

Clears SSHS's and SubSeg's

<u>cSubSeg</u>

cSubSeg defines one line subsegment. Collections of cSubSeg objects are maintained by each line segment.

Properties:

SES Form 3C data items.

Methods:

Public Sub getSubSeg(n1 As Integer, n2 As Integer, TWall As String, TDry As String, TWet As String)

Returns subsegment data.

Public Function ReadData() As Boolean

Reads SES Form 3C data. Returns True for success; False for failure.

Public Sub setSubSeg(n1 As Integer, n2 As Integer, TWall As String, TDry As String, TWet As String)

Sets subsegment values from the arguments.

Public Sub WriteData()

Writes SES Form 3C data to the data file.

Public Sub XCopy(src As cSubSeg)

Private Sub Class_Initialize()

<u>cSSHS</u>

cSSHS contains the data for one steady state heat source (SES Form 3D). Collections of cSSHS objects are maintained by line segments.

Properties:

SES Form 3D data items.

Methods:

Public Function ReadData() As Boolean

Reads SES Form 3D data from the data file.

Public Sub setSSHS(n1 As Integer, n2 As Integer, T As Integer, HS As String, HL As String, id As String)

Sets steady state heat source data values from the arguments.

Public Sub getSSHS(n1 As Integer, n2 As Integer, T As Integer, HS As String, HL As String, id As String)

Gets steady state heat source data values into the arguments.

Public Sub WriteData()

Writes SES Form 3D data to the data file.

Public Sub XCopy(ss As cSSHS)

Private Sub Class_Initialize()

cVents

cVents is a special class to manage collections of Vent Sections. It contains a collection to hold all the vent sections in the data set and separate section objects to hold the current default values and the currently cut or copied section. It also contains the default buffer for vent shaft data since this is the lowest level common to all segments. (The vent shaft copy buffer is maintained by the shaft form.)

Properties:

colVents	- Collection to hold vent sections.
DefaultVent	- Section object to hold default values.
BufferVent	- Section object to hold cut/copy values.
DefaultShaft	- Segment object to hold default values.

Methods:

The methods for cVents are very similar to those for cSections. Refer to cSections for definitions not provided here.

Public Function Add(ni As String) As cVent

Public Function Copy(isect As Integer)

Public Sub VentList(gg As Grid)

Public Sub SetDefault(ivent As Integer)

Public Sub Cut(ivent As Integer)

Public Function Paste(ivent As Integer) As cVent

Public Function Delete(ni As Integer)

Public Function ReadVShafts() As Boolean

Public Function ReadVents(nn As Integer) As Boolean

Public Sub WriteVents()

Public Function vent(Vid) As cVent

Public Sub WriteVShafts()

Public Sub VentZList(cc As Collection)

Public Sub VShaftList(gg As Grid, cc As Collection)

Public Sub FanList(gg As Grid, cc As Collection)

Loops through all the vent sections to load the grid and collection with data for the fan table form.

Private Sub Class_Initialize()

Private Sub Class_Terminate()

cVent

The cVent class defines one vent section. cVent is very similar to cSection except that since there can only be one shaft per vent, there is only a shaft object instead of a collection, and fewer methods since there is no collection to be managed.

Properties:

SES Form 2B data items.

uVShaft	cVShaft	Vent Shaft Object for this Vent Section. (Not a collection.) This object is public for coding efficiency purposes. There is little to be gained by making it private and providing a method to access it.

Methods:

All the methods are very basic in nature.

Public Function ReadFile() As Boolean

Public Sub WriteData()

Public Sub XCopy(ssrc As cVent)

Private Sub Class_Initialize()

Creates a cVShaft object and sets its parent reference.

Private Sub Class_Terminate()

Frees the vent shaft object.

cVShaft

One cVShaft object is allocated in each cVent object. It contains the data for one vent shaft.

Properties:

SES Form 5 Data.

colVSegs	cVSeg	Collection of Vent segments.
Daddy	cVent	Reference to the parent Vent Section.

Methods:

Public Function ReadData() As Boolean

Public Sub WriteData()

Public Function AddVSeg() As cVentSeg

Adds a vent segment to colVSegs and returns a reference to it.

Public Sub ClearVSegs()

Clears colVSegs.

Public Sub SubList(gg As Grid)

Loops through the subsegment collection to load *gg* with the subsegment data for this shaft.

Public Sub XCopy(vs As cVShaft)

Private Sub Class_Initialize()

Private Sub Class_Terminate()

cVentSeg

cVentSeg objects contain the data for one vent segment (SES Form 5D). A collection of cVentSeg objects is kept by each vent shaft object.

Properties:

SES Form 5D data items.

Methods:

Public Sub getVSeg(sLen As String, Area As String, Perim As String, FPHL As String, FNHL As String, BPHL As String, BNHL As String)

Gets the data for a vent segment into the arguments.

Public Function ReadData() As Boolean

Public Sub setVSeg(sLen As String, Area As String, Perim As String, FPHL As String, FNHL As String, BPHL As String, BNHL As String)

Sets the data for a vent segment from the arguments.

Public Sub WriteData()

Public Sub XCopy(src As cVentSeg)

Private Sub Class_Initialize()

<u>cNodes</u>

cNodes is the collection management function for node data. It contains a collection of nodes and the default and copy buffer node objects.

Properties:

colNodes	collection	Collection of cNode objects.
DefaultNode	cNode	Default Node object.
BufferNode	cNode	Copy Buffer Node object.

Methods:

Public Function Add(ni As Integer) As cNode

Public Sub Copy(nn As Integer)

Public Sub Cut(nn As Integer)

Public Sub Delete(indx As Integer)

Public Sub NodeList(gg As Grid)

Loads *gg* with node numbers.

Public Sub Paste(nn As Integer)

Public Function ReadNodes(nn As Integer) As Boolean

Public Sub SetDefault(nn As Integer)

Public Sub WriteNodes()

Private Sub Class_Initialize()

Private Sub Class_Terminate()

<u>cNode</u>

The cNode object contains the data for one node. A collection of cNode objects is maintained by the Nodes object in SESDS.

Properties:

Because different types of nodes require different data items, the cNode object contains general properties that are used as needed by different node types. The aerodynamic and thermodynamic type properties are accessed via the AType and TType property methods. Other data is accessed and updated through special Get/Set methods described below.

Methods:

The GetA*n*/SetA*n* and GetT*n*/SetT*n* methods Get and Set the appropriate data for Aerodynamic and Thermodynamic node type *n*.

Public Sub GetA1(i1 As Integer, i2 As Integer, i3 As Integer, i4 As Integer, AR As String)
Public Sub GetA2(i1 As Integer, i2 As Integer, i3 As Integer)
Public Sub GetA3(i1 As Integer, i2 As Integer, i3 As Integer, AR As String)
Public Sub GetA4(i1 As Integer, i2 As Integer, i3 As Integer, AR As String, AA As String)
Public Sub GetA5(i1 As Integer, i2 As Integer, i3 As Integer, AR As String, AA As String)
Public Sub SetA1(i1 As Integer, i2 As Integer, i3 As Integer, i4 As String, AR As String)
Public Sub SetA2(i1 As Integer, i2 As Integer, i3 As Integer)
Public Sub SetA3(i1 As Integer, i2 As Integer, i3 As Integer, AR As String)
Public Sub SetA4(i1 As Integer, i2 As Integer, i3 As Integer, AR As String, AA As String)
Public Sub SetA5(i1 As Integer, i2 As Integer, i3 As Integer, AR As String, AA As String)
Public Sub GetT3(s1 As String, s2 As String, s3 As String, s4 As String, s5 As String, s6 As String)
Public Sub SetT2(s1 As String, s2 As String, s3 As String, s4 As String, s5 As String, s6 As String, s7 As String)
Public Sub SetT3(s1 As String, s2 As String, s3 As String, s4 As String, s5 As String, s6 As String)
Public Sub GetT2(s1 As String, s2 As String, s3 As String, s4 As String, s5 As String, s6 As String, s7 As String)
Public Function ReadData() As Boolean
Public Sub WriteData()
Public Sub XCopy(nn As cNode)
Private Sub Class_Initialize()

cFires

cFires is the collection management class for fire heat sources. It is maintained as Fires in SESDS. Usually there is only one fire source per run but more are possible.

Properties:

colFires	Collection of cFire objects.

Methods:

Public Function Add() As cFire
Public Sub Clear()

Clears the collection, freeing all objects.

Public Sub Delete(indx As Integer)

Public Sub FireList(gg As Grid)

Loops through the collection to load *gg* with fire data.

Public Function ReadFires(nn) As Boolean

Public Sub WriteFires()

cFire

Each cFire object contains the data for one fire source. All cFire objects are maintained in the cFire object SESDS.Fires.

Properties:

SES Form 4 Data.

Methods:

Public Sub SetFire(FID As String, ixseg As Integer, ixsub As Integer, HSens As String, HLatent As String, TStart As String, TStop As String, TFlame As String, Area As String)

Sets the data for one fire source into the arguments.

Public Sub GetFire(FID As String, ixseg As Integer, ixsub As Integer, HSens As String, HLatent As String, TStart As String, TStop As String, TFlame As String, Area As String)

Gets the data for one fire source from the arguments.

Public Function ReadData() As Boolean

Public Sub WriteData()

Public Sub XCopy(ff As cFire)

Private Sub Class_Initialize()

cFans

cFans is the collection management class for both Supply/Exhaust and Impulse fans. *SESDS.Fans* is a cFans object containing all the fan objects for the data set.

Properties:

colFans		Collection of cFan objects.
BufferFan	cFan	Copy buffer for Supply/Exhaust Fans.
collFans		Collection of clFan objects.
BufferlFan	clFan	Copy buffer for impulse fans.

Methods:

The methods with an I added to the name are for Impulse fans; the others are for Supply/Exhaust fans.

Public Function Add(ii As Integer) As cFan

Public Function AddI(ii As Integer) As clFan

Public Sub Copy(ii As Integer)

Public Sub Cut(ii As Integer)

Public Sub CopyI(ii As Integer)

Public Sub CutI(ii As Integer)

Public Sub Delete(indx As Integer)

Public Sub DeleteI(indx As Integer)

Public Sub Paste(ii As Integer)

Public Sub PasteI(ii As Integer)

Public Sub List(cc As ComboBox)

Loads the fan type selection combo box used by the Shaft and FanTable forms.

Public Function ReadFans(nn As Integer, ni As Integer) As Boolean

Public Sub WriteFans()

Private Sub Class_Initialize()

cFan

Each cFan object contains the data for one supply/exhaust fan.

Properties:

SES Form 7A & 7B data.

Methods

Public Sub getFan(id As String, rho As String, runup As String, QLow As String, QHi As String, FanP() As String, FanQ() As String)

Public Sub setFan(id As String, rho As String, runup As String, QLow As String, QHi As String, FanP() As String, FanQ() As String)

Public Function ReadData() As Boolean

Public Sub WriteData()

Public Sub XCopy(ff As cFan)

Private Sub Class_Initialize()

clFan

Each cFan object contains the data for one impulse fan.

Properties

SES Form 7C data.

Methods

Public Sub GetlFan(FanQ As String, Feff As String, fVel As String, TmOn As Integer, TmOff As Integer)

Public Sub SetlFan(FanQ As String, Feff As String, fVel As String, TmOn As Integer, TmOff As Integer)

Public Function ReadData() As Boolean

Public Sub WriteData()

Public Sub XCopy(ff As clFan)

cECZones

cECZones is the collection management class for Environmental Control Zones. It is maintained as SESDS.Zones.

Properties

colECZones		Collection of cECZone objects.
bufferECZone	cECZone	Copy buffer.

Methods:

Public Function Add(indx As Integer) As cECZone

Public Sub Copy(ii As Integer)

Public Sub Paste(ii As Integer)

Public Sub Delete(indx As Integer)

Public Function ReadECZones(nn As Integer) As Boolean

Public Sub WriteECZones()

Private Sub Class_Initialize()

Private Sub Class_Terminate()

cECZone

Each cECZone object is kept in SESDS.Zones and contains the data for one environmental contol zone. Depending on the Zone type, the collection of section numbers may include Line or Vent sections or both.

Properties:

SES Form 11A data.

colZSects	Collection of Line and/or Vent Section IDs as strings with - sign if required.

Methods:

Public Sub getZone(nType As Integer, s1 As String, s2 As String, s3 As String, s4 As String)

Gets the zone type and temperature data, but not the section list.

Public Sub setZone(nType As Integer, s1 As String, s2 As String, s3 As String, s4 As String)

Sets the zone type and temperature data, but not the section list.

Public Sub ZSectList(LL As ListBox, cc As Collection)

Clears the listbox and then loops through the zone's section list putting the matching section IDs from *cc* in the list box.

Public Sub ZSectSave(LL As ListBox)

Clears the section list and replaces it with the section IDs in *LL*.

Public Sub ZSectStrip(cc As Collection)

Called by ECForm's Form_Load method to mark this zone's segments as used in the Zsect objects in *cc*.

Public Function ReadData(nn As Integer) As Boolean

Public Sub WriteData()

Public Sub XCopy(EZ As cECZone)

Private Sub Class_Initialize()

Private Sub Class_Terminate()

ZSect

ZSect is a simple class used to track the type and assignment status of sections for the Environmental Control Zone form, *ECZone*. The form calls ZList methods in the Lines and Vents objects to build a collection of ZSect objects and then updates the used status to keep track of which sections are currently in use and which are available. Use of this class simplifies the bookkeeping required when adding and deleting sections to different zone types.

Properties:

Public sid As String	Line or Vent ID
Public vent As Boolean	True if it is a vent
Public used As Boolean	True if currently assigned to a zone

Methods:

None

cRoutes

This is the collection class for all the train route data.

Properties:

colRoutes	collection of cRoute	The routes defined in the system.
BufferRoute	cRoute	The copy buffer.

Methods:

Public Function Add(ii As Integer) As cRoute

Public Sub Copy(ii As Integer)

Public Sub Cut(ii As Integer)

Public Sub Paste(ii As Integer)

Public Sub Delete(indx As Integer)

Public Function ReadRoutes(nn As Integer) As Boolean

Public Sub WriteRoutes()

Private Sub Class_Initialize()

Private Sub Class_Terminate()

cRoute

cRoute contains the data for one train route.

Properties:

Form 8 Data.

colTGroups	collection of cRtGroups	Train Groups.
colTrack	collection of cRtTrack	Alignment (grade and curve) data.
colStops	collection of cRtStops	Train Stops.
colTrnPerf	collection of cRtTPerf	Train Performance data.
colTSects	collection of integers	Signed Segment numbers through which route passes.

Methods:

The various Save and List methods load and unload the collection data to and from the grid or listbox passed as an argument.

