U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-258 194

DYNALIST II. A Computer Program for Stability & Dynamic Response Analysis of Rail Vehicle Systems. Volume IV

Wiggins (J E) Co, Redondo Beach, Calif

Prepared for

Federal Railroad Administration, Washington, D C Office of Research and Development

Jul 76

REPORT NO. FRA-OR&D-75-22.IV

DYNALIST II
A COMPUTER PROGRAM FOR STABILITY AND DYNAMIC RESPONSE ANALYSIS OF RAIL VEHICLE SYSTEMS
Volume IV: Revised User's Manual

Allen Bronowicki
T. K. Hasselman

J. H. Wiggins Company
1650 South Pacific Coast Highway
Redondo Beach CA 90277

JULY 1976
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No.
FRA-OR&D-75-22.IV

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
DYNALIST II - A COMPUTER PROGRAM FOR STABILITY AND DYNAMIC RESPONSE ANALYSIS OF RAIL VEHICLE SYSTEMS,
Volume IV: Revised User's Manual

5. Report Date
July 1976

6. Performing Organization Code

7. Author(s)
Allen Bronowicki and T. K. Hasselman

8. Performing Organization Report No.
DOT-TSC-FRA-74-14.IV

9. Performing Organization Name and Address
J. H. Wiggins Company*
1650 South Pacific Coast Highway
Redondo Beach CA 90277

10. Work Unit No. (TRAIS)
RR628/R6320

11. Contract or Grant No.
DOT-TSC-990

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Railroad Administration
Research and Development
Washington DC 20590

13. Type of Report and Period Covered
Final Report
February 1975 -
March 1976

14. Sponsoring Agency Code

15. Supplementary Notes
*Under contract to:
U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

16. Abstract

Several new capabilities have been added to the DYNALIST II computer program. These include: (1) a component matrix generator that operates as a 3-D finite element modeling program where elements consist of rigid bodies, flexural bodies, wheelsets, suspension elements, and point masses assembled on a nodal skeleton; (2) a periodic and transient time-history response capability; (3) a component update capability for parametric studies; (4) an orthogonality check on component and system complex eigenvectors; (5) an option for improving low-frequency convergence under modal truncation; (6) a more general sine-amplitude forcing function capability; (7) automatic phase lag generation; (8) user-controlled scaling options on all response plots; and a number of additional minor improvements. A Technical Report Addendum and a completely Revised User's Manual document these changes to the previous version of DYNALIST II.

17. Key Words
Rail Vehicle Dynamics, Rail Vehicle Stability, Rail Vehicle Response, Ride Quality, Computer Modeling, Modal Synthesis

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	156	6.75/2.25

Form DOT F 1700.7 (8-72)
Reproduction of completed page authorized

PREFACE

The Federal Railroad Administration (FRA) is sponsoring research, development, and demonstration programs to provide improved safety, performance, speed, reliability, and maintainability of rail transportation systems at reduced life-cycle costs. A major portion of these efforts is related to improvement of the dynamic characteristics of rail vehicles, track structures, and train consists.

Transportation Systems Center (TSC) is maintaining a center for resources to be applied to programs for improved passenger service, improved safety, and more cost-effective freight service. As part of this effort, TSC is identifying computer programs, analytic models, and analysis tools required to support the FRA objectives. In particular, TSC is acquiring, developing, and extending computer programs to provide realistic predictions of rail system dynamic performance under field conditions.

The DYNALIST II computer program was developed for the Department of Transportation by the J. H. Wiggins Company in 1974. Documentation was contained in two volumes, a technical report documenting the theoretical basis of the program and a user's manual. The present report also consists of two volumes. Volume III, entitled "Technical Report Addendum," is written as an addendum to the previous technical report. Volume IV, entitled "Revised User's Manual," is self-contained and supersedes the previous user's manual.

Numerous detailed comments provided by Dr. Russel Brantman, the TSC Technical Monitor, have been incorporated in both of these reports. The time which he and others at TSC have spent in reviewing the material from the standpoint of new users has, in the opinion of the authors, contributed significantly to its clarity. The authors wish to express their appreciation for this dedicated effort.

The Revised User's Manual reflects current modifications in output format which have been written into the program at TSC. These modifications were performed by Duncan Sheldon under the direction of Dr. Brantman.

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS
(continued)

LIST OF TABLES

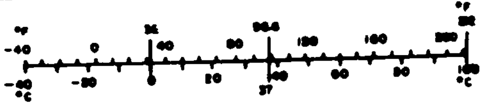
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

This manual describes the use of the DYNALIST II computer program for dynamic analysis of general linear systems. The program provides a capability for stability analysis and for computing response to sinusoidal, random, periodic, and transient excitations. System components may be modeled either by directly inputting the matrix coefficients of the equations of motion, or by using a finite element type subroutine to automatically generate these coefficients. Components can then be assembled to form complete systems.

DYNALIST II has been developed with three basic objectives in mind:

Simplified input
Modeling flexibility
Computational efficiency

Briefly stated, simplified input is provided for by using a NAMELIST format, and by the ability to generate component data files which may be added to and accessed in future runs. Modeling flexibility is provided for by the generality of the mathematical formulation which utilizes a subsystems modeling approach. Computational efficiency is achieved through the use of the QR algorithm to compute complex eigenvalues and eigenvectors which are used in both stability and response analysis. Modal synthesis provides a means of keeping the size of any single eigenproblem small by using a truncated set of complex component eigenvectors as a basis for the system equations of motion.

Subsequent chapters in this manual describe the program in detail and specify operating instructions as well as preparation of input data. Both printed and plotted forms of program generated output are described, and sample problems are presented.

2. PROGRAM DESCRIPTION

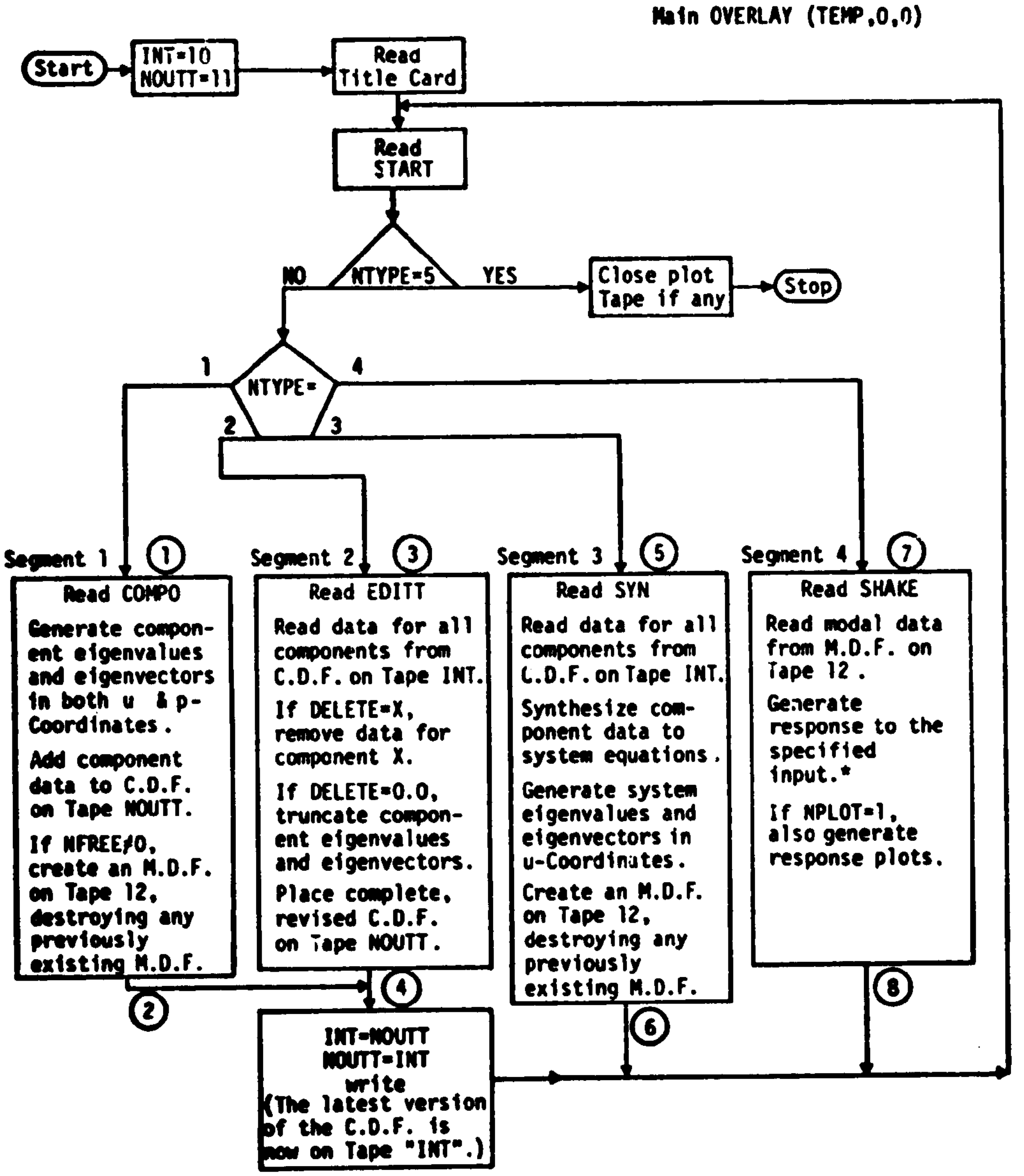
DYNALIST II is constructed of four segments. A top level flow diagram is shown in Figure 1. Detailed flow diagrams are included in Appendix D. The four segments function as follows:

Segment 1. Define equations of motion for a component and create, or add to, a component data file (C.D.F.). Modes may be computed, in which case a modal data file (M.D.F.) will be created for use in calculating response in Segment 4. (Note, however, that any previously existing M.D.F. from the same run will be destroyed).

Segment 2. Edit (truncate modes from) the various components on the component data file (C.D.F.); or a component may be deleted from the file.

Segment 3. Synthesize component data into a system and determine system modes. A modal data file (M.D.F.) will be created for use in Segment 4. (Note, however, that any previously existing M.D.F. will be destroyed).

Segment 4. Use modal data to obtain frequency response at selected physical coordinates due to harmonic forces applied at specified physical coordinates. Response due to random forces, or sinusoidal forces whose amplitudes vary as a function of the excitation frequency, may also be found. Lastly, response to a general periodic or transient input may be found using a Fourier series. Response (and excitation) characteristics may be plotted on a standard plotting device.



*If NFREQ ≠ 0, generate frequency response.

If NPSD ≠ 0, generate random response.

If NSINE ≠ 0, generate response to an amplitude varying sinusoidal input.

If NFOUR ≠ 0, generate response to a general periodic or transient input.

78-1333

Figure 1. DYNALIST II Flow Diagram

2.1 Segment 1: Component Modeling

Segment 1 develops the component equations of motion and may calculate the complex eigenvalues and eigenvectors for linear dynamic systems which can be described in terms of matrix equations of motion of the form

$$[m]\{\ddot{p}\} + [c]\{\dot{p}\} + [k]\{p\} = \{0\}$$

where m, c, and k are real matrices input in the dynamic p-coordinate system. Thus these matrices may be non-symmetric, representing non-conservative systems. Rigid body (free-free) modes may not be computed, nor will diagonal equations be solved, except in the case of the one degree of freedom oscillator. Because of its common application, a separate logic has been set up to handle this special type of diagonal system.

To enhance its general modeling capabilities, DYNALIST II operates in two coordinate systems. In addition to the dynamic p-coordinate system, a physical u-coordinate system is defined by

$$\{u\} = [\phi]\{p\}$$

Additional response coordinates may thus be defined and real structural modes may be included in the model. It is the physical u-coordinate system to which constraints and forces will be applied in later segments.

The dynamic p-coordinate system must be ordered such that all "constrained" coordinates are listed first, followed by the "free" coordinates. Eigenvectors will be computed only for the free coordinates. If NFREE=0, no eigenproblem will be solved.* The eigenvalue $\lambda = \sigma + i\omega$ gives the damping σ and the vibrational frequency ω. A positive σ means that mode is unstable. The eigenvectors ψ and ψ_u in p and u-coordinates, respectively, are printed out giving the real and imaginary parts, from which amplitude and phase may be determined. To ensure that an independent set of modes has been found, an orthogonality check is performed. If the eigenvectors do indeed diagonalize the equations within a fine tolerance, a confirming message is printed. If the dynamic matrix D is not diagonalized, a warning message and the partially diagonalized matrix is printed. A modal data file will be created if an eigenproblem is solved, from which response may be computed directly for a one-component system, by passing directly to Segment 4. [However, if modal truncation is to be performed on this system, then a new M.D.F. must be generated by using Segment 3 (and coupling with a dummy component) before passing to Segment 4.]

The matrices m, c, k, and ϕ may be input directly (IGEN=0), or they may be generated automatically using one of two modeling routines. IGEN=1 will activate the general COMGEN routine. IGEN=2 or 3 will respectively generate the pre-programmed truck or car model contained in subroutine TRAIN. These will be explained in detail in Section 3.4 and 3.5.

---

*The category of constrained coordinates should be thought of as a complementary category to the free coordinates; that is, constrained = not free. Recalling that the sole purpose of the free coordinate category is to partition component matrices for the component eigenproblem solution, one should recognize that constrained coordinates are used for all other purposes; e.g., to constrain components whose equations of motion are already in diagonal form, or to constrain components which would otherwise be free-free and would thus have rigid body modes which DYNALIST will not compute. It is emphasized that the constraints discussed here apply only to the isolated component phase of analysis, and that all such constraints are relaxed when evaluating the motion of the composite system. The constraints that actually apply to the composite system are specified in the constraint matrix, G, with the resulting dependent system coordinates defined in KDEP.

2.2 Segment 2: Editing the Component Data File (C.D.F.)

Segment 2 has the capability of removing modes from any or all of the components on the component data file. See Figure 2. The number of modes to be retained for each component must be specified in the vector NMODE2. The modes to be retained are listed in MODES. Remember that Segment 1 produces two modes for each degree of freedom in the eigenproblem it solves. These modes are in order, from lowest to highest of the magnitude of the complex eigenvalue, $\lambda = \sigma + i\omega$.

Segment 2 may also be used to delete a component from the C.D.F., enabling components to be continually added to and deleted from the file.

2.3 Segment 3: Component Synthesis

Segment 3 uses component data to create a new set of system coordinates. There are two basic methods for doing this. In the Direct Sub-Systems Method, the system is modeled as an assembly of components (subsystems) without having any individual component modes computed. In the Modal Synthesis Method, the system is modeled as an assembly of components some of which have had component modes computed. If some of these modes have been truncated, the results will be approximate. Segment 3 will then solve an eigenproblem of the kind discussed in Section 2.1 and convert the eigenvectors back to the system u-coordinates. A Modal Data File (M.D.F.) will be created (see Figure 3) which will have the infor-

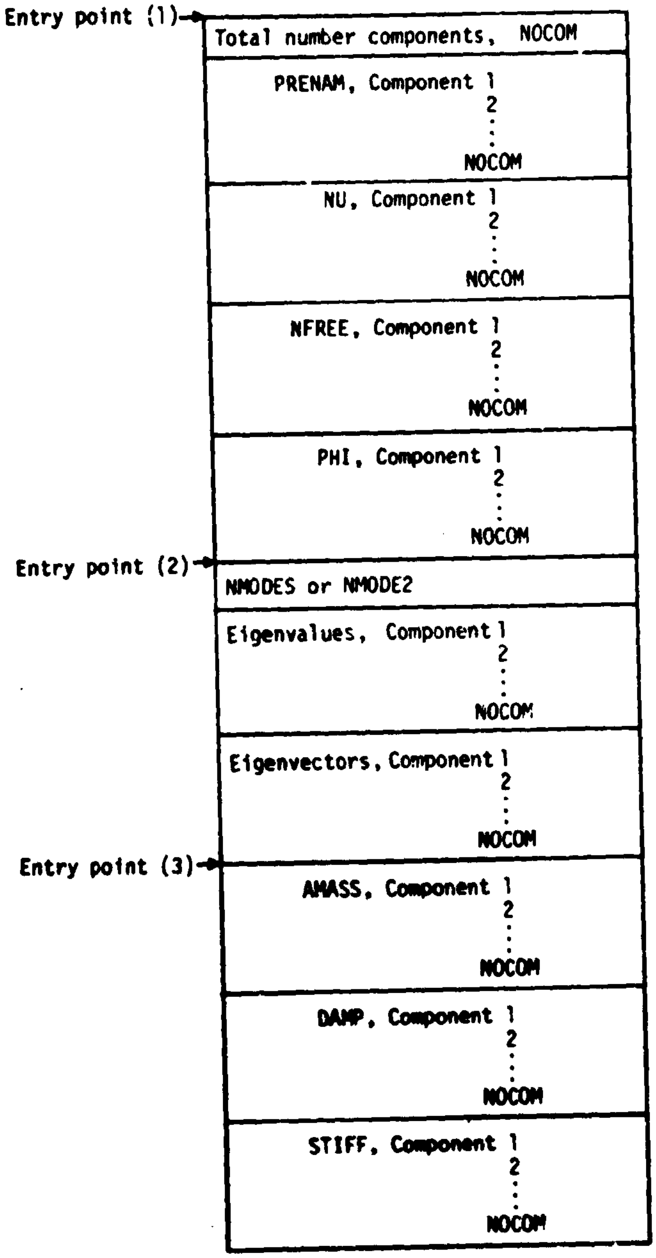


Figure 2. Layout of Component Data File (C.D.F.)

KONV	If KONV=0, data is for a component. If KONV=1, data is for a system.	
NUNCOT	Number of physical U-coordinates.	
NCTOTS	Number of uncoupled system P-coordinates.	For a system level model only.
$[\phi]$	$\{U\} = [\phi]\ \{P\}$; NUNCOTxNCTOTS.	
NINDEP	Number of independent system P-coordinates.	
$[\bar{\beta}]$	$\{P\} = [\bar{\beta}]\ \{q\}$; NCTOTSxNINDEP.	
$[K]$	System stiffness; NCTOTSxNCTOTS.	
NCOLT	Number of eigenvalues.	
$[\Psi_u]$	Physical eigenvectors.	
$[A_z]$	$[\Psi]^T\ [A]\ [\Psi]$.	
$[\Lambda]$	Eigenvalues.	

78-1233

Figure 3. Layout of Modal Data File (M.D.F.)

mation necessary to compute the static correction if modal truncation is used.

Segment 3 assembles components in order. The coupled system has a p-coordinate system and a u-coordinate system, the same as for a component. The coupled system coordinates are the same as the component coordinates, but are renumbered in one continuous sequence according to the order in which the components are assembled. The component assembly order is that listed in the vector PRENAM. The three-car train of Figure 4 is assembled using five components, NCOMP=5, from two unique components, 1 and 2. These components are assembled using PRENAM(1)=1, 2, 1, 2, 1, which results in the system p- and u-coordinates being numbered as shown in Figure 4. Eight physical displacement constraints are applied to the components in the system to form them into a train. The constraints are applied in the u-coordinate system and have the form

$$
\begin{aligned}
[G]\{u\} = \quad & u_4 - u_7 = 0 \\
& u_{13} - u_9 = 0 \\
& (u_3 - u_4)/L - u_8 = 0 \\
& (u_{13} - u_{14})/L - u_{10} = 0 \\
& u_{14} - u_{17} = 0 \\
& u_{23} - u_{19} = 0 \\
& (u_{13} - u_{14})/L - u_{18} = 0 \\
& (u_{23} - u_{24})/L - u_{20} = 0
\end{aligned}
$$

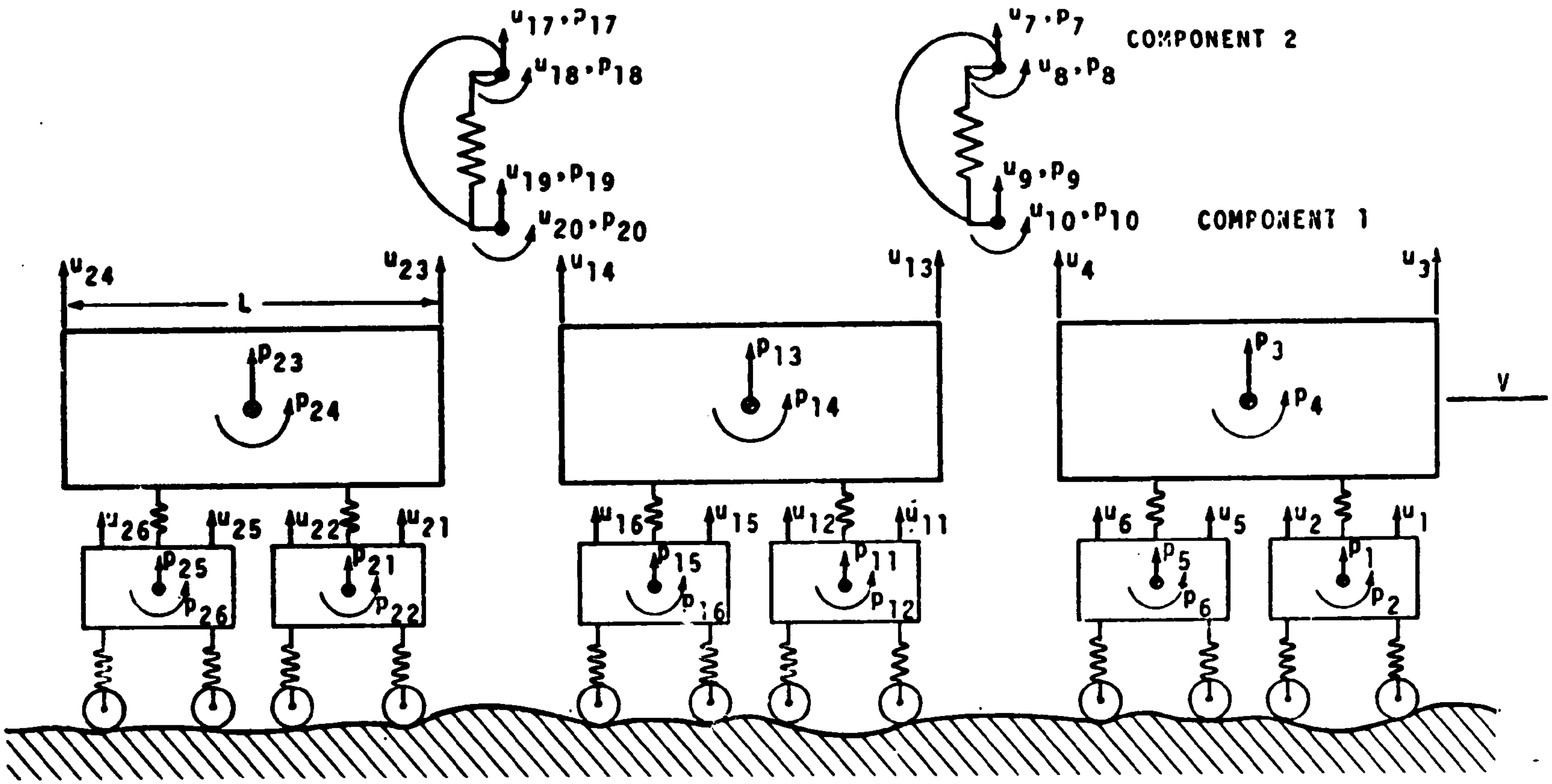


Figure 4. A Three-Car Train Modeled with Two Unique Components

Thus, NROWG will equal 8 and the third constraint, for example, would be input as G(3, 3) = 1/L, G(3, 4) = -1/L, G(3, 8) = -1.

It is important to appreciate the fact that constraint equations specified in terms of u-coordinates eliminate degrees of freedom associated with p-coordinates, on a one-for-one basis. That is, each constraint equation must eliminate one degree of freedom from the system. There are three general rules to follow when applying constraints to the system:

(1) For every constraint equation, one p-coordinate must be eliminated as a system degree of freedom by specifying it in the vector KDEP.

(2) Each degree of freedom (p-coordinate) eliminated by placing it in the vector KDEP must be expressible in terms of the remaining degrees of freedom which themselves must be independent.

(3) Only p-coordinates from the set NCON (constrained coordinates) may be eliminated. Never eliminate a p-coordinate which is a member of the set NFREE (free coordinates).*

For example, in the system of Figure 4, KDEP(1) = 7, 8, 9, 10, 17, 18, 19, 20.

---

*Note that the original partitioning of p-coordinates into "constrained" and "free" coordinates at the component level does not imply that the "constrained" coordinates are constrained in the system model. In fact they are not. The only significance of the terminology "constrained" is that (1) those coordinates are constrained at the component level for the purpose of computing complex component modes for the remaining "free" coordinates, and (2) are the only coordinates which may be eliminated by the system constraint equations when establishing displacement compatibility among the various components.

2.4 Segment 4: System Response

Segment 4 calculates response at specified physical u-coordinates due to forces applied in the u-coordinate system. The form of the force vector is discussed in detail in Appendix A of this manual. NAXLE specifies the number of u-coordinates having applied forces; the numbers of these coordinates are contained in LAXLE. NLOOK specifies the number of u-coorindates for which response is desired; LOOK contains the coordinate numbers. NPLOT contains a "1" for each coordinate to be plotted. Thus, for the train in Figure 4, if response is desired at coordinates u_4, u_{14}, u_{24}, and u_{26}, and if u_4 and u_{26} are to plotted: NAXLE=12; LAXLE(1)=1, 2, 5, 6, 11, 12, 15, 16, 21, 22, 25, 26; NLOOK=4; LOOK(1)=4, 14, 24, 26; NPLOT(1)=1, 0, 0, 1.

Frequency response and response to a general periodic input are computed independently of each other. Frequency response is computed over a spectrum defined by OMIN and OMAX using a mesh defined by NFREQ. Either power-spectral-density (PSD) or sinusoidal response may then also be computed based upon a frequency dependent input which is specified by the vectors AMP and CYCLS. The root-mean-square (RMS) response and the median power frequency of the response are computed along with the PSD. For a general periodic or transient input, the waveform of the excitation may be given as a function of time in the vectors WAVE and TIME, in which case the Fourier coefficients of the input are computed automatically. Alternatively, the Fourier coefficients (AOVER2, A, and B) may be input directly. The input and response are approximated using NFOUR harmonic terms. Response is output with Fourier coefficients, time history, peak response, and root-mean-square response.

When computing system response, it is important that the user note whether the eigenvector orthogonality check was satisfied, since, if it was not, the generated system response may yield incorrect results.

2.5 Data Files

DYNALIST II uses three working files, TAPE 10, TAPE 11, and TAPE 12, which may be tapes or disks. Any of these may be saved at the end of program execution using the CATALOG Statement (see Section 5). They may then be used to restart the program at a later time using the ATTACH Statement (see Section 5).

TAPE 10 and TAPE 11 are used only as component data files. A component data file (C.D.F.) contains the information necessary to describe one or more unique components. [Each component has a unique "name", COMNAM (an F6.2 number)]. Component data files are created and added to in program Segment 1. To create a new C.D.F., specify NEWTAP=0. To add to an existing C.D.F., specify NEWTAP=1. Editing of a C.D.F. (modal truncation and component deletion) is handled by program Segment 2. Program Segment 3 then assembles the components to generate system modes using the latest revised C.D.F. Program Segment 3 finds information for the various components it wants to assemble by looking for their names (given in PRENAM) on the C.D.F. Segment 3 does not alter any of the information on the C.D.F.

Each time either Segment 1 or Segment 2 is executed, information is taken from the C.D.F. on Tape INT (initially TAPE 10), then updated or revised, and then transferred to Tape NOUTT, (initially TAPE 11). At the completion of the segment, the designations are switched, so that what was Tape NOUTT is now Tape INT, and vice versa. Accordingly, after each time Segment 1 or Segment 2 is completed, the latest version of the C.D.F. will be on the newly designated Tape INT, while the other tape will contain the version of the C.D.F. that existed just prior to execution of that segment.

Therefore, within any one run (which might consist of calls to any number of program segments, including repeated calls), Tape INT is automatically alternated back and forth between TAPES 10 and 11 such that when any program segment reads Tape INT, it reads the latest version of the C.D.F. This permits cases to be stacked - where a stacked case may use a C.D.F. produced in the previous case or may generate a new C.D.F. completely from scratch. Furthermore, execution of any case may begin with any of the program segments. The only caution is that if the very first case is to use an existing C.D.F. that has been previously stored, then that C.D.F. must be mounted on TAPE 10 (since Tape INT is initially set to TAPE 10). To enable the user to keep track of which tape has the lastest C.D.F. version (for purposes of storage after run completion), each time program Segments 1 and 2 are completed the following message is printed: "THE LATEST VERSION OF THE COMPONENT DATA FILE IS NOW ON TAPE XX" (where XX = 10 or 11, as the case may be). (Note that no message is printed after execution of Segment 3, since this segment does not alter any of the information on the C.D.F and, accordingly, does not switch tape designations). The layout of the C.D.F. is shown in Figure 2.

TAPE 12 is used as a modal data file (M.D.F.) only. An M.D.F. is created in Segment 1 whenever a component eigenproblem is solved. Segment 3 always creates an M.D.F. The creation of a new M.D.F. destroys any previous M.D.F. on TAPE 12. The M.D.F. is used in Segment 4, but is not destroyed, so Segment 4 may be entered several times consecutively using the same M.D.F. and response may be computed in different ways. The M.D.F. may be saved and used to compute response in later runs without solving another eigenproblem.