Public Sub GetRoute(sid As String, s0 As String, s1 As String, s2 As String, s3 As String, n1 As Integer, n2 As Integer, n3 As Integer)

Public Sub SetRoute(sid As String, s0 As String, s1 As String, s2 As String, s3 As String, n1 As Integer, n2 As Integer, n3 As Integer)

Public Function ReadData() As Boolean

Public Sub TGroupList(gg As Grid)

Public Sub TGroupSave(gg As Grid)

Public Sub TStopList(gg As Grid)

Public Sub TStopSave(gg As Grid)

Public Sub TPerfList(gg As Grid)

Public Sub TPerfSave(gg As Grid)

Public Sub TrackList(gg As Grid)

Public Sub TrackSave(gg As Grid)

Public Sub TSectList(LL As ListBox)

Public Sub TSectSave(LL As ListBox)

Public Sub WriteData()

Public Sub XCopy(rr As cRoute)

Private Sub Class_Initialize()

Private Sub Class_Terminate()

cRtGroup

Each cRtGroup object contains the data for one train group and is kept in the colTGroup collection of its cRoute object.

Properties:

SES Input Form 8B data.

Methods:

Public Sub getRtGroup(n1 As Integer, n2 As Integer, n3 As Integer)

Public Function ReadData() As Boolean

Public Sub setRtGroup(n1 As Integer, n2 As Integer, n3 As Integer)

Public Sub WriteData()

Public Sub XCopy(src As cRtGroup)

Private Sub Class_Initialize()

cRtStop

Train Stop Data. Each object contains the data describing one stop on the route.

Properties:

SES Input Form 8D data.

Methods:

Public Sub getRtStop(s1 As String, s2 As String, s3 As String)

Public Function ReadData() As Boolean

Public Sub setRtStop(s1 As String, s2 As String, s3 As String)

Public Sub WriteData()

Public Sub XCopy(src As cRtStop)

Private Sub Class_Initialize()

cRtPerf

Train performance data. Each object contains one speed vs time data point with acceleration and deceleration resistor power input.

Properties:

SES Input Form 8E data.

Methods:

Public Sub getRtTPerf(s1 As String, s2 As String, s3 As String, s4 As String)

Public Function ReadData() As Boolean

Public Sub setRtTPerf(s1 As String, s2 As String, s3 As String, s4 As String)

Public Sub WriteData()

Public Sub XCopy(src As cRtTPerf)

Private Sub Class_Initialize()

cRtTrack

Each cRtTrack object contains the geometry alignment description and related data for one continuous section of track.

Properties:

SES Input Form 8C data.

Methods:

Public Sub getRtTrack(s1 As String, s2 As String, s3 As String, s4 As String, s5 As String, n1 As Integer, n2 As Integer)

Public Function ReadData() As Boolean

Public Sub setRtTrack(s1 As String, s2 As String, s3 As String, s4 As String, s5 As String, n1 As Integer, n2 As Integer)

Public Sub WriteData()

Public Sub XCopy(src As cRtTrack)

Private Sub Class_Initialize()

<u>cTrains</u>

This is the collection class which manages train definitions. It is maintained as Trains in SESDS.

Properties:

colTrains	collection of cTrain	All the train definitions.

Methods:

Public Function Add(indx As Integer)

Public Sub Delete(indx As Integer)

Public Sub Copy(ii As Integer)

Public Sub Cut(ii As Integer)

Public Sub Paste(ii As Integer)

Public Function ReadTrains(nt As Integer) As Boolean

Public Sub WriteTrains()

Private Sub Class_Initialize()

Private Sub Class_Terminate()

<u>cTrain</u>

Each cTrain object contains one set of SES Input Form 9 data, i.e. the definition of one train.

Properties:

SES Input Form 9A-E and J Data

Tmotor	cMotor	Motor and Controller data.
TFlyWheel	cFlyWheel	Flywheel data (if required).

Methods:

Due to the large number of data fields, the Get and Set routines are grouped by category and closely parallel the corresponding SSPanel and textbox controls on the trains form.

Public Sub GetPhysical(ByRef sid As String, ByRef nCars As String, nPwrd As String, Mtr As String, TLen As String, AFront As String, Perim As String, CWt As String)

Public Sub SetPhysical(ByRef sid As String, ByRef nCars As String, nPwrd As String, nMtr As String, TLen As String, AFront As String, Perim As String, CWt As String)

Public Sub getResist(CSkin As String, CTruck As String, CFront As String, CRR1 As String, CRR2 As String, CRR3 As String, ARRP As String)

Public Sub setResist(CSkin As String, CTruck As String, CFront As String, CRR1 As String, CRR2 As String, CRR3 As String, ARRP As String)

Public Sub getHtLoads(SAux As String, LAux As String, sPac As String, lPac As String, paux As String, ppac As String)

Public Sub setHtLoads(SAux As String, LAux As String, sPac As String, lPac As String, paux As String, ppac As String)

Public Sub getRGrid(ss() As String)

The resistor grid data textboxes are defined as an array of controls and the data is accessed and returned in the same form.

Public Sub setRGrid(ss() As String)

Public Sub getRates(AMax As String, DV1 As String, V1 As String, DV2 As String, V2 As String)

Public Sub setRates(AMax As String, DV1 As String, V1 As String, DV2 As String, V2 As String)

Public Function ReadData() As Boolean

Public Sub WriteData()

Public Sub XCopy(TT As cTrain)

Private Sub Class_Initialize()

Private Sub Class_Terminate()

cMotor

Each cMotor object contains the motor and controller description for one train. It is contained within a cTrain object.

Properties:

SES Input Form 9F,G, H & I data.

Methods:

Motor and Controller data is set and returned through arrays which match the corresponding arrays of textboxes on the Trains form.

Public Sub getMtrSpecs(id As String, Spec() As String)

Gets the SES Input Form 9F motor description data.

Public Sub setMtrSpecs(id As String, Spec() As String)

Sets the above data.

Public Sub getMtrData(MData() As String)

Gets the motor speed vs tractive effort and current data (SES Input Form 9G).

Public Sub setMtrData(MData() As String)

Sets the above data.

Public Sub getChopper(LI() As String, Chop() As String)

Gets chopper controller data.

Public Sub setChopper(LI() As String, Chop() As String)

Sets the above data.

Public Sub getCam(Cam() As String)

Gets cam controller data

Public Sub setCam(Cam() As String)

Sets the above data.

Public Function ReadData() As Boolean

Public Sub WriteData()

Public Sub XCopy(MM As cMotor)

Private Sub Class_Initialize()

cFlyWheel

One cFlywheel object is included in each cTrain object where the Onboard FlyWheel option is 1.

Properties:

SES Input Form 9K and L data.

Methods:

Public Sub getFlyWheel(ss() As String)

Gets the flywheel description as an array of values matching the textbox array on the FlyWheel tab of the Trains form.

Public Sub setFlyWheel(ss() As String)

Sets the above data.

Public Function ReadData() As Boolean

Public Sub WriteData()

Public Sub XCopy(FW As cFlyWheel)

Private Sub Class_Initialize()

cInitTrains

This is the collection management class for the Train Initialization Data. It is maintained as InitTrains in SESDS.

Properties:

collTrains	collection of cInitTrain objects.

Methods:

Public Function Add() As cInitTrain

Public Sub Clear()

Clears the collection, freeing the objects.

Public Sub Delete(indx As Integer)

Public Sub TrainList(gg As Grid)

Loads the grid, gg, with the Train initialization data.

Public Function ReadITrains(nn As Integer) As Boolean

Public Sub WriteITrains()

Private Sub Class_Initialize()

Private Sub Class_Terminate()

cInitTrain

Each cInitTrain object contains the data for one train operating on the system at the start of the simulation.

Properties:

SES Input Form 10 data.

Methods:

Public Sub getITrain(s1 As String, s2 As String, s3 As String, s4 As String, n1 As Integer, n2 As Integer, n3 As Integer, n4 As Integer)

Public Sub setITrain(s1 As String, s2 As String, s3 As String, s4 As String, n1 As Integer, n2 As Integer, n3 As Integer, n4 As Integer)

Public Function ReadData() As Boolean

Public Sub WriteData()

cPGroup

Each cPGroup object contains the data for one Print Control Group. These objects are contained in the array PGroups in SESDS.

Properties:

SES Input Form 12 print group data.

Methods:

Public Sub getPGroup(n1 As Integer, s1 As String, n2 As Integer, n3 As Integer, n4 As Integer, n5 As Integer)

Public Sub setPGroup(n1 As Integer, s1 As String, n2 As Integer, n3 As Integer, n4 As Integer, n5 As Integer)

Public Sub WriteData()

Public Sub XCopy(src As cPGroup)

5. FORMS

Each of the Visual Basic Forms used in SESIN is described below. Most of the data is entered into either textboxes or grids with a smattering of checkboxed and dropdown combo boxes. The event procedures for the textboxes and most of the grids are essentially identical, with the exception of the prompts and the upper and lower limit values. Likewise, the code for the OK, Cancel and Help buttons and for the Cut, Copy and Paste menu functions are essentially identical on each form. Multi-record data types are selected by either a selection list grid control or by a spinner control in a selection panel. Since the code for these controls is essentially the same wherever they are used, they will be described only once. These controls will not be listed or discussed on individual panels unless there is some unique feature.

Common Control Event Code

a) Forms

Form Load - Each form other than *frmMain* and *About* is positioned to fit between the title bar and the status bar on the main form. The size and location of *frmMain* is checked and scale factors are calculated. The Move function of the new form is then called to position the form correctly. This results in the Resize event being called. The Resize event calls the SizeIt routine in the *Misc* code module. This routine loops through all controls on the form, adjusting their locations and sizes to fit properly on the form. The font size is not currently adjusted due to inconsistent results when reversing the scaling.

If grids are present on the form, the column widths are set during form load. A “Loading” flag is used to prevent processing of RowColChange during setup and grid processing.

The initial record for multi-record data is determined and the form data fields are initialized, typically by calling a *ShowData* or similar procedure.

Form Unload - For most forms, the Cancelling flag (Set by the Cancel button) is checked. If Cancelling is not set, but RecChanged is set, the data updated from the form to the appropriate object. For most multi-record forms, a last minute check is made for a blank record at the end of the collection and it is deleted if present.

b) Text Boxes

Typical text boxes used for data entry include code for three events:

_GotFocus	Sets prompt in the status bar on frmMain and set SelStart to 0 and SelLength to the non-blank length of the field. This results in the standard Windows functionality which permits the user to simply start typing to replace the text in the field or to use the cursor keys to move within the field for editing.
_Change	Sets Change flag.
_LostFocus	Clears the prompt and, if the change flag is set, clears the change flag, sets the RecChanged flag, and validates the value of the numeric entries.

c) Grids

The standard grid control provided with VB 4.0 does not support in place data entry and editing. The data bound grid control can be used in an unbound mode to get in-place editing, but it does not display the cursor nor support the editing features most users expect. The solution used in this program is a modified version of a procedure suggested in the Microsoft Knowledge Base.

Functionally, this implementation appears as two modes to the user: I) a “Browse” mode where the navigation keys move the focus cell within the grid and the insert and delete keys insert and delete rows, and ii) an “Edit” mode where the left and right arrow keys and the insert and delete keys operate on the text in the cell. Typing any alphanumeric key enters edit mode replacing the content of the cell with the typed text. Pressing Enter or F2, or double clicking on the cell enters edit mode with the cell’s text highlighted. Pressing Enter, Tab, or the up or down arrow keys in edit mode exit edit mode. Enter and Tab move the focus to the next cell in the row or the first cell on the next row.

Essentially, upon entering edit mode, a textbox is positioned over the current cell for data entry and the contents are transferred to the grid cell upon loss of focus. There are numerous details that need to be dealt with in using this technique.

There are typically three controls involved in implementing a single grid-based table. The grid itself, a textbox for data entry (hidden except when in use), and another, “bouncer”, textbox to intercept the focus when the user presses the Tab key. The TabIndex for the bouncer is set to 1 greater than the grid and the GotFocus event simply returns focus to the grid. (Visible is set true on this textbox so it can receive the focus, but the colors are set to blend with the background so it cannot be seen.) The TabIndex for the data entry textbox is set to 1 less than the grid so that pressing tab from the textbox returns control to the grid.

See the TrnInit form for typical grid processing code. The grid control is Grid1, the input textbox is gtext and the bouncer is Text1. The event processing involved includes:

Grid1_GotFocus	Sets the prompt for the current column.
Grid1_DblClick	Sends an Enter.
Grid1_RowColChange	Sets the prompt for the new column
Grid1_KeyDown	Check for and process Insert, Delete, and F2.
Grid1_KeyPress	Calls the function *grid_text_move*(Grid1, gtext) in the Misc module to move and size the textbox and to save the row and column number for future reference. Then sets the focus to the text cell and passes the key pressed (if not Enter) to the textbox.
gtext_Change	Sets the change flag.
gtext_KeyPress	Calls the function *txtKeyPress Grid1, KeyAscii* to check for Enter. The processing for Enter moves the focus to the next cell in the grid. If on the last cell of the last row, a new row is usually added.
gtext_KeyDown	Calls the function *txtKeyDown Grid1, KeyCode, Shift* to check for the Up and Down arrow keys.
gtext_LostFocus	The processing here is complicated by the sequence of events. The grid row and column are already changed before this event is processed. Saves the new row and column numbers, restores the row and column numbers for the cell just edited, checks the value in the textbox against the allowable range for the column. If the value is valid or the user chooses to ignore the error, saves the text in the grid, restores the new row and column number and exits. If the value is invalid, the grid focus must be returned to the edited cell and focus must be returned to the textbox. Due to a VB quirk, display of a textbox (the error message) from the LostFocus event prevents processing of the next GotFocus event so the setting of the selected text must be done here. There are some variations in the LostFocus processing with the specific requirements of the grid contents.
Text1_GotFocus	Sets focus back to the grid.

d) OK Button

The processing of the OK button usually involves nothing more than unloading the form. The form unload event processing handles checking for and processing unsaved data.

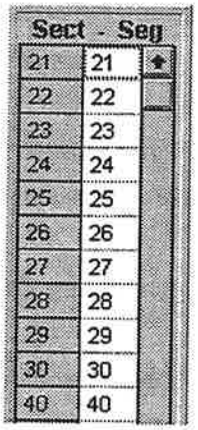
e) Cancel Button

The cancel button typically sets the Cancelling flag and unloads the form. The form unload event checks the cancelling flag and does not save any changed data if it is set.

f) Cut/Copy/Paste

The cut, copy, and paste edit functions vary somewhat depending on the context. When processed for grids including item selection grids, they assume browse mode and operate on rows of the grid/table. Otherwise, they generally operate on the selected text as for typical Windows operation.

g)Selection List Grids



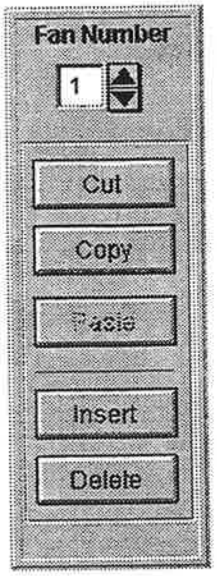
Sect - Seg	
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
40	40

Selection list grids are used for Line Segments, Vent Shafts and Nodes to select the record to be edited. The Segment, Shaft or Node number may be changed in the grid. For lines and vents, the section number may not be changed here, it must be changed on the Line Section or Vent Section form. The grid operates much as any other grid described above except that there is only one column. When the current cell changes on the selection grid (RowColChange event), the record currently displayed on the form is updated and the new record data is displayed. The focus may be changed by the up and down arrow keys or selecting with the mouse. The page up and page down functions and movement of the slider affect which rows are displayed in the selection grid but do <u>not</u> change the current cell.

When the selection grid has the focus, cut, copy, paste, insert and delete generally apply to the entire record. There are a few instances where specific functions may not be permitted. For example, deleting or inserting vent shafts is not permitted because it requires deleting or inserting the entire vent. By the same token, deleting the last line segment of a section is not permitted because it would require deleting the entire section.

There is a known problem that when the data entry cell has the focus to enter or modify a cell value in the selection grid and the slider is moved, there is no event generated and therefore no way to detect the slider movement. The result is that the grid contents scroll, but the edit textbox stays in place and does not follow the grid cell. When the textbox loses focus, the correct cell data is updated and the correct new cell gets the focus but it can be quite confusing to the user.

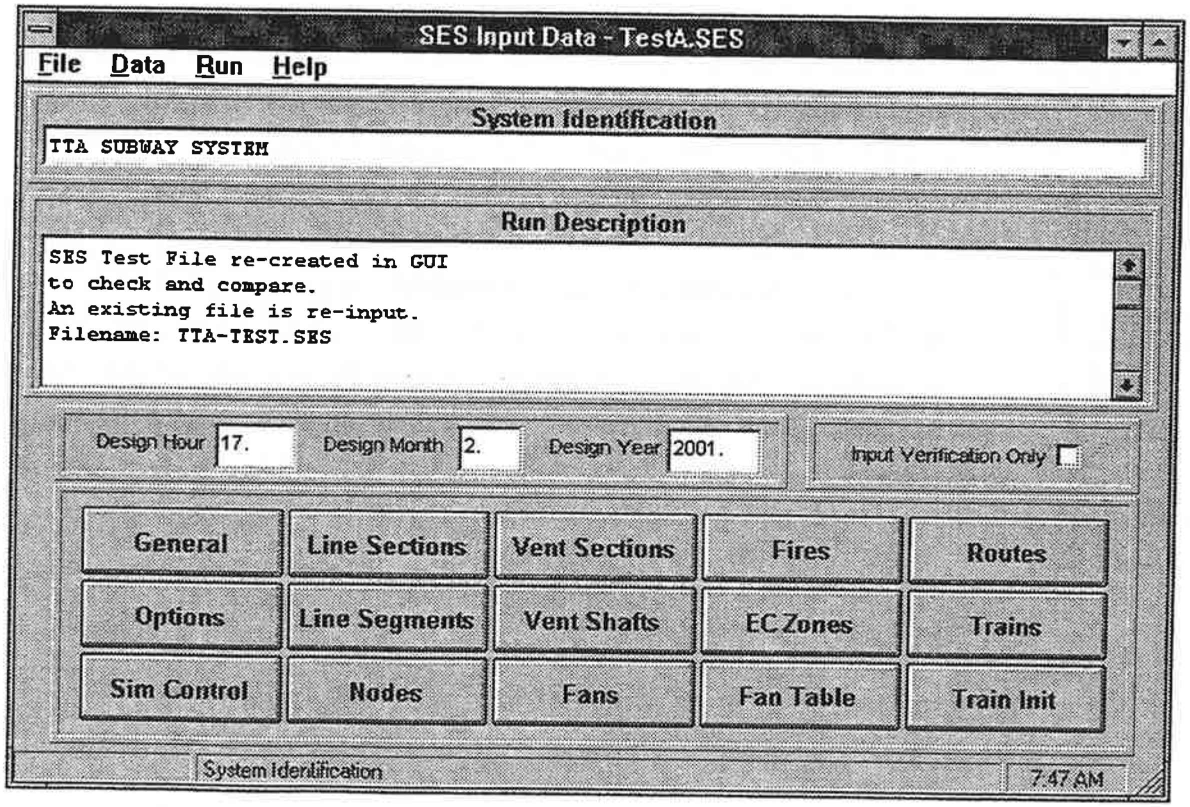
h) Selection Spinner Panel



This type of selection panel is used for fans, environmental control zones, routes and trains. The buttons apply to the entire fan, zone, route or train. The normal keyboard and menu edit functions apply at the text or table level as normal. The Paste button is not enabled unless something has been cut or copied to the edit buffer. For environmental control zones, cut, copy and paste are not permitted because it could lead to duplicate sections in different zones.

The processing of the spinner button simply adds or deducts the record number. The current record is updated and the next record is displayed. When the record number is increased beyond the number of records currently defined, a new record is added. Data must be entered for the new record before another new record can be created.

frmMain - Main Program Screen



System Identification

```
TTA SUBWAY SYSTEM
```

Run Description

```
SES Test File re-created in GUI
to check and compare.
An existing file is re-input.
Filename: TTA-TEST.SES
```

Design Hour 17.

Design Month 2.

Design Year 2001.

Input Verification Only ☐

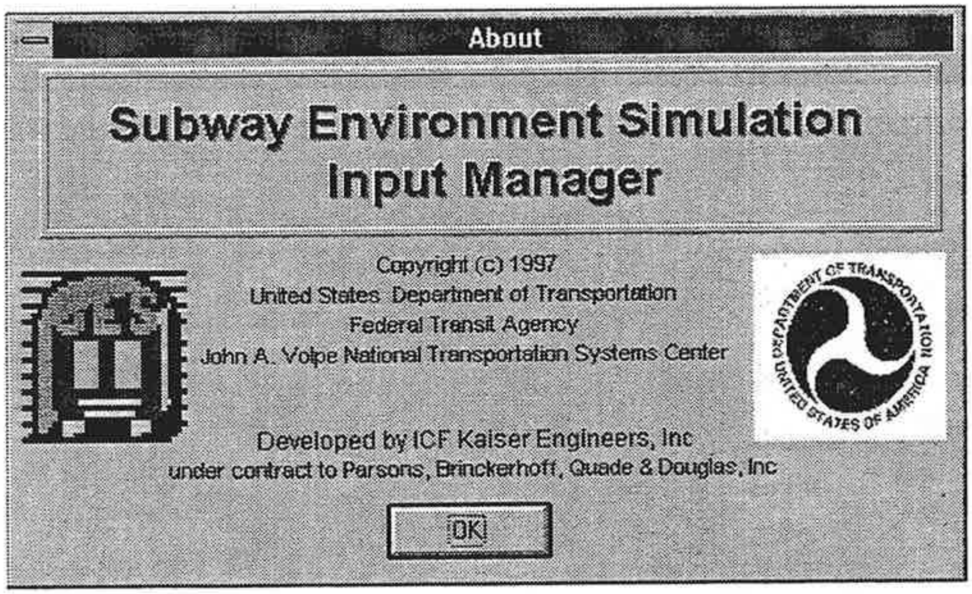
System Identification

7:47 AM

The main form includes System Identification, Run Description, Design Date, and a check box for Input Verification Only. Buttons and menu entries are provided to access the other forms. The file management and processing options are provided on the menu. The status bar at the bottom of the panel is used to display prompts for all of the forms.

Selecting or clearing the Input Verification Only checkbox modifies the allowable number of input errors variable in SESDS, setting it to -1 when the option is checked and setting it to 0 when the option is cleared, but only if it was previously -1. It does not change a positive value to zero.

About



Subway Environment Simulation Input Manager

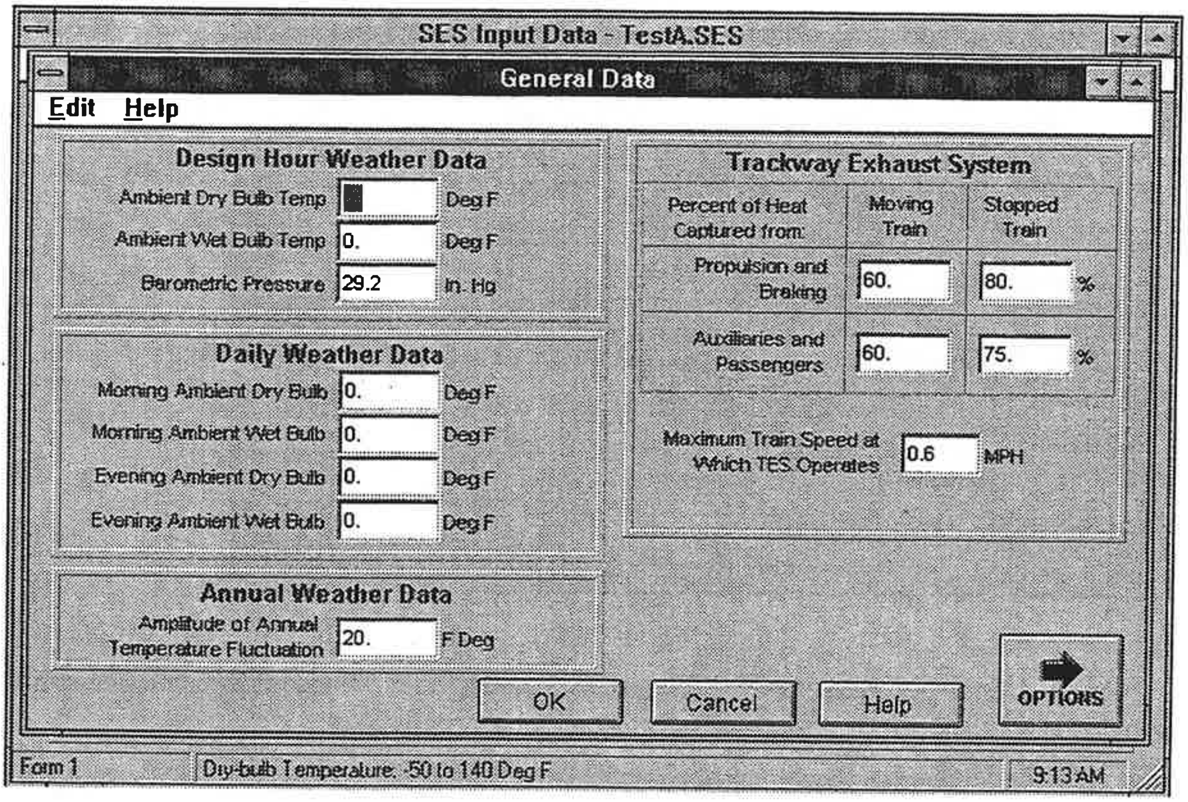
Copyright (c) 1997
United States Department of Transportation
Federal Transit Agency
John A. Volpe National Transportation Systems Center

Developed by ICF Kaiser Engineers, Inc
under contract to Parsons, Brinckerhoff, Quade & Douglas, Inc

The About & Welcome Panel - Displayed at the beginning of the program for a pre-determined time or until the OK button is pressed. Also displayed from Help /About.

When the Main procedure in Misc.bas displays About.frm as a Welcome panel, sets the Abouts Timer control to the desired delay time. When the time expires, the Timer event closes the form. When the form is displayed from Help/About, the timer is not set so the form stays displayed until closed by the user.

General - Weather and Trackway Exhaust Data - SES Input Form 1



Design Hour Weather Data

Ambient Dry Bulb Temp Deg F
Ambient Wet Bulb Temp 0. Deg F
Barometric Pressure 29.2 In. Hg

Daily Weather Data

Morning Ambient Dry Bulb 0. Deg F
Morning Ambient Wet Bulb 0. Deg F
Evening Ambient Dry Bulb 0. Deg F
Evening Ambient Wet Bulb 0. Deg F

Annual Weather Data

Amplitude of Annual Temperature Fluctuation 20. F Deg

Trackway Exhaust System

Percent of Heat Captured from:	Moving Train	Stopped Train	
Propulsion and Braking	60.	80.	%
Auxiliaries and Passengers	60.	75.	%

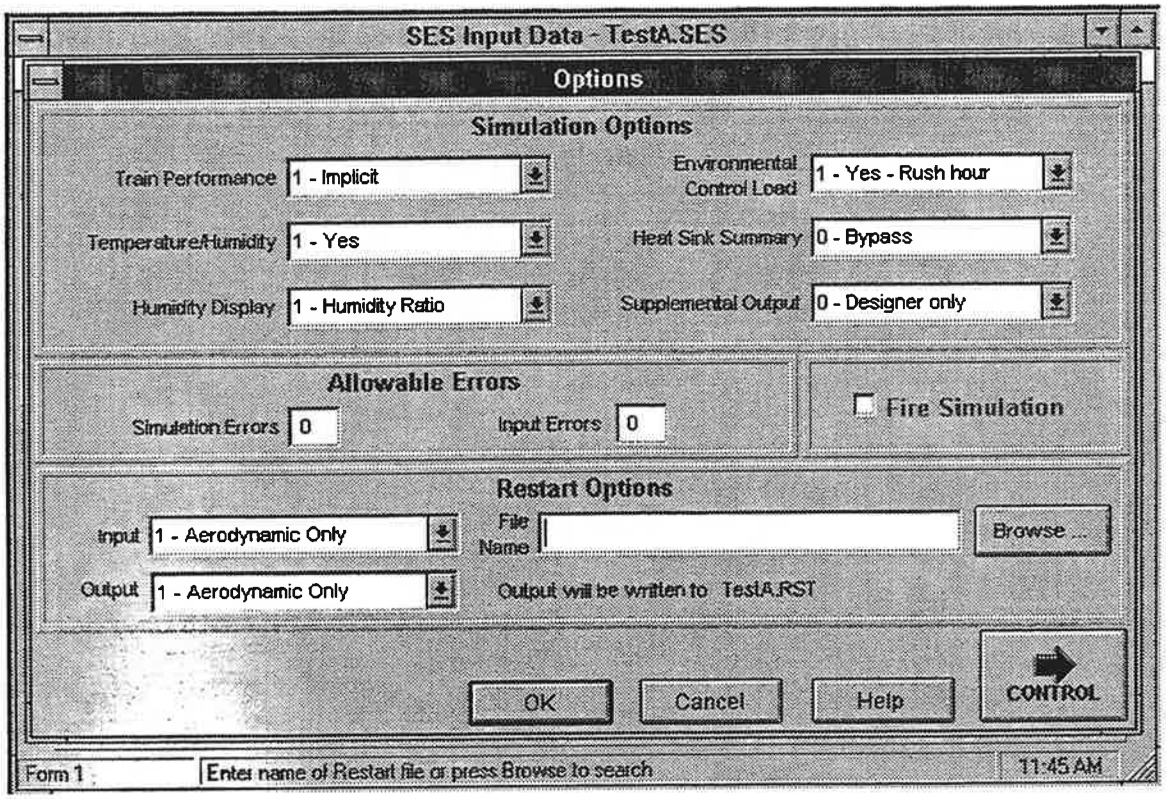
Maximum Train Speed at Which TES Operates 0.6 MPH

Form 1 | Dry-bulb Temperature: -50 to 140 Deg F | 9:13 AM

Weather and Trackway Exhaust data from SES Input Form 1.