2.6 Program Limits

DYNALIST II was designed to require no more than $163,000_8$ of core for the compiled overlay structure and all storage. Less may be required depending on the particular operating system. In order to limit the size of the program, there are limits to the sizes of various matrices and vectors read into the program and generated within the program. These are listed below.

- Maximum number of nodes in COMGEN, NNOD=100.
- Maximum size of m, c, and k matrices = 25 x 25.
- Maximum number of component p-coordinates, NCON + NFREE=25.
- Maximum number of component u-coordinates NU=50.
- Maximum size of ϕ matrix = 50 x 25.
- Maximum number of components on a C.D.F. = 10.
- Maximum number of assembled components, NCOMP=10.
- Maximum number constraints, NROWG=25.
- Maximum number of system p-coordinates, NCTOTS=50.*
- Maximum number of system u-coordinates, NUNCOT=100.
- Maximum number of system eigenvalues found in Segment 3, NCOLT=50.*
- Maximum number of applied forces, NAXLE=100.
- Maximum number of response coordinates, NLOOK=100.
- Maximum number of power spectral density data points, NPSD=50.
- Maximum number of sinusoidal input data points, NSINE=50.

---

*The number of system p-coordinates equals the sum of all component p-coordinates for components comprising the system. However, the system may have no more than 25 degrees of freedom after constraint equations have been applied and complex component modes have been truncated. The 25 dynamic degrees of freedom result in 2 x 25 = 50 system eigenvalues.

- Maximum number of divisions in frequency spectrum, NFREQ=250; and maximum number of frequency increments times number of system modes, NFREQ x NCOLT=7500.
- Maximum number of terms in the Fourier series NFOUR=100.
- Maximum number of periodic data points, NTIME=100.

NCTOTS, NUNCOT, and NCOLT may be found using the following formulae:

$$\text{NCTOTS} = \sum_{\text{I}=1}^{\text{NCOMP}} (\text{NCON(I)} + \text{NFREE(I)})$$

$$\text{NUNCOT} = \sum_{\text{I}=1}^{\text{NCOMP}} \text{NU(I)}$$

$$\text{NCOLT} = 2\text{x}\left[-\text{NROWG} + \sum_{\text{I}=1}^{\text{NCOMP}} \text{NCON(I)}\right] + \sum_{\text{I}=1}^{\text{NCOMP}} \text{NMODE2(I)}$$

3. PROGRAM INPUT

3.1 Namelist Strategy

Namelist data input, once learned, gives the user an extremely flexible tool for controlling the execution of DYNALIST II and for supplying the program with the information it needs. DYNALIST II has six namelists: START, COMPO, EDITT, SYN, SHAKE, and UPDATE. Except for UPDATE, these namelist blocks are stacked in pairs with the first block of the pair always being START, and with the second block of the pair being either COMPO, EDITT, SYN, or SHAKE. These last four blocks supply information necessary to program Segments 1, 2, 3, and 4, respectively; while namelist START supplies the particular control information required for each block. Namelist START identifies its paired block through the parameter NTYPE. The only exception to this paired format is namelist block UPDATE, which instead immediately follows namelist COMPO, and which is used to enter revisions to the matrix data listed in COMPO (see Section 3.7 for general update procedure). Control for UPDATE is provided through the parameter NEWDAT specified directly in namelist COMPO.

A namelist line begins with a blank, then a dollar sign directly followed by the namelist name. The name is itself followed by one or more blanks, and then the members of the namelist are given, always followed by a comma. Having specified the data to be given to the program, each namelist block is terminated with another dollar sign and the word END. The user must be careful to note that the first column of every data card (including the title card) must be blank. Only the JCL starts in the first column.

It should be noted that the sequence of program flow from segment to segment is dictated by the requirements of the problem to be solved; there is no special required ordering. For example, a run might consist solely of program Segment 4 (computation of response using a previously generated Modal Data File); or it might consist of program Segment 2 followed by program Segment 1 (editing (2) and updating (1) of a previously generated Component Data File); or it might consist of a set of stacked cases whose program flow follows the Segment order 1, 4, 2, 1, 1, 3, 4 (generate a component (1) and directly compute its response (4), then edit (2), add two new components (1, 1) to the C.D.F., then synthesize the components into a new system (3) and compute its response (4)). Further information on how files are generated and handled is presented in Section 2.5.

As a practical illustration of the namelist format, however, consider the following example. Suppose the user wishes to edit the C.D.F. for the system of Figure 4. This system has two unique components: Component 1 and Component 2. Component 1 has six free coordinates, so it will have twelve modes on the C.D.F. The modes will be in order from lowest eigenvalue modulus to highest. We will retain the six lowest modes for this component. Component 2 has no free coordinates and therefore, no modes on the C.D.F. The data setup to transfer control to Segment 2, edit modes and then terminate program execution, is shown below.

```
$START NTYPE=2, $END
$EDITT NMODE2(1)=6,0,MODES(1,1)=1,2,3,4,5,6,$END
$START NTYPE=5, $END
```

Note that the elements of a vector may be entered sequentially without giving the position of each element within the vector. A matrix may also have its elements entered sequentially, column by column. If Component 2 had six modes altogether, and we wished to retain the four highest of them these modes could be entered as MODES(1,2)=3,4,5,6,.

3.2 Namelist Directory

Overlay(0,0): Namelist START
NTYPE,IFOUT, NEWTAP ,IMATX,IALT,INOVEC,IPLOT,
SIZE,FREQSC(2,100),SINESC(2,100),PSDSC(2,100),
PERDSC(2,100)

Segment 1: Namelist COMPO
COMNAM,IGEN,NU,NCON,NFREE,ISYMM,ISYMC,ISYMK,
AMASS(25,25),DAMP(25,25),STIFF(25,25),
PHI(50,25),NEWDAT

Namelist UPDATE
AMASS(25,25),DAMP(25,25),STIFF(25,25),
PHI(50,25)

Segment 2: Namelist EDITT
NMODE2(10),MODES(50,10),DELETE

Segment 3: Namelist SYN
NCOMP,PRENAM(10),NROWG,KDEP(25),G(25,100)

Segment 4: Namelist SHAKE
NAXLE,NWHEEL,LAXLE(100),FORC0(100),FORC1(100),
FORC2(100),PHAS0(100),PHAS1(100),KIND,KONVS,
NLOOK,LOOK(100),NFLOT(100),OMIN,OMAX,NFREQ,
NPSD,FLIM,NSINE,AMP(50),CYCLS(50),NFOUR,AOVER2,
A(100),B(100),PERIOD,NTIME,WAVE(100),TIME(100)

3.3 Input Parameters and Structure

All input to the program - with the exception of Card 1 (a title card of up to 80 characters), the data for COMGEN and TRAIN following namelist COMPO, and the wheelset cards following namelist SHAKE - is namelist input. There are five primary namelist blocks: START, COMPO, EDITT, SYN, and SHAKE. These namelist blocks, with their associated parameters, are described below. (A secondary namelist block, UPDATE, is described in Section 3.7). When specifying these parameters, the user should pay careful attention to the program limits specified in Section 2.6.* The following twelve parameters are input in namelist block START.†

NTYPE: NTYPE specifies whether the data following is for defining a component (NTYPE=1), editing a component data file (NTYPE=2), synthesizing the components and finding system modes (NTYPE=3), or computing response at physical coordinates (NTYPE=4). Upon completion of all steps, termination is achieved by specifying NTYPE=5.

IFOUT: IFOUT is a flag for printing results of intermediate calculations in the ensuing program segments. Once specified, IFOUT remains unchanged until re-specified. IFOUT=0 means print only the input and the final results. IFOUT=1 means print the results of most intermediate calculations. IFOUT defaults to zero.

---

*When specifying physical parameters, the user must also be careful to adhere consistently to one system of units. If he is using the FPS system, then all dimensions must be in feet, all forces in pounds, all masses in slugs, all times in seconds, and all angles in radians (except where an input parameter specifically calls for frequencies in Hertz).

†All parameter values read in namelist block START are retained throughout the run unless changed in a subsequent block of namelist START input data.

NEWTAP: NEWTAP only has to be specified when NTYPE=1 and is ignored, when NTYPE=2, 3, or 4. If a new C.D.F. is to be created, NEWTAP=0. If the data for the component is to be added to an existing C.D.F., NEWTAP=1. NEWTAP defaults to zero.

IMATX: IMATX is a flag for suppressing the printout of selected component and system modeling data. IMATX=1 means do not print. IMATX=0 permits normal printout. Printed output suppressed by this option includes:

- Component matrices (but prints out the title card and the sequence of one-line coordinate information about each component) (NTYPE=1),
- All additional data generated by COMGEN (NTYPE=1), and
- The G Matrix at the system level (but prints out all of the one-line system information statements) (NTYPE=3).

IMATX defaults to zero.

IALT: Setting IALT=1 activates a flag for suppressing the printout of every other eigenvector at both component and system levels. When the eigenvectors correspond to oscillatory modes, they are complex and occur in conjugate pairs, in which case it is not necessary to print out both eigenvectors of the pair. The eigenvectors for non-oscillatory modes are real and do not necessarily occur in identifiable pairs. Setting IALT=1 will result in the loss of every other real eigenvector whenever real roots (eigenvalues) are found. It is therefore suggested that IALT=1 be exercised only when the user is not interested in the over-critically damped (non-oscillatory) modes. However, in either case, all eigenvalues are still printed. IALT defaults to zero (NTYPE=1,3).

INOVEC: Setting INOVEC=1 activates a flag for suppressing the printout of all component and system eigenvectors, and the dynamic matrix if it is to be printed after the orthogonality check, (but the eigenvalues and the orthogonality check and trace of matrix statements are still printed out). INOVEC defaults to zero (NTYPE=1,3).

IPLOT: If response plots are to be made in Segment 4, set IPLOT=1. IPLOT defaults to zero.

SIZE: SIZE specifies the height from the bottom to the top of the plot in inches. It scales all dimensions of the plot in the same proportion. SIZE defaults to 11.0 inches, which fills a standard Cal-Comp plotter. SIZE=8.0 gives notebook size plots. It should be specified only once per run.

FREQSC: FREQSC(I,J) is the fixed plot scale parameter for frequency response. FREQSC(1,J) is the smallest value on the y-axis while FREQSC(2,J) is the largest value on the y-axis. The index J is the Jth response coordinate as specified in the vector LOOK. If FREQSC(1,J) or FREQSC(2,J) is zero, automatic scaling takes place. All FREQSC(I,J) values default to zero.

SINESC: SINESC(I,J) is the fixed plot scale parameter for sinusoidal response. SINESC(1,J) is the smallest value on the y-axis while SINESC(2,J) is the largest value on the y-axis. The index J is the Jth response coordinate as specified in the vector LOOK. If SINESC(1,J) or SINESC(2,J) is zero, automatic scaling takes place. All SINESC(I,J) values default to zero.

PSDSC: PSDSC(I,J) is the fixed plot scale parameter for PSD response. PSDSC(1,J) is the smallest value on the y-axis while PSDSC(2,J) is the largest value on the y-axis. The index J is the Jth response coordinate as specified in the vector LOOK. If PSDSC(1,J) or PSDSC(2,J) is zero, automatic scaling takes place. All PSDSC(I,J) values default to zero.

PERDSC: PERDSC(I,J) is the fixed plot scale parameter for periodic response (which is not a logarithmic plot). PERDSC(1,J) is the smallest value on the y-axis while PERDSC(2,J) is the largest value on the y-axis. The index J is the Jth response coordinate as specified in the vector LOOK. Automatic scaling takes place only if PERDSC(1,J) and PERDSC(2,J) are both zero. All PERDSC(I,J) values default to zero.

The following parameters are input only when NTYPE=1. They are in namelist block COMPO.*

COMNAM: A six-digit "name" (F5.2) to be associated with the component data.

IGEN: A flag to indicate whether component data are to be given in matrix form or the matrices are to be generated automatically. IGEN=1 means call COMGEN and read the necessary data on cards following COMPO. IGEN=2 or 3 means call TRAIN and generate a truck or car model, respectively. IGEN=0 means the matrix equations of motion are to be input directly in COMPO. IGEN defaults to zero.

---

*Complete data must be input for each component. There is no general carry-over from one component to another.

NU:	The number of physical u-coordinates of the component.
NCON:	The number of component dynamic p-coordinates which are constrained in the component eigenvalue solution.
NFREE:	The number of component dynamic p-coordinates which are free in the component eigenvalue solution. (Remember that the free coordinates must be ordered so as to follow the constrained coordinates when formulating the problem).
PHI:	A matrix relating the component p-coordinates to the u-coordinates. PHI has NU rows and NCON+NFREE columns. Only the non-zero terms of PHI need be entered.
AMASS:	The component mass matrix. AMASS is of order NCON+NFREE. Only the non-zero terms need be entered.
DAMP:	The component damping matrix of the same order as AMASS. Only the non-zero terms need be entered.
STIFF:	The component stiffness matrix. Only the non-zero terms need be entered.
ISYMM, ISYMC, ISYMK:	Symmetry indicators for the mass, damping, and stiffness matrices, respectively. If the matrix is a non-diagonal, symmetric matrix, the appropriate flag should be set to 1 and only the non-zero upper-triangular terms need be entered. Default is to zero.

NEWDAT: If it is desired to read updated elements in COMPO, set NEWDAT=1. The updated elements of AMASS, DAMP, STIFF, and PHI should then be read in namelist block UPDATE immediately following COMPO. NEWDAT defaults to zero.

The following parameters are input only when NTYPE=2. They are input in namelist block EDITT.

DELETE: DELETE is the component name (F6.2) of the component which is to be purged from the component data file. IF DELETE is non-zero, modal editing will not occur and NMODE2 and MODES should not be entered. DELETE defaults to 0.0.

NMODE2: NMODE2 is a vector which must contain one element for each component on the component data file. The elements of NMODE2 are the number of modes to be retained on the edited component data tape for the corresponding component. The first element of NMODE2 corresponds to the first component on the component data file, the second element corresponds to the second component, etc. The elements of NMODE2 must be less than or equal to the number of modes on the input component data file for the corresponding component. (Remember that each degree of freedom corresponds to two modes). If no modes for a particular component are to be retained, or the component had no normal modes to begin with, a zero must be entered for the corresponding element of NMODE2. Read only if DELETE=0.0.

MODES: MODES is a matrix which specifies the modes to be retained for each component on the edited component modes data file. MODES(1,1) through MODES(NMODE2(1),1) are the modes to be retained for the first component on the data file. MODES(1,2) through MODES(NMODE2(2),2) are the modes to be retained for the second component on the data file, etc. The values of MODES(1,I) through MODES(NMODE2(I),I) must be greater than or equal to one and less than or equal to the number of modes recorded for component I on the input component data file. If component I is to have no modes retained or if component I has no modes to begin with, MODES(X,I) need have no entries. Read only if DELETE=0.0.

The following parameters are input only when NTYPE=3. They are entered in namelist block SYN.

NCOMP: The number of components involved in the synthesis. (Not the number of unique components). Each time a particular component is to be used, it must be counted again.

PRENAM: A vector of length NCOMP. The values of PRENAM are floating point names (numbers) of the format F6.2. The values of PRENAM correspond to the names given to the desired components on the input component data file. (The names on the input component data file were set by the parameter COMNAM which was input in common block COMPO). The system components are assembled according to the order in which they are listed in the vector PRENAM. (The system u- and p-coordinates are then renumbered in one continuous sequence according to this component assembly order). The values of the vector PRENAM will in general not be unique, since each time a particular component is to be used, its name must be listed again.

NROWG: The number of rows of the constraint matrix (G) described below.

G: The matrix defining the constraint relationships among the component coordinates. G has NROWG rows and a column for each u-coordinate of the complete system. NROWG is the number of constraint relationships. Only the non-zero terms of G need be entered.

KDEP: A vector containing a list of all those system p-coordinates which are actually dependent due to the system constraints and component interconnections. KDEP should have NROWG entries since each connection constraint equation is used to eliminate one degree-of-freedom. No coordinates which were "free" at the component level should be named in KDEP.

The following parameters are input in namelist block SHAKE.

MAXLE: The number of physical coordinates where external forces of any type are applied.

LAXLE: The numbers of the system u-coordinates where the forces are applied.

For the mathematical definitions of FORC0, FORC1, FORC2, PHAS0, and PHAS1, see Appendix A.

FORC0: The coefficients of the harmonic force or displacement excitation. FORC0 has entries for each of the coordinates named in LAXLE, in the same order in which they are named in LAXLE. Only the non-zero terms need be entered.

FORC1: The coefficients of the harmonic velocity-dependent forces resulting from a displacement excitation. FORC1 has entries for each of the coordinates named in LAXLE. Only the non-zero terms need be entered.

FORC2: The coefficients of the harmonic acceleration-dependent forces resulting from a displacement excitation. FORC2 has entries for each of the coordinates named in LAXLE. Only the non-zero terms need be entered.

PHAS0: The constant *phase* lag in cycles at each force coordinate named in LAXLE. For use in such applications as unbalanced spinning shafts where the phase lag of an imbalance is constant at all spinning frequencies. Only the non-zero terms need be entered.

PHAS1: The constant *time* lag in seconds (of a frequency-dependent phase lag) at each force coordinate named in LAXLE. For the train application, the lead wheelset has PHAS1 equal to zero. The trailing wheelset has PHAS1 equal to the ℓ/V

ratio, where ℓ is the distance between the two wheelsets and V is the vehicle forward velocity. Only the non-zero terms need be entered.

NWHEEL: The number of wheelset cards (which are read in following namelist block SHAKE) to be used to generate FORC0 and PHAS1 automatically. NWHEEL defaults to zero.

NLOOK: The number of physical coordinates where response output is desired.

LOOK: The numbers of the system u-coordinates where response output is desired.

KIND: KIND determines whether the response calculated is for displacement response, velocity response, or acceleration response. KIND=0 means zero-order or displacement response will be computed. KIND=1 gives first-order, or velocity response. KIND=2 gives second-order, or acceleration response. KIND defaults to zero.

KONVS: If modal truncation has occurred, the static correction to both frequency and periodic response may be employed by setting KONVS=1. If KONVS=0 the static correction will not be employed. KONVS defaults to 1, thus the only time KONVS need be specified is when modal truncation has occurred and the correction is not to be used, in which case KONVS must be set to zero.

NPLOT: NPLOT is a vector with elements corresponding to LOOK. For each coordinate specified in LOOK, NPLOT should contain a "1" if response (either frequency or periodic) is to be plotted, and NPLOT should contain a zero if response at that coordinate is not to be plotted. The entries of NPLOT default to zero.

OMIN: The lower bound of the frequency spectrum over which frequency response will be computed. OMIN is given in Hertz and should be greater than zero since the frequency spectrum is converted to a logarithmic scale.

OMAX: The upper bound of the frequency spectrum over which frequency response will be computed. OMAX is given in Hertz.

NFREQ: The number of divisions into which the frequency spectrum will be divided. For plots, NFREQ should be large, such as 150 for a frequency spectrum having four cycles on a logarithmic scale. (Note program limit of NFREQ x NCOLT = 7500). The plots will also look better if OMIN and OMAX are given in powers of 10, such as OMIN=.1 and OMAX=100.0. If NFREQ is equal to zero, frequency response will not be computed. If random (PSD) or sinusoidal response is to be computed, NFREQ must be specified in addition to NPSD or NSINE.

NPSD: When NPSD is given some value greater than or equal to two, response to a stationary random excitation will be computed in addition to frequency response. NPSD represents the number of frequency points where power spectral density data will be input. DYNALIST II interpolates along a straight line on a log-log scale between these points, thus at least two points must be given to properly define the PSD of the input over the frequency spectrum. NPSD defaults to zero.

NSINE: When NSINE is given some value greater than or equal to two, response to a sinusoidal excitation whose amplitude varies as a function of frequency will be computed in addition to frequency response. NSINE represents the number of frequency points where amplitude data will be input. NSINE and NPSD should not both be specified in the same call to Segment 4. NSINE defaults to zero.

CYCLS: CYCLS is a vector containing the frequencies in Hertz, from lowest to highest, at which the forcing function data (either PSD or sine amplitude) are given in the vector AMP. CYCLS must contain either NPSD or NSINE entries (whichever is non-zero). CYCLS must bound the frequency spectrum, thus CYCLS(1)$\leq$OMIN and CYCLS(NPSD or NSINE) $\geq$OMAX. CYCLS(1) must be greater than zero since it is converted to a logarithmic scale. The elements of the vector CYCLS default to zero.

AMP: AMP is a vector containing the values of the forcing function amplitude (either PSD or sine amplitude) at the frequencies given in CYCLS. AMP will have NPSD or NSINE entries (whichever is non-zero). The elements of the vector AMP default to zero.

FLIM: When power spectral density data are given, the root-mean-square of the input and of the response is computed by integrating the PSD from OMIN to OMAX. If the influence of the high frequency response is not desired in the RMS, FLIM may be set to a frequency in Hertz less than OMAX and the integration will be performed from OMIN to FLIM. When modal truncation has occurred, the frequency response at higher frequencies may be inaccurate and this option is desirable. FLIM defaults to OMAX.

NFOUR: NFOUR is the number of terms to be used in the Fourier series approximation of a periodic or transient input. If NFOUR equals zero, periodic response will not be computed. Either frequency or periodic response or both may be computed in the same call to Segment 4 by specifiying NFREQ or NFOUR or both non-zero. NFOUR defaults to zero.

PERIOD: PERIOD is the period in seconds of the periodic excitation. (For a transient input, it should be much longer than the response decay time.)

NTIME: NTIME is the number of data points used to describe the waveform of the excitation over one period in time. NTIME should be equal to or greater than 2, in which case the Fourier coefficients of the excitation will be computed automatically. If NTIME=0 the Fourier coefficients must be input in AOVER2 and the vectors A and B. NTIME defaults to zero.

TIME: TIME is a vector containing the times in seconds, in increasing order, at which the excitation waveform data are given in the vector WAVE. TIME(1) should equal zero and TIME(NTIME) should equal PERIOD. The elements of the vector TIME default to zero.

WAVE: WAVE is a vector containing the values of the waveform amplitude at the times specified in TIME. The elements of the vector WAVE default to zero.

AOVER2: AOVER2 is the Fourier coefficient of the static amplitude of the periodic excitation.

$$\mathrm{AOVER2}=1/T\int_0^T \delta(t)\,dt$$

AOVER2 defaults to zero. Input only if NTIME=0.

A: A is a vector containing the Fourier cosine coefficients of the periodic excitation. The elements of A default to zero. NFOUR elements are required. Input only if NTIME=0.

B: B is a vector similar to A except it contains the Fourier coefficients of the sine terms.

3.4 COMGEN: Component Matrix Generator

The function of the DYNALIST II Component Matrix Generator, COMGEN, is to create the four matrices input to Segment 1 using a finite element model. Segment 1 operates in two coordinate systems, the physical u-coordinate system, and the dynamic p-coordinate system in which the component equations of motion are written. Thus it is necessary that both coordinate systems be defined in COMGEN. Nodal references points are given positions in space, and physical constraints appropriate to the problem are applied to the motion of these nodes. The unconstrained nodal degrees of freedom constitute the original u-coordinate system.* Rigid body elements, which constrain several nodes to move as a unit, and flexible body elements, which allow the motion of several nodes to be described as linear combination of the motion of one or more real structural modes, may be added to facilitate modeling and to reduce the size of the problem. The relation between the u and p-coordinates $\{u\} = [\phi] \{p\}$ is thus generated. The element which will contribute to the m, c, and k matrices are then added onto the nodal skeleton. The spring-damper elements, nodal masses, and wheelset elements have their properties transformed into the p-system in the manner $[k] = [\phi]^T [k]_u [\phi]$ and are added element by element onto the matrices AMASS, DAMP, and STIFF.

The user numbers the p-coordinates himself; and, again, these must be sequenced with constrained coordinates first, followed by the component's free coordinates (see Section 2.1). The u-coordinates are also numbered by the user, and he may retain any or all of the physical coordinates for later use as response, forcing, or boundary attachment points.

---

*The number of u-coordinates later retained for application of component compatibility constraints, input forces, or response may be smaller than the number of original u-coordinates. See descriptions of "Nodal u-Coordinate Cards" near the end of this section.

COMGEN is initiated by specifying IGEN=1 in Namelist COMPO. Input data are entered on formatted data cards (rather than using namelist quantities). These cards immediately follow Namelist COMPO (in which COMNAM, IGEN, NU, NCON, and NFREE are still required). Following, is a list of these formatted data cards in the order in which they must be read. (A detailed description of the data elements, card by card, is presented after the summary listing).

<u>COMGEN Data Directory</u>

1) Control Card: Format (6I5)
   Parameters: NNOD, NMOD, NRIG, NWL, NSPRN, NMAS.
2) Nodal Geometry Cards: (I5,3F15.0): NNOD cards read.
   Parameters: N, x_n, y_n, z_n.
3) Nodal Constraint Cards: (7I5): NNOD cards read.
   Parameters: N, c-x, c-y, c-z, c-θ_x, c-θ_y, c-θ_z.
4) Nodal p-Coordinate Cards: (7I5): NNOD cards read.
   Parameters: N, p-x, p-y, p-z, p-θ_x, p-θ_y, p-θ_z.
5) Modal p-Coordinate Cards: (2I5): NMOD cards read.
   Parameters: M, p-M.
6) Mode Cards: (2I5,3F15.0): NMOD cards read.
   Parameters: M, NENOD, Mass, Damping, Stiffness.
7) Mode Shape Cards: (I5,6F10.0): NENOD cards read.
   Parameters: N, Δ_x, Δ_y, Δ_z, θ_x, θ_y, θ_z.
8) Rigid Body Element Cards: (16I5): NRIG cards read.
   Parameters: Body, Master Node, NENOD, Slave Nodes.
9) Wheelset Element Cards: (I5,5F10.0,24X,I1): NWL cards read.

Parameters: N, Gauge, Radius, Cone Angle, Creep Coefficient, Velocity, Update Code.

10) Spring-Damper Element Cards: (5I5,2F15.0,24X,I1): NSPRN cards read.
Parameters: Element, N1, N2, NR, NDIR, SP, DA, Update Code.

11) Nodal Mass Cards: (I5,6F10.0,14X,I1): NMAS cards read.
Parameters: N, M-x, M-y, M-z, I-xx, I-yy, I-zz, Update Code.

12) Nodal u-Coordinate Cards: (7I5): NNOD cards read.
Parameters: N, u-x, u-y, u-z, u-θ_x, u-θ_y, u-θ_z.

Detailed descriptions of each data card are given as follows:

Control Card: Format (6I5)

Parameters:
NNOD - Number of nodes in the model.
NMOD - Number of flexible body modes.
NRIG - Number of rigid body elements.
NWL - Number of lateral wheelset elements.
NSPRN - Number of spring-damper elements.
NMAS - Number of nodes having mass.

These control parameters tell the program how large a problem to set up and how many data cards to read. NU, NCON, and NFREE are read in COMPO and must be compatible with the model used in COMGEN. There is a limit of 100 nodes.

Nodal Geometry Cards: (I5,3F15.0)
Parameters: N, x_n, y_n, z_n.

The node number and the x, y, and z coordinates defining the initial location of that node are specified. These cards should be read in increasing order of node number. NNOD cards are read.

<u>Nodal Constraint Cards</u>: (7I5)
Parameter: N, c-x, c-y, c-z, c-θ_x, c-θ_y, c-θ_z.

Displacement constraints in the x, y, and z directions and rotational constraints about the x, y, and z directions are specified for each node. A "0" means the node is free to move in that direction and a "1" means the node is not allowed to move in that direction. NNOD cards are read in order.

<u>Nodal p-Coordinate Cards</u>: (7I5)
Parameters: N, p-x, p-y, p-z, p-θ_x, p-θ_y, p-θ_z.

Any <u>unconstrained nodal degree of freedom</u> whose motion is independent must be assigned a p-coordinate number. However, if the motion of an unconstrained nodal d.o.f. is to conform to that of a flexible body mode or be slaved to a rigid body element, it should not be given a p-coordinate number. The data card entries are the p-coordinate numbers to be assigned to each nodal d.o.f. When no p-coordinate number is assigned, the entry should be "0" or it may be left blank. Care must be taken not to use a p-coordinate number more than once and not to assign a p-coordinate number to a nodal d.o.f. which is physically constrained (as specified by a Nodal Constraint Card). The p-coordinates assigned to the nodes are combined with the p-coordinates assigned to the flexible body modes (if any) to form the total component p-coordinate system. This total component p-coordinate system must be defined with "constrained" p-coordinates numbered first, followed by the "free" p-coordinates, (see Section 2.1). Thus both nodal and modal p-coordinates may be "constrained" or "free", depending upon the order in which the user chooses to number them. NNOD cards are read in order of increasing node number.

Modal P-Coordinate Cards: (2I5)
Parameters: M, p-M.

The flexible body mode number and the p-coordinate number to be assigned to that mode are read. NMOD cards are read; none are read if NMOD=0.

Mode Cards: (2I5,3F15.0)
Parameters: M, NENOD, Mass, Damping, Stiffness.