The **OPTIONS** button saves the data if there have been any changes, closes the form and displays the Options form. There is no other unique processing for this form.

Options - Simulation Options - SES Input Form 1



SES Input Data - TestA.SES

Options

Simulation Options

Train Performance: 1 - Implicit

Environmental Control Load: 1 - Yes - Rush hour

Temperature/Humidity: 1 - Yes

Heat Sink Summary: 0 - Bypass

Humidity Display: 1 - Humidity Ratio

Supplemental Output: 0 - Designer only

Allowable Errors

Simulation Errors: 0

Input Errors: 0

☐ Fire Simulation

Restart Options

Input: 1 - Aerodynamic Only

File Name:

Output: 1 - Aerodynamic Only

Output will be written to TestA.RST

Form 1

Enter name of Restart file or press Browse to search

11:45 AM

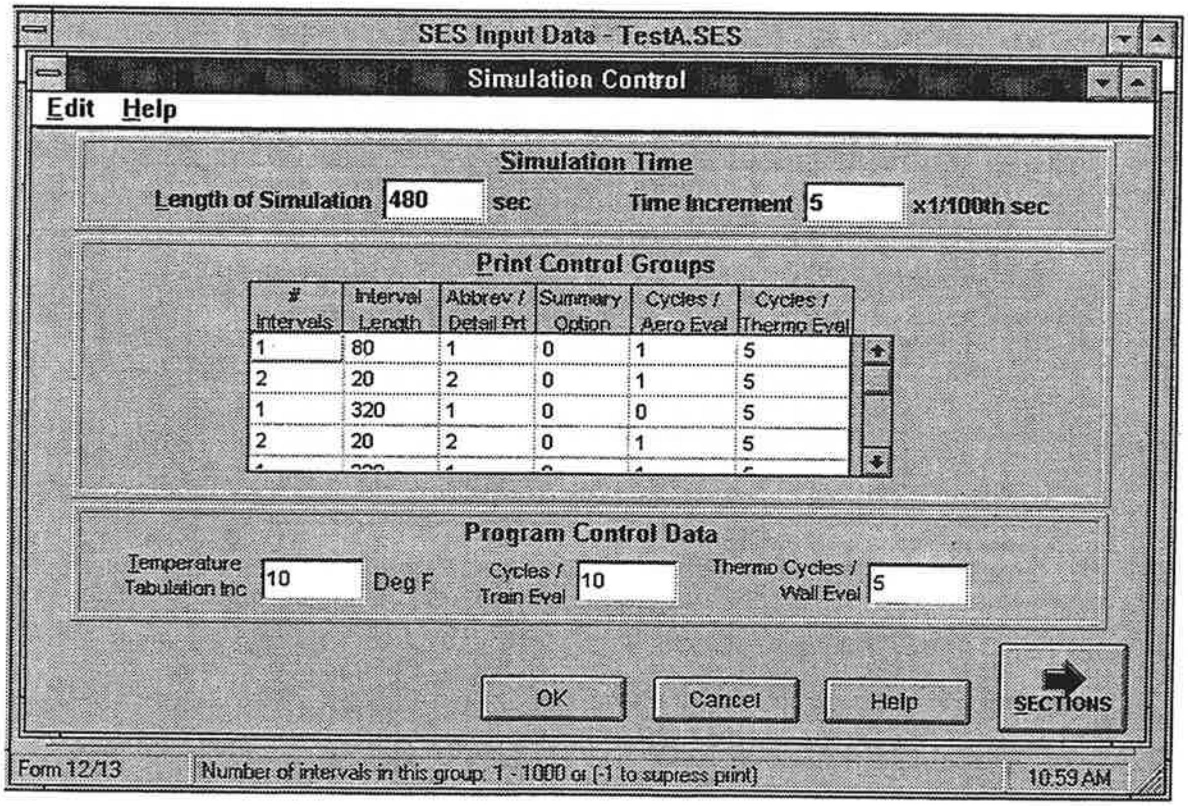
Simulation Options from Form 1.

Most of the controls on this form are drop down combo boxes. The processing for the *Train Performance* and *Environmental Control* Options enable or disable the appropriate frmMain command buttons and menu options. Changing the *Allowable Errors/Input Errors* value to or from -1 will affect the Input Verification Only option on frmMain.

If one of the "Use Restart File" options is selected, the associated textbox and Browse button are enabled to permit specifying the Restart file to be used as input. The filename may be typed in directly or the Browse button may be pressed to open a Common Dialog/File Open dialog box. A standard VB Common Dialog control is included on the form for this purpose.

The CONTROL button saves any changed data, closes the form and opens the Simulation Control form.

SimCtrl - Simulation Control SES Input Forms 12 & 13



Simulation Time

Length of Simulation 480 sec

Time Increment 5 x1/100th sec

Print Control Groups

# Intervals	Interval Length	Abbrev / Detail Prt	Summary Option	Cycles / Aero Eval	Cycles / Thermo Eval
1	80	1	0	1	5
2	20	2	0	1	5
1	320	1	0	0	5
2	20	2	0	1	5

Program Control Data

Temperature Tabulation Inc 10 Deg F

Cycles / Train Eval 10

Thermo Cycles / Wall Eval 5

Form 12/13

Number of intervals in this group: 1 - 1000 or (-1 to supress print)

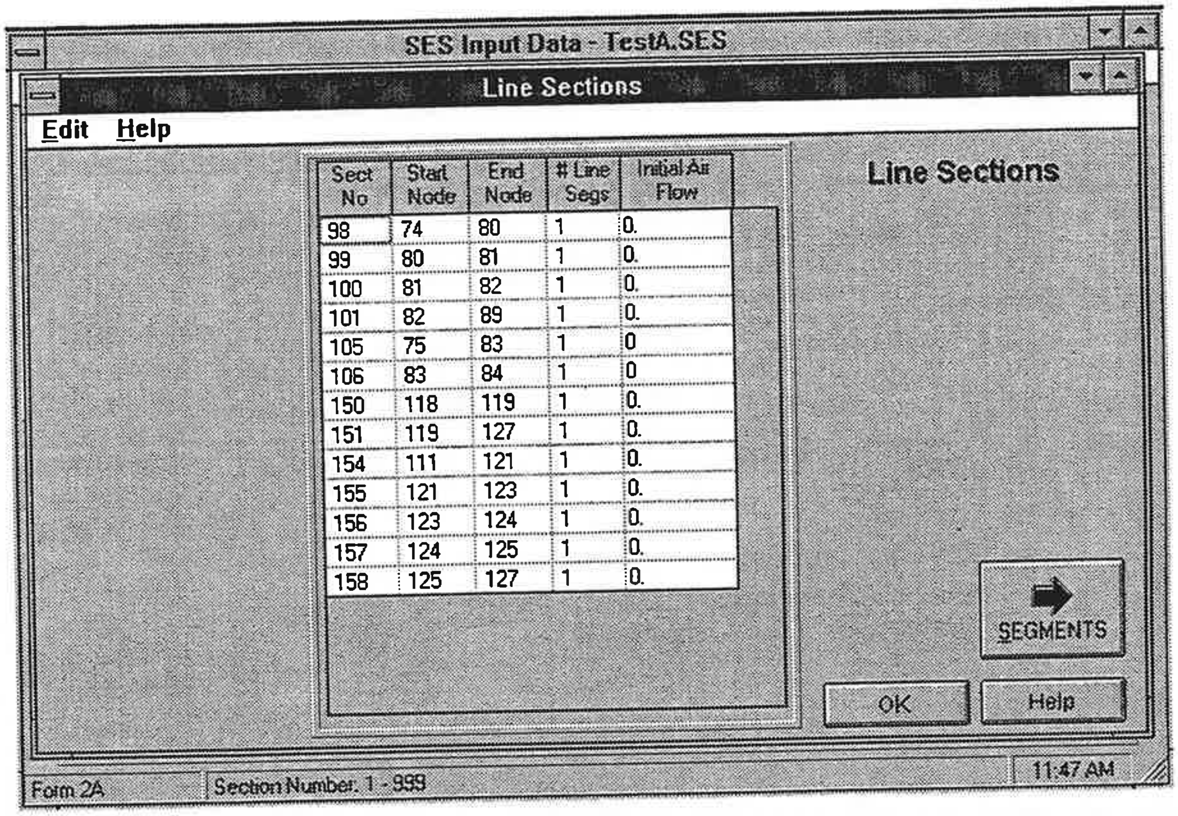
10:59 AM

Simulation and print control data from forms 12 and 13. This is where the maximum simulation time and the time increment are entered.

The *Print Control Groups* table uses the standard Grid/Table processing.

The **SECTIONS** button saves any changes, closes the form and opens the line sections form, frmLSect.

frmLSect - Line Section Data - SES Input Form 2A



Sect No	Start Node	End Node	# Line Segs	Initial Air Flow
98	74	80	1	0.
99	80	81	1	0.
100	81	82	1	0.
101	82	89	1	0.
105	75	83	1	0
106	83	84	1	0
150	118	119	1	0.
151	119	127	1	0.
154	111	121	1	0.
155	121	123	1	0.
156	123	124	1	0.
157	124	125	1	0.
158	125	127	1	0.

Line Section Form - Form 2A - Table of Lines Sections

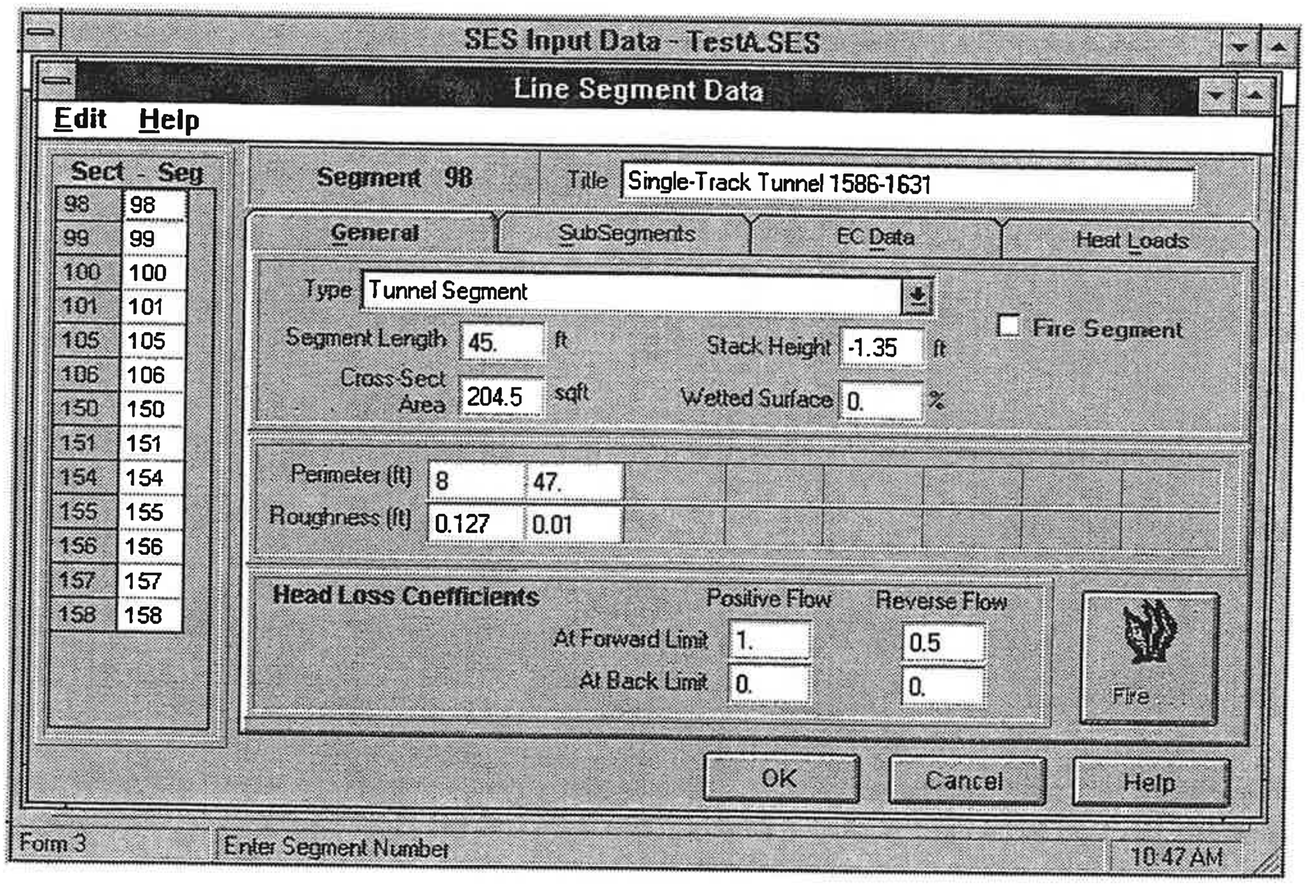
The processing for the Line Sections grid varies somewhat from the typical grid/table processing because a line section, with its related vents, is created, deleted, cut, copied or pasted whenever that operation is performed on a row.

The number of line segments is allowed to be increased on this form and new segments are added after any existing segments in the section. The number of segments is <u>not</u> allowed to be decreased because there is no way to know which segments are to be deleted.

There is no cancel button because line sections and segments may be added or deleted as the table is modified and the book-keeping required to undo the effects is prohibitive.

When the **SEGMENTS** button is selected, the form is <u>not</u> closed, but the Line Segments form, lseg, is opened with the first segment of the currently selected line section selected and displayed.

lseg - Line Segment Data Form - SES Input Form 3



Sect	Seg
98	98
99	99
100	100
101	101
105	105
106	106
150	150
151	151
154	154
155	155
156	156
157	157
158	158

Segment 98

Title: Single-Track Tunnel 1586-1631

Type: Tunnel Segment

Segment Length: 45. ft

Stack Height: -1.35 ft

☐ Fire Segment

Cross Sect Area: 204.5 sqft

Wetted Surface: 0. %

Perimeter (ft)	8	47.
Roughness (ft)	0.127	0.01

Head Loss Coefficients	Positive Flow	Reverse Flow
At Forward Limit	1.	0.5
At Back Limit	0.	0.

Enter Segment Number

Line Segment Form - One line segment is displayed at a time. The form uses 4-tabs to display all the data for the currently selected segment. The current record is selected from the selection grid. If this form is entered from the Line Section Form instead of the main form, the first segment of the section currently selected on the Line Section Form is selected and displayed. Otherwise the first segment in the system is displayed.

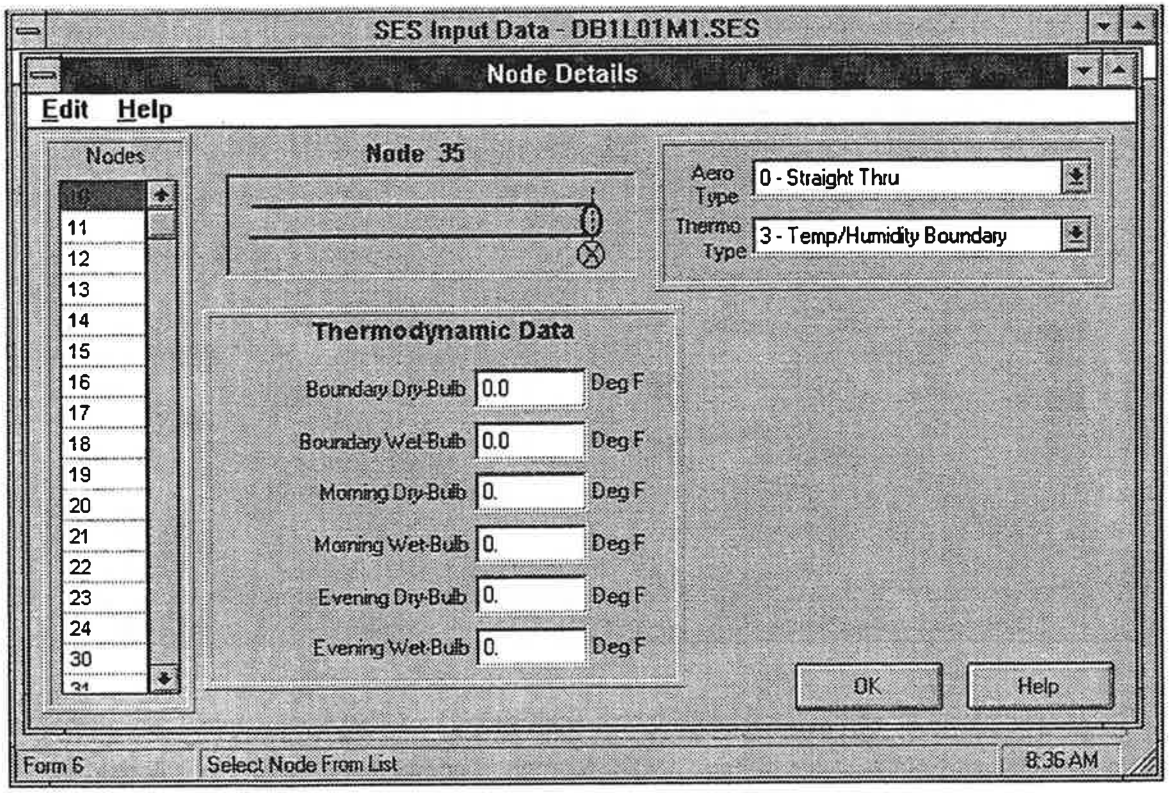
The **FIRE** button opens the Fire form without updating the segment data and closing the form. This is provided simply as a convenience. No data is connected between the two forms.

The tabs control which is provided with VB4.0 has certain features which create some problems. For one thing, the tabindex is continuous regardless of whether or not the tab is displayed. Tabbing from the last control on the current tab transfers the focus to the next control in the tab sequence, regardless of the tab it is on. If the next control is on a tab that is not displayed, the new tab is not displayed and the focus essentially disappears. This happens even if the tab is disabled. To work around this, when the first tab in the tab sequence on a tabform gets the focus, the owning tab is selected in the GotFocus event. When a tab is disabled due to simulation options selected, the frames on the disabled panel should also be disabled to prevent the contained controls from gaining the focus.

Another problem noted with the tab control is that, while hot key selection of a particular tab is theoretically possible using Alt and the underlined key on the tab label, it does not always work. The tab control also fails to size properly using the Move method, but seems to respond properly when the width and height properties are set separately.

The EC Data and Heat Load tabs are only enabled if the appropriate simulation options are selected. The Subsegments tab is a simple grid/table. The EC Data tab has tunnel wall and soil thermal properties. The Heat Load tab has a grid/table for entering any Steady State Heat Load data. The first field of this grid is a text field rather than numeric so it requires special handling in the text box LostFocus processing. These tabs are shown in the User's Manual.

frmNode - Node Data - SES Input Form 6



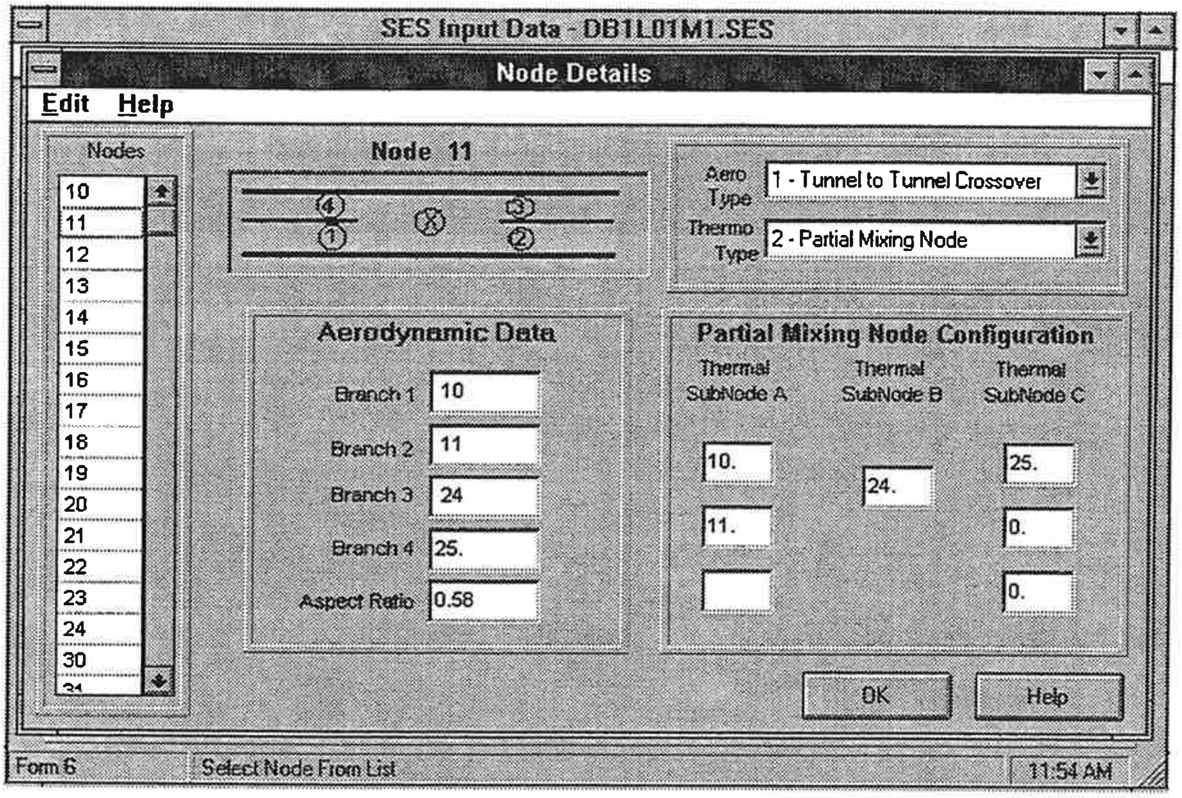
Aero Type: 0 - Straight Thru
Thermo Type: 3 - Temp/Humidity Boundary

Thermodynamic Data

Boundary Dry-Bulb 0.0 Deg F
Boundary Wet-Bulb 0.0 Deg F
Morning Dry-Bulb 0. Deg F
Morning Wet-Bulb 0. Deg F
Evening Dry-Bulb 0. Deg F
Evening Wet-Bulb 0. Deg F

Displays data for one node at a time. A diagram shows the configuration of each aerodynamic type as the selection changes and labels the order in which branch information is to be entered. The figure and the data requested change according to aerodynamic and thermodynamic type selection. One or two of the three data panels (Aerodynamic Data, Thermodynamic Data, and Partial Mixing Node Data) are used depending on the combination of aerodynamic and thermodynamic node type. The actual data fields on the Aerodynamic Data and Thermodynamic Data panels vary according to the specific types and other program options such as the Environmental Control Option.

The figure is provided by an image control. The ShowData procedure executes LoadPicture to load the appropriate figure from the program directory. The figures are named aero01.dib, aero1.dib, etc., dependent upon the aerodynamic type. These files must be present in the program directory. The Thermodynamic Data panel is shown above. It only applies to thermo node type 3. The last four fields are only displayed if the Environmental Control Option is not 0. The other two type-dependent panels are shown below. The number of branches and the presence of the angle and aspect ratio fields on the Aerodynamic Data panel are dependent upon the particular aerodynamic type. The Partial Mixing Node Configuration panel applies only to thermo node type 2.



SES Input Data - DB1L01M1.SES

Node Details

Node 11

Aero Type: 1 - Tunnel to Tunnel Crossover

Thermo Type: 2 - Partial Mixing Node

Aerodynamic Data

Branch 1: 10

Branch 2: 11

Branch 3: 24

Branch 4: 25.

Aspect Ratio: 0.58

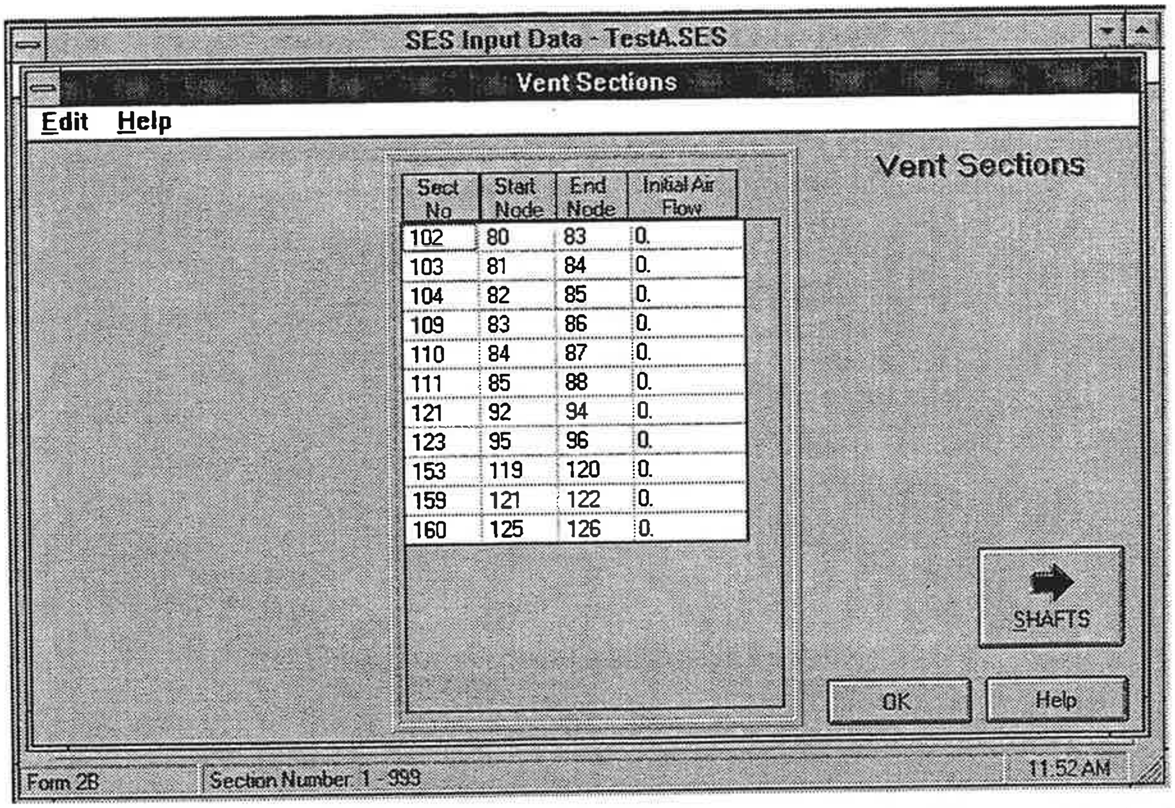
Partial Mixing Node Configuration

Thermal SubNode A	Thermal SubNode B	Thermal SubNode C
10.	24.	25.
11.		0.
		0.

Form 6 | Select Node From List | 11:54 AM

There are only a limited number of allowable combinations of Aerodynamic and Thermodynamic node types, as described in the User's Manual, so the program ensures only those types are selected. This is done in the Click event procedures for the Aero Type and Thermo Type drop down list boxes. The ShowData procedure shows and hides the appropriate panels and data fields based upon the node type.