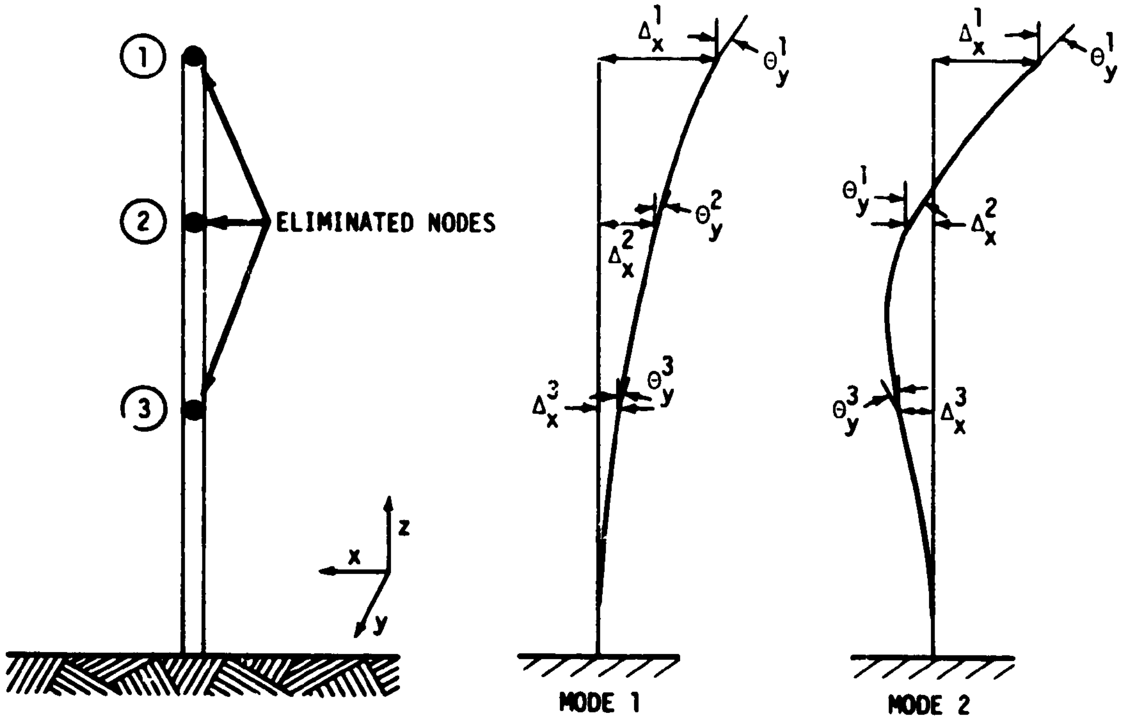
One of these cards is read for each mode M. NENOD is the number of eliminated nodes, i.e., the number of nodes whose motion will be represented in terms of that mode. The modal

Mass, Damping and Stiffness are also entered on the Mode Card. These terms are added onto the diagonal of the matrices AMASS, DAMP and STIFF, respectively, in the position given for that mode by the Modal p-Coordinate Card. Thus if the p-coordinate assigned to a mode is p_4, its modal mass goes in AMASS(4,4). The use of normal (orthogonal) modes uncouples the mass, damping and stiffness, allowing these terms to be placed on the diagonal of the matrices. The use of non-orthogonal modes (as described in Appendix B) leads to coupling of the matrices and the off-diagonal terms must be entered separately in the matrices AMASS, DAMP and STIFF prior to entering COMGEN.* Thus if two modes have been given coordinates p_3 and p_4 and they have intermodal mass coupling, the coupling terms must be entered as AMASS(3,4) and AMASS(4,3) in Namelist COMPO, while the diagonal terms may still be entered on the Mode Card.

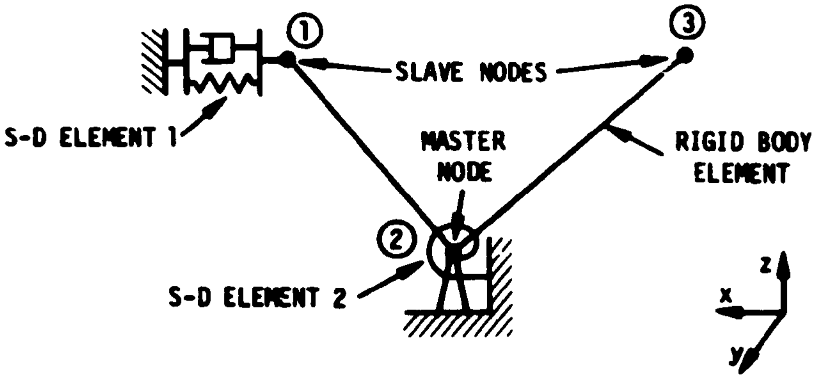
The mode shape of the flexible body element is represented by the modal displacements and rotations (in radians) at each of the "eliminated" nodes. Immediately following the Mode Card will be NENOD associated Mode Shape Cards, giving the modal displacements at each node affected by the mode. In Example Situation 1 of Figure 5 are shown two modes used to describe the motion of a cantilever beam. In this instance, NENOD is 3 for each mode. The cantilever is allowed only lateral motion, so the lateral displacement, Δ_x, and rotation, θ_y, must be input at each of nodes 1, 2, and 3. The amplitude of the nodal displacements and rotations depend on the method of normalization of the mode shapes. Care should be taken to ensure that the modal mass, damping and stiffness are consistent with the way the mode

---

*This situation is illustrated in Sample Problem 1.

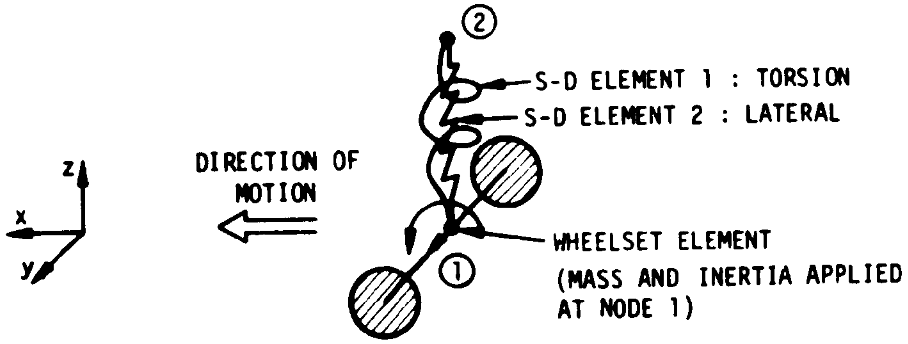


SITUATION 1

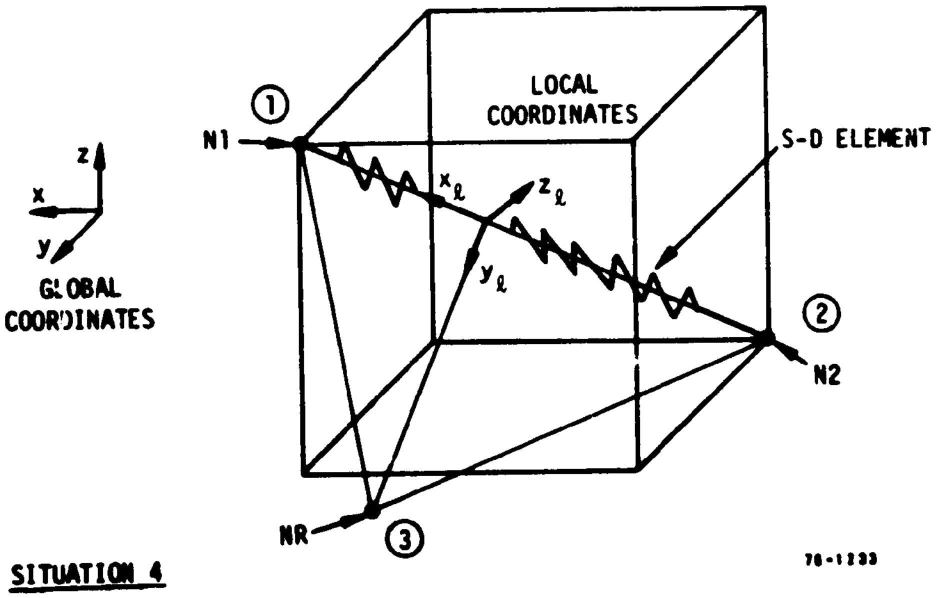


SITUATION 2

Figure 5. COMGEN Example Situations



SITUATION 3



SITUATION 4

Figure 5. COMGEN Example Situations (Cont'd)

shapes are normalized. If a flexible body exhibits rigid body motion, this motion must be represented in the same manner as the flexible motion and not by using a rigid body element. NMOD cards are read; none if NMOD=0.

Mode Shape Cards: (I5,6F10.0)
Parameters: N, Δ_x, Δ_y, Δ_z, θ_x, θ_y, θ_z

N is the node number of the node attached to the flexible body. The displacements and rotations of that node due to the mode are read in. (The rotation of the node corresponds to the slope of the mode at that point). Nodal degrees of freedom which are physically constrained may be given zero displacement or be left blank. If additional response u-coordinates are desired, such as stress or strain at a point, relative displacement across a suspension element, wheel-rail interaction force, etc., dummy nodes may be defined to create additional u-coordinates. Then the modal stress, strain, relative displacement, interaction force, etc., may be associated with one of these additional coordinates, and entered on the Mode Shape Card. In this case, the conventional u-coordinate headings Δ-x, Δ-y, etc. have no meaning and should be ignored. NENOD cards are read immediately following the Mode Card; none if NMOD=0.

Rigid Body Element Cards: (16I5)
Parameters: Body No., Master Node, NENOD,
Slave Nodes.

Each rigid body is assigned a body number. The node number of the master node, the number of eliminated (slave) nodes, and the node numbers of the slave nodes are read in. Each body has NENOD slave nodes tied to the motion of a master node. p-coordinate numbers should not be assigned to any degrees of freedom of a slave node. p-coordinate numbers should be assigned to the unconstrained degrees of freedom of the master node. The motion of the rigid body is completely controlled by the motion of the master node. A physical constraint applied at the master node constrains the entire body to move about the master node accordingly. A constraint at a slave node specifies that the displacement of that nodal d.o.f. is zero. It is good practice to apply physical displacement and rotation constraints at all the nodes of a rigid body consistent with the motion of the system. To illustrate this point see Example Situation 2 in Figure 5. Nodes 1, 2, and 3 are linked as a rigid body. As we desire the body to move only in the x-z plane, all three nodes will have physical constraints in the y, θ-x, and θ-z directions. By constraining node 2 in the x and z directions and making it the master node, the rigid body will rotate about node 2 as a hinge. Only one p-coordinate may be specified, the rotational d.o.f. at node 2. One should never link a node to more than one rigid body; this will not link the rigid bodies together and the results are unpredictable. NRIG cards are read in order; none if NRIG=0.

Wheelset Element Cards: (I5,5F10.0,24X,I1)

Parameters: N, Gauge, Radius, Cone Angle, Creep Coefficient, Velocity, Update Code.

N is the number of the node at which the lateral wheelset element is placed. Gauge is the full gauge of the tracks to the nominal wheel/rail contact points (about 2.5 inches greater than the inside gauge of the tracks). Radius is the wheel radius at its nominal contact point. The Cone Angle of the wheel is given in radians. Creep Coefficient is self-explanatory. Velocity is the forward velocity of the train. By placing an Update Code of 1 in column 80, it will indicate that these data are to replace those in an existing component. The updated data will then be labeled in the printout, thereby facilitating parametric studies. These terms will be used to generate the proper damping and asymmetic stiffness terms for the wheelset as described in the DYNALIST II Technical Report [1]. It is important to note that the program assumes that the wheelset moves laterally in the y-direction, and that the wheelset rotates (yaws) about the θ-z direction. The node at which the wheelset is placed should therefore be physically unconstrained in the y and θ-z direction, and this node should be given the wheelset mass and moment of inertia. See Example Situation 3 in Figure 5. A duplicate of this card may be used later in Segment 4 to generate wheelset cards by changing N to the proper system u-coordinate number and by adding the wheelset lag distance. NWL cards are read; none if NWL=0.

Spring-Damper Element Cards: (5I5,2F15.0,24X,I1)

Parameters: Element No., N1, N2, NR, NDIR, SP, DA, Update Code.

Each S-D Element is given an Element Number. The element may connect the first node N1 to ground, the second node N2 to ground, or node N1 to node N2. By specifying the reference node NR in addition to nodes N1 and N2, a local coordinate system will be set up, and the element will be applied between nodes N1 and N2 in that local coordinate system. Otherwise the element is assumed to act in the global x, y, z coordinate system. NDIR specifies the direction in which the element acts on the nodes. NDIR equal to 1, 2, or 3 indicates an element providing resistance to displacement in the x, y, and z directions, respectively. NDIR equal to 4, 5, or 6 indicates an element providing resistance to rotations about the x, y, or z directions (θ_x, θ_y, θ_z), respectively. If the reference node, NR, is not specified, the element acts in one of the six global directions. If node NR is specified in addition to nodes N1 and N2, then the element acts in one of the six local directions (x_ℓ, y_ℓ, z_ℓ, $\theta_{x\ell}$, $\theta_{y\ell}$, $\theta_{z\ell}$). SP is the spring stiffness and DA is the damping value. An Update Code of 1 in column 80 identifies the element as being an UPDATE.

To illustrate these points, let us first look at Example Situation 2 in Figure 5. Element 1 connects node 1 to ground. It would have N1=1, N2=0, and NR=0. Equivalently it could have N1=0, N2=1, and NR=0. The spring acts in the global x-direction, so NDIR=1. Both SP and DA would be given positive values. Element 2 connects node 2 to ground and could have N1=2, N2=0, and NR=0; or N1=0, N2=2, and NR=0. Element 2 is a torsion spring about the y-axis, so NDIR=5. An element connecting two nodes in global coordinates is shown in Situation 3. Assume nodes 1 and 2 are unconstrained in the y and θ_z directions. S-D Element 1 connects the two nodes providing torsional resistance about the global θ_z direction. We could define this element using N1=1, N2=2, NR=0, NRID=6. S-D Element 2 connects the two nodes providing lateral resistance in the y-direction: N1=1, N2=2, NR=0, NDIR=2. An illustration of the local coordinate system is given in Situation 4. The S-D Element connects nodes 1 and 2, using node 3 as the reference node. Thus N1=1, N2=2, and NR=3. Local Coordinate x_ℓ goes from N2 to N1. y_ℓ is in the plane of N1-N2-NR and is normal to x_ℓ. z_ℓ is formed by the cross-product of x_ℓ and y_ℓ. Note that N1, N2, and NR must <u>not</u> be co-linear. NDIR=1 connects N1 and N2 such as to provide axial resistance. NDIR=2 and NDIR=3 connect N1 and N2 such as to provide lateral resistance in the y_ℓ and z_ℓ directions respectively. NDIR=4-6 act similarly providing torsional resistance about the local axes. The program prints out the direction cosines of the local axis, specified by NDIR, with respect to the global coordinates. NSPRN cards are read in order; none if NSPRN=0.

<u>Nodal Mass Cards</u>: (I5,6F10.0,14X,I1)
Parameters: N, M-x, M-y, M-z, I-xx, I-yy, I-zz, Update Code.

Each node at which the mass properties are to be applied, N, is read in. The node may be given a different mass in each of three global directions x, y, and z. The node may also have different moments of inertia about the three directions. Products of inertia may not be entered directly. The principal axes of the node are assumed to lie along the global axes.

If a node has constrained degrees of freedom, the masses and inertias for those degrees of freedom may be left zero or blank. By providing mass to a node existing on a flexible body, that body's modes will be given this lumped mass in addition to its modal mass. Nodal masses may be placed upon any of the nodes of a Rigid Body element, and the mass center and inertias (<u>including products of inertia</u>) of the rigid body will be accounted for consistently in the model generated. NMAS cards are read; non if NMAS=0.

<u>Nodal u-Coordinate Cards</u>: (7I5)
Parameters: N, u-x, u-y, u-z, u-θ_x, u-θ_y, u-θ_z.

Any unconstrained nodal degree of freedom may be assigned a u-coordinate number. Not all unconstrained d.o.f.'s need be assigned numbers; the purpose here is to retain only those d.o.f.'s needed in later segments of the program for specifying force input, response output, and component coupling. Care must be taken not to use duplicate u-coordinate numbers and not to assign a u-coordinate number to any constrained d.o.f. When no u-coordinate number is to be assigned, the data entry for that nodal d.o.f. should be "0" or it may be left blank. NNOD cards are read in order of increasing node number.

3.5 TRAIN: Truck and Car Matrix Generator

The function of TRAIN is to automatically generate the matrices AMASS, DAMP, STIFF, and PHI for either of two preprogrammed rail vehicle models. By specifying IGEN = 2 in Namelist COMPO, the matrices for the 8 degree of freedom lateral truck model depicted in Figure 6(a) will be generated. IGEN = 3 will generate the matrices for the 14 degree of freedom lateral car model of Figure 6(b). For both of these models, the PHI matrix is merely the identity matrix; thus the component u- and p-coordinates will be identical. These models use the lateral wheelset damping and stiffness terms derived in Reference [1].

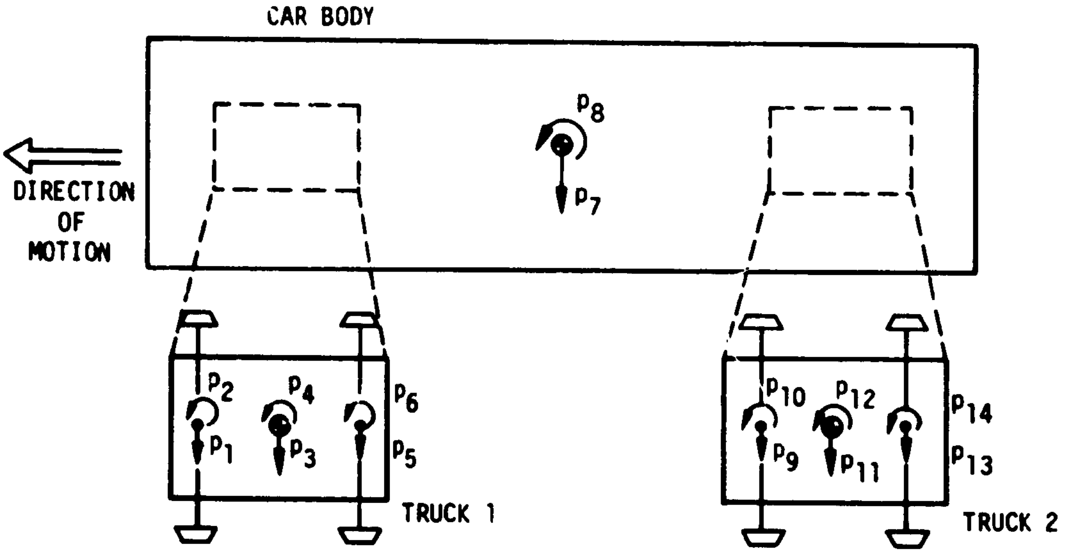
Input to TRAIN is in the form of formatted data cards immediately following Namelist COMPO. The cards must be read-in in the order listed below. An Update Code of 1 punched in column 80 of any of the cards will cause that parameter to be labeled as an update on the printout. Otherwise leave column 80 blank. All cards have the format (F15.0,64X,I1), except the wheelset card, which is almost identical to the wheelset card of COMGEN.* If a truck model is being generated (IGEN=2), the cards relating to car body parameters must be left out. NU, NCON, and NFREE must still be specified in COMPO. Note that the truck model has two coordinates, p_1 and p_2, which may be used as boundary coordinates to link the truck to car components.

Parameters - (F15.0,64X,I1)[one data element per card]

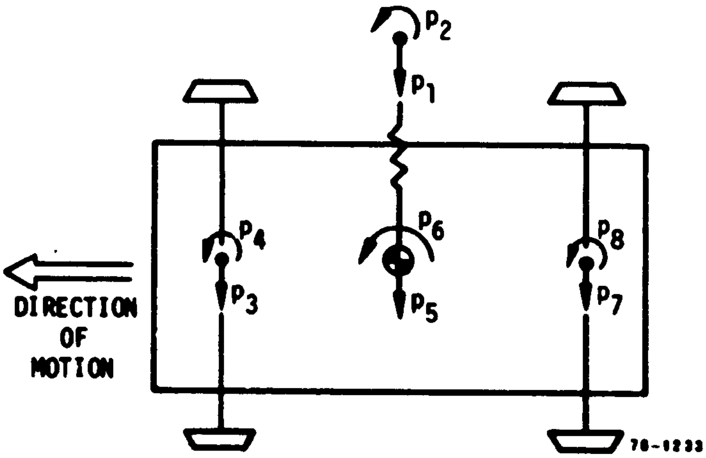
- Car wheel base, the distance between truck attachment points. Leave out if IGEN = 2.
- Truck wheel base, the spacing between wheelsets on a truck.

---

*It is identical except that a node number is not read in the first field of five columns.



(b) LATERAL CAR MODEL (IGEN = 3)



(a) LATERAL TRUCK MODEL (IGEN = 2)

Figure 6. TRAIN Models

- Car mass. Leave out if IGEN = 2.
- Car inertia, the moment of inertia of the car in the yaw direction. Leave out if IGEN = 2.
- Truck mass.
- Truck yaw inertia.
- Wheelset mass.
- Wheelset yaw inertia.
- Truck lateral stiffness, the lateral stiffness between the truck and the attachment point.
- Truck yaw stiffness.
- Truck lateral damping
- Truck yaw damping.
- Wheelset lateral stiffness.
- Wheelset yaw stiffness.
- Wheelset lateral damping
- Wheelset yaw damping.
- Wheelset Parameter Card: (5X,5F10.0,24X,I1)

  Gauge: Track gauge to nominal wheel/rail contact points.
  Radius: Wheelset radius.
  Cone Angle: Wheelset cone angle in radians.
  Creep Coefficient.
  Velocity: Vehicle forward velocity.

  The wheelset parameter card may be slightly modified to give forces and phase lags in Segment 4.

3.6 Force and Phase Lag Generation

Forces and phase lags for wheelsets may be generated automatically by setting NWHEEL, in namelist SHAKE, equal to the number of wheelsets to be generated. The wheelset data are read in on formatted data cards immediately following Namelist SHAKE. If forces and phase lags are to be generated for a lateral wheelset, the card has format (I5,6F10.0). The parameters are: u_i, Gauge, Radius, Cone Angle, Creep Coefficient, Velocity, and Distance. All the parameters are as described in Section 3.4 except for u_i and "Distance." u_i is the number of the system u-coordinate where the wheelset force is to be applied. The generated wheelset force is consistent with the derivation of wheelset forces given in Reference [1]. The force should be applied to a yaw coordinate. "Distance" is the wheelset's distance behind the leading wheelset. It is used to compute PHAS1, the ℓ/V ratio. If, as in the case of a vertical car model, it is desired to compute only the lag PHAS1, then only the parameters u_i, "Velocity," and "Distance" should be given (in their proper locations on the data card), and the other parameters on the card should be left blank. NWHEEL cards are read; none if NWHEEL = 0.

3.7 General Update Procedure

The Update Capability in DYNALIST II is designed to accomplish three objectives: (1) to minimize the effort required to prepare new input data when making parametric studies involving changes to mass, damping, stiffness, or wheelset parameters; (2) to indicate on the printed output for a run those parameters which have been updated, and their new values; and (3) to allow previous versions of updated components to be deleted from the Component Data File so that its capacity (10 components) is not exceeded. This also permits the user to minimize the I/O time required to read and write component data on the C.D.F. by deleting unneeded components from the file. Since, in all cases, updating a component requires that the entire component data deck be re-read, component data decks from previous runs should be kept intact.

The labeling of component revisions is accomplished by entering all of the component data and by indicating to the program which pieces of information are revisions. This is done differently for the three component modeling options given by IGEN = 0, 1, or 2 and 3. When IGEN = 0, the component data are entered as matrix data in Namelist COMPO. To update the model, enter the old data in COMPO and specify NEWDAT=1. Then enter the revisions to the matrices AMASS, DAMP, and STIFF in Namelist UPDATE, following COMPO. The new matrix terms will be noted on the output. When IGEN = 1, COMGEN is being employed and revisions to the wheelset, spring-damper, and nodal mass elements may be indicated by placing a 1 in column 80 of the data card used for the revised element.* This will cause the word "UPDATE" to be printed out next to the revised element parameters. When IGEN = 2 or 3, TRAIN is being employed. Again, revisions to parameters are indicated by placing a 1 in column 80 of the data card. The word "UPDATE" will be printed out next to these data.

Deletions to the C.D.F. are accomplished by calling program Segment 2 (NTYPE=2). In namelist EDITT the name of the component to be deleted is entered as DELETE = X.XX. The revised component may then be placed on the C.D.F. by calling program Segment 1 (NTYPE=1) and using the same or a different component name. If the same name is to be used, the deletion of the old component data must be done first so that two components having the same name will not appear on the C.D.F.

---

*It may still be necessary to specify NEWDAT=1, e.g., if coupling (off-diagonal) terms are to be changed in AMASS, DAMP, or STIFF. See Sample Problem 1, Cards 4,5.

4. PROGRAM OUTPUT

DYNALIST II produces both printed and plotted outputs. All output is given with explanatory headings. There are four general categories of output. These are as follows:

4.1 Program Card Input

Card input to the program is listed sequentially at the beginning of the program output for quick reference. The input data is also printed as it is used along with appropriate headings.

4.2 Intermediate Results

The results of many intermediate calculations are printed if the input flag IFOUT is set non-zero (see definitions of input parameters). This option will, hopefully, see very limited use. If it is used, however, the printed variables, or matrices, are preceded by headings including the name of the variable or matrix printed.

4.3 Primary Results

Results of program Segment 1 are considered to be the eigenvalues and eigenvectors of the component. These are given in both the p- and u-coordinate systems. Each eigenvector is printed along with its associated eigenvalue, and the eigenvalues are numbered sequentially. The order in which the eigenvalues and eigenvectors appear on the printed output (and the order in which they are numbered) is the same order as they are written on the output Component Data File. To edit the modes of the component (program Segment 2), the numbers appearing with the eigenvalues and eigenvectors in the output of program Segment 1 can be used.

The results of the orthogonality check are also printed. The statement "THE EIGENVECTORS DIAGONALIZE THE DYNAMIC MATRIX" is printed if the eigenvectors are orthogonal. If not, the statement "THE EIGENVECTORS DO NOT DIAGONALIZE THE DYNAMIC MATRIX" is printed along with the matrix - $[\psi]^T [D] [\psi]$.

In each case, the value for the "TRACE OF MATRIX" is also printed. This value is the sum of the diagonal elements of the dynamic matrix used to solve the component or system eigenproblem. Similar matrices have the same trace. Therefore, since the diagonal matrix of eigenvalues is similar to the dynamic matrix, the trace of the dynamic matrix is equal to the <u>sum of the eigenvalues</u>. For a real system, complex eigenvalues will always occur in conjugate pairs; the trace of the dynamic matrix should therefore always be real. When truncating component modes, the complex modes should be truncated in pairs so that the trace of the dynamic matrix stays real, even under modal truncation. The trace of the dynamic matrix provides a good check on the validity of the eigenvalues.

Printed results of Segment 2 consist of editing information.

Printed results of Segment 3 consist of the final system eigenvalues and eigenvectors. The eigenvectors have been transformed back to the system u-coordinates. The results of the orthogonality check are printed along with the trace of the dynamic matrix.

Printed results of Segment 4 consist of frequency response and/or periodic response data at each u-coordinate specified in the vector LOOK. The frequency response at a coordinate u is the response amplitude that occurs due to all the forces acting on the system, when the waveform of each force is assumed to be a simple sinusoidal excitation.

The phase is the phase lag in degrees of the response at coordinate u, with respect to the sinusoidal excitation, assumed to have zero phase. The response output is presented in terms of the amplitude and phase lag at the selected excitation frequencies. If an input power spectral density is specified, both the input and response PSD's are printed. The root-mean-square values of response and input are also printed, along with the median power frequency (which is the frequency which has equal power above and below it). If an amplitude varying sinusoidal input is given, then both the input magnitude and the response magnitude are given at the selected excitation frequencies. Output for a general periodic excitation consists of the time history, the Fourier coefficients, the peak values, and the root-mean-square, both for the input and the response.

4.4 Plotted Output

Plotted output for Segment 4 consists of response curves for each u-coordinate specified in both LOOK and NPLOT. The number of the u-coordinate is written on the plot, along with a heading indicating if acceleration, velocity, or displacement response is given. If frequency response is calculated, the plots are on a Log-Log scale to accurately represent response over a full range of frequencies and amplitudes. If a power spectral density or sinusoidal input is given, then plots are provided for both the input and the response over the frequency spectrum specified. If periodic response is calculated, the plots consist of the Fourier series approximation over one period in time, for both the input waveform and the response waveform. The scales in both amplitude and time are linear.

An option is provided to allow the user to specify the vertical scale on each response plot. The purpose of this option is to facilitate the direct comparison of plots. If this option is not exercized, the scale of each plot is automatically selected to span the range of computed response. If the user specifies a scale which does not span this range, clipping will occur.

5. OPERATING INSTRUCTIONS

5.1 Creating the Overlay Structure

DYNALIST II is delivered in the form of a seven track source tape. The job control language, JCL, necessary to read this tape, generates the overlay structure and places this overlay structure on tape as shown below. It is necessary to store the overlay structure on tape because of its large size and the high cost of disk storage. The program is so large that generating the overlay structure from the compiled program each time a run is made also becomes expensive. This JCL pertains to the CDC-6000 series Scope operating system. It is recommended that a system programmer be consulted when installing the program and that particular attention be paid to the plot statements in the main overlay to ensure compatibility with the operating system.

```
                                                CARD
JOB,T300,P2,TP1.                                  1
REQUEST,TAPE1,HI,VSN=JHW200.  NO RING             2
COPYCF,TAPE1,DISK.                                3
REWIND,DISK.                                      4
COPYBF,DISK,DYNA.                                 5
REWIND,DYNA.                                      6
FTN(I=DYNA,OPT=2)                                 7
LOAD(LGO)                                         8
NOGO.                                             9
UNLOAD,TAPE1                                     10
REQUEST,TAPE2,HY,VSN=DOT100.  RING IN            11
REWIND,TEMP.                                     12
COPYBF,TEMP,TAPE2.                               13
6/7/8/9
```

Card 1 gives the run time limit, establishes job priority and sets aside a tape unit. Card 2 requests that the source tape, having volume serial number JHW200, be mounted. The tape is written at HI density, 556 characters per inch, on seven track tape in a packed coded format. Card 3 copies the coded file onto disk storage. If for some reason it is not possible to read the file another copy may be inserted after this since the source file is written on the tape twice. Card 5 converts the coded file into binary format on file DYNA. Card 7 compiles the program using file DYNA as input. Cards 8 and 9 generate the overlay structure and place it on file TEMP. Card 11 mounts a tape which the user must supply. HY designates a writing density of 800 characters per inch. Card 13 copies file TEMP onto the tape for future use.