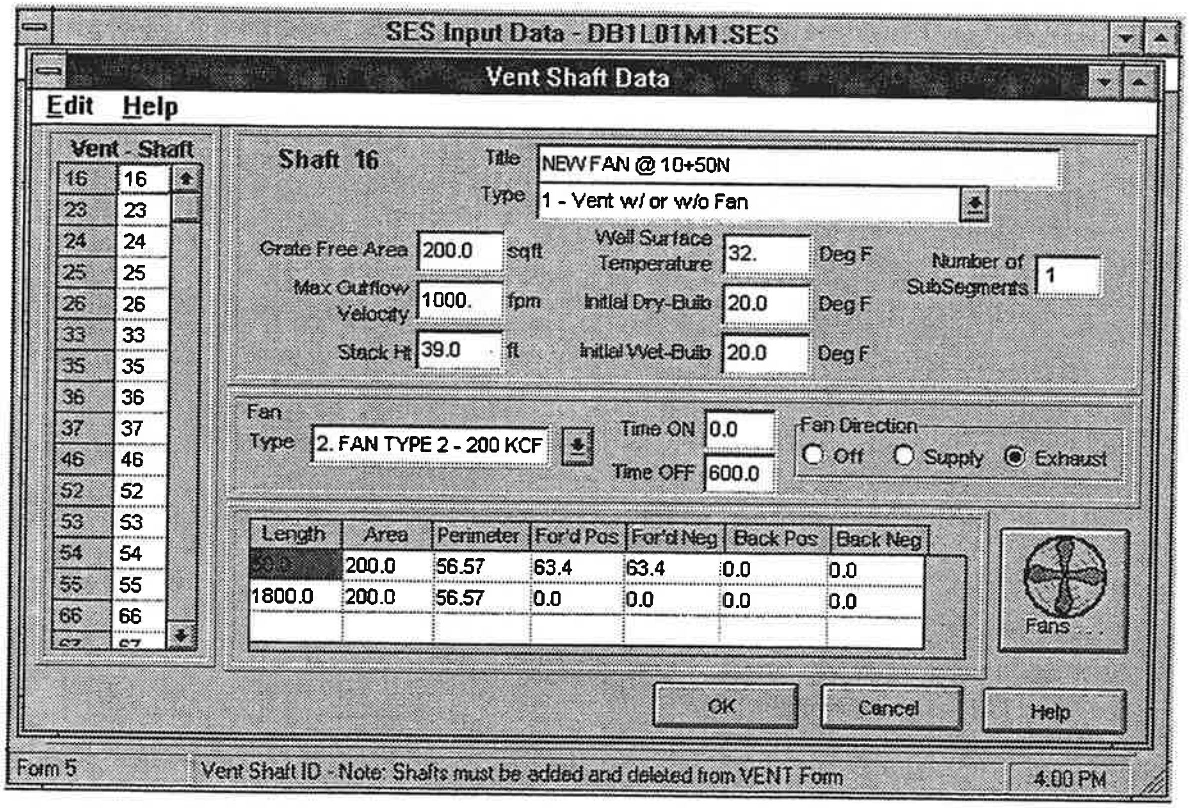
frmV.Sect - Vent Section Form - SES Input Form 2B



Sect No	Start Node	End Node	Initial Air Flow
102	80	83	0.
103	81	84	0.
104	82	85	0.
109	83	86	0.
110	84	87	0.
111	85	88	0.
121	92	94	0.
123	95	96	0.
153	119	120	0.
159	121	122	0.
160	125	126	0.

The vent section input form is nearly identical to the line section input form except for the *Number of Segments* column. It functions exactly the same way except the **SHAFTS** button opens the Vent Shaft data form, vshaft.

vshaft - Vent Shafts - SES Input Form 5



Vent - Shaft

16	16
23	23
24	24
25	25
26	26
33	33
35	35
36	36
37	37
46	46
52	52
53	53
54	54
55	55
66	66

Shaft 16

Title: NEW FAN @ 10+50N
Type: 1 - Vent w/ or w/o Fan
Grate Free Area: 200.0 sqft
Max Outflow Velocity: 1000. fpm
Stack Ht: 39.0 ft
Wall Surface Temperature: 32. Deg F
Initial Dry-Bulb: 20.0 Deg F
Initial Wet-Bulb: 20.0 Deg F
Number of SubSegments: 1

Fan
Type: 2. FAN TYPE 2 - 200 KCF
Time ON: 0.0
Time OFF: 600.0
Fan Direction: ○ Off ○ Supply ● Exhaust

Length	Area	Perimeter	For'd Pos	For'd Neg	Back Pos	Back Neg
50.0	200.0	56.57	63.4	63.4	0.0	0.0
1800.0	200.0	56.57	0.0	0.0	0.0	0.0

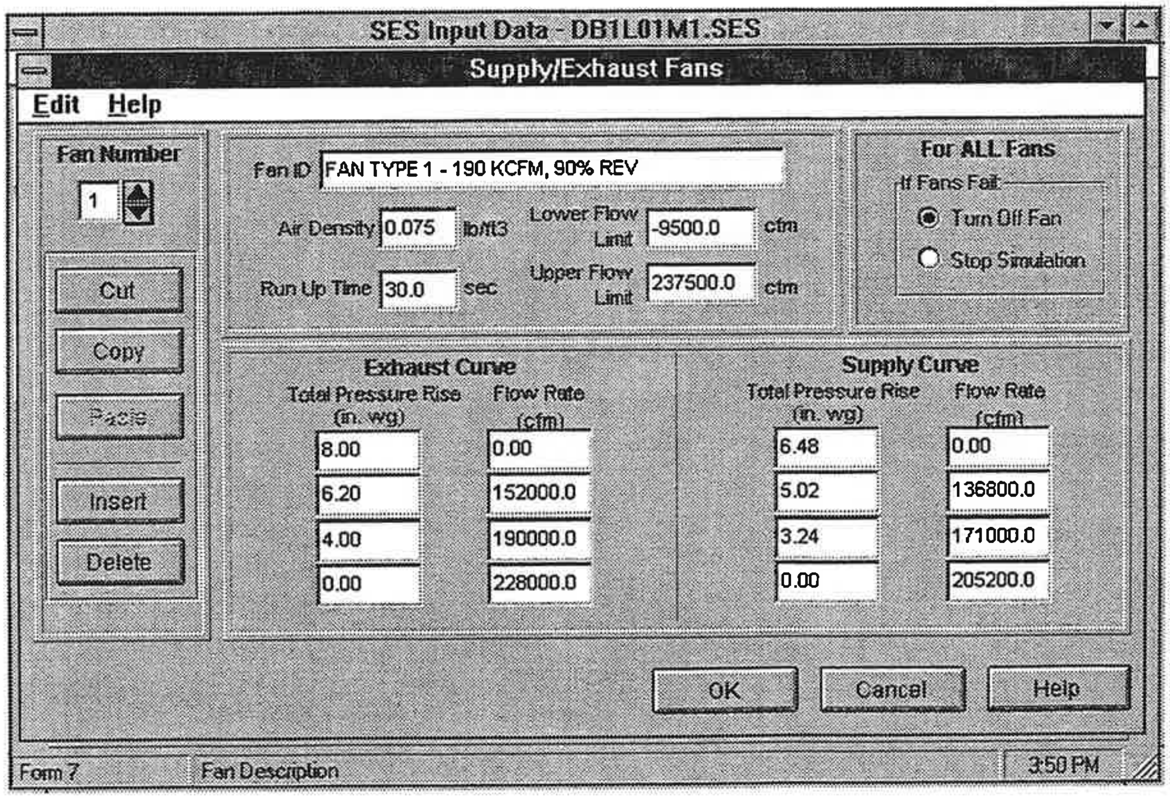
Vent Shaft ID - Note: Shafts must be added and deleted from VENT Form

The vent shaft form displays the data for one vent shaft at a time. The selection grid is as described at the beginning of this section.

When the form is loaded, the Fan Type drop down combo box is loaded with the currently defined fan types.

The **FANS** button provides convenient access to the Supply/Exhaust Fan definition form. Upon return the Fan Type combo box is reloaded to ensure it includes any changes to the fan definitions. Once a fan has been defined for a shaft (Fan Type not 0), all the values on the Fan Panel are also available through the Fan Table which may be accessed from the main form.

<u>Fans - Supply/Exhaust Fan Description Form - SES Input Form 9A-F</u>



Fan Number: 1

Fan ID: FAN TYPE 1 - 190 KCFM, 90% REV

Air Density: 0.075 lb/ft3

Lower Flow Limit: -9500.0 cfm

Run Up Time: 30.0 sec

Upper Flow Limit: 237500.0 cfm

For ALL Fans

If Fans Fail

● Turn Off Fan

○ Stop Simulation

Exhaust Curve

Total Pressure Rise (in. wg)	Flow Rate (cfm)
8.00	0.00
6.20	152000.0
4.00	190000.0
0.00	228000.0

Supply Curve

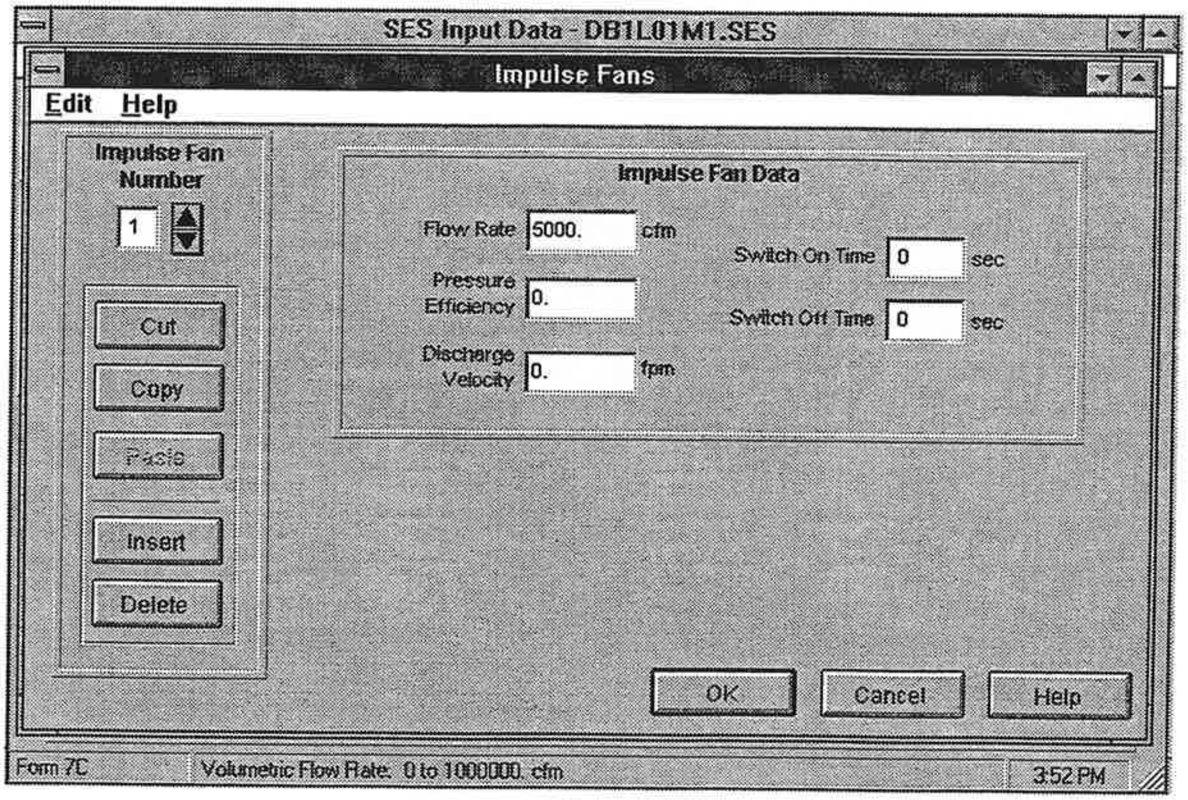
Total Pressure Rise (in. wg)	Flow Rate (cfm)
6.48	0.00
5.02	136800.0
3.24	171000.0
0.00	205200.0

Form 7 | Fan Description | 3:50 PM

One fan per form, selected by selection panel.

The *If Fans Fail* selection applies to ALL fans, not just the fan displayed. It is the Fan Stopping/Windmilling Option on SES Input Form 1E.

frmIFan - Impulse Fans - SES Input Form 7G,H



Impulse Fan Number: 1

Impulse Fan Data

Flow Rate 5000. cfm

Pressure Efficiency 0.

Discharge Velocity 0. fpm

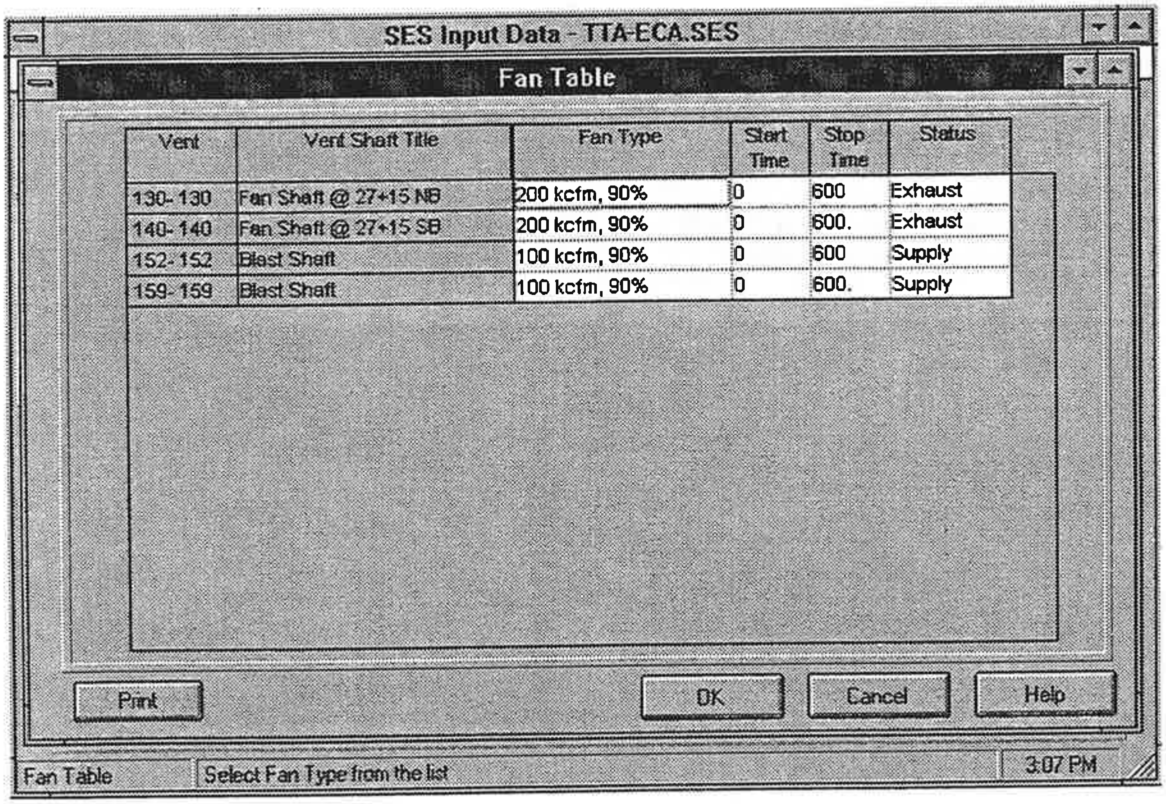
Switch On Time 0 sec

Switch Off Time 0 sec

Form 7C | Volumetric Flow Rate: 0 to 1000000. cfm | 3:52 PM

The impulse fan panel displays data for one impulse fan at a time using standard selection panel procedures. No surprises here.

FanTable



Vent	Vent Shaft Title	Fan Type	Start Time	Stop Time	Status
130- 130	Fan Shaft @ 27+15 NB	200 kcfm, 90%	0	600	Exhaust
140- 140	Fan Shaft @ 27+15 SB	200 kcfm, 90%	0	600.	Exhaust
152- 152	Blast Shaft	100 kcfm, 90%	0	600	Supply
159- 159	Blast Shaft	100 kcfm, 90%	0	600.	Supply

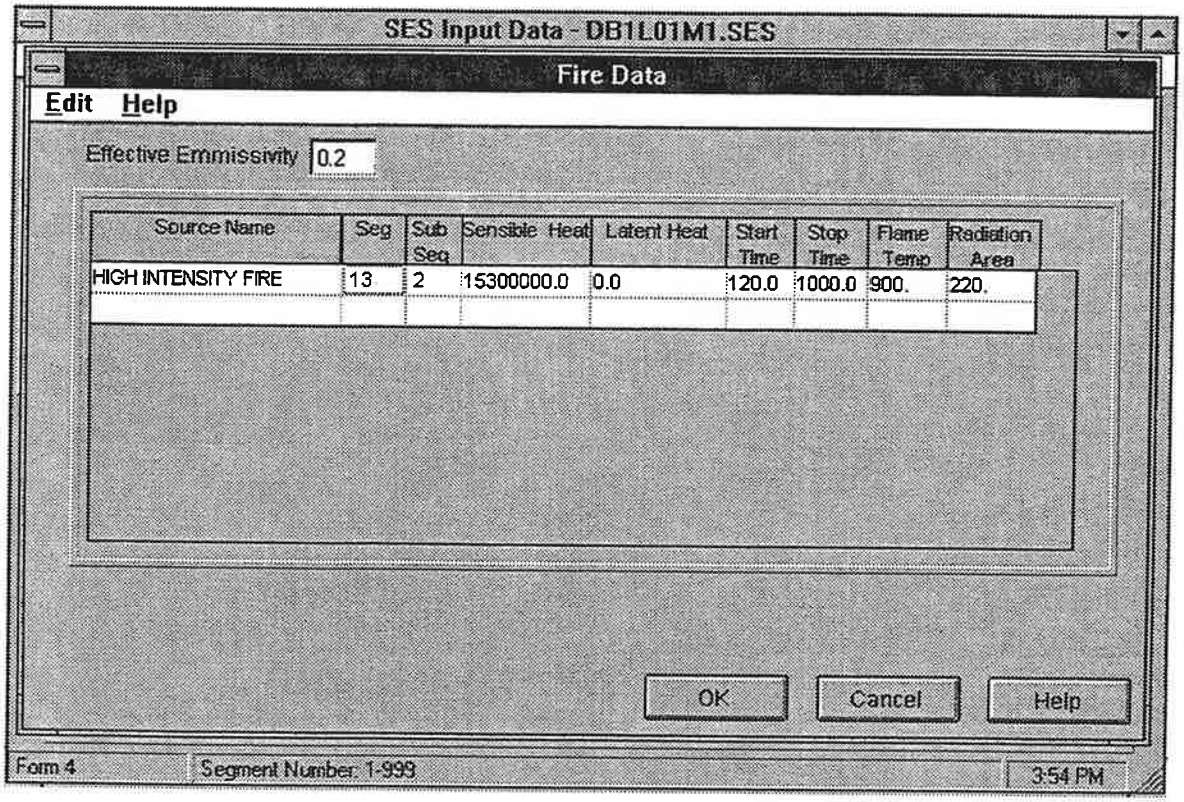
Fan Location Table - If the user has entered the fan type for all of the fan shafts in the system, this form displays the vent shaft number and description and the fan number, description, start and stop times and status (Supply, Exhaust or Off) in tabular form. It provides a single location where the user may adjust fan operation to set up various ventilation scenarios.

The form's Load event processing calls *Vents.FanList* to load the table and *Fans.List* to load a FanType combo box similar to that used on the Vent Shaft data form.

A modified version of the GridTextMove function is used in this table to overlay combo boxes for the fan type and fan mode columns instead of the usual text box.

The **PRINT** button permits the user to print a list of the fans and their status.

Fires - Fires Table (Unsteady Heat Sources) - SES Input Form 4



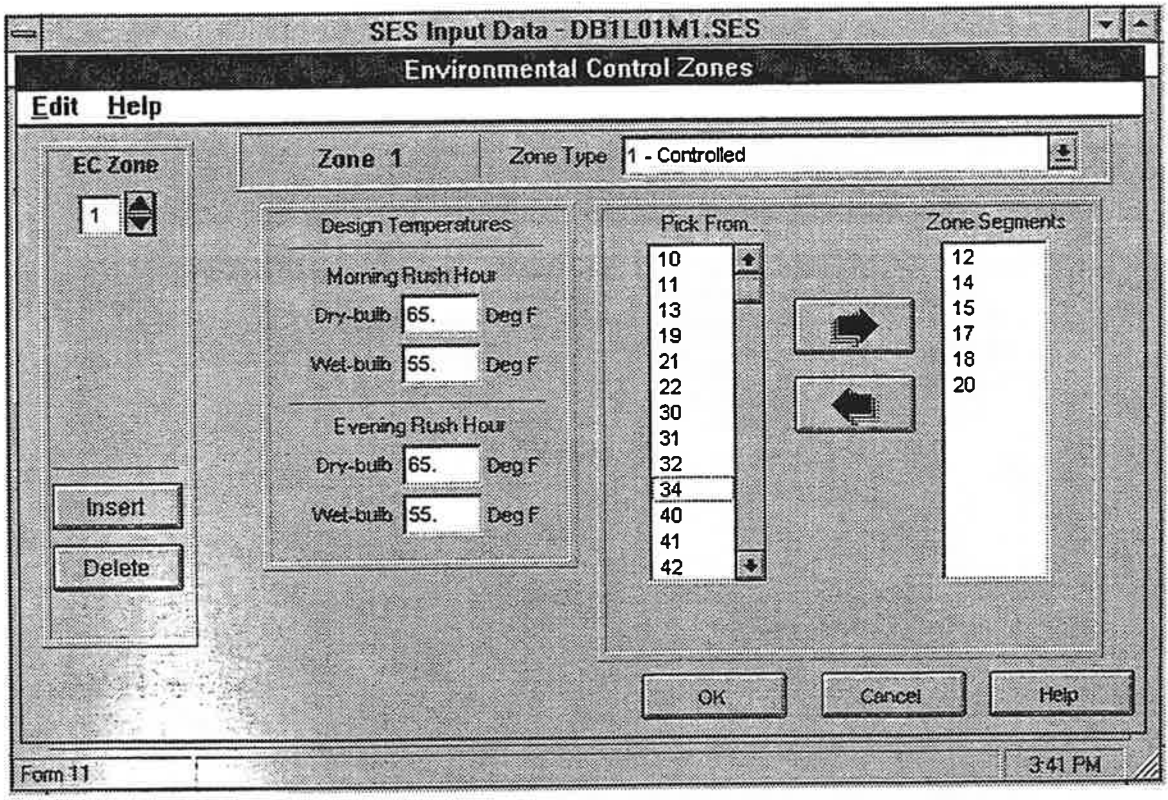
Effective Emmissivity 0.2

Source Name	Seg	Sub Seq	Sensible Heat	Latent Heat	Start Time	Stop Time	Flame Temp	Radiation Area
HIGH INTENSITY FIRE	13	2	15300000.0	0.0	120.0	1000.0	900.	220.

Shows fire data in tabular form. The standard grid/table procedures are used, noting that special handling is required for the text field in the first column.

The Effective Emmissivity is from SES Input Form 1G.

ECZones - Environmental Control Zones - SES Input Form 11



EC Zone: 1

Zone 1

Zone Type: 1 - Controlled

Design Temperatures

Morning Rush Hour

Dry-bulb: 65. Deg F

Wet-bulb: 55. Deg F

Evening Rush Hour

Dry-bulb: 65. Deg F

Wet-bulb: 55. Deg F

Pick From...: 10, 11, 13, 19, 21, 22, 30, 31, 32, 34, 40, 41, 42

Zone Segments: 12, 14, 15, 17, 18, 20

Allows assignment of line and vent sections to environmental control zones. Each zone type permits different combinations of either lines or vents or both. This form is different from most of the other forms in the interface.

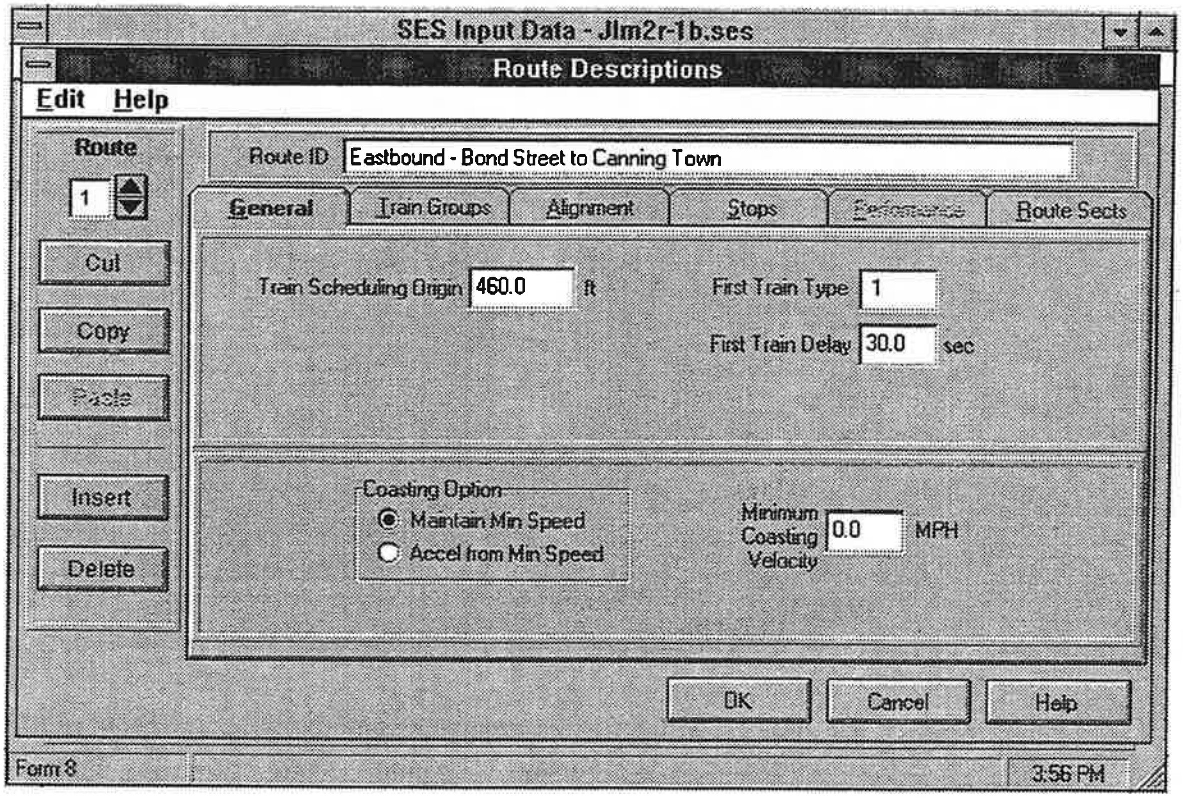
The Cut, Copy and Paste buttons have been eliminated from the selection panel to avoid having the same sections appear in more than one environmental control zone. The Design Temperatures Panel is only displayed for Zone Type 1 - Controlled Zones.

The Form Load procedure calls *Lines.SegZList* and *Vents.VentZList* to build an ordered collection of ZSect objects, colPick, for lines and vents. The ZSectStrip procedure is then called for each existing zone to flag the ZSect objects for sections in that zone as used. As each zone is displayed, the zone's ZSectList method is called to load the Zone Sections listbox, *ZList,* and the form's LoadList method is called to load the *PickList* listbox with unused line and/or vent sections dependent upon the zone type. The right arrow button Click event processing loops through selected items in the pick list and adds them to the section list, marking them used in colPick. The left arrow button removes selected items from the section list and marks them as unused in colPick.

If the zone type is changed for an existing zone, the pick list is updated to show the correct sections types, but it is the user's responsibility to ensure only the correct section types are included.

Invalid section types will not be deleted automatically in case the change is in error or only temporary. The SES program input verification will, of course, check that the correct types are used in each section.

Route1 - Route Data - SES Input Form 9



Route: 1

Route ID: Eastbound - Bond Street to Canning Town

Train Scheduling Origin: 460.0 ft

First Train Type: 1

First Train Delay: 30.0 sec

Coasting Option
● Maintain Min Speed
○ Accel from Min Speed

Minimum Coasting Velocity: 0.0 MPH

Displays route information for one route at a time using a tabbed dialog box to access the different types of route data. Some tabs are always enabled and some are dependent upon the Train Control Option in effect when the form is loaded. The Selection box is standard and permits cutting, copying, pasting, inserting and deleting entire routes.

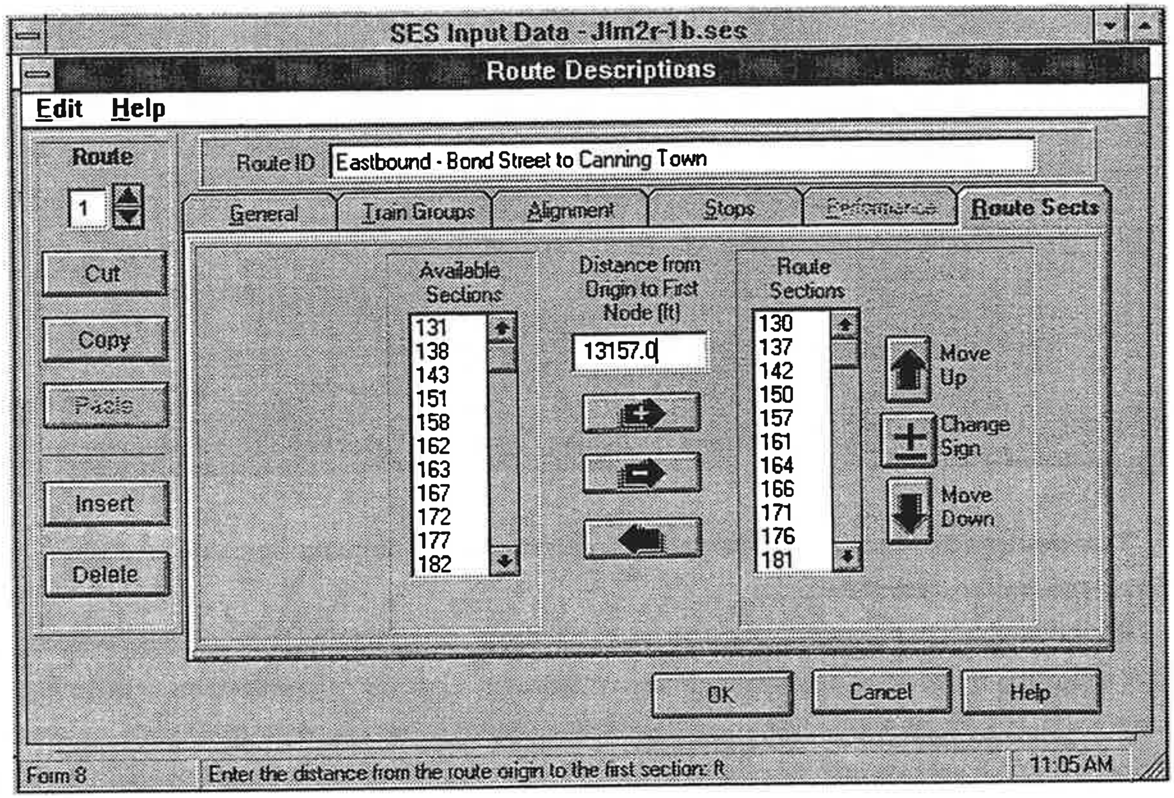
The General tab contains only routine textbox controls and the Coasting Option Radio Button control.