5.2 Executing the Program

The JCL necessary to obtain the program from tape, attach any files necessary for the run, execute the program and catalog any files for later use is given below.

```
                                                     CARD
JOB,T200,P2,TP1.                                      1
REQUEST,TAPE,HY,VSN=DOT100.  NO RING                  2
COPYBF,TAPE,TEMP.                                     3
RETURN,TAPE.                                          4
COPYBR,INPUT,TAPE5.                                   5
REWIND,TAPE5.                                         6
COPYSBF,TAPE5,OUTPUT.                                 7
REWIND,TAPE5.                                         8
REQUEST,TAPEXX,*PF.                                   9
REQUEST,TAPE12,*PF.                                  10
ATTACH,CDF,OLDCDF.                                   11
ATTACH,MDF,OLDMDF.                                   12
```

```
                                                    CARD
COPYBF,CDF,TAPE10.                                   13
REWIND,TAPE10.                                       14
COPYBF,MDF,TAPE12.                                   15
REWIND,TAPE12.                                       16
TEMP.                                                17
CATALOG,TAPEXX,NEWCDF.                               18
CATALOG,TAPE12,NEWMDF.                               19
7/8/9
DYNALIST II Data Deck
6/7/8/9
```

Card 1 establishes the run time limit, the priority, and requests a tape unit. Card 2 mounts the tape containing the overlay structure. Card 3 copies the program onto file TEMP. Cards 5 through 8 place a listing of the input data onto the program output. The programs restart capability allows a component data file, C.D.F., or a modal data file, M.D.F., generated in a previous run to be attached to the program and used to pick up where the last run left off. In order to save a C.D.F. or M.D.F. a permanent file must first be established. This is done on cards 9 and 10. A C.D.F. may be on either TAPE 10 or TAPE 11, designated here as TAPE XX. The M.D.F. is on TAPE 12. A C.D.F. or M.D.F. to be used from a previous run is brought into the program with the ATTACH statements of Cards 11 and 12. The C.D.F. should then be copied to TAPE 10 and the M.D.F. to TAPE 12 as on Cards 13 through 16. These files may be attached directly onto TAPE 10 and TAPE 12 as long as they are not written on, since the system does not allow a permanent file to be altered. Card 17 executes the program. Any newly generated C.D.F. or M.D.F. may then be cataloged as on Cards 18 and 19. The 7/8/9 card signifies the end of the JCL. This is followed by the data deck and a 6/7/8/9 card indicating the end of information. For further information on the data files see Section 2.5.

6. SAMPLE PROBLEMS

There are five sample problems included with the DYNALIST II source tape which accompanies this USER'S MANUAL. The sample problems are intended to check out as many program options as possible as well as to acquaint the user with these options. Sample problems 1 through 3 illustrate the use of COMGEN, while sample problems 4 and 5 show how to directly input the matrix coefficients of the equations of motion using IGEN=0. Listings of input data for these sample problems are included at the end of this section. The job control language necessary to run these problems is included with the input data.

6.1 Sample Problem 1

Sample Problem 1 uses COMGEN to develop an eight d.o.f. lateral truck model and a four d.o.f. flexible carbody model. These components are then assembled (using the Direct Sub-System Method) by connecting two coordinates from each truck to the carbody; thereby producing a sixteen d.o.f. flexible car model. Frequency response, and periodic response to a lateral track irregularity are then found. Sample problems 2 and 3 are variations of this one. Printed output for Sample Problem 1 is given in Appendix C.

6.1.1 Flexible Carbody Model

The derivation of the mass, damping, and stiffness matrices for the four mode flexible carbody is given in Appendix B. Card input necessary to place the car component on the C.D.F. (using COMGEN) is given below.

Card 1. The title card for the run.

Card 2. NTYPE=1 directs program control to Segment 1, where the car component data will be placed on a newly created C.D.F. since NEWTAP defaults to 0.

Card 3. Segment 1 reads Namelist COMPO. COMNAM=1.00 gives the carbody the "name" 1.00 on the C.D.F. NU=7, NCON=4, and NFREE=0 means there are 7 u-coordinates, 4 constrained p-coordinates, and no free p-coordinates for the car. Thus no eigenproblem will be solved. IGEN=1 indicates that COMGEN data will be read following Namelist COMPO.

Cards 4-5. The *off-diagonal* mass terms derived in Appendix B are entered in COMPO. The positions in the mass matrix correspond to the p-coordinate numbers given to each of the four modes in COMGEN. The modal mass, damping and stiffness of each mode correspond to the diagonal elements of AMASS, DAMP and STIFF, and do not need to be entered in COMPO. If inter-model coupling exists for the mass, damping or stiffness, the off-diagonal terms representative of this coupling must be entered in COMPO in the appropriate matrix.

Card 6. The COMGEN control card specifies that data for 5 nodes and 4 flexible body modes will be read. No rigid body, wheelset, spring-damper, or mass elements will be entered.

Cards 7-11. x, y, and z coordinates are specified for the nominal locations of each of the 5 nodes. Nodes 1 through 5 are, respectively, the center, front, rear, front truck attachment, and rear truck attachment nodes. These nodes are shown on the car model in Figure 7. The vertical plane is assumed to be the x-z plane, but the z-coordinates are not necessary for the physics of the problem and are included merely for illustration.

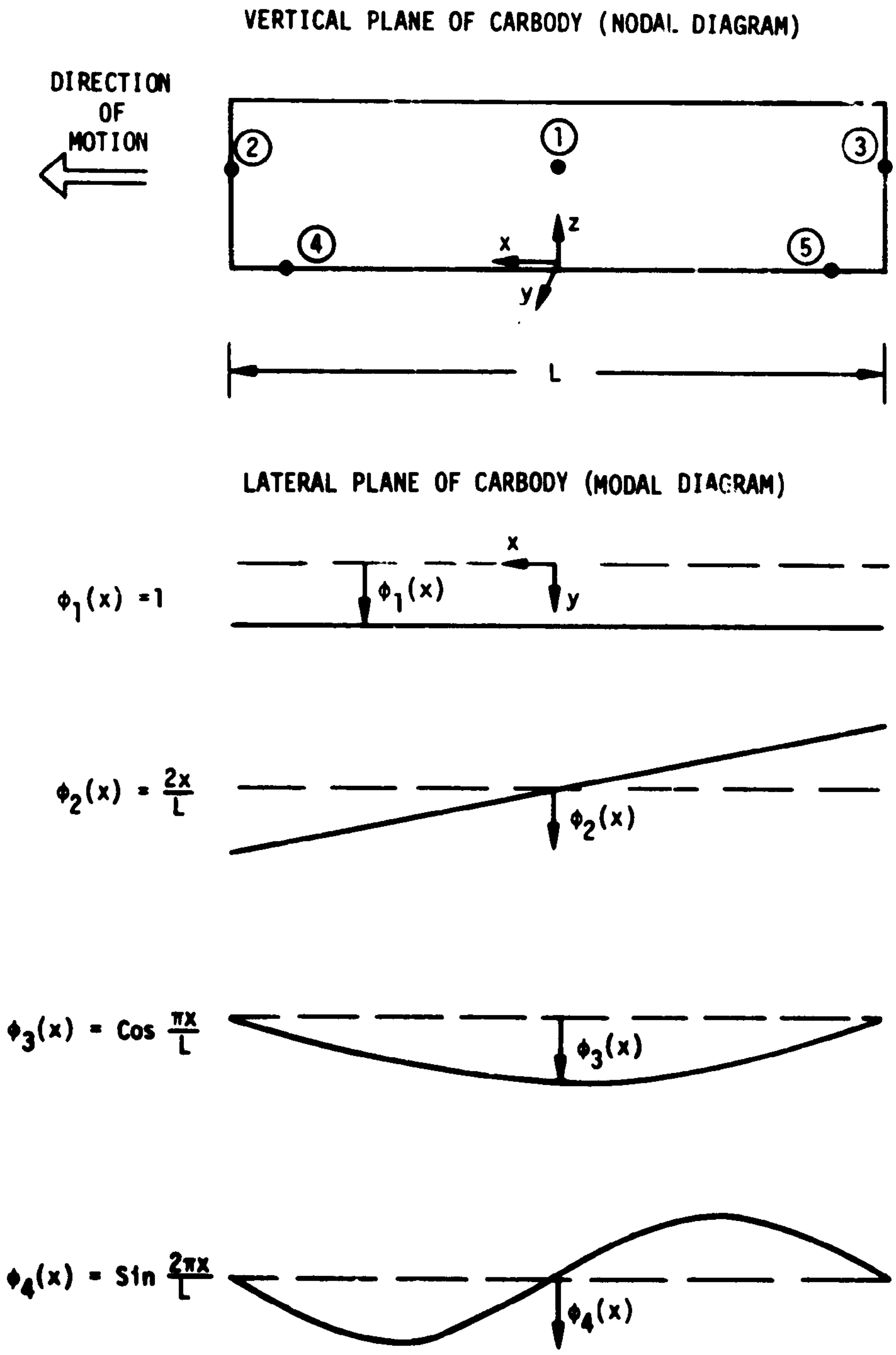


Figure 7. Flexible Car Component and Modes

Cards 12-16. Displacement constraints are applied at each of the five nodes. The nodes are allowed to move in the y and θ-z directions, which are indicated by 0's. The nodes are constrained in all other directions, indicated by 1's.

Cards 17-21. p-coordinates are assigned to any unconstrained *nodal* d.o.f.'s here, but since the only p-coordinates for this component correspond to modes, 0's are entered for each node, indicating no nodal p-coordinates.

Cards 22-25. The first column of each card indicates the rigid or flexible body mode number, and the second column gives the p-coordinate number assigned to that mode. Thus p_1 will correspond to mode ϕ_1, p_2 to ϕ_2, etc.

Card 26. The Mode Card for ϕ_1, the rigid body mode for translation in the y-direction. The first column gives the mode number. The second column gives the number of Mode Shape Cards to be read, describing the motion of the 5 nodes associated with the mode. The next three entries are the modal mass, damping, and stiffness (the diagonal terms of the m, c, and k matrices). Since this is a rigid body mode it has only mass, as derived in Appendix B.

Cards 27-31. The Mode Shape Cards for $\phi_1=1$ show unit displacement in the y-direction at each of the 5 nodes.

Card 32. The Mode Card for ϕ_2 indicates 5 mode shape cards will be read. This rigid body mode for rotation in the θ-z direction has only a modal mass.

Cards 33-37. The Mode Shape Cards for $\phi_2(x)=\frac{2x}{L}$ show the y-displacements, and the θ-z rotations in radians obtained from $\phi_2'(x)$ at the 5 nodes.

Card 38. The Mode Card for the first bending mode, ϕ_3, gives the modal mass, damping, and stiffness. The damping is $2\zeta\sqrt{mk}$, where the damping ratio, ζ, is taken as 1 percent.

Cards 39-43. The Mode Shape Cards for $\phi_3(x)=\cos\frac{\pi x}{L}$ show the y-displacements, and the θ-z rotations in radians obtained from $\phi_3'(x)$.

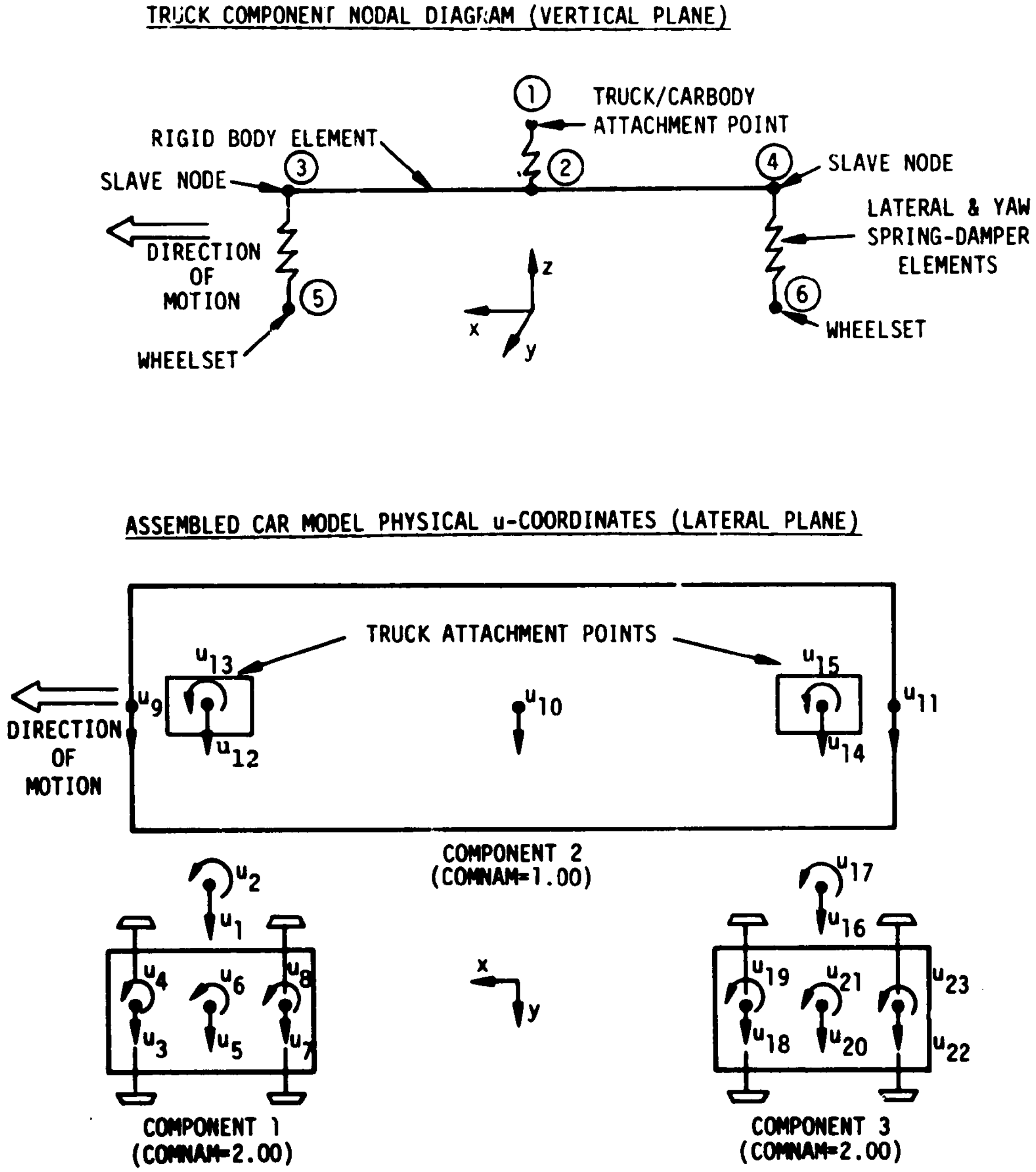
Card 44. The Mode Card for ϕ_4 giving modal mass, damping, and stiffness. ζ is taken as 1 percent.

Cards 45-49. The Mode Shape Cards for ϕ_4, where $y=\phi_4(x)=\sin\frac{2\pi x}{L}$ and $\theta\text{-}z=\phi_4'(x)$.

Cards 50-54. Seven of the ten unconstrained nodal degrees of freedom are given u-coordinate numbers. A "0" indicates that the d.o.f. is not to be retained for response. u_1, u_2, and u_3 are the lateral displacements at the front, mass center, and rear of the car, respectively. u_4 and u_5 are the displacement and rotation at the front truck attachment point. u_6 and u_7 are the displacement and rotation at the rear attachment point.

6.1.2 Truck Model

The lateral truck model being used here is identical to the one generated by TRAIN and described in Reference [1]. The truck, shown in Figure 8, consists of a rigid frame connected by springs and dampers to the truck-carbody attachment point and to two lateral wheelset elements. Card input necessary to place the truck model on the C.D.F. (using COMGEN) is given below.



TRUCK COMPONENT NODAL DIAGRAM (VERTICAL PLANE)

ASSEMBLED CAR MODEL PHYSICAL u-COORDINATES (LATERAL PLANE)

Figure 8. Truck and Assembled Car Models

Card 55.	NTYPE=1 directs program control to Segment 1, where the truck component data will be added to the existing C.D.F. since NEWTAP=1.
Card 56.	Segment 1 reads Namelist COMPO. COMNAM=2.00 gives the truck the "name" 2.00 on the C.D.F. NU=8, NCON=8, and NFREE=0 means there are 8 u-coordinates, 8 constrained p-coordinates, and no free p-coordinates for the truck. IGEN=1 indicates that COMGEN data will be read following Namelist COMPO.
Card 57.	The COMGEN control card specifies 6 nodes, no flexible body modes, 1 rigid body element, 2 lateral wheelset elements, 6 spring-damper elements, and 3 nodes having mass.
Cards 58-63.	x, y, and z coordinates are entered for the nominal locations of each of the six nodes. Node 1 is the truck-carbody attachment point. Node 2 is the center of the truck frame. Nodes 3 and 4 are the front and rear of the truck frame, which connect with springs to the front and rear wheelsets at nodes 5 and 6. The vertical plane is the x-z plane, with the z-coordinates given only for illustration.
Cards 64-69.	Displacement constraints consistent with a lateral model are applied at the six nodes. 0's in columns 3 and 7 indicate the nodes are free to move in the y and θ-z directions. 1's in columns 2, 4, 5, and 6 indicate that the nodes may not move in the x, z, θ-x, and θ-y directions.

Cards 70-75. p-coordinate numbers are assigned at unconstrained nodal degrees of freedom which are to remain independent degrees of freedom (generalized coordinates) in the component model. The truck-carbody attachment point is given the first two p-coordinates since in Sample Problem 3 they will be used as boundary points while the other nodes will be free p-coordinates.* Node 2 is given p-coordinates since it will be the master node of a rigid body element. Nodes 3 and 4 will be slave nodes and so are given no p-coordinates. The wheelset nodes, 5 and 6, are given p-coordinate numbers.

Card 76. A rigid body element is defined. Column 1 defines this as Rigid Body Element 1. Column 2 defines node 2 as the master node. Column 3 specifies that there are 2 slave nodes. Columns 4 and 5 define nodes 3 and 4 as the slave nodes.

Cards 77-78. Wheelsets are defined at nodes 5 and 6. The track gauge is given as 5 feet. The wheel radius is given as 1.33 feet. The wheel cone angle is .025 radians. The creep coefficient is 3 million pounds. The train's forward velocity is given as 450 ft/sec.

Cards 79-84. Six spring-damper elements are defined. Column 1 gives the element number, and columns 2 and 3 specify the nodes between which the element is tied. Column 4 contains the reference node and,

---

*In the present case, Sample Problem 1, the ordering of the p-coordinates is immaterial because with the DSS method, all p-coordinates belong to the "constrained" (NCON) category.

since no reference node is entered, the springs are assumed to act in global x-y-z directions. The directions in which the springs provide resistance are given in column 5; a 2 indicating a y-direction lateral resistance spring, and a 6 indicating a θ-z direction torsional resistance spring. The next two entries are the stiffnesses in lb/ft or ft-lb/rad and the damping in lb-sec/ft or lb-ft-sec/rad.

Cards 85-87. Nodes 2, 5, and 6 are given masses and moments of inertia. The center of the truck frame (node 2) is given a mass of 250 slugs in the y-direction and an inertia of 2800 slug-ft^2 in the θ-z direction. The wheelsets (nodes 5 and 6) are given a y-mass of 60 slugs and a θ-z inertia of 290 slugs-ft^2. Masses and inertias in the constrained directions are unnecessary, and so are set equal to zero.

Cards 88-93. 8 u-coordinates are numbered at the 6 nodes. The u-coordinates are given the same numbers as the p-coordinates above, so the ϕ matrix will be the identity matrix.

6.1.3 Component Coupling

In order to generate a full lateral car model, it is necessary to couple the motion of the attachment point on the truck components to the motion of the attachment points on the flexible carbody component. Since no component modes were found for the truck or the carbody, the components will be coupled by what is known as the Direct Sub-Systems Method. Card input necessary to generate a full lateral car model is given below.

Card 94. NTYPE=3 directs program control to Segment 3, which generates the system equations of motion, solves the resulting eigenproblem, and creates a Modal Data File for use in Segment 4.

Card 95. Namelist SYN contains the coupling information. NCOMP=3 means 3 components will be used to form the model. PRENAM(1)=2,1,2 gives the names of the components in the order in which they will be assembled: the truck, the carbody, and the truck, respectively. The system u- and p-coordinates are then renumbered internally in one continuous sequence according to this component assembly order. The system u-coordinates for the assembled car model are shown in Figure 8. They are u_1-u_8 for the first truck, u_9-u_{15} for the carbody, and u_{16}-u_{23} for the second truck. The system p-coordinates are p_1-p_8 for the first truck, p_9-p_{12} for the modes of the carbody, and p_{13}-p_{20} for the second truck. Constraint equations are written in terms of the system u-coordinates as $[G]\{u\}=\{0\}$, where G is the constraint matrix. NROWG=4 specifies that there are 4 rows in the constraint matrix and thus 4 constraints. KDEP(1)=1,2,13,14 specifies that the four dependent p-coordinates to be eliminated by these constraints are the degrees of freedom of the attachment points on the trucks. The carbody modes, p_9-p_{12}, will remain as independent p-coordinates in this case.

Cards 96-97. The four constraint equations are given here. The first index of G is the constraint equation number and the second index is the u-coordinate the constraint is to be applied to. The information on the two cards may be translated as follows:

$$u_1 - u_{12} = 0$$

$$u_2 - u_{13} = 0$$

$$u_{16} - u_{14} = 0$$

$$u_{17} - u_{15} = 0$$

These equations link the displacements and rotations on the truck's attachment points to the corresponding displacements and rotations on the carbody.

6.1.4 System Response

Card input necessary to generate the response characteristics of the full lateral car model to a lateral track irregularity is given below. Both frequency response and response to a specified periodic excitation are requested.

Card 98.	NTYPE=4 directs program control to Segment 4 for response computation. IPLOT=1 indicates that plotted output will be generated, and SIZE=10.0 will scale the plots to a ten inch width.
Card 99.	System forcing information is contained in Namelist SHAKE. NAXLE=4 means that forces will be applied at four u-coordinate locations. NWHEEL=4 means that four wheelset cards will be read to automatically compute the wheelset forces and phase lags. The u-coordinates where forces are applied are the yaw coordinates of the wheelsets. They are named in the vector LAXLE as u_4, u_8, u_{19}, and u_{23}. NLOOK=3 means that response will be requested at three u-coordinates. These response coordinates are the lateral displacement

at the middle of the car, at the rear of the car, and at the middle of the rear truck. They are named in the vector LOOK as u_{10}, u_{11}, and u_{20}, respectively.

Card 100. NPLOT(1)=1,1,1 means that response will be plotted at the first three u-coordinates named in LOOK. Frequency response due to a unit input is initiated by setting NFREQ=150, which will generate a frequency spectrum with 150 divisions. The spectrum ranges from OMIN=.1 Hertz to OMAX=100. Hertz. Response to a periodic input is initiated by setting NFOUR=25, which causes the input and response Fourier series to have 25 terms. PERIOD=0.2 means that the duration, or period, of the excitation waveform is to be 0.2 seconds.

Card 101. NTIME=3 means that the excitation waveform is to be specified at three time points. WAVE(1)=0,.02,0 describes the amplitude of the waveform at each of the three times given in TIME(1)=0.0,0.1,0.2. Thus the waveform is that of a sawtooth wave, which would correspond to straight tracks being laid down in a zig-zag manner. Since the train is travelling at 450 ft/sec and the period is 0.2 seconds, the length of each track section may be taken as one half the period multiplied by the train speed, or 45 feet. The length of one cycle of the waveform is 90 feet.

Cards 102-105. The wheelset cards are identical to the ones used in COMGEN, except that the first column has been replaced by the u-coordinate where each wheelset force is applied. Also, in the last column, the distance of each wheelset behind the leading wheelset is provided in order to generate the corresponding phase lag term PHAS1.

Card 106. Normal program termination is achieved by setting NTYPE=5.

6.2 Sample Problem 2

Sample Problem 2 is the same as Problem 1, except that a few spring-damper elements and nodal masses in the truck model were revised. These revisions were marked with a 1 in column 80. The C.D.F. generated in Problem 1 was attached, and component 2.00 (the previous truck model) was deleted from the file. The revised truck model was then generated and given the same name. Thus the flexible carbody component did not need to be entered again and the synthesis in Segment 3 could use the same component names. In addition, the revised data are specially indicated on the printed output.

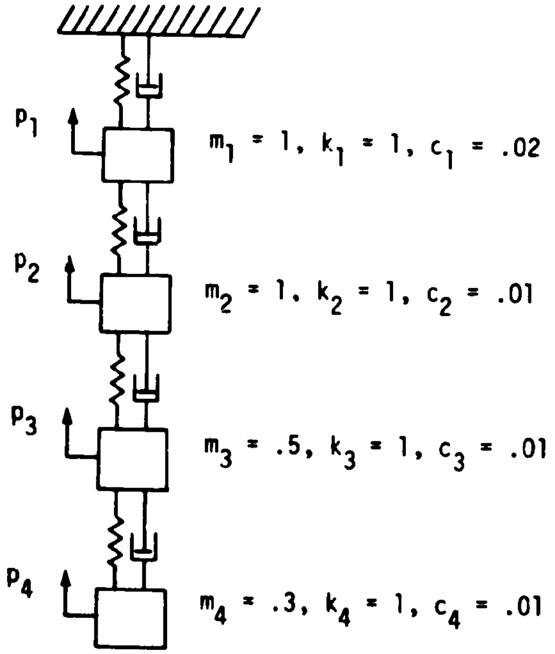
6.3 Sample Problem 3

Sample Problem 3 is the same as Problem 1, except that now component modes are calculated for the truck. These modes are then truncated before using Modal Synthesis to assemble the system. System response is then calculated for a stationary random input (rather than the Fourier input of Problem 1), and the static correction factor is applied to minimize truncation error in the low frequency range. To execute Sample Problem 3, the C.D.F. created in Problem 1 is attached, and component 2.00 (the old truck model) is deleted. A new identical truck model is generated but there are 6 free coordinates this time. Note that the first two p-coordinates, at the truck attachment point, remain constrained in the component eigenvalue solution. Four of the twelve component modes are truncated in Segment 2, the lowest eight truck modes being retained. The car model is then coupled as before. Response is computed and, since modal truncation has been employed and KONVS defaults to 1, the static correction is automatically used. Note that KIND defaults to zero, giving displacement response.

6.4 Sample Problem 4

Sample Problem 4 is included to demonstrate the use of the standard matrix input method, i.e., IGEN=0. The spring-mass-damper system shown in Figure 9 is modeled as a single component. Solution of the component eigenproblem is sought; thus the four dynamic degrees of freedom (p-coordinates) are all identified as "free" coordinates (NFREE=4). Setting INOVEC=1 will suppress the printout of the component eigenvectors, and the dynamic matrix if the orthogonality test fails. Setting IMATX=1 will suppress printout of selected component modeling data.

In this case, provision has been made to compute relative response between masses (presumably for a later run). Therefore, the ϕ matrix shown in Figure 9 includes additional u-coordinates u_5, u_6, and u_7, whereby the relative displacements are defined. Since the spring constants are unity, the relative displacements may also be interpreted as forces. If the spring constants were not unity, the only modification required would be to substitute the appropriate k values in place of the unit values appearing in rows 5 through 7 of the PHI matrix.



$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \\ u_7 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \end{bmatrix}$$

$$\{u\} = [\phi]\{p\}$$

Figure 9. Lumped Parameter System for Sample Problem 4

One interesting point about data entry when inputting the coefficient matrices, is that a matrix column (or any portion of the column) may be entered as an element string following the first named element, without having to name each successive element in that column. For example, column 2 of the PHI matrix could be specified by using any of the following three data entry techniques:

- PHI(2,2)=1, PHI(5,2)=1, PHI(6,2)=-1,.
- PHI(2,2)=1,0,0,1,-1,.
- PHI(2,2)=1, PHI(5,2)=1,-1,.

Note that zero values need not be entered, <u>unless</u> they appear within an element string. One additional caution is that if an element string exceeds its column length, it will not be truncated, but will continue to fill that column up to the maximum length acceptable by DYNALIST.

6.5 Sample Problem 5

Sample Problem 5 is identical to Sample Problem 4, except that the update capability is used to change the value of m_4 from $m_4 = 0.3$ to $m_4 = 0.5$. Note that in this case, a new component is created with the "name" 2.00. This example also serves to illustrate the overwrite feature of Namelist input. Thus, one may leave the card in the original data deck which specified COMNAM=1.00. Subsequently specifying COMNAM=2.00 will read the new "value" of COMNAM over the old one. By specifying NEWDAT=1, the user indicates that Namelist UPDATE is to be read, following Namelist COMPO. (Note that while only the new data is specified in Namelist UPDATE, <u>all</u> of the old data must be specified in Namelist COMPO. Also note that Namelist UPDATE follows directly after the END of COMPO without a separate START block.)