The Stops tab has two text boxes, one for initial number of passengers and one for passenger weight, which is from SES Input Form 1G and a grid/table control. The Train Groups, Alignment and Performance tabs use grid/table format. The grids are all treated as an array of controls and share common event routines. Arrays for the upper and lower limits are initialized with the allowable range values in the Form Load event procedure. The input textboxes and the bouncer textboxes are also arrays and share event code.

The Route Sects tab is used to select the line segments through which the route passes and is quite different from most of the other forms.

The Available Sections list is originally loaded with all the line sections in the model.

The segment data for SES uses a minus sign to indicate the direction of travel through the nodes from the end node to the start. The +⇨ and −⇨ buttons loop through the Available sections list and transfer all selected sections to the Route Sections list with no sign for the + arrow button, or with a minus sign for the - arrow button. The left arrow button removes sections from the Route Sections list and restores them to the end of the available sections list. They are added to the end because there is no bookkeeping mechanism to keep track of the original order. (A future modification might use a ZSect collection similar to ECZones to keep the segments in order.)



Route: 1

Route ID: Eastbound - Bond Street to Canning Town

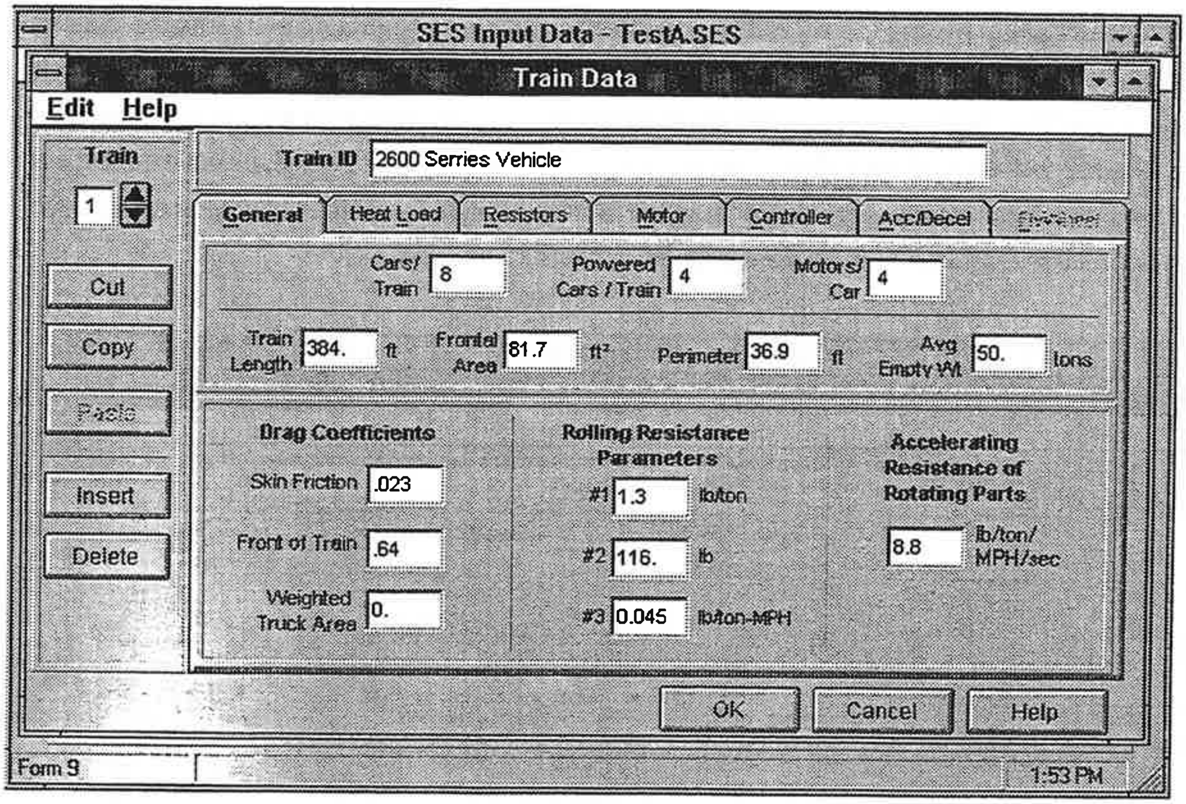
Distance from Origin to First Node (ft): 13157.0

Available Sections	Route Sections
131	130
138	137
143	142
151	150
158	157
162	161
163	164
167	166
172	171
177	176
182	181

Form 8 | Enter the distance from the route origin to the first section: ft | 11:05 AM

The Move Up and Move Down arrow buttons move a single selected segment in the Route Sections list up or down in the list. The ± button changes the sign of the selected segment, adding or deleting the - sign.

Trains - Train Descriptions - SES Input Form 9



Train: 1

Train ID: 2600 Serries Vehicle

Cars/Train: 8

Powered Cars / Train: 4

Motors/Car: 4

Train Length: 384. ft

Frontal Area: 81.7 ft²

Perimeter: 36.9 ft

Avg Empty Wt: 50. tons

Drag Coefficients

Skin Friction: .023

Front of Train: .64

Weighted Truck Area: 0.

Rolling Resistance Parameters

#1: 1.3 lb/ton

#2: 116. lb

#3: 0.045 lb/ton-MPH

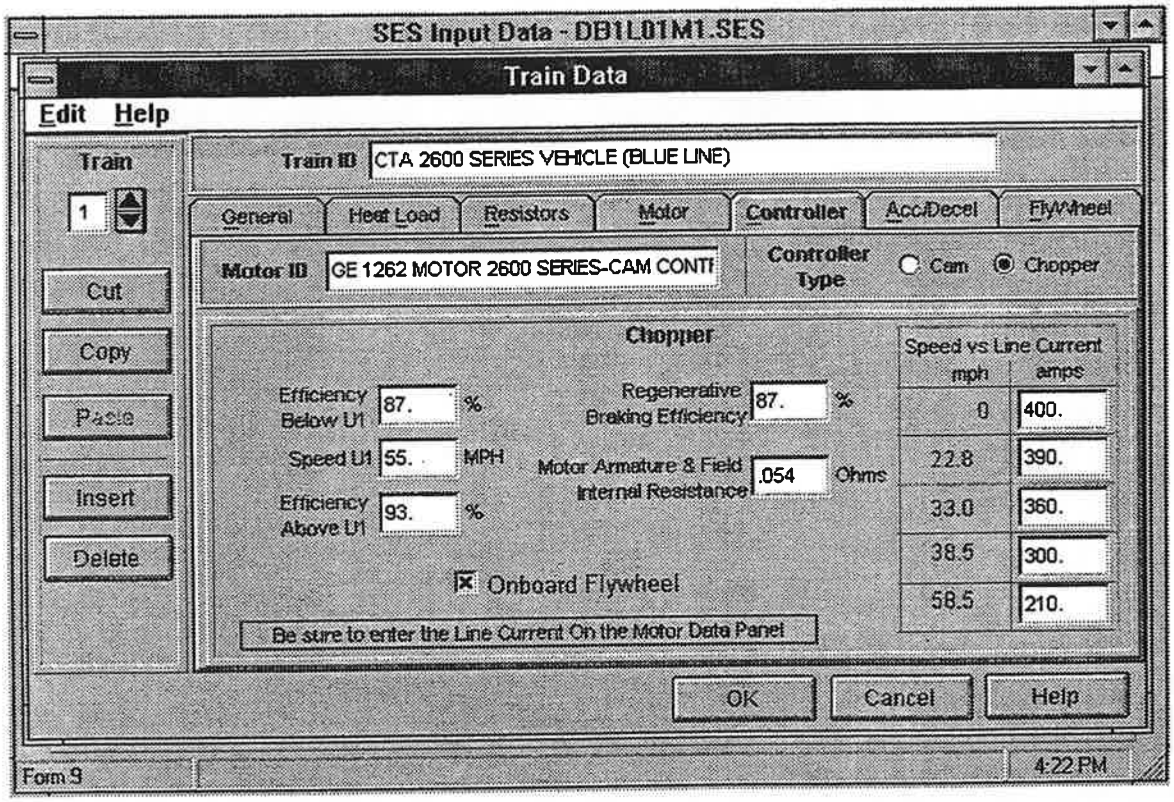
Accelerating Resistance of Rotating Parts

8.8 lb/ton/MPH/sec

Trains selected by number with spin control. One multiple tab form per train. Some tabs are disabled depending on options selected.

Most of the tabs have groups of text boxes for data entry with no particularly unusual processing. Arrays of textboxes are used on several of the tabs to reduce the number of event routines. The tab sequence from one tab panel to another must be maintained and the tab selected when the first control gets the focus. When a tab is enabled or disabled due to a change in options, the SSPanels which contain the controls for that tab must also be disabled to ensure the controls do not get the focus.

The only panel that is particularly unique is the Controller panel. The Motor ID is repeated from the Motor tab but is displayed for information only and cannot be edited here. The data displayed on the panel is dependent upon the type of controller selected, Cam or Chopper. There are separate SSPanels for each type of data and they are made visible or invisible when the controller type is changed. The chopper controller data panel is shown below. There is a note that the line current must be entered on the Motor Data tab if the Chopper controller is used. The textboxes for the line current are disabled when the Cam Controller is selected. One data item, the Motor and Armature Internal Resistance, appears on both the Cam and Chopper panels. This is from SES Input Form 9I and is the only item on that SES Input Form that applies to both controllers. The Chopper data panel also contains a Flywheel Option Checkbox. If this checkbox is checked, the Flywheel tab is enabled; if it is not checked, the Flywheel tab is not enabled.



Train: 1

Train ID: CTA 2600 SERIES VEHICLE (BLUE LINE)

Motor ID: GE 1262 MOTOR 2600 SERIES-CAM CONT

Controller Type: ○ Cam ● Chopper

Chopper

Efficiency Below U1: 87. %

Speed U1: 55. MPH

Efficiency Above U1: 93. %

Regenerative Braking Efficiency: 87. %

Motor Armature & Field Internal Resistance: .054 Ohms

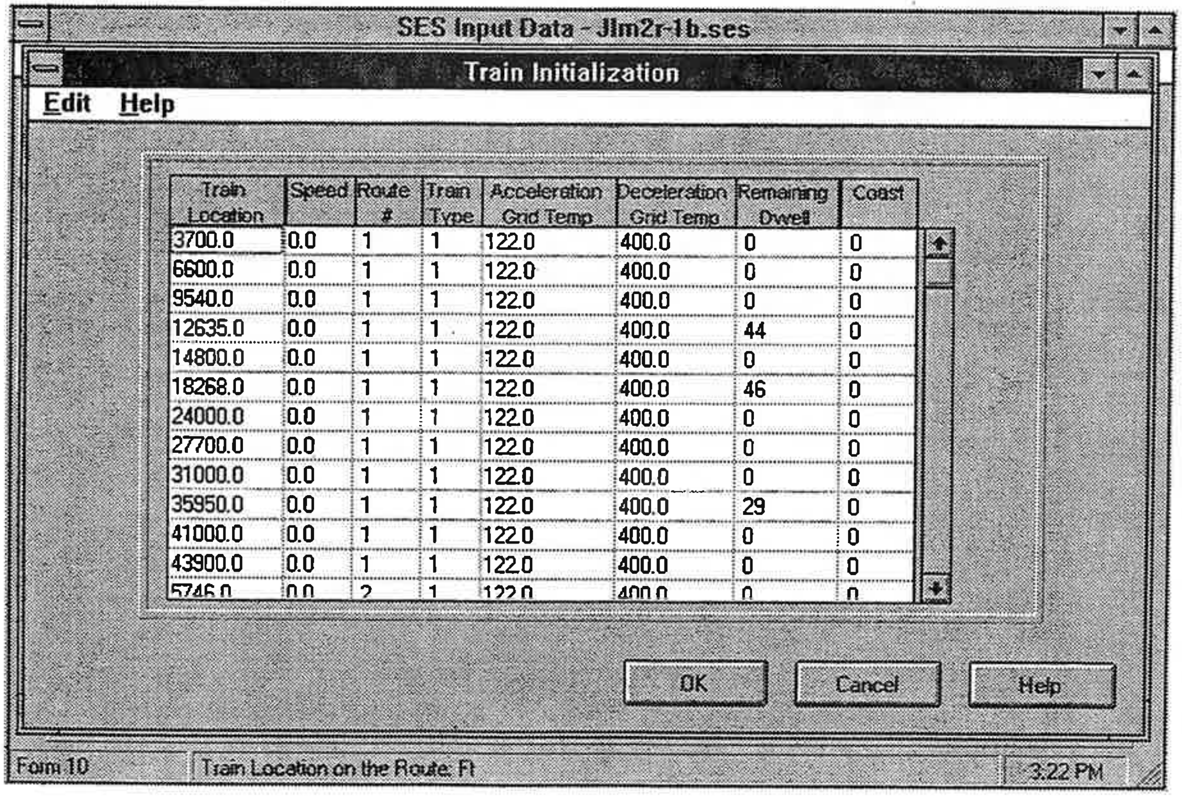
☒ Onboard Flywheel

Be sure to enter the Line Current On the Motor Data Panel

Speed vs Line Current

mph	amps
0	400.
22.8	390.
33.0	360.
38.5	300.
58.5	210.

TrnInit - Train Initialization - SES Input Form 10



Train Location	Speed	Route #	Train Type	Acceleration Grid Temp	Deceleration Grid Temp	Remaining Dwell	Coast
3700.0	0.0	1	1	122.0	400.0	0	0
6600.0	0.0	1	1	122.0	400.0	0	0
9540.0	0.0	1	1	122.0	400.0	0	0
12635.0	0.0	1	1	122.0	400.0	44	0
14800.0	0.0	1	1	122.0	400.0	0	0
18268.0	0.0	1	1	122.0	400.0	46	0
24000.0	0.0	1	1	122.0	400.0	0	0
27700.0	0.0	1	1	122.0	400.0	0	0
31000.0	0.0	1	1	122.0	400.0	0	0
35950.0	0.0	1	1	122.0	400.0	29	0
41000.0	0.0	1	1	122.0	400.0	0	0
43900.0	0.0	1	1	122.0	400.0	0	0
5746.0	0.0	2	1	122.0	400.0	0	0

Trains operating at system start. This is a typical grid/table with no special handling required.