Sample Problem #1

```
$WIGG,T500,P3,TP1.
COMMENT. CHARGE WIGG1233 01 7954
REQUEST,TAPE,VSN=JMW100.  NO RING  WIGGINS TAPE
COPYBF,TAPE,TEMP.
RETURN,TAPE.
COPYBR,INPUT,TAPE5.
REWIND,TAPE5.
COPYSBF,TAPE5,OUTPUT.
REWIND,TAPE5.
REQUEST,TAPE10,*PF.
TEMP.
CATALOG,TAPE10,COMDATFILW1233,ID=WIGG.                                           Data
DISPOSE,TAPE9,PR=IBM.                                                             Card
#
 4-DOF FLEXIBLE CAR COUPLED WITH TWO TRUCKS                                          1
 $START NTYPE=1,$END                                                                 2
 $COMPO COMNAM=1.00,NU=7,NCOM=4,NFPEE=0,IGEN=1,                                      3
 AMASS(1,3)=1082.25,AMASS(3,1)=1082.25,AMASS(2,4)=541.13,                            4
 AMASS(4,2)=541.13,$END                                                              5
   5    4    0    0    0    0                                                        5
   1    0.             0.             6.                                             6
   2   50.             0.             6.                                             7
   3  -50.             0.             6.                                             8
   4   41.5            0.             3.                                             9
   5  -41.5            0.             3.                                            10
   1    1    0    1    1    1    0                                                  11
   2    1    0    1    1    1    0                                                  12
   3    1    0    1    1    1    0                                                  13
   4    1    0    1    1    1    0                                                  14
   5    1    0    1    1    1    0                                                  15
   1    0    0    0    0    0    0                                                  16
   2    0    0    0    0    0    0                                                  17
   3    0    0    0    0    0    0                                                  18
   4    0    0    0    0    0    0                                                  19
   5    0    0    0    0    0    0                                                  20
   1    1                                                                           21
   2    2                                                                           22
   3    3                                                                           23
   4    4                                                                           24
   1    5    1700.          0.            0.                                        25
   1    0.          1.      0.       0.         0.        0.                        26
   2    0.          1.      0.       0.         0.        0.                        27
   3    0.          1.      0.       0.         0.        0.                        28
   4    0.          1.      0.       0.         0.        0.                        29
   5    0.          1.      0.       0.         0.        0.                        30
   2    5    566.66667      0.            0.                                        31
   1    0.          0.      0.       0.         0.       .02                        32
   2    0.          1.      0.       0.         0.       .02                        33
   3    0.         -1.      0.       0.         0.       .02                        34
   4    0.         .83      0.       0.         0.       .02                        35
   5    0.        -.83      0.       0.         0.       .02                        36
   3    5    850.        232.45     1589[illegible].6                               37
   1    0.          1.      0.       0.         0.        0.                        38
   2    0.          0.      0.       0.         0.    -.031416                      39
   3    0.          0.      0.       0.         0.     .031416                      40
   4    0.      .26387      0.       0.         0.    -.030302                      41
   5    0.      .26387      0.       0.         0.     .030302                      42
   4    5    850.           929.79  2542665.6                                       43
   1    0.          0.      0.       0.         0.     .062832                      44
   2    0.          0.      0.       0.         0.    -.062832                      45
   3    0.          0.      0.       0.         0.    -.062832                      46
   4    0.     .509041      0.       0.         0.    -.054082                      47
                                                                                    48
```

Sample Problem #1 (Continued)

```
                                                                              Data
                                                                              Card
                                                                               49
 5    0.     -.509041     0.        0.        0.     -.054082                  50
 1    0    2    0    0    0    0                                               51
 2    0    1    0    0    0    0                                               52
 3    0    3    0    0    0    0                                               53
 4    0    4    0    0    0    5                                               54
 5    0    6    0    0    0    7                                               55
$START NTYPE=1,NEATAP=1,$END                                                   56
$COMPO COMNAM=2.00,NU=8,NCON=8,NFREE=0,IGEN=1,$END                             57
 6    0    1    2    6    5                                                    58
 1     0.             0.             3.                                        59
 2     0.             0.             2.                                        60
 3     4.             0.             2.                                        61
 4    -4.             0.             2.                                        62
 5     4.             0.             0.                                        63
 6    -4.             0.             0.                                        64
 1    1    0    1    1    1    0                                               65
 2    1    0    1    1    1    0                                               66
 3    1    0    1    1    1    0                                               67
 4    1    0    1    1    1    0                                               68
 5    1    0    1    1    1    0                                               69
 6    1    0    1    1    1    0                                               70
 1    0    1    0    0    0    2                                               71
 2    0    5    0    0    0    6                                               72
 3    0    0    0    0    0    0                                               73
 4    0    0    0    0    0    0                                               74
 5    0    3    0    0    0    4                                               75
 6    0    7    0    0    0    8                                               76
 1    2    2    3    4                                                         77
 5       5.0 1.33333333      .025   3.0E+06   4.5E+02                          78
 6       5.0 1.33333333      .025   3.0E+06   4.5E+02                          79
 1    1    2    0    2        1.75E+04        1.55E+03                         80
 2    1    2    0    6             5E6                                         81
 3    3    5    0    2             5E5                                         82
 4    3    5    0    6             3E7                                         83
 5    4    6    0    2             5E5                                         84
 6    4    6    0    6             3E7                                         85
 2         0.       250.         0.         0.        0.      2800.            86
 5         0.        60.         0.         0.        0.       290.            87
 6         0.        60.         0.         0.        0.       290.            88
 1    0    1    0    0    0    2                                               89
 2    0    5    0    0    0    6                                               90
 3    0    0    0    0    0    0                                               91
 4    0    0    0    0    0    0                                               92
 5    0    3    0    0    0    4                                               93
 6    0    7    0    0    0    8                                               94
$START NTYPE=3,$END                                                            95
$SYN NCOMP=3,PHENAM(1)=2,1,2,NRGAG=4,KOMP(1)=1,2,13,14,                        96
G(1,1)=1,G(1,2)=-1,G(2,2)=1,G(2,13)=-1,                                        97
G(3,16)=1,G(3,14)=-1,G(4,17)=1,G(4,15)=-1,$END                                 98
$START NTYPE=4,IPLOT=1,SIZE=10.0,$END                                          99
$SHAKE NAXLE=4,NWHEEL=4,NLOOK=3,LAXLE(1)=4,8,19,23,LOOK(1)=10,11,20,          100
NPLOT(1)=1,1,1,DMIN=0.1,DMAX=100,NFREQ =150,NFOUR=25,PERIOD=0.2,              101
NTIME =3, WAVE(1)=0,.02,0,TIME(1)=0.0,0.1,0.2,$END                            102
  4      5.0 1.33333333      .025   3.0E+06   4.5E+02     0.0                 103
  8      5.0 1.33333333      .025   3.0E+06   4.5E+02     8.0                 104
 19      5.0 1.33333333      .025   3.0E+06   4.5E+02    83.0                 105
 23      5.0 1.33333333      .025   3.0E+06   4.5E+02    91.0                 106
$START NTYPE=5,$
```

Sample Problem #2

```
$WIGG,T500,P3,TP1.
COMMENT. CHARGE WIGG1233 01 7954
REQUEST,TAPE,VSN=JHW100.  NO RING  WIGGINS TAPE
COPYBF,TAPE,TEMP.
RETURN,TAPE.
COPYBR,INPUT,TAPE5.
REWIND,TAPE5.
COPYSBF,TAPE5,OUTPUT.
REWIND,TAPE5.
ATTACH,CDF,COMDATFILW1233,ID=WIGG.
COPYBF,CDF,TAPE10.
REWIND,TAPE10.
TEMP.
DISPOSE,TAPE9,PR=IBM.
#
 8-DOF FLEXIBLE CAR COUPLED WITH TWO TRUCKS  -  TRUCKS ARE STIFFENED
 $START NTYPE=2,$END
 $EDITT DELETE=2.00,$END
 $START NTYPE=1,NEWTAP=1,$END
 $COMPO COMNAM=2.00,NU=6,NCON=8,IFREE=0,IGEN=1,$END
    6    0    1    2    6    3
     1     0.              0.              3.
     2     0.              0.              2.
     3     4.              0.              2.
     4    -4.              0.              2.
     5     4.              0.              0.
     6    -4.              0.              0.
     1    1    0    1    1    1    0
     2    1    0    1    1    1    0
     3    1    0    1    1    1    0
     4    1    0    1    1    1    0
     5    1    0    1    1    1    0
     6    1    0    1    1    1    0
     1    0    1    0    0    0    2
     2    0    5    0    0    0    6
     3    0    0    0    0    0    0
     4    0    0    0    0    0    0
     5    0    3    0    0    0    4
     6    0    7    0    0    0    8
     1    2    2    3    4
     5       5.0 1.33333333       .025   3.0E+06   4.5E+02
     6       5.0 1.33333333       .025   3.0E+06   4.5E+02
     1    1    2    0    2        2.75E+04       1.00E+03                    1
     2    1    2    0    6             8E6                                 1
     3    3    5    0    2             7E5                                 1
     4    3    5    0    6             3E7
     5    4    6    0    2             7E5                                 1
     6    4    6    0    6             3E7
     2         0.        200.        0.        0.        0.      2000.      1
     5         0.         60.        0.        0.        0.       290.
     6         0.         60.        0.        0.        0.       290.
     1    0    1    0    0    0    2
     2    0    5    0    0    0    6
     3    0    0    0    0    0    0
     4    0    0    0    0    0    0
     5    0    3    0    0    0    4
     6    0    7    0    0    0    8
 $START NTYPE=3,$END
 $SYN NCOMP=3,PHENAM(1)=2,1,2,NKUNG=4,KDEP(1)=1,2,13,14,
 G(1,1)=1,G(1,12)=-1,G(2,2)=1,G(2,13)=-1,
 G(3,16)=1,G(3,14)=-1,G(4,17)=1,G(4,15)=-1,$END
 $START NTYPE=4,IPLOT=1,SIZE=10.0,$END
 $SHAKE NAXLE=4,NWHEEL=4,NLOOK=3,LAXLE(1)=4,8,19,23,LOOK(1)=10,11,20,
 NPLOT(1)=1,1,1,OMIN=0.1,OMAX=100,NFREQ=150,NFOUR=25,PERIOD=0.2,
 NTIME,=3, WAVE(1)=0,.02,0,TIME(1)=0.0,0.1,0.2,$END
    4        5.0 1.33333333      .025   3.0E+06   4.5E+02    0.0
    8        5.0 1.33333333      .025   3.0E+06   4.5E+02    8.0
   19        5.0 1.33333333      .025   3.0E+06   4.5E+02   83.0
   23        5.0 1.33333333      .025   3.0E+06   4.5E+02   91.0
 $START NTYPE=5,$
```

Sample Problem #3

```
$WIGG,T500,P3,TP1.
COMMENT. CHARGE WIGG1233 01 7954
REQUEST,TAPE,VSN=JHW100.  NO RING  WIGGINS TAPE
COPYBF,TAPE,TEMP.
RETURN,TAPE.
COPYBR,INPUT,TAPE5.
REWIND,TAPE5.
COPYSBF,TAPE5,OUTPUT.
REWIND,TAPE5.
ATTACH,CDF,COMDATFILW1233,ID=WIGG.
COPYBF,CDF,TAPE10.
REWIND,TAPE10.
TEMP.
DISPOSE,TAPE9,PR=IBM.
#
 8-DOF FLEXIBLE CAR COUPLED WITH TWO TRUCKS  -  MODAL TRUNCATION
 $START NTYPE=2,$END
 $EDITT DELETE=2,00,$END
 $START NTYPE=1,NEWTAP=1,$END
 $COMPU COMNAM=2,00,NDS=8,NCON=2,NFREE=6,IGEN=1,$END
    6     0     1     2     6     3
    1      0.                 0.             3.
    2      0.                 0.             2.
    3      4.                 0.             2.
    4     -4.                 0.             2.
    5      4.                 0.             0.
    6     -4.                 0.             0.
    1     1     0     1     1     1     0
    2     1     0     1     1     1     0
    3     1     0     1     1     1     0
    4     1     0     1     1     1     0
    5     1     0     1     1     1     0
    6     1     0     1     1     1     0
    1     0     1     0     0     0     2
    2     0     5     0     0     0     6
    3     0     0     0     0     0     0
    4     0     0     0     0     0     0
    5     0     3     0     0     0     4
    6     0     7     0     0     0     8
    1     2     2     3     4
    5        5.0 1.33333333       .025    3.0E+06    4.5E+02
    6        5.0 1.33333333       .025    3.0E+06    4.5E+02
    1     1     2     0     2        1.75E+04         1.55E+03
    2     1     2     0     6             5E6
    3     3     5     0     2             5E5
    4     3     5     0     6             3E7
    5     4     6     0     2             5E5
    6     4     6     0     6             3E7
    2           0.       250.         0.         0.         0.        2800.
    5           0.        60.         0.         0.         0.         290.
    6           0.        60.         0.         0.         0.         290.
    1     0     1     0     0     0     2
    2     0     5     0     0     0     6
    3     0     0     0     0     0     0
    4     0     0     0     0     0     0
    5     0     3     0     0     0     4
    6     0     7     0     0     0     8
$START NTYPE=2,$END
$EDITT NNAME2(1)=0,0,MODES(1,2)=1,2,3,4,5,6,7,8,$END
$START NTYPE=3,$END
$SYN NCOMP=3,PRENAM(1)=2,1,2,NCONG=4,KDEP(1)=1,2,13,14,
G(1,1)=1,G(1,12)=-1,G(2,2)=1,G(2,13)=-1,
G(3,16)=1,G(3,14)=-1,G(4,17)=1,G(4,15)=-1,$END
$START NTYPE=4,IPLOT=1,SIZE=10.0,$END
$SHAKE NAXLE=4,NWHEEL=4,NL(K,K=3,LAXLE(1)=4,8,19,23,LOOK(1)=10,11,20,
NPSD=2,AMP(1)=9E-3,9E-9,CYCLE(1)=0.1,100.0,FLIM=10.0,
NPLOT(1)=1,1,1,OMIN=0.1,OMAX=100.,NFREQ=150,$END
   4        5.0 1.33333333       .025    3.0E+06    4.5E+02     0.0
   8        5.0 1.33333333       .025    3.0E+06    4.5E+02     8.0
  19        5.0 1.33333333       .025    3.0E+06    4.5E+02    83.0
  23        5.0 1.33333333       .025    3.0E+06    4.5E+02    91.0
$START NTYPE=5,$
```

Sample Problem #4

```
SPRING-MASS SYSTEM
$START NTYPE=1,NEWTAP=0,
INOVEC=1,
IMATX=1,
$END
$COMPO
COMNAM=1.00,IGEN=0,NU=7,NCON=0,NFREE=4,
PHI(1,1)=1,PHI(2,2)=1,PHI(3,3)=1,
PHI(4,4)=1,
PHI(5,1)=-1,PHI(5,2)=1,-1,PHI(6,3)=1,-1,PHI(7,4)=1,
ISYMC=1,ISYMK=1,
AMASS(1,1)=1.,AMASS(2,2)=1.,AMASS(3,3)=0.5,
AMASS(4,4)=0.3,
DAMP(1,1)=0.03,
DAMP(1,2)=-.01,.02,DAMP(2,3)=-.01,
DAMP(3,3)=0.02,
DAMP(3,4)=-0.01,0.01,
STIFF(1,1)=2.,STIFF(1,2)=-1.,2.,STIFF(2,3)=-1.,
STIFF(3,3)=2,
STIFF(3,4)=-1,1,
$END
$START NTYPE=5,$
```

Sample Problem #5

```
SPRING-MASS SYSTEM
$START NTYPE=1,NEWTAP=0,
INOVEC=1,
INATX=1,
$END
$COMPO
COMNAM=1.00,IGEN=0,NU=7,NCON=0,NFREE=4,
PHI(1,1)=1,PHI(2,2)=1,PHI(3,3)=1,
PHI(4,4)=1,
PHI(5,1)=-1,PHI(5,2)=1,-1,PHI(6,3)=1,-1,PHI(7,4)=1,
ISYMC=1,ISYMK=1,
AMASS(1,1)=1.,AMASS(2,2)=1.,AMASS(3,3)=0.5,
AMASS(4,4)=0.3,
DAMP(1,1)=0.03,
DAMP(1,2)=-.01,.02,DAMP(2,3)=-.01,
DAMP(3,3)=0.02,
DAMP(3,4)=-0.01,0.01,
STIFF(1,1)=2.,STIFF(1,2)=-1.,2.,STIFF(2,3)=-1.,
STIFF(3,3)=2,
STIFF(3,4)=-1,1,
NEWDAT=1,COMNAM=2.00,$END
$UPDATE AMASS(4,4)=0.5,
$END
$START NTYPE=5,$
```

APPENDIX A

CHARACTERIZATION OF FORCING FUNCTIONS

Some of the user feedback on DYNALIST II has revealed that the form of the forcing function built into the program is not immediately apparent, and at least to some extent, confusion has been generated as a consequence. This appendix has been added in an attempt to clarify this area. Whereas an introduction to the forcing function in Reference [1] was by way of specific examples, the approach taken here is to begin with the general and then proceed to the specific. Hopefully this treatment will help to resolve some of the difficulty.

In pursuing this objective, some different notation will be introduced. While it is usually desirable to maintain the same notation within a given subject area, the changes here are to some degree necessary for the generalization, and are furthermore intended to interrupt any thought patterns which may have lead to the initial confusion. In this regard, an attempt is made to recast the subject in a different light. Thus, the forces discussed here can be visualized as wheel/rail forces acting on a train, seismic forces on a building, hydrodynamic forces on a ship, or simple point forces acting on a beam. In fact, different examples will be presented to illustrate the generality of the forcing function capability within DYNALIST II.

A.1 General Form

Before taking up the characterization of a particular force environment such as seismic or wave, it will be useful to consider the general form of the forcing function built into DYNALIST II. In simplest terms, a distributed force, f(u,t), where u denotes position or spatial dependency, and t denotes time dependency, is assumed to be variable-separable so that

$$f(u,t) = P(u)g(t) \tag{A-1}$$

where $P(u)$ is a function depending only on position (not to be confused with the lower case "p" used to denote generalized coordinates) and $g(t)$ is a scalar function depending only on time.

Actually, the functional form used in DYNALIST II is somewhat more general. In particular,

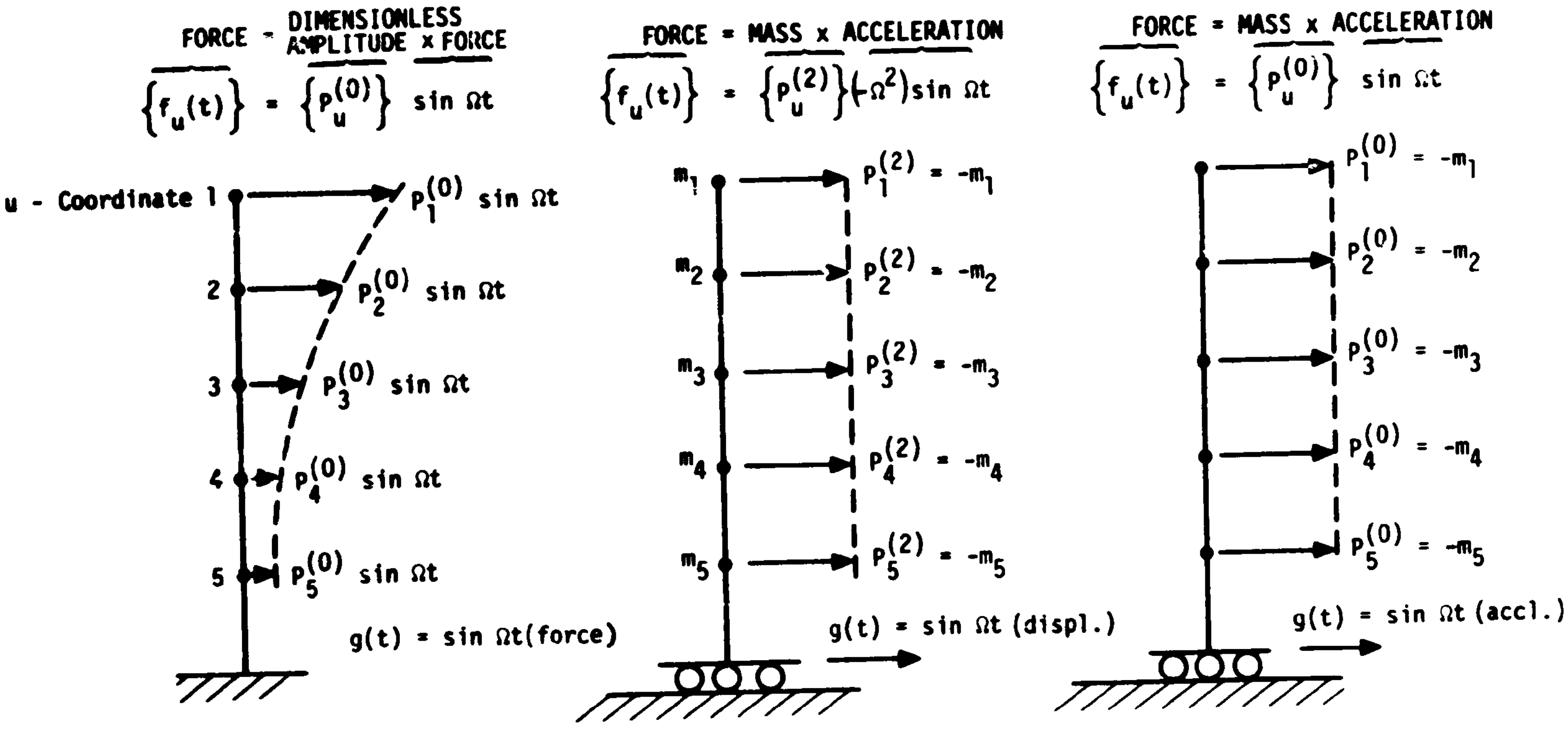
$$f(u,t) = \sum_{k=0}^{2} P^{(k)}(u)\frac{d^k}{dt^k}[g(t)] \tag{A-2}$$

Since DYNALIST II is formulated on the basis of discrete variables rather than continuous variables, a vector form is used instead of (A-2):

$$\{f_u(t)\} = \sum_{k=0}^{2} \{P_u^{(k)}\} \frac{d^k}{dt^k}[g(t)]$$

$$= \{P_u^{(0)}\}g(t) + \{P_u^{(1)}\}\dot{g}(t) + \{P_u^{(2)}\}\ddot{g}(t) \tag{A-3}$$

Typical force distributions are shown in Figure A-1, for example. In part (a) of that figure, a cantilever beam is subjected to a distributed load which varies sinusoidally with time, similar



(A) DISTRIBUTED FORCE INPUT

(B) BASE DISPLACEMENT INPUT

(C) BASE ACCELERATION INPUT

Figure A-1. Examples of Force Vectors Used in DYNALIST II to wave action on a pier. In part (b) the cantilever beam is subjected to base motion whose waveform is defined in terms of displacement. In part (c) the same beam is subjected to base motion whose waveform is defined in terms of acceleration. In all cases, equations of motion are of the form

$$[m]\{\ddot{u}\} + [c]\{\dot{u}\} + [k]\{u\} = \{f_u(t)\} \qquad \text{(A-4)}$$

where the u-coordinates numbered 1 through 5 denote lateral displacements of the beam <u>relative to its base</u>, and where in parts (b) and (c) the inertial forces due to base acceleration have been transposed to the right hand side of the equations.

A.2 Frequency Domain Analysis

DYNALIST II solves equations of motion in the frequency domain, rather than in the time domain. This makes it convenient to use Equation (A-3) in a form where the vectors $\{P_u^{(0)}\}$, $\{P_u^{(1)}\}$ and $\{P_u^{(2)}\}$ <u>are complex</u>, i.e. have both real and imaginary parts. In other words, the force distribution functions allow phase distribution in addition to amplitude distribution. In order to pursue this discussion further, it is helpful to consider the equations of motion given by (A-4) and transform them to the frequency domain. This is done by first taking the Laplace transform of the equations, which maps them from the time variable t into the complex variable $s = \sigma + i\Omega$, and then let $\sigma \to 0$. The resulting equations in the frequency domain are

$$\left([k] + i\Omega[c] - \Omega^2[m]\right)\{U(i\Omega)\} = \{F_u(i\Omega)\} \qquad \text{(A-5)}$$

where $\{U(i\Omega)\}$ and $\{F_u(i\Omega)\}$ denote the transformed vectors $\{u(t)\}$ and $\{f(t)\}$ respectively. The vectors $\{U(i\Omega)\}$ and $\{F(i\Omega)\}$ are the Fourier transforms of their time dependent

counterparts whenever the Fourier integrals exist.* Transformation of $\{f_u(t)\}$, as expressed in (A-3), to the frequency domain leads to

$$\{F_u(i\Omega)\} = \Big(\{P_u^{(0)}\} + (i\Omega)\{P_u^{(1)}\} + (i\Omega)^2\{P_u^{(2)}\}\Big)G(i\Omega) \qquad \text{(A-6)}$$

where the P_u-vectors are still complex. Finally the P_u-vectors are resolved into amplitude and phase vectors of the form

$$\{P_u^{(0)}\} + (i\Omega)\{P_u^{(1)}\} + (i\Omega)^2\{P_u^{(2)}\}$$

$$= \Big(\{\bar{P}_u^{(0)}\} + (i\Omega)\{\bar{P}_u^{(1)}\} + (i\Omega)^2\{\bar{P}_u^{(2)}\}\Big)e^{-i[\{\theta_u^{(0)}\} + \Omega\{\theta_u^{(1)}\}]}$$

$$\text{(A-7)}$$

where the "P-bars" are now real and the phase shifts implied by $\{\theta_u^{(0)}\}$ and/or $\{\theta_u^{(1)}\}$ operate on the three force vectors - $\{\bar{P}_u^{(0)}\}$, $\{\bar{P}_u^{(1)}\}$ and $\{\bar{P}_u^{(2)}\}$ - simultaneously.** The superscript notation (k), where k=0,1,2, may be associated with multiplication by Ω to kth power. See examples which follow in Tables A-1 and A-2.

A.3 Position Dependency (Force Distribution)

The frequency domain formulation given in the preceding section is particularly well suited to the dynamic response analysis of systems subjected to wave environments, either traveling waves or standing waves, where the forces acting on different parts

---

*Although the Fourier integral transform of a periodic function is not defined, a Fourier series representation does exist so that the formal treatment given here is physically meaningful and practically useful.

**If at a particular u-location, multiple forces exist which have different phases, then the simplest approach would be to multiply define identical u-coordinates at that location, and to apply one force to each such coordinate.

of the system may all be assumed to have the same time dependency, but have different amplitudes and phase angles. Recalling the rail-vehicle application for which the program was originally designed, one may visualize forces acting on the vehicle through each wheel. In the two-dimensional case where differences between rails are ignored, one can show that the driving forces acting on all of the wheels have the same time dependency as determined by the velocity of the vehicle and the profile of the rail surface. Aside from differences in wheel geometry, mass, and suspension parameters which are system dependent and show up in the force distribution, each trailing wheel sees the same input as the lead wheel with a time lag equal to its distance behind the lead wheel divided by the forward velocity of the vehicle, i.e., ℓ/V. In the frequency domain, this lag term is represented by the phase angle vector $\Omega\{\theta_u^{(1)}\}$ where Ω is the circular frequency associated with the wavelength of the rail surface profile irregularity and the vehicle's forward velocity.

A similar situation prevails in the case of an offshore platform excited by traveling sea waves. If the wave displacement profile is represented by the scalar time function g(t), the wave forces acting on the platform can be separated into

- Hydrostatic forces $\{P_u^{(0)}\}$
- Drag forces $\{P_u^{(1)}\}$
- Inertia forces $\{P_u^{(2)}\}$

and their phasing relative to wherever g(t) is measured will be specified by the phase angle vector $\Omega\{\theta_u^{(1)}\}$, where in this case Ω is associated with wave length and propagation velocity (celerity), and $\{\theta_u^{(1)}\}$ will again be of the form ℓ/V. This application is illustrated by Figure A-2 and Table A-1, except in this particular case, the hydrostatic forces are zero.

If the platform were situated in a standing wave environment, the phase angle distribution would be specified in terms of $\{\theta_u^{(0)}\}$ instead of $\{\theta_u^{(1)}\}$. Another example of the use of $\{\theta_u^{(0)}\}$ is in the vibration of machinery due to rotor unbalance, where the relative phase angles among different eccentric masses are independent of the frequency of rotation, Ω.

Force distribution is input to DYNALIST II via the NAMELIST variable arrays

FORC0 = $\{P_u(0)\}$
FORC1 = $\{P_u^{(1)}\}$
FORC2 = $\{P_u^{(2)}\}$
PHAS0 = $\{\theta_u^{(0)}\}/2\pi$ (units in cycles)
PHAS1 = $\{\theta_u^{(1)}\}$ (units in seconds)

as explained in this manual.

A.4 Time Dependency (Waveform)

It has already been stated that DYNALIST II offers the capability to compute dynamic response to

- Sinusoidal,
- Periodic,
- Transient, and
- Random

forcing functions. These categories relate to different ways of characterizing the time dependency of $\{f_u(t)\}$ as embodied in the scalar waveform function $g(t)$. Figure A-3 illustrates

TIME DOMAIN FORCES

$$\left\{f_u(t)\right\} = \left\{P_u^{(1)}\right\} \dot{g}(t) + \left\{P_u^{(2)}\right\} \ddot{g}(t)$$

$$g(t) = \begin{cases} \text{SINUSOIDAL} \\ \text{PERIODIC} \\ \text{TRANSIENT} \\ \text{RANDOM} \end{cases}$$

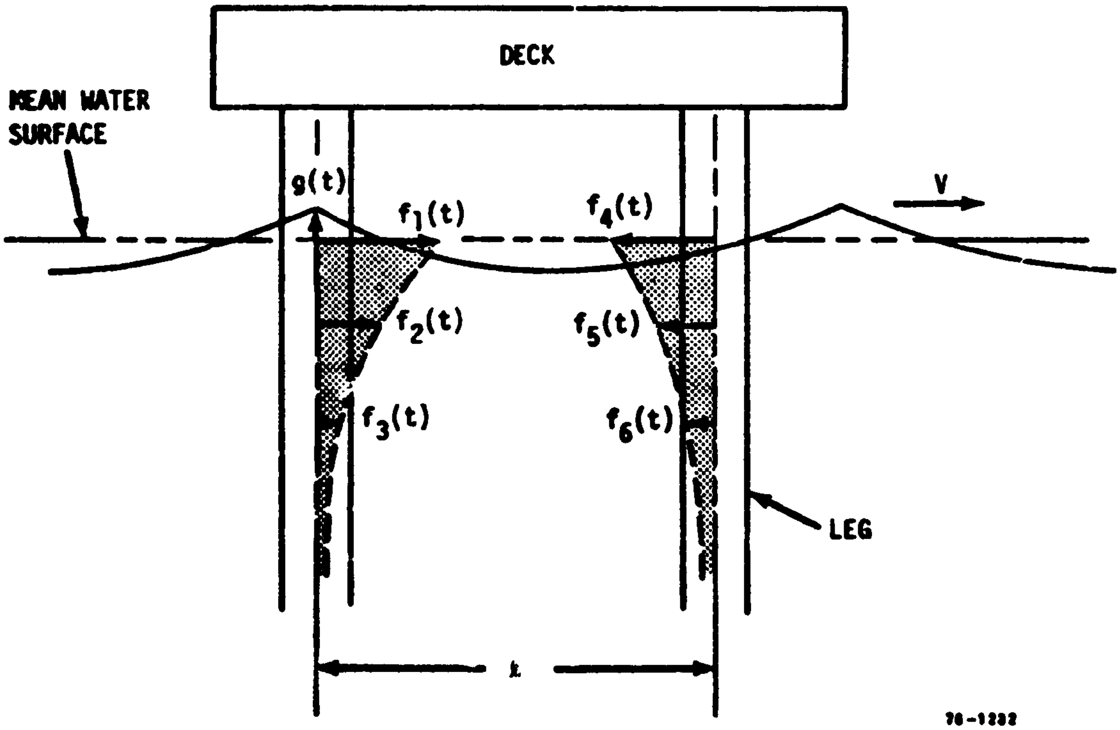


Figure A-2. Force Distribution for Wave Excitation

TABLE A-1. CHARACTERIZATION OF WAVE FORCES IN FIGURE A-2

FREQUENCY DOMAIN FORCES

$$F_1(i\Omega) = \left[(i\Omega)\bar{P}_1^{(1)} + (i\Omega)^2\bar{P}_1^{(2)}\right] G(i\Omega)$$

$$F_2(i\Omega) = \left[(i\Omega)\bar{P}_2^{(1)} + (i\Omega)^2\bar{P}_2^{(2)}\right] G(i\Omega)$$

$$F_3(i\Omega) = \left[(i\Omega)\bar{P}_3^{(1)} + (i\Omega)^2\bar{P}_3^{(2)}\right] G(i\Omega)$$

$$F_4(i\Omega) = \left[(i\Omega)\bar{P}_4^{(1)} + (i\Omega)^2\bar{P}_4^{(2)}\right] e^{-i\Omega\ell/V} G(i\Omega)$$

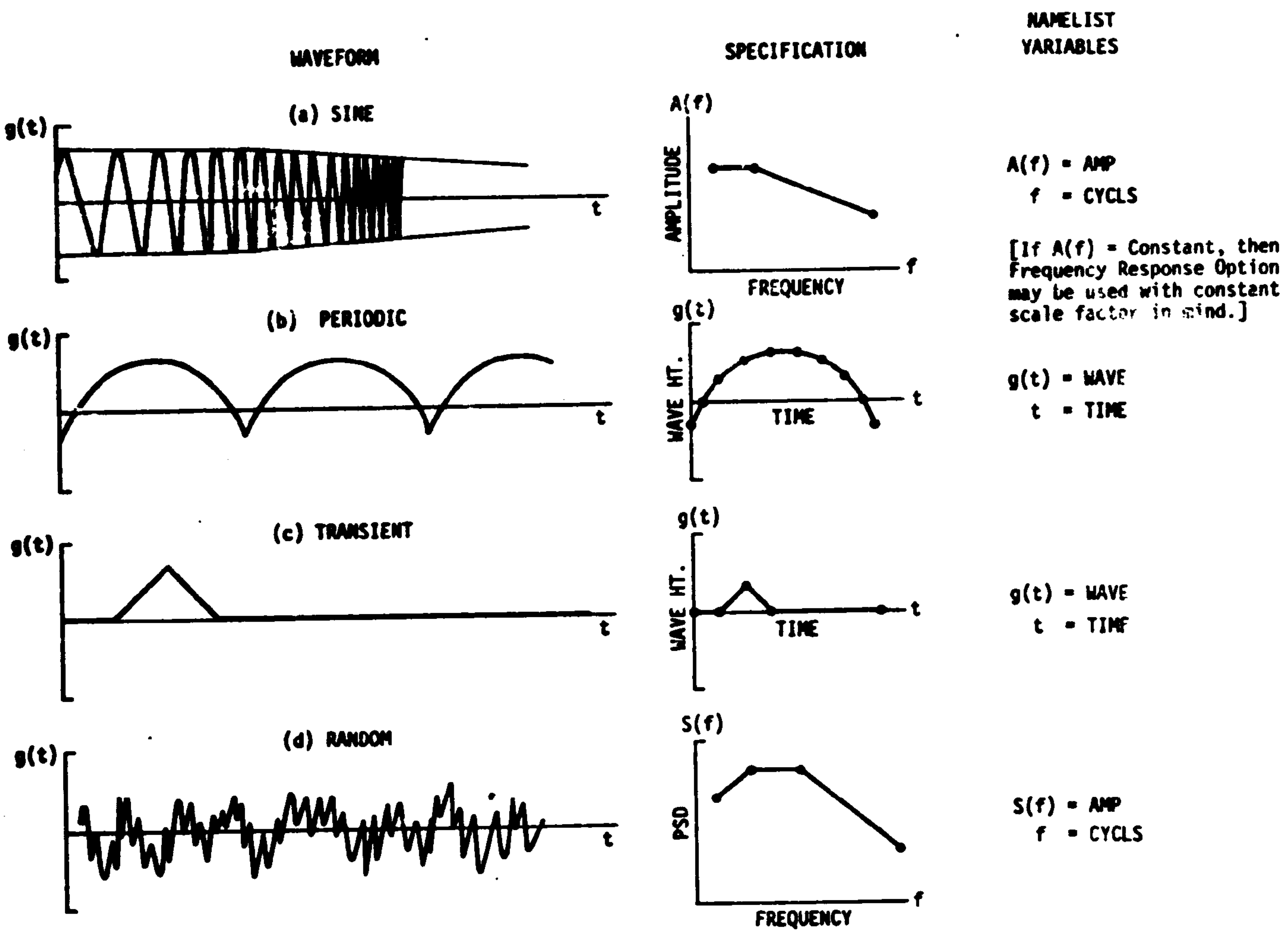
$$F_5(i\Omega) = \left[(i\Omega)\bar{P}_5^{(1)} + (i\Omega)^2\bar{P}_5^{(2)}\right] e^{-i\Omega\ell/V} G(i\Omega)$$

$$F_6(i\Omega) = \left[(i\Omega)\bar{P}_6^{(1)} + (i\Omega)^2\bar{P}_6^{(2)}\right] e^{-i\Omega\ell/V} G(i\Omega)$$

FORCE DISTRIBUTION INPUT TO DYNALIST II

u-COORD	FORC0	FORC1	FORC2	PHAS0	PHAS1
1	0	$\bar{P}_1^{(1)}$	$\bar{P}_1^{(2)}$	0	0
2	0	$\bar{P}_2^{(1)}$	$\bar{P}_2^{(2)}$	0	0
3	0	$\bar{P}_3^{(1)}$	$\bar{P}_3^{(2)}$	0	0
4	0	$\bar{P}_4^{(1)}$	$\bar{P}_4^{(2)}$	0	ℓ/V
5	0	$\bar{P}_5^{(1)}$	$\bar{P}_5^{(2)}$	0	ℓ/V
6	0	$\bar{P}_6^{(1)}$	$\bar{P}_6^{(2)}$	0	ℓ/V

Note: If the two legs shown in Figure A-2 are identical, then $\bar{F}_4 = \bar{F}_1$, $\bar{F}_5 = \bar{F}_2$, and $\bar{F}_6 = \bar{F}_3$.



[If A(f) = Constant, then Frequency Response Option may be used with constant scale factor in mind.]

Figure A-3. Waveform Specifications in DYNALIST II the four basic waveform input options, and the means by which they are entered in DYNALIST II.

In the case of the amplitude varying sinusoidal waveform, steady state response is assumed. Thus, even though the waveform in Part (a) of the figure is actually changing with respect to both frequency and time, the implication is that the variations with time are slow so that the system is able to "track" the variations with virtually steady state response. Input to the program can therefore be specified in terms of excitation amplitude vs. frequency as shown in the figure.

Periodic excitation is specified in terms of the typical waveform over one fundamental period of the excitation. Thus, where the actual waveform repeats itself over every successive period, all of the information is contained in one period of the motion. The same argument applies to response. Only one peroid of the response time-history is computed, and only one period is plotted.

Transient excitation and response is treated by Fourier series approximation and is therefore considered to be a periodic function with a very long fundamental period as illustrated in Part (c) of the figure. The length of this period is artificial and is chosen on the basis of the time constants of the system, i.e., natural frequencies and damping rates. The artificial period must be long enough to allow all motion from one transient to damp out before another transient (in a successive period) is encountered. Since transient excitation and response are treated as periodic functions, program input and output are identical in form to the periodic case. The program in fact recognizes no distinction between the two.

Random excitation is assumed to be stationary. It is specified in terms of the power spectral density (PSD) function as illustrated in Part (d) of Figure A-3. Since the waveform is random, stationary and assumed to be ergodic (establishing statistical equivalence between one sample function and an ensemble), no phase information and no particular wave shape characteristics are implied. Only the power (energy type information) distribution with respect to frequency is specified.

A.5 Notation

Now that the general form of the forcing function has been developed in terms of some different notation, we can go back to relate the original notation of Reference [1] to the notation of this appendix.

The system force vector $\{f_u(t)\}$ shown in Equation (A-4) of this appendix is related to the ℓth component force vector $\{f_u^\ell(t)\}$ of Reference [1], Equation (2-5) as follows

$$\{f_u(t)\} = \left\{ \begin{bmatrix} f_u^1(t) \\ f_u^2(t) \\ \vdots \\ f_u^\ell(t) \\ \vdots \\ f_u^N(t) \end{bmatrix} \right\} \; ; \quad \text{where } f_u^\ell(t) \equiv \{f_u^\ell(t)\} \text{ for } 1 \le \ell \le N$$

The Fourier transform of $\{f_u(t)\}$ as denoted by $\{F_u(i\Omega)\}$ in (A-5) is similarly related to the $\{F_u^{\ell}(i\Omega)\}$ in Reference [1], Equation (2-37) by

$$\{F_u(i\Omega)\} = \left\{\begin{bmatrix} F_u^1(i\Omega) \\ F_u^2(i\Omega) \\ \vdots \\ F_u^{\ell}(i\Omega) \\ \vdots \\ F_u^N(i\Omega) \end{bmatrix}\right\} ; \text{ where } F_u^{\ell}(i\Omega) \equiv \{F_u^{\ell}(i\Omega)\} \text{ for } 1 \leq \ell \leq N$$

In the case where the excitation waveform corresponds to the rail irregularity (track geometry profile) $\delta(t) = \delta_1^{\ell}(t)$* as implied by Reference [1], Equation (2-34), it follows that the function $g(t)$ in (A-3) becomes

$$g(t) = \delta(t) \equiv \delta_1^{\ell}(t)$$

Similarly, in the frequency domain,

$$G(i\Omega) = \Delta(i\Omega) \equiv \Delta_1^{\ell}(i\Omega)$$

---

* This equality implies that the general waveform $\delta(t)$ is measured with respect to a particular axle "1" of a particular component "ℓ", i.e., a fixed point on the vehicle.

This "G" of course bears no relationship to the constraint matrix "G" used in Reference [1], Equation (2-1).

In the case of the train application, the complex vectors $\{P_u^{(0)}\}$, and $\{P_u^{(1)}\}$ and $\{P_u^{(2)}\}$ of (A-3) are

$$\{P_u^{(0)}\} \equiv \{F_0(i\Omega)\}$$

$$\{P_u^{(1)}\} \equiv \{F_1(i\Omega)\}$$

$$\{P_u^{(2)}\} \equiv \{F_2(i\Omega)\}$$

where the terms on the right hand side appear in Reference [1], Equation (2-38). Again, these capital "P's" bear no relation to the lower case "p's" of Reference [1], Equation (2-14).

Referring back to the truck example of Reference [1], Figure 2-2, and the force vector given by Equation (2-37) which follows that figure, we find that we can generate another table analogous to Table A-1, for the truck model. See Table A-2. Either the sine, periodic, transient or random type waveform input can be specified for this force distribution.

TABLE A-2. CHARACTERIZATION OF WHEEL/RAIL FORCES IN REFERENCE [1], FIGURE 2-2

FREQUENCY DOMAIN FORCES

$$F_1(i\Omega) = 0$$

$$F_2(i\Omega) = P_1^{(0)}\ G(i\Omega) = \left(\frac{2f\ \lambda_o\ L_o}{r_o}\right) \Delta(i\Omega)$$

$$F_3(i\Omega) = 0$$

$$F_4(i\Omega) = 0$$

$$F_5(i\Omega) = 0$$

$$F_6(i\Omega) = P_6^{(0)}\ e^{-i\Omega L/V}\ G(i\Omega) = \left(\frac{2f\ \lambda_o\ L_o}{r_o}\right)\ e^{-i\Omega L/V}\ \Delta(i\Omega)$$

FORCE DISTRIBUTION INPUT TO DYNALIST II

υ-COORD	FORC0	FORC1	FORC2	PHAS0	PHAS1
1	0	0	0	0	0
2	$\left(\frac{2f\ \lambda_o\ L_o}{r_o}\right)$	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	$\left(\frac{2f\ \lambda_o\ L_o}{r_o}\right)$	0	0	0	L/V

APPENDIX B

MODAL REPRESENTATION OF A FLEXIBLE COMPONENT

The basic procedure for modeling any flexible component in DYNALIST II is to write the equations of motion for that component in generalized p-coordinates and to specify a transformation relating selected physical u-coordinates to the generalized coordinates. The generalized coordinates may or may not correspond to normal modes of the component. The relevant equations are:

$$[m]\{\ddot{p}\} + [c]\{\dot{p}\} + [k]\{p\} = \{0\}$$

$$\{u\} = [\phi]\{p\}$$

where [m], [c], [k] and [ϕ] are the matrices AMASS, DAMP, STIFF, and PHI, respectively.

The simplest case results whenever the motion of the component is represented by a set of normal modes which are mutually orthogonal. Assuming natural frequencies, ω_j, modal damping coefficients, ζ_j, and modes which are <u>normalized</u> to give unit modal mass, one finds that

$$[m] = \begin{bmatrix} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & \cdots & 1 \end{bmatrix} \quad \text{(diagonal)}$$

$$[k] = \begin{bmatrix} \omega_1^2 & & & & \\ & \omega_2^2 & & & \\ & & \omega_3^2 & & \\ & & & \cdots & \\ & & & & \omega_n^2 \end{bmatrix} \quad \text{(diagonal)}$$

In the case of light structural damping ($\zeta_j < 0.1$) and well separated modes, a diagonal damping matrix may be assumed such that

$$[c] = 2\begin{bmatrix} \zeta_1\omega_1 & & & & \\ & \zeta_2\omega_2 & & & \\ & & \zeta_3\omega_3 & & \\ & & & \cdots & \\ & & & & \zeta_n\omega_n \end{bmatrix} \quad \text{(diagonal)}$$

The case where car-body modes are given as free-free modes is an example of this form. Considering a lateral model having only sway and yaw degrees of freedom and two bending modes, the natural frequencies will be $\omega_1 = \omega_2 = 0$ for the rigid body modes and ω_3 and ω_4 for the bending modes.

A slightly different form results whenever fixed boundary normal bending modes are used, i.e, if car-body modes are obtained under the assumption that the car body is simply supported. If the modal matrix $[\phi]$ were not normalized to give unit modal mass, but a maximum modal displacement of unity, for example, the form of [m], [c] and [k] would be

$$[m] = \left[\begin{array}{c:c} m^{RR} & m^{RN} \\ \hdashline m^{NR} & m^{NN} \end{array}\right]$$

$$[c] = \left[\begin{array}{c:c} 0 & 0 \\ \hdashline 0 & c^{NN} \end{array}\right]$$

$$[k] = \left[\begin{array}{c:c} 0 & 0 \\ \hdashline 0 & k^{NN} \end{array}\right]$$

where the superscripts R and N refer to rigid body and normal modes. The submatrix $[m^{RN}] = [m^{NR}]^T$ reflects coupling between the rigid-body modes and fixed-boundary normal bending modes.

The flexible car component used in Sample Problem 1 is depicted in Figure 7. The car is assumed to act as a uniform beam with bending stiffness EI and mass per unit length, M. The rigid body modes $\phi_1(x)$ and $\phi_2(x)$ are shown with the flexible body modes $\phi_3(x)$ and $\phi_4(x)$. The matrices [m] and [k] may be found using Lagrange's Equation:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{p}_j}\right) + \frac{\partial U}{\partial p_j} = 0$$

where T denotes the kinetic energy of the system and U denotes the potential energy, or strain energy in this case.

$$T = \frac{M}{2}\int_{-L/2}^{L/2} [\dot{u}(x,t)]^2\, dx$$

$$U = \frac{EI}{2} \int_{-L/2}^{L/2} [u''(x,t)]^2 \, dx$$

where

$$u(x,t) = \sum_{j=1}^{4} \phi_j(x) p_j(t)$$

From this it is found that elements of the mass and stiffness matrices are given by

$$m_{ij} = M \int_{-L/2}^{L/2} \phi_i(x) \phi_j(x) dx$$

$$k_{ij} = EI \int_{-L/2}^{L/2} \phi_i''(x) \phi_j''(x) \, dx$$

Using the mode shapes $\phi_1(x) = 1$, $\phi_2(x) = 2x/L$, $\phi_3(x) = \text{Cos}(\pi x/L)$ and $\phi_4(x) = \text{Sin}\,(2\pi x/L)$, which are normalized to a maximum displacement of one, we obtain

$$[m] = ML \left[\begin{array}{cc|cc} 1 & 0 & 2/\pi & 0 \\ 0 & 1/3 & 0 & 1/\pi \\ \hline 2/\pi & 0 & 1/2 & 0 \\ 0 & 1/\pi & 0 & 1/2 \end{array} \right]$$

$$[c] = \left[\begin{array}{cc|cc} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \hline 0 & 0 & c_{33} & 0 \\ 0 & 0 & 0 & c_{44} \end{array}\right]$$

$$[k] = \frac{\pi^4 EI}{L^3} \left[\begin{array}{cc|cc} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 1/2 & 0 \\ 0 & 0 & 0 & 8 \end{array}\right]$$

The only parameters which have not previously been defined are the damping terms c_{33} and c_{44}. The frequencies, ω_3^N and ω_4^N associated with normal modes $\phi_3(x)$ and $\phi_4(x)$ are

$$\omega_3^N = \sqrt{\frac{k_{33}}{m_{33}}} = \pi^2 \sqrt{\frac{EI}{ML^4}}$$

$$\omega_4^N = \sqrt{\frac{k_{44}}{m_{44}}} = 4\pi^2 \sqrt{\frac{EI}{ML^4}}$$

Assuming damping ratios ζ_3 and ζ_4 for the two flexure modes, one finds that

$$c_{33} = 2m_{33}\zeta_3\omega_3^N = 2\zeta_3\sqrt{m_{33}k_{33}}$$

$$c_{44} = 2m_{44}\zeta_4\omega_4^N = 2\zeta_4\sqrt{m_{44}k_{44}}$$

All of the parameters have now been defined; the next step is to assign values to use in computation. In particular, our objective here is to establish some values which are meaningful for the sample problems contained in Section 6. We must therefore determine values for M, L, EI, c_{33} and c_{44}. From Reference [1] we obtain values for M and L

$$M = 17 \text{ slugs/ft}$$

$$L = 100 \text{ ft}$$

Next we need a value for the flexural rigidity, EI, of the carbody. We will choose this value so that we obtain a first carbody bending mode of 5 Hz taking into account the secondary suspension. The value of this case is $EI = 3.263 \times 10^9 \text{lb-ft}^2$, whereupon it follows that

$$\omega_3^N = 13.67 \text{ rad/sec}$$

$$\omega_4^N = 54.69 \text{ rad/sec}$$

Finally, considering that

$$m_{33} = m_{44} = ML/2 = 850 \text{ slugs}$$

and assuming

$$\zeta_3 = \zeta_4 = 0.01$$

enables us to evaluate c_{33} and c_{44} as

$$c_{33} = 2m_{33}\zeta_3\omega_3^N = 232.45 \quad \text{lb-sec/ft}$$

$$c_{44} = 2m_{44}\zeta_4\omega_4^N = 929.79 \quad \text{lb-sec/ft}$$

The mass, damping and stiffness properties of the flexible carbody model are thus numerically defined.

APPENDIX C

OUTPUT FOR SAMPLE PROBLEM #1

(Only the first and last pages of eigenvector printout are included, and response is shown only for coordinate 10)

```
4-DOF FLEXIBLE CAR COUPLED WITH TWO TRUCKS
---------------------------------------------------------------------
```

```
                    DYNALIST II COMPONENT MATRIX GENERATOR FOR RAIL VEHICLES   COMPONENT  1.00
                                                                               --------------

 THE NUMBER OF CONSTRAINED DYNAMIC DOF (NCON) =   4
 THE NUMBER OF UNCONSTRAINED DYNAMIC DOF (NFREE) =  0
 THE NUMBER OF PHYSICAL RESPONSE COORDINATES (NU) =  7
 THE NUMBER OF NODES =   5
 THE NUMBER OF FLEXIBLE BODY NODES =   4
 THE NUMBER OF RIGID BODY ELEMENTS =   0
 THE NUMBER OF LATERAL WHEELSET ELEMENTS =   0
 THE NUMBER OF SPRING-DAMPER ELEMENTS =   0
 THE NUMBER OF NODAL MASSES =   0

                         NODAL GEOMETRY                                      PHYSICAL CONSTRAINTS
   NODE        X             Y                  Z                        X   Y   Z   R-X  R-Y  R-Z
     1        .0            .0              6.000000                     1   0   1    1    1    0
     2      50.00000        .0              6.000000                     1   0   1    1    1    0
     3     -50.00000        .0              6.000000                     1   0   1    1    1    0
     4      41.50000        .0              3.000000                     1   0   1    1    1    0
     5     -41.50000        .0              3.000000                     1   0   1    1    1    0


         COMPONENT P-COORDINATE SYSTEM   DYNAMIC DEGREES OF FREEDOM

              NODAL DEGREES OF FREEDOM
            NODE    X     Y     Z    R-X   R-Y   R-Z
              1     0     0     0     0     0     0
              2     0     0     0     0     0     0
              3     0     0     0     0     0     0
              4     0     0     0     0     0     0
              5     0     0     0     0     0     0

         FLEXIBLE BODY (NODAL) DEGREES OF FREEDOM

 NODE              1   2   3   4
 P-COORDINATE      1   2   3   4

         THERE ARE   4  P-COORDINATES
         P-COORDINATES  1  THROUGH  4  ARE CONSTRAINED IN THE COMPONENT EIGENVALUE SOLUTION
         THERE ARE NO FREE P-COORDINATES
```

```
        FLEXIBLE BODY MODES

MODE  1 HAS MASS =    1700.000      DAMPING =    .0           AND STIFFNESS =    .0
ITS MODE SHAPE HAS THE FORM
NODE     D-X                D-Y              D-Z              R-X              R-Y              R-Z
  1     .0               1.00000             .0               .0               .0               .0
  2     .0               1.00000             .0               .0               .0               .0
  3     .0               1.00000             .0               .0               .0               .0
  4     .0               1.00000             .0               .0               .0               .0
  5     .0               1.00000             .0               .0               .0               .0

MODE  2 HAS MASS =    566.6667      DAMPING =    .0           AND STIFFNESS =    .0
ITS MODE SHAPE HAS THE FORM
NODE     D-X                D-Y              D-Z              R-X              R-Y              R-Z
  1     .0                 .0                .0               .0               .0          2.000000E-02
  2     .0               1.00000             .0               .0               .0          2.000000E-02
  3     .0              -1.00000             .0               .0               .0          2.000000E-02
  4     .0                .030000            .0               .0               .0          2.000000E-02
  5     .0               -.030000            .0               .0               .0          2.000000E-02

MODE  3 HAS MASS =    850.0000      DAMPING =    232.4500     AND STIFFNESS =    158916.6
ITS MODE SHAPE HAS THE FORM
NODE     D-X                D-Y              D-Z              R-X              R-Y              R-Z
  1     .0               1.00000             .0               .0               .0               .0
  2     .0                 .0                .0               .0               .0         -3.141600E-02
  3     .0                 .0                .0               .0               .0          3.141600E-02
  4     .0                .263070            .0               .0               .0         -3.030200E-02
  5     .0                .263070            .0               .0               .0          3.030200E-02

MODE  4 HAS MASS =    850.0000      DAMPING =    929.7900     AND STIFFNESS =    2542666
ITS MODE SHAPE HAS THE FORM
NODE     D-X                D-Y              D-Z              R-X              R-Y              R-Z
  1     .0                 .0                .0               .0               .0          6.283200E-02
  2     .0                 .0                .0               .0               .0         -6.283200E-02
  3     .0                 .0                .0               .0               .0         -6.283200E-02
  4     .0                .509041            .0               .0               .0         -5.408200E-02
  5     .0               -.509041            .0               .0               .0         -5.408200E-02


       COMPONENT U-COORDINATE SYSTEM   PHYSICAL RESPONSE COORDINATES

         NODE     X      Y      Z     R-X    R-Y    R-Z
           1      0      2      0      0      0      0
           2      0      1      0      0      0      0
           3      0      3      0      0      0      0
           4      0      4      0      0      0      5
           5      0      6      0      0      0      7


       THERE ARE   7 U-COORDINATES
```

```
THE FOLLOWING INFORMATION IS FOR COMPONENT     1.00
---------------------------------------------------

THE TOTAL NUMBER OF PHYSICAL COORDINATES (NM) =    7

THE NUMBER OF CONSTRAINED DYNAMIC DOF (NCON) =    4

THE NUMBER OF UNCONSTRAINED DYNAMIC DOF (NFREE) =    0

THE TOTAL NUMBER OF DYNAMIC DEGREES OF FREEDOM (NJ) =    4


      SOLUTION OF THE COMPONENT EIGENPROBLEM HAS BEEN BYPASSED.


THE LATEST VERSION OF THE COMPONENT DATA FILE IS NOW ON TAPE  11



                                                -- COLUMN LOCATIONS --
 1           2           3           4           5           6           7           8           9          10
11          12          13          14          15          16          17          18          19          20

 THE MASS MATRIX (AMASS) LISTED BY ROWS.
 ---------------------------------------

ROW   1
 1.700E+03    .0         1.002E+03    .0

ROW   2
  .0         5.667E+02    .0         5.411E+02

ROW   3
 1.002E+03    .0         8.503E+02    .0

ROW   4
  .0         5.411E+02    .0         8.500E+02
```

```
                                      -- COLUMN LOCATIONS --
    1        2        3        4        5        6        7        8        9        10
   11       12       13       14       15       16       17       18       19       20

    THE DAMPING MATRIX (DAMP) LISTED BY ROWS.
    -----------------------------------------

  ROW   1
    .0       .0       .0       .0
  ROW   2
    .0       .0       .0       .0
  ROW   3
    .0       .0    2.324E+02   .0
  ROW   4
    .0       .0       .0    9.290E+02
```

```
                                      -- COLUMN LOCATIONS --
    1        2        3        4        5        6        7        8        9        10
   11       12       13       14       15       16       17       18       19       20

    THE STIFFNESS MATRIX (STIFF) LISTED BY ROWS.
    --------------------------------------------

  ROW   1
    .0       .0       .0       .0
  ROW   2
    .0       .0       .0       .0
  ROW   3
    .0       .0    1.509E+05   .0
  ROW   4
    .0       .0       .0    2.543E+06
```

```
                                        -- COLUMN LOCATIONS --
    1          2          3          4          5          6          7          8          9          10
    11         12         13         14         15         16         17         18         19         20

THE MATRIX RELATING THE PHYSICAL COORDINATES TO THE DYNAMIC COORDINATES (MATRIX PHI).
-------------------------------------------------------------------------------------

ROW   1
 1.000E+00  1.000E+00   .0          .0

ROW   2
 1.000E+00   .0         1.000E+00   .0

ROW   3
 1.000E+00 -1.000E+00   .0          .0

ROW   4
 1.000E+00  8.300E-01  2.633E-01  5.190E-01

ROW   5
  .0        2.000E-02 -1.833E-02 -5.400E-02

ROW   6
 1.000E+00 -8.300E-01  2.633E-01 -5.190E-01

ROW   7
  .0        2.000E-02  1.833E-02 -5.400E-02
```

```
                          DYNALIST II COMPONENT MATRIX GENERATOR FOR RAIL VEHICLES   COMPONENT  2.00
                                                                                      --------------
THE NUMBER OF CONSTRAINED DYNAMIC DOF (NCON) =   8
THE NUMBER OF UNCONSTRAINED DYNAMIC DOF (NFREE) =   0
THE NUMBER OF PHYSICAL RESPONSE COORDINATES (NR) =   0
THE NUMBER OF NODES =   6
THE NUMBER OF FLEXIBLE BODY MODES =   0
THE NUMBER OF RIGID BODY ELEMENTS =   1
THE NUMBER OF LATERAL WHEELSET ELEMENTS =   2
THE NUMBER OF SPRING-DAMPER ELEMENTS =   6
THE NUMBER OF NODAL MASSES =   3

                        NODAL GEOMETRY                                     PHYSICAL CONSTRAINTS
  NODE        X                   Y                   Z                  X   Y   Z   R-X  R-Y  R-Z
   1         .0                  .0                3.000000              1   0   1    1    1    0
   2         .0                  .0                2.000000              1   0   1    1    1    0
   3        4.000000             .0                2.000000              1   0   1    1    1    0
   4       -4.000000             .0                2.000000              1   0   1    1    1    0
   5        4.000000             .0                 .0                   1   0   1    1    1    0
   6       -4.000000             .0                 .0                   1   0   1    1    1    0



      COMPONENT P-COORDINATE SYSTEM   DYNAMIC DEGREES OF FREEDOM

          NODAL DEGREES OF FREEDOM
        NODE    X     Y     Z    R-X   R-Y   R-Z
         1      0     1     0     0     0     2
         2      0     5     0     0     0     6
         3      0     0     0     0     0     0
         4      0     0     0     0     0     0
         5      0     3     0     0     0     4
         6      0     7     0     0     0     8

       THERE ARE   8  P-COORDINATES
       P-COORDINATES  1  THROUGH  8  ARE CONSTRAINED IN THE COMPONENT EIGENVALUE SOLUTION
       THERE ARE NO FREE P-COORDINATES

      RIGID BODY ELEMENTS

BODY   MASTER NODE          SLAVE NODES
  1         2                  3    4
```

```
THE FOLLOWING INFORMATION IS FOR COMPONENT      2.00
---------------------------------------------------------

THE TOTAL NUMBER OF PHYSICAL COORDINATES (NU) =     8
THE NUMBER OF CONSTRAINED DYNAMIC DOF (NCON) =     0
THE NUMBER OF UNCONSTRAINED DYNAMIC DOF (NFREE) =     8
THE TOTAL NUMBER OF DYNAMIC DEGREES OF FREEDOM (NJ) =     8

      SOLUTION OF THE COMPONENT EIGENPROBLEM HAS BEEN BYPASSED.


THE LATEST VERSION OF THE COMPONENT DATA FILE IS NOW ON TAPE  10


                                        -- COLUMN LOCATIONS --
    1            2            3            4            5            6            7            8            9            10
   11           12           13           14           15           16           17           18           19            20

  THE MASS MATRIX (AMASS) LISTED BY ROWS.
  ---------------------------------------
ROW   1
   .0          .0           .0           .0           .0           .0           .0           .0
ROW   2
   .0          .0           .0           .0           .0           .0           .0           .0
ROW   3
   .0          .0       6.000E+01        .0           .0           .0           .0           .0
ROW   4
   .0          .0           .0       2.980E+02        .0           .0           .0           .0
ROW   5
   .0          .0           .0           .0       2.980E+02        .0           .0           .0
ROW   6
   .0          .0           .0           .0           .0       2.000E+03        .0           .0
ROW   7
   .0          .0           .0           .0           .0           .0       6.000E+01        .0
ROW   8
   .0          .0           .0           .0           .0           .0           .0       2.980E+02
```

```
            LATERAL WHEELSET ELEMENTS

WHEELSET   NODE   GAUGE           RADIUS         CONE ANGLE        CREEP          VELOCITY
   1        5     5.000000        1.333333       2.5000000E-02     3000000        450.0000
   2        6     5.000000        1.333333       2.5000000E-02     3000000        450.0000


THE TRAIN IS ASSUMED TO MOVE IN THE PLUS X DIRECTION.  THE WHEELSET MOVES LATERALLY IN THE Y DIRECTION
AND ROTATES ABOUT THE Z DIRECTION.



                SPRING AND DAMPER ELEMENTS

          FIRST   SECOND  REFERENCE                                  ELEMENT                  DIRECTION  COSINES
ELEMENT   NODE    NODE      NODE       STIFFNESS      DAMPING       DIRECTION            X              Y             Z
   1        1       2         0        17500.00       1350.000      GLOBAL   Y
   2        1       2         0         5000000       -.0           GLOBAL R-Z
   3        3       5         0        500000.0       -.0           GLOBAL   Y
   4        3       5         0       3.0000000E+07   -.0           GLOBAL R-Z
   5        4       6         0        500000.0       -.0           GLOBAL   Y
   6        4       6         0       3.0000000E+07   -.0           GLOBAL R-Z



         NODAL MASSES AND MASS MOMENTS OF INERTIA
 NODE      M-X             M-Y             M-Z            I-XX            I-YY            I-ZZ
   2      .0             250.0000          .0              .0              .0            2000.000
   5      .0             60.00000          .0              .0              .0            290.0000
   6      .0             60.00000          .0              .0              .0            290.0000



     COMPONENT U-COORDINATE SYSTEM   PHYSICAL RESPONSE COORDINATES

       NODE     X     Y     Z    R-X   R-Y   R-Z
         1      0     1     0     0     0     2
         2      0     5     0     0     0     6
         3      0     0     0     0     0     0
         4      0     0     0     0     0     0
         5      0     3     0     0     0     4
         6      0     7     0     0     0     8


     THERE ARE   8 U-COORDINATES
```

```
                                          -- COLUMN LOCATIONS --
    1          2          3          4          5          6          7          8          9          10

    11         12         13         14         15         16         17         18         19         20

    THE DAMPING MATRIX (DAMP) LISTED BY ROWS.
    -----------------------------------------

  ROW   1
   1.550E+03  .0         .0         .0        -1.550E+03  .0         .0         .0
  ROW   2
   .0         .0         .0         .0         .0         .0         .0         .0
  ROW   3
   .0         .0         1.333E+04  .0         .0         .0         .0         .0
  ROW   4
   .0         .0         .0         8.333E+04  .0         .0         .0         .0
  ROW   5
  -1.550E+03  .0         .0         .0         1.550E+03  .0         .0         .0
  ROW   6
   .0         .0         .0         .0         .0         .0         .0         .0
  ROW   7
   .0         .0         .0         .0         .0         .0         1.333E+04  .0
  ROW   8
   .0         .0         .0         .0         .0         .0         .0         8.333E+04
```

```
                                    -- COLUMN LOCATIONS --
    1          2          3          4          5          6          7          8          9          10
   11         12         13         14         15         16         17         18         19          20

  THE STIFFNESS MATRIX (STIFF) LISTED BY ROWS.
  --------------------------------------------

ROW   1
 1.750E+06    .0         .0         .0        -1.750E+06  .0         .0         .0
ROW   2
  .0        5.000E+06    .0         .0         .0        -5.000E+06  .0         .0
ROW   3
  .0         .0        5.003E+05  -6.000E+06 -5.000E+05  -2.000E+06  .0         .0
ROW   4
  .0         .0        2.013E+05   3.000E+07  .0        -3.000E+07  .0         .0
ROW   5
-1.750E+06    .0       -5.000E+05   .0        1.817E+06   .0        -5.000E+05  .0
ROW   6
  .0       -5.000E+06 -2.000E+06  -3.000E+07  .0         8.100E+07  2.000E+06 -3.000E+07
ROW   7
  .0         .0         .0         .0        -5.000E+05  2.000E+06  5.000E+05 -6.000E+06
ROW   8
  .0         .0         .0         .0         .0        -3.000E+07  2.013E+05  3.000E+07
```

```
                                                  -- COLUMN LOCATIONS --
    1          2          3          4          5          6          7          8          9          10
    11         12         13         14         15         16         17         18         19         20

    THE MATRIX RELATING THE PHYSICAL COORDINATES TO THE DYNAMIC COORDINATES (MATRIX PHI).
    -------------------------------------------------------------------------------------

  ROW   1
   1.000E+00    .0         .0         .0         .0         .0         .0         .0

  ROW   2
    .0       1.000E+00     .0         .0         .0         .0         .0         .0

  ROW   3
    .0         .0       1.000E+00     .0         .0         .0         .0         .0

  ROW   4
    .0         .0         .0       1.000E+00     .0         .0         .0         .0

  ROW   5
    .0         .0         .0         .0       1.000E+00     .0         .0         .0

  ROW   6
    .0         .0         .0         .0         .0       1.000E+00     .0         .0

  ROW   7
    .0         .0         .0         .0         .0         .0       1.000E+00     .0

  ROW   8
    .0         .0         .0         .0         .0         .0         .0       1.000E+00
```

```
THE FOLLOWING INFORMATION IS FOR THE FINAL SYSTEM
-------------------------------------------------


THE STRUCTURE IS TO BE CONSTRUCTED OF     3 COMPONENTS.
THE NAMES ASSOCIATED WITH EACH COMPONENT ARE AS FOLLOWS.

COMPONENT NUMBER    COMPONENT NAME
        1                 2.00
        2                 1.00
        3                 2.00

THE NUMBER OF ROWS OF G IS    4

THE TOTAL NUMBER OF SYSTEM U-COORDINATES IS    23

THE DEPENDENT SYSTEM P-COORDINATES ARE

   1    2   13   14


        THE EIGENVALUES ARE LISTED AS A GROUP, IN INCREASING
        ORDER OF MAGNITUDE. AFTER THE EIGENVECTOR PRINTOUT,
        THE FREQUENCY AND DAMPING RATIO OF EACH EIGENVALUE IS
        ALSO PROVIDED.

        IN ADDITION, FOR EACH EIGENVALUE, THE THREEMOST PRINCIPAL
        U-SYSTEM EIGENVECTOR COMPONENTS ARE LISTED IN TERMS OF
        THEIR RESPECTIVE U-COORDINATE NUMBERS. THE ORDER IN WHICH
        THEY ARE LISTED IS THAT OF DECREASING COMPONENT AMPLITUDE.


THE MODAL DATA FILE TO GENERATE SYSTEM RESPONSE IS ON TAPE 12
```

```
                                                  -- COLUMN LOCATIONS --
     1           2           3           4           5           6           7           8           9          10

    11          12          13          14          15          16          17          18          19          20

  THE CONSTRAINT MATRIX (G) LISTED BY ROWS.
  ------------------------------------------

ROW   1
 1.000E+00      .0          .0          .0          .0          .0          .0          .0          .0          .0
    .0     -1.000E+00       .0          .0          .0          .0          .0          .0          .0          .0
    .0          .0          .0

ROW   2
    .0      1.000E+00       .0          .0          .0          .0          .0          .0          .0          .0
    .0          .0     -1.000E+00       .0          .0          .0          .0          .0          .0          .0
    .0          .0          .0

ROW   3
    .0          .0          .0          .0          .0          .0          .0          .0          .0          .0
    .0          .0          .0     -1.000E+00       .0      1.000E+00       .0          .0          .0          .0
    .0          .0          .0

ROW   4
    .0          .0          .0          .0          .0          .0          .0          .0          .0          .0
    .0          .0          .0          .0     -1.000E+00       .0      1.000E+00       .0          .0          .0
    .0          .0          .0
```

```
                              *** SYSTEM EIGENVECTORS ***
                              ---------------------------

EIGENVALUE NO.  1  =  (-8.15704E-01,  -4.36749E+00)                 PRINCIPAL U-COORDINATES = 10, 16, 14

 COORDINATE      U-SYSTEM (PHYSICAL) EIGENVECTORS       RELATIVE AMPLITUDE     PHASE
   NUMBER          REAL PART        IMAG PART              (U-SYSTEM)          (DEG)
     1            9.03470E-01      2.07272E-02               .90893               2
     2           -3.07750E-03      1.02465E-03               .00324             162
     3           -1.95301E-02     -1.16934E-03               .01967            -177
     4           -1.13766E-03      5.95001E-04               .00134             154
     5            5.52736E-04     -6.39906E-03               .00642             -86
     6           -1.37166E-03      5.97029E-04               .00150             156
     7           -9.21960E-03     -4.46242E-03               .01024            -154
     8           -1.23977E-03      6.24768E-04               .00144             154
     9            8.01001E-01      3.76017E-02               .00260               2
    10            1.00000E+00     -8.00170E-16              1.00000              -0
    11            9.73945E-01      1.52810E-02               .97966               1
    12            9.03470E-01      2.07272E-02               .90893               2
    13           -3.07750E-03      1.02465E-03               .00324             162
    14            9.83513E-01      1.01652E-02               .98957               1
    15            1.12140E-03     -5.76515E-04               .00126             -27
    16            9.83513E-01      1.01652E-02               .98957               1
    17            1.12140E-03     -5.76515E-04               .00126             -27
    18            1.03210E-02     -1.24982E-02               .02215             -34
    19           -1.63957E-03      3.11099E-04               .00147             168
    20            3.87682E-02     -1.90600E-02               .04311             -26
    21           -1.25052E-03      2.11702E-04               .00128               0
    22            2.75442E-02     -1.30281E-02               .03056               0
    23           -1.52722E-03      3.16278E-04               .00156               0

EIGENVALUE NO.  2  =  (-8.15704E-01,   4.36749E+00)                 PRINCIPAL U-COORDINATES = 10, 16, 14

 COORDINATE      U-SYSTEM (PHYSICAL) EIGENVECTORS       RELATIVE AMPLITUDE     PHASE
   NUMBER          REAL PART        IMAG PART              (U-SYSTEM)          (DEG)
     1            9.03470E-01     -2.07272E-02               .90893              -2
     2           -3.07750E-03     -1.02465E-03               .00324            -162
     3           -1.95301E-02      1.16934E-03               .01967             177
     4           -1.13766E-03     -5.95001E-04               .00134            -154
     5            5.52736E-04      6.39906E-03               .00642              86
     6           -1.37166E-03     -5.97029E-04               .00150            -156
     7           -9.21960E-03      4.46242E-03               .01024             154
     8           -1.23977E-03     -6.24768E-04               .00144            -154
     9            8.01001E-01     -3.76017E-02               .00260              -2
    10            1.00000E+00       .0                      1.00000               0
    11            9.73945E-01     -1.52810E-02               .97966              -1
    12            9.03470E-01     -2.07272E-02               .90893              -2
    13           -3.07750E-03     -1.02465E-03               .00324            -162
    14            9.83513E-01     -1.01652E-02               .98957              -1
    15            1.12140E-03      5.76515E-04               .00126              27
    16            9.83513E-01     -1.01652E-02               .98957              -1
    17            1.12140E-03      5.76515E-04               .00126              27
    18            1.03210E-02      1.24982E-02               .02215              34
    19           -1.63957E-03     -3.11099E-04               .00147            -168
    20            3.87682E-02      1.90600E-02               .04311              26
    21           -1.25052E-03     -2.11702E-04               .00128               0
    22            2.75442E-02      1.30281E-02               .03056               0
    23           -1.52722E-03     -3.16278E-04               .00156               0
```

```
EIGENVALUE NO. 31   =   (-1.12901E+02,  -3.13128E+02)                    PRINCIPAL U-COORDINATES = 22, 19, 23

COORDINATE          U-SYSTEM (PHYSICAL) EIGENVECTORS          RELATIVE AMPLITUDE        PHASE
  NUMBER              REAL PART          IMAG PART               (U-SYSTEM)              (DEG)
     1               8.51757E-05        1.52267E-03                .00153                  87
     2               2.91452E-05        1.03604E-04                .00011                  74
     3              -7.60015E-01        2.61935E-01                .00389                 161
     4               8.25491E-01       -2.37425E-01                .05896                 -16
     5               2.85433E-02        1.31323E-02                .03142                  25
     6              -1.65467E-01       -1.18537E-01                .20353                -144
     7              -8.62257E-01        1.02014E-01                .00126                 160
     8               8.21435E-01       -2.36831E-01                .05371                 -16
     9               3.67405E-04        2.41780E-03                .00244                  82
    10              -2.05109E-04       -1.33951E-03                .00135                 -99
    11               5.23003E-04        2.31261E-03                .00237                  77
    12               8.51757E-05        1.52267E-03                .00153                  87
    13               2.91452E-05        1.03604E-04                .00011                  74
    14               4.51053E-04        1.25470E-03                .00133                  70
    15              -9.92914E-06       -1.20677E-04                .00012                 -95
    16               4.51053E-04        1.25470E-03                .00133                  70
    17              -9.92914E-06       -1.20677E-04                .00012                 -95
    18               9.03214E-01       -1.12609E-01                .91220                  -7
    19              -9.72161E-01        7.01396E-02                .97469                 176
    20              -2.86669E-02       -2.12888E-02                .03571                -143
    21               1.55918E-01        1.70383E-01                .23095                   0
    22               1.00000E+00       -1.77636E-15               1.00000                   0
    23              -9.66221E-01        6.97762E-02                .96874                   0

EIGENVALUE NO. 32   =   (-1.12901E+02,   3.13128E+02)                    PRINCIPAL U-COORDINATES = 22, 19, 23

COORDINATE          U-SYSTEM (PHYSICAL) EIGENVECTORS          RELATIVE AMPLITUDE        PHASE
  NUMBER              REAL PART          IMAG PART               (U-SYSTEM)              (DEG)
     1               8.51757E-05       -1.52267E-03                .00153                 -87
     2               2.91452E-05       -1.03604E-04                .00011                 -74
     3              -7.60015E-01       -2.61935E-01                .00389                -161
     4               8.25491E-01        2.37425E-01                .05896                  16
     5               2.85433E-02       -1.31323E-02                .03142                 -25
     6              -1.65467E-01        1.18537E-01                .20353                 144
     7              -8.62257E-01       -1.02014E-01                .00126                -160
     8               8.21435E-01        2.36831E-01                .05371                  16
     9               3.67405E-04       -2.41780E-03                .00244                 -82
    10              -2.05109E-04        1.33951E-03                .00135                  99
    11               5.23003E-04       -2.31261E-03                .00237                 -77
    12               8.51757E-05       -1.52267E-03                .00153                 -87
    13               2.91452E-05       -1.03604E-04                .00011                 -74
    14               4.51053E-04       -1.25470E-03                .00133                 -70
    15              -9.92914E-06        1.20677E-04                .00012                  95
    16               4.51053E-04       -1.25470E-03                .00133                 -70
    17              -9.92914E-06        1.20677E-04                .00012                  95
    18               9.03214E-01        1.12609E-01                .91220                   7
    19              -9.72161E-01       -7.01396E-02                .97469                -176
    20              -2.86669E-02        2.12888E-02                .03571                 143
    21               1.55918E-01       -1.70383E-01                .23095                   0
    22               1.00000E+00       -1.77636E-15               1.00000                   0
    23              -9.66221E-01       -6.97762E-02                .96874                   0
```

```
TRACE OF MATRIX  =  ( -2.06596206067E+03,     .0

THE EIGENVECTORS DIAGONALIZE THE DYNAMIC MATRIX

                                       *** SYSTEM EIGENVALUES ***
                                       --------------------------

 COMPLEX     REAL PART       IMAG PART       MAGNITUDE       FREQUENCY      DAMPING       PRINCIPAL
  MODE       ---------       ---------       ---------         (CPS)         RATIO      U-COORDINATES

    1      -4.57046E-01    -4.36769E+00     4.3914E+00          .695          .104        10  16  14
    2      -4.57046E-01     4.36769E+00
    3      -1.67508E+00     6.69174E+00     6.8982E+00         1.065          .243        11  16  14
    4      -1.67508E+00    -6.69174E+00
    5      -5.69044E+00     2.18043E+01     2.2537E+01         3.470          .253        20  18  22
    6      -5.69044E+00    -2.18043E+01
    7      -4.92991E+00     2.29668E+01     2.3498E+01         3.655          .210        20   5  18
    8      -4.92991E+00    -2.29668E+01
    9      -2.40127E+00    -3.22769E+01     3.2366E+01         5.137          .074         9  11  12
   10      -2.40127E+00     3.22769E+01
   11      -2.57357E+01    -7.86453E+01     8.2749E+01        12.517          .311         3   5   7
   12      -2.57357E+01     7.86453E+01
   13      -2.51909E+01     7.88674E+01     8.2793E+01        12.552          .304        18  20  22
   14      -2.51909E+01    -7.88674E+01
   15      -5.21814E+01    -6.85076E+01     8.6117E+01        10.903          .606         3   7   5
   16      -5.21814E+01     6.85076E+01
   17      -5.25627E+01    -6.86721E+01     8.6479E+01        10.929          .608        18  22  20
   18      -5.25627E+01     6.86721E+01
   19      -1.99367E+00    -8.82606E+01     8.8283E+01        14.047          .023         9  11  12
   20      -1.99367E+00     8.82606E+01
   21      -1.72432E+02    -7.36909E+00     1.7259E+02         1.172          .999         3   7   5
   22      -1.72432E+02     7.36909E+00
   23      -1.72430E+02     7.35652E+00     1.7259E+02         1.171          .999        18  22  20
   24      -1.72430E+02    -7.35652E+00
   25      -1.44104E+02    -2.85856E+02     3.2012E+02        45.495          .450        18   3  19
   26      -1.44104E+02    -2.85856E+02
   27      -1.44104E+02     2.85856E+02     3.2012E+02        45.495          .450        18  19  22
   28      -1.44104E+02     2.85856E+02
   29      -1.12929E+02     3.13127E+02     3.3286E+02        49.836          .339         7   4   8
   30      -1.12909E+02    -3.13127E+02
   31      -1.12901E+02    -3.13128E+02     3.3286E+02        49.836          .339        22  19  23
   32      -1.12901E+02     3.13128E+02
```

```
                                        *** SYSTEM RESPONSE ***
                                        -----------------------

THE NUMBER OF PHYSICAL COORDINATES HAVING APPLIED FORCES  =     4

FORCES FOR LATERAL WHEELSETS AND PHASE LAGS ARE BEING GENERATED
COORDINATE     GAUGE           RADIUS          CONE ANGLE          CREEP          VELOCITY        LAG DISTANCE
     4        5.000000        1.333333        2.5000000E-02       3000000         450.0000          .0
     8        5.000000        1.333333        2.5000000E-02       3000000         450.0000         8.000000
    19        5.000000        1.333333        2.5000000E-02       3000000         450.0000        83.00000
    23        5.000000        1.333333        2.5000000E-02       3000000         450.0000        91.00000

COORDINATE   ZERO-ORDER FORCE   FIRST-ORDER FORCE   SECOND-ORDER FORCE   ZERO-ORDER PHASE   FIRST-ORDER PHASE

     4           2.013E+05             .0                   .0                  .0                 .0
     8           2.013E+05             .0                   .0                  .0              1.770E-02
    19           2.013E+05             .0                   .0                  .0              1.844E-01
    23           2.013E+05             .0                   .0                  .0              2.022E-01

WE ARE LOOKING FOR 0 -ORDER RESPONSE AT    3 COORDINATES.

THE FREQUENCY RANGES FROM    1.000E-01 HERTZ    TO    1.000E+02 HERTZ    CUT INTO 150 DIVISIONS.

THE COORDINATES BEING OBSERVED ARE

   10     11     20
```

```
DISPL FREQUENCY RESPONSE AT COORDINATE  18        (FREQUENCY IN HERTZ, PHASE IN DEGREES)
------------------------------------------

FREQUENCY     AMPLITUDE       PHASE       FREQUENCY    AMPLITUDE     PHASE       FREQUENCY    AMPLITUDE     PHASE

1.0000E-01    1.021E+00          4          .1047      1.023E+00        4          .1096      1.025E+00        4
 .1148        1.027E+00          4          .1202      1.030E+00        4          .1259      1.033E+00        5
 .1318        1.036E+00          5          .1380      1.040E+00        5          .1445      1.044E+00        5
 .1514        1.049E+00          6          .1585      1.053E+00        6          .1660      1.059E+00        6
 .1738        1.065E+00          7          .1820      1.072E+00        7          .1905      1.079E+00        7
 .1995        1.087E+00          8          .2089      1.096E+00        8          .2188      1.106E+00        9
 .2291        1.110E+00          9          .2399      1.130E+00       10          .2512      1.144E+00       10
 .2630        1.160E+00         11          .2754      1.178E+00       11          .2884      1.198E+00       12
 .3020        1.220E+00         13          .3162      1.246E+00       14          .3311      1.275E+00       15
 .3467        1.300E+00         16          .3631      1.346E+00       17          .3802      1.390E+00       18
 .3981        1.441E+00         19          .4169      1.501E+00       21          .4365      1.570E+00       23
 .4571        1.652E+00         25          .4786      1.749E+00       28          .5012      1.866E+00       31
 .5248        2.009E+00         34          .5495      2.170E+00       39          .5754      2.365E+00       43
 .6026        2.505E+00         52          .6310      2.812E+00       61          .6607      2.997E+00       73
 .6918        3.069E+00         87          .7244      2.971E+00      101          .7586      2.722E+00      115
 .7943        2.403E+00        126          .8318      2.087E+00      136          .8710      1.812E+00      143
 .9120        1.506E+00        150          .9550      1.402E+00      156         1.000       1.249E+00      161
1.047         1.117E+00        167         1.096       9.941E-01      173         1.148       8.770E-01      179
1.202         7.604E-01       -175         1.259       6.691E-01     -170         1.318       5.819E-01     -166
1.380         5.069E-01       -162         1.445       4.429E-01     -158         1.514       3.882E-01     -155
1.585         3.411E-01       -152         1.660       3.008E-01     -148         1.738       2.637E-01     -145
1.820         2.310E-01       -141         1.905       2.012E-01     -138         1.995       1.734E-01     -134
2.089         1.469E-01       -130         2.188       1.211E-01     -126         2.291       9.521E-02     -122
2.399         6.858E-02       -118         2.512       4.056E-02     -118         2.630       1.320E-02     -158
2.754         2.992E-02        116         2.884       7.082E-02      112         3.020       1.183E-01      119
3.162         1.794E-01        131         3.311       2.413E-01      144         3.467       3.129E-01      161
3.631         3.830E-01        179         3.802       4.459E-01     -161         3.981       4.953E-01     -142
4.169         5.365E-01       -122         4.365       5.882E-01     -102         4.571       6.399E-01      -81
4.786         7.296E-01        -55         5.012       7.953E-01      -19         5.248       6.737E-01       27
5.495         4.220E-01         64         5.754       2.457E-01       90         6.026       1.446E-01      107
6.310         8.537E-02        121         6.607       4.942E-02      130         6.918       2.765E-02      131
7.244         1.633E-02        119         7.586       1.379E-02       97         7.943       1.525E-02       90
8.318         1.677E-02         95         8.710       1.721E-02      100         9.120       1.650E-02      124
9.550         1.482E-02        163        10.00        1.240E-02      166        10.47        9.490E-03     -168
10.96         6.401E-03       -130        11.48        3.549E-03      -96        12.02        1.819E-03      -19
12.59         2.304E-03         60        13.18        3.841E-03      119        13.80        3.044E-03      162
14.45         2.527E-03       -160        15.14        1.693E-03     -117        15.85        8.401E-04      -61
16.60         4.740E-04         40        17.38        6.826E-04      120        18.20        7.741E-04      170
19.05         6.501E-04       -166        19.95        4.184E-04     -103        20.89        1.597E-04      -55
21.88         5.140E-05        123        22.91        1.433E-04     -169        23.99        1.453E-04     -120
25.12         9.019E-05        -71        26.30        2.608E-05      -18        27.54        1.220E-05     -151
28.84         1.737E-05        -78        30.20        1.060E-05       31        31.62        8.431E-06      130
33.11         5.079E-06         29        34.67        2.394E-05       97        36.31        2.395E-05      164
38.02         6.970E-07        138        39.81        2.617E-05      128        41.69        2.508E-05     -159
43.65         3.601E-06        113        45.71        2.496E-05     -176        47.86        1.255E-05      -92
50.12         1.331E-05       -177        52.48        1.438E-05      -85        54.95        5.123E-06     -162
57.54         9.071E-06        -63        60.26        2.463E-06     -132        63.10        5.136E-06      -26
66.07         2.882E-06        -88        69.18        1.771E-06       20        72.44        1.363E-06      -26
75.86         5.164E-08         86        79.43        3.379E-07       59        83.18        6.665E-08       38
87.10         1.741E-08        156        91.20        1.886E-07      -51        95.50        2.152E-07      -78
100.0         2.103E-07        -83
```

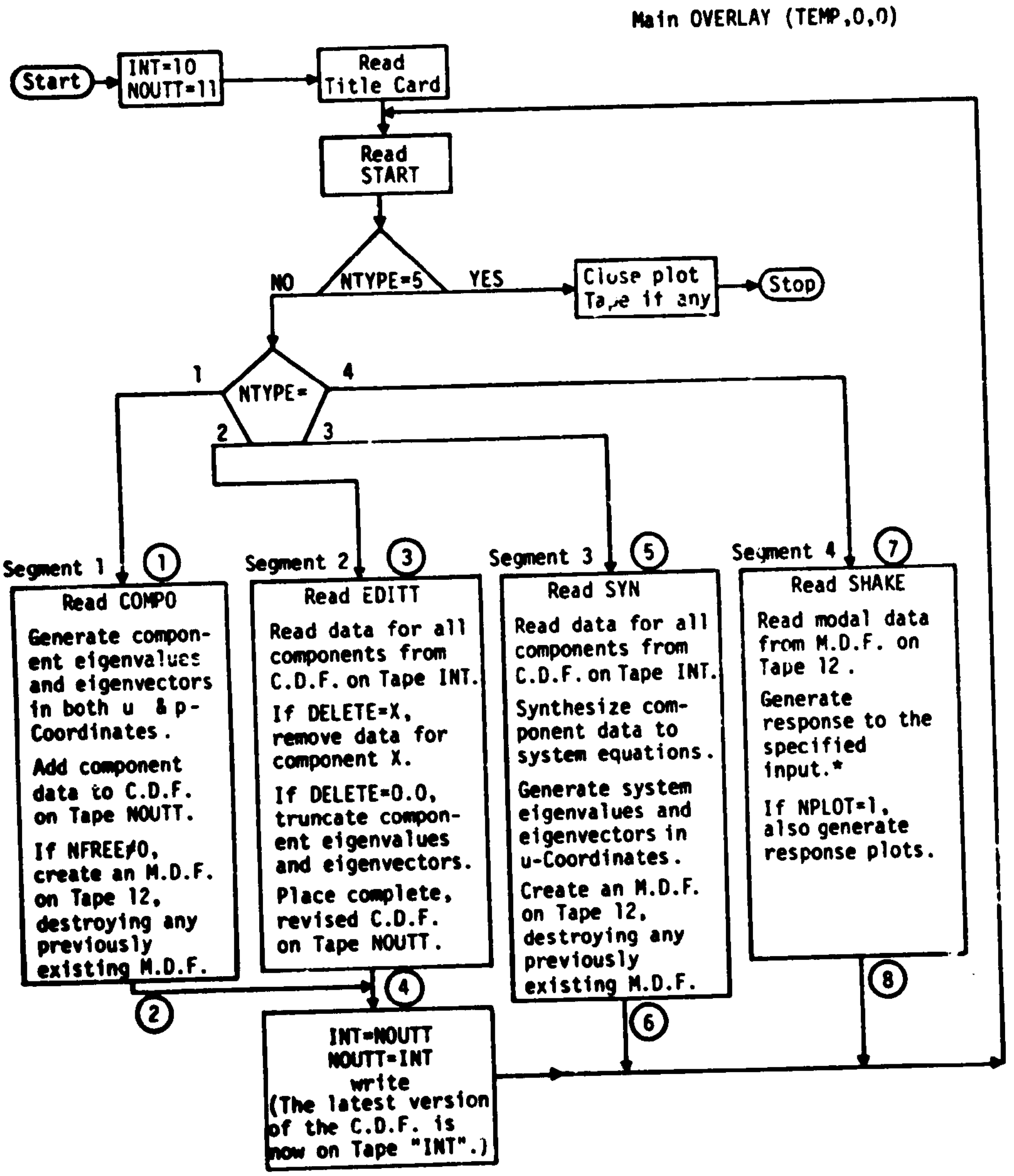
```
SYSTEM RESPONSE TO A PERIODIC INPUT IS BEING COMPUTED.
*********************************************************

THE PERIOD IS     .20000      SECONDS     AND THE FUNDAMENTAL FREQUENCY IS    5.0000      HERTZ.

   DISPL RESPONSE IS BEING OBSERVED AT THESE COORDINATES

   10   11   20

THE PERIODIC EXCITATION HAS BEEN GIVEN AS A FUNCTION OF TIME OVER ONE PERIOD AT   3 POINTS.

   TIME          EXCITATION        TIME          EXCITATION        TIME          EXCITATION

   .0               .0            .10000        2.000000E-02     .20000            .0

THE PERIODIC EXCITATION IS BEING APPROXIMATED AS A FOURIER SERIES HAVING  25 TERMS.

WAVE      A (COS)          B (SIN)           WAVE      A (COS)          B (SIN)
  0     1.000000E-02      .0                  1    -8.105695E-03     7.867998E-17
  2     1.000441E-30     1.766397E-17         3    -9.006333E-04     2.355597E-17
  4     1.000441E-30     8.056137E-18         5    -3.242280E-04     2.027166E-17
  6     1.339821E-30     5.083332E-18         7    -1.654222E-04     1.889786E-17
  8     1.000441E-30     4.417646E-18         9    -1.000700E-04     7.053222E-18
 10    -1.667099E-30     3.533356E-18        11    -6.698928E-05     6.625336E-18
 12     1.339821E-30     2.966316E-18        13    -4.796277E-05     1.187137E-17
 14      .0              2.526156E-18        15    -3.602538E-05     4.711198E-18
 16     1.000441E-30     2.280728E-18        17    -2.804746E-05     4.157596E-18
 18     6.920000E-31     1.963311E-18        19    -2.245346E-05     3.719958E-18
 20    -1.667099E-30     1.766397E-18        21    -1.838082E-05     3.365667E-18
 22    -4.560649E-32     1.606306E-18        23    -1.532227E-05     3.073080E-18
 24     1.339821E-30     1.472668E-18        25    -1.296911E-05     2.827166E-18
```

```
                    THE APPROXIMATED EXCITATION OVER ONE PERIOD

   TIME          EXCITATION       TIME          EXCITATION       TIME          EXCITATION

    .0           1.95002E-04    2.00000E-03    3.49197E-04    4.00000E-03    7.87381E-04
 6.00000E-03     1.22831E-03    8.00000E-03    1.68032E-03    1.00000E-02    1.98163E-03
 1.20000E-02     2.40306E-03    1.40000E-02    2.81316E-03    1.60000E-02    3.19562E-03
 1.80000E-02     3.59009E-03    2.00000E-02    4.00586E-03    2.20000E-02    4.40766E-03
 2.40000E-02     4.79459E-03    2.60000E-02    5.19402E-03    2.80000E-02    5.60563E-03
 3.00000E-02     6.00464E-03    3.20000E-02    6.39423E-03    3.40000E-02    6.79640E-03
 3.60000E-02     7.20506E-03    3.80000E-02    7.60294E-03    4.00000E-02    7.99408E-03
 4.20000E-02     8.39835E-03    4.40000E-02    8.80593E-03    4.60000E-02    9.20081E-03
 4.80000E-02     9.94603E-03    5.00000E-02    1.00000E-02    5.20000E-02    1.04060E-02
 5.40000E-02     1.07992E-02    5.60000E-02    1.11940E-02    5.80000E-02    1.16016E-02
 6.00000E-02     1.20059E-02    6.20000E-02    1.23973E-02    6.40000E-02    1.27941E-02
 6.60000E-02     1.32035E-02    6.80000E-02    1.36050E-02    7.00000E-02    1.39954E-02
 7.20000E-02     1.43944E-02    7.40000E-02    1.48060E-02    7.60000E-02    1.52054E-02
 7.80000E-02     1.55923E-02    8.00000E-02    1.59953E-02    8.20000E-02    1.64099E-02
 8.40000E-02     1.68044E-02    8.60000E-02    1.71063E-02    8.80000E-02    1.75978E-02
 9.00000E-02     1.80184E-02    9.20000E-02    1.83997E-02    9.40000E-02    1.87717E-02
 9.60000E-02     1.92126E-02    9.80000E-02    1.96508E-02    1.00000E-01    1.98442E-02
   .10200        1.96508E-02      .10400       1.92126E-02      .10600       1.87717E-02
   .10800        1.83997E-02      .11000       1.80184E-02      .11200       1.75978E-02
   .11400        1.71063E-02      .11600       1.68044E-02      .11800       1.64099E-02
   .12000        1.59953E-02      .12200       1.55923E-02      .12400       1.52054E-02
   .12600        1.48060E-02      .12800       1.43944E-02      .13000       1.39954E-02
   .13200        1.36050E-02      .13400       1.32035E-02      .13600       1.27941E-02
   .13800        1.23979E-02      .14000       1.20059E-02      .14200       1.16016E-02
   .14400        1.11940E-02      .14600       1.07992E-02      .14800       1.04060E-02
   .15000        1.00000E-02      .15200       9.94603E-03      .15400       9.20081E-03
   .15600        8.80593E-03      .15800       8.39835E-03      .16000       7.99408E-03
   .16200        7.60294E-03      .16400       7.20506E-03      .16600       6.79640E-03
   .16800        6.39423E-03      .17000       6.00464E-03      .17200       5.60563E-03
   .17400        5.19402E-03      .17600       4.79459E-03      .17800       4.40766E-03
   .18000        4.00586E-03      .18200       3.59009E-03      .18400       3.19562E-03
   .18600        2.81316E-03      .18800       2.40306E-03      .19000       1.98163E-03
   .19200        1.68032E-03      .19400       1.22831E-03      .19600       7.87381E-04
   .19800        3.49197E-04      .20000       1.95002E-04

 THE RMS AMPLITUDE ABOUT EQUILIBRIUM  =   5.77340E-03

 THE MINIMUM AMPLITUDE IS  1.95002E-04    OCCURING AT   .0            SECONDS.

 THE MAXIMUM AMPLITUDE IS  1.98442E-02    OCCURING AT  1.00000E-01 SECONDS.
```

```
                    DISPL RESPONSE AT COORDINATE  10 OVER ONE PERIOD
                    ------------------------------------------------

    TIME          RESPONSE          TIME          RESPONSE          TIME          RESPONSE

    .0           3.98078E-03    2.00000E-03     4.14600E-03    4.00000E-03     4.32644E-03
 6.00000E-03     4.52914E-03    8.00000E-03     4.75338E-03    1.00000E-02     4.99828E-03
 1.20000E-02     5.26206E-03    1.40000E-02     5.56609E-03    1.60000E-02     5.84684E-03
 1.80000E-02     6.16393E-03    2.00000E-02     6.49612E-03    2.20000E-02     6.84211E-03
 2.40000E-02     7.20053E-03    2.60000E-02     7.56999E-03    2.80000E-02     7.94984E-03
 3.00000E-02     8.33619E-03    3.20000E-02     8.72993E-03    3.40000E-02     9.12071E-03
 3.60000E-02     9.53096E-03    3.80000E-02     9.93511E-03    4.00000E-02     1.03396E-02
 4.20000E-02     1.07427E-02    4.40000E-02     1.11438E-02    4.60000E-02     1.15380E-02
 4.80000E-02     1.19280E-02    5.00000E-02     1.23103E-02    5.20000E-02     1.26840E-02
 5.40000E-02     1.30446E-02    5.60000E-02     1.33972E-02    5.80000E-02     1.37344E-02
 6.00000E-02     1.40569E-02    6.20000E-02     1.43634E-02    6.40000E-02     1.46526E-02
 6.60000E-02     1.49235E-02    6.80000E-02     1.51763E-02    7.00000E-02     1.54050E-02
 7.20000E-02     1.56154E-02    7.40000E-02     1.58020E-02    7.60000E-02     1.59672E-02
 7.80000E-02     1.61080E-02    8.00000E-02     1.[illegible]67E-02   8.20000E-02     1.63167E-02
 8.40000E-02     1.63830E-02    8.60000E-02     1.64256E-02    8.80000E-02     1.64420E-02
 9.00000E-02     1.64330E-02    9.20000E-02     1.63908E-02    9.40000E-02     1.63309E-02
 9.60000E-02     1.62542E-02    9.80000E-02     1.61460E-02    1.00000E-01     1.60112E-02
   .10200        1.58539E-02      .10400        1.56736E-02      .10600        1.54703E-02
   .10800        1.52466E-02      .11000        1.50017E-02      .11200        1.47371E-02
   .11400        1.44539E-02      .11600        1.41532E-02      .11800        1.38361E-02
   .12000        1.35039E-02      .12200        1.31573E-02      .12400        1.27995E-02
   .12600        1.24308E-02      .12800        1.20518E-02      .13000        1.16638E-02
   .13200        1.12701E-02      .13400        1.08713E-02      .13600        1.04690E-02
   .13800        1.00649E-02      .14000        9.66864E-03      .14200        9.25727E-03
   .14400        8.85649E-03      .14600        8.46116E-03      .14800        8.07136E-03
   .15000        7.68912E-03      .15200        7.31597E-03      .15400        6.95337E-03
   .15600        6.60277E-03      .15800        6.26557E-03      .16000        5.96309E-03
   .16200        5.63662E-03      .16400        5.34738E-03      .16600        5.07652E-03
   .16800        4.82512E-03      .17000        4.59418E-03      .17200        4.38460E-03
   .17400        4.19726E-03      .17600        4.03282E-03      .17800        3.89281E-03
   .18000        3.77539E-03      .18200        3.68338E-03      .18400        3.61626E-03
   .18600        3.57441E-03      .18800        3.55797E-03      .19000        3.56693E-03
   .19200        3.60142E-03      .19400        3.66118E-03      .19600        3.74581E-03
   .19800        3.85510E-03      .20000        3.98078E-03

THE RMS AMPLITUDE ABOUT EQUILIBRIUM  =   4.55642E-03

THE MINIMUM AMPLITUDE IS  3.55784E-03     OCCURING AT    .18850      SECONDS.

THE MAXIMUM AMPLITUDE IS  1.64422E-02     OCCURING AT  8.85000E-02 SECONDS.

 WAVE      A (COS)          B (SIN)              WAVE      A (COS)          B (SIN)
   0     1.00000E-02      .0                       1    -6.01220E-03     2.31221E-03
   2    -5.30472E-20     -2.12441E-19              3     9.34053E-07     1.36785E-06
   4     3.51137E-21     -6.74096E-22              5    -7.30002E-09     3.09934E-08
   6    -1.40004E-23      6.37636E-23              7     1.54020E-09    -4.01435E-09
   8    -8.62409E-23     -8.66403E-23              9     1.32544E-09    -8.32147E-10
  10    -1.16630E-24     -4.36759E-23             11     3.41927E-10     1.23500E-10
  12     2.72709E-24     -3.06354E-24             13    -1.30365E-11    -8.14295E-12
  14    -1.45390E-24      9.39722E-25             15    -6.74560E-12    -1.77174E-11
  16    -4.99560E-25      8.95016E-26             17     4.32621E-13     4.70275E-13
  18     3.29144E-25     -3.23447E-26             19    -1.29065E-13     5.06463E-12
  20     3.02990E-25      4.60490E-26             21    -6.46420E-13     3.14025E-12
  22     1.06879E-25      5.38959E-26             23    -3.67600E-13     1.01368E-12
  24     4.30290E-26      1.91593E-26             25    -5.12290E-14     9.16773E-14
```

APPENDIX D

FLOW DIAGRAMS



*If NFREQ ≠ 0, generate frequency response.

If NPSD ≠ 0, generate random response.

If NSINE ≠ 0, generate response to an amplitude varying sinusoidal input.

If NFOUR ≠ 0, generate response to a general periodic or transient input.

Figure D-1. DYNALIST II Flow Diagram

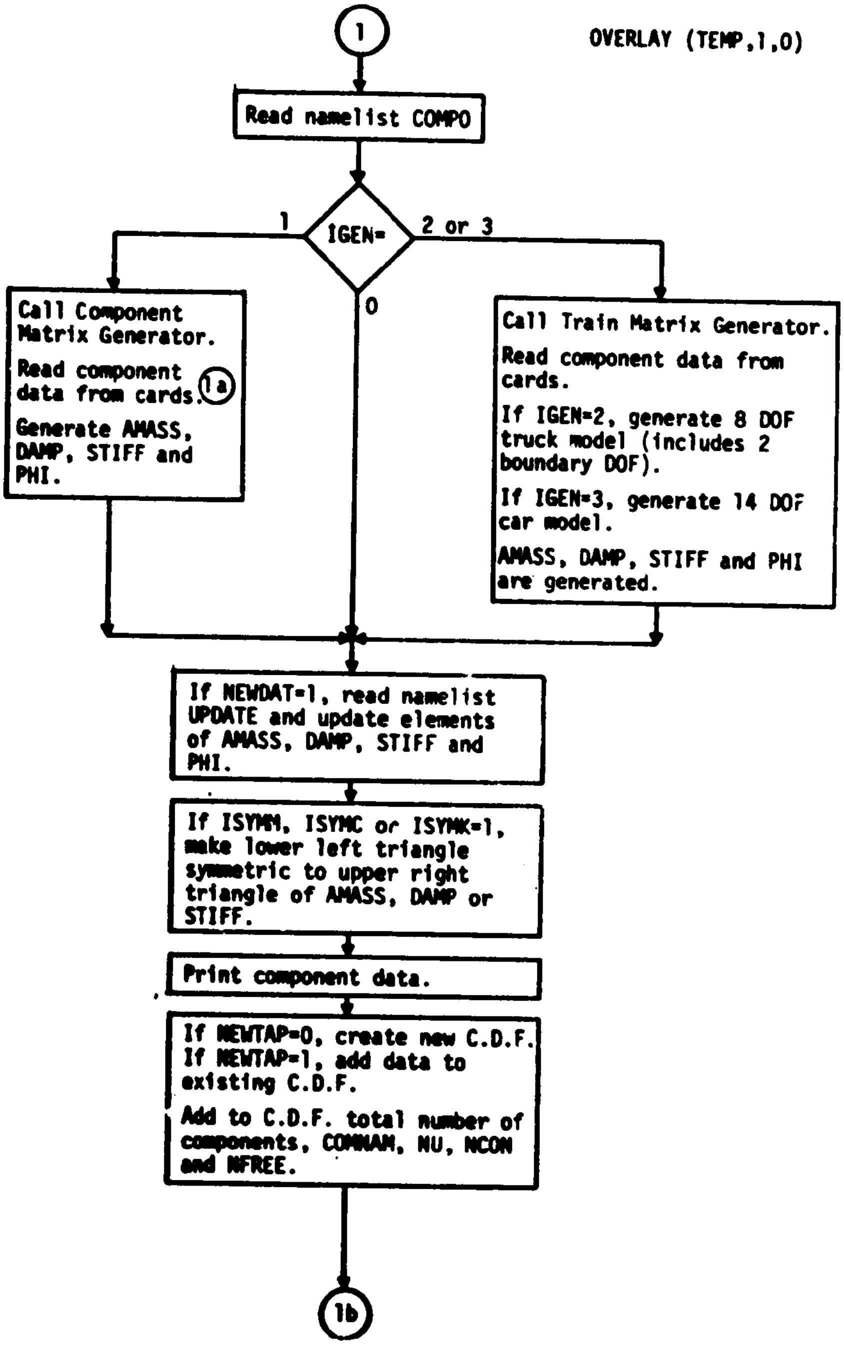


Figure D-2. Flow Diagram for Segment 1

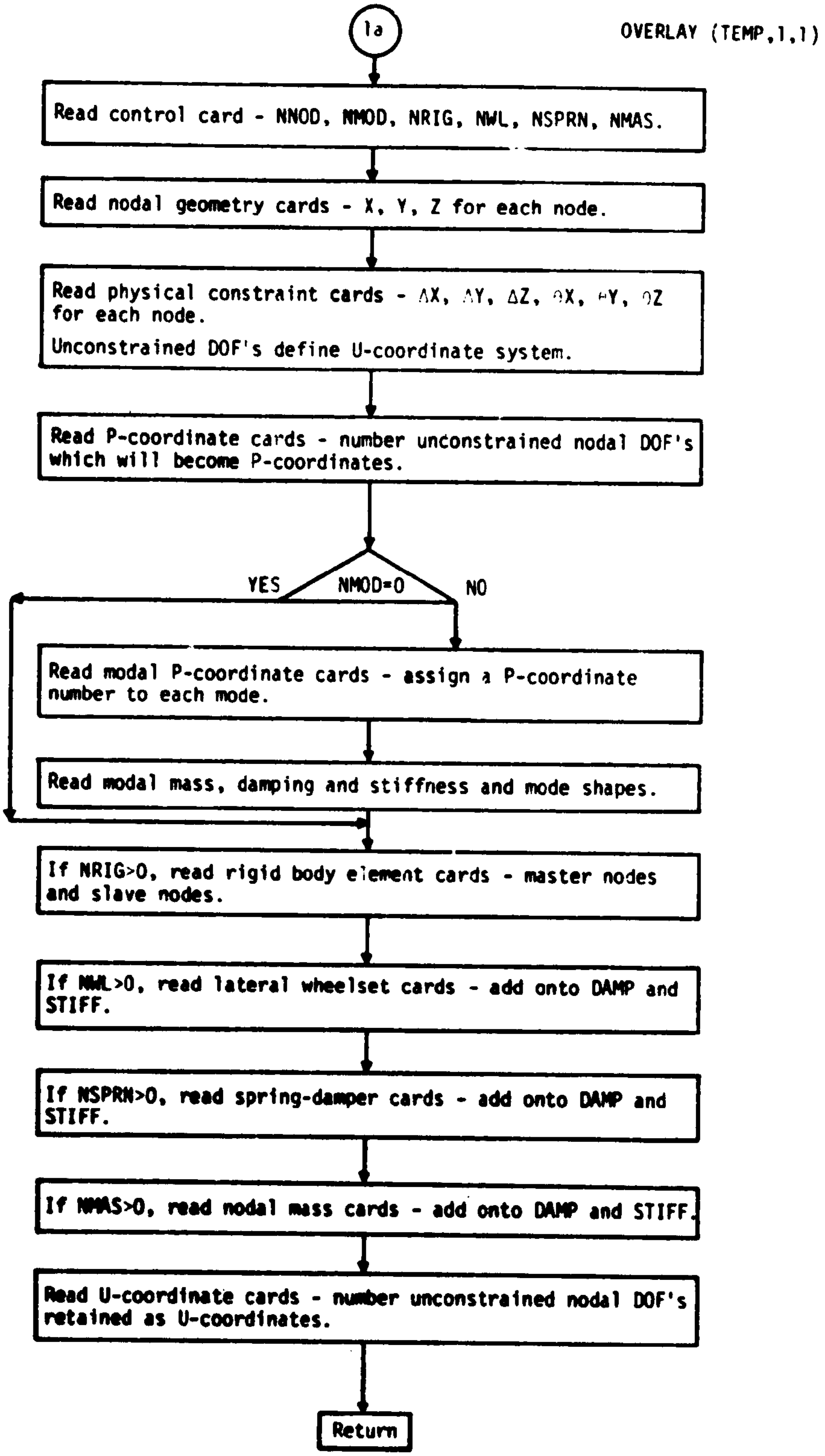


Figure D-3. Flow Diagram for Component Matrix Generator

OVERLAY (TEMP,1,2)

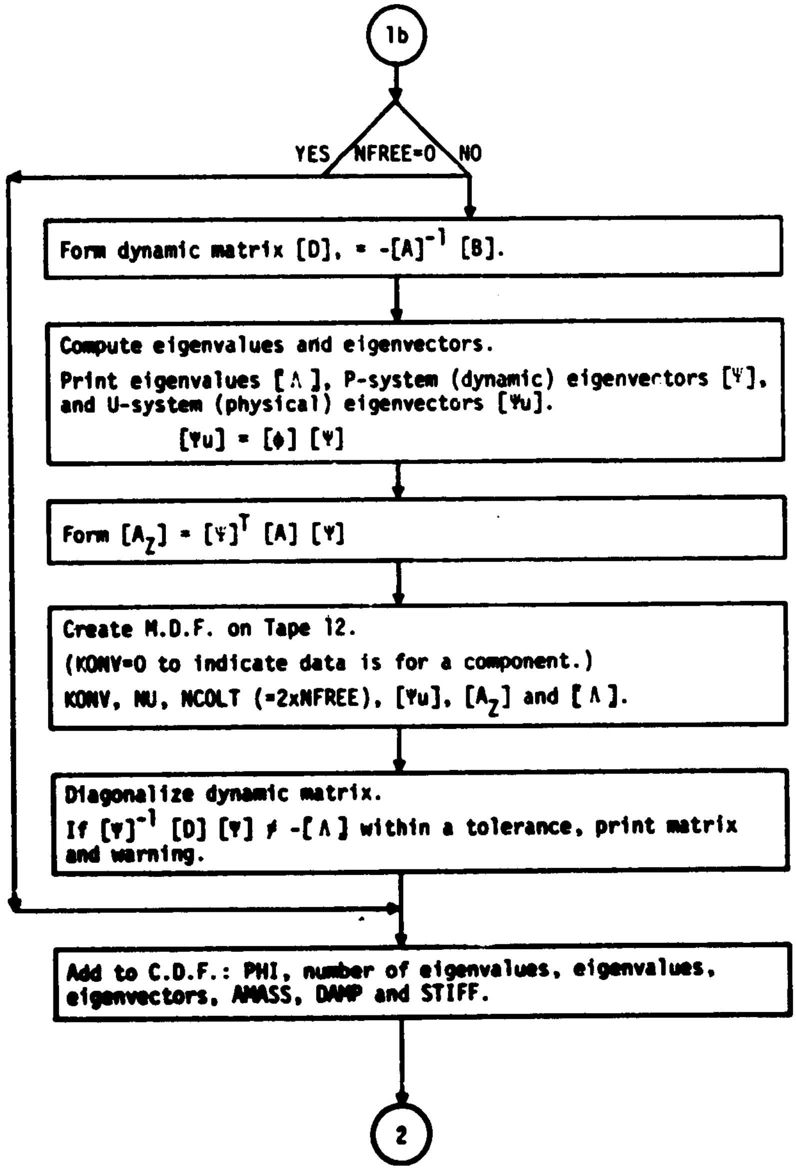


Figure D-4. Flow Diagram for Segment 1b

OVERLAY (TEMP,5,0)

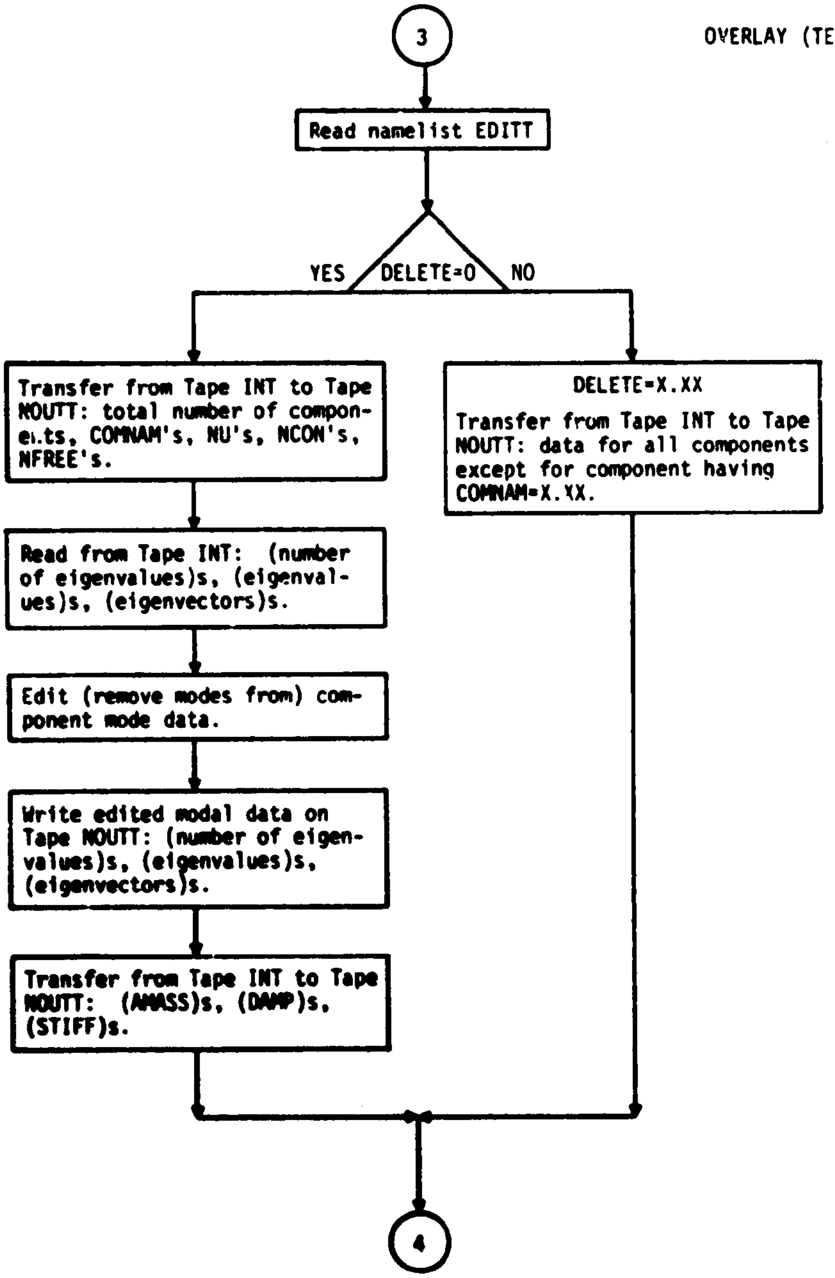


Figure D-5. Flow Diagram for Segment 2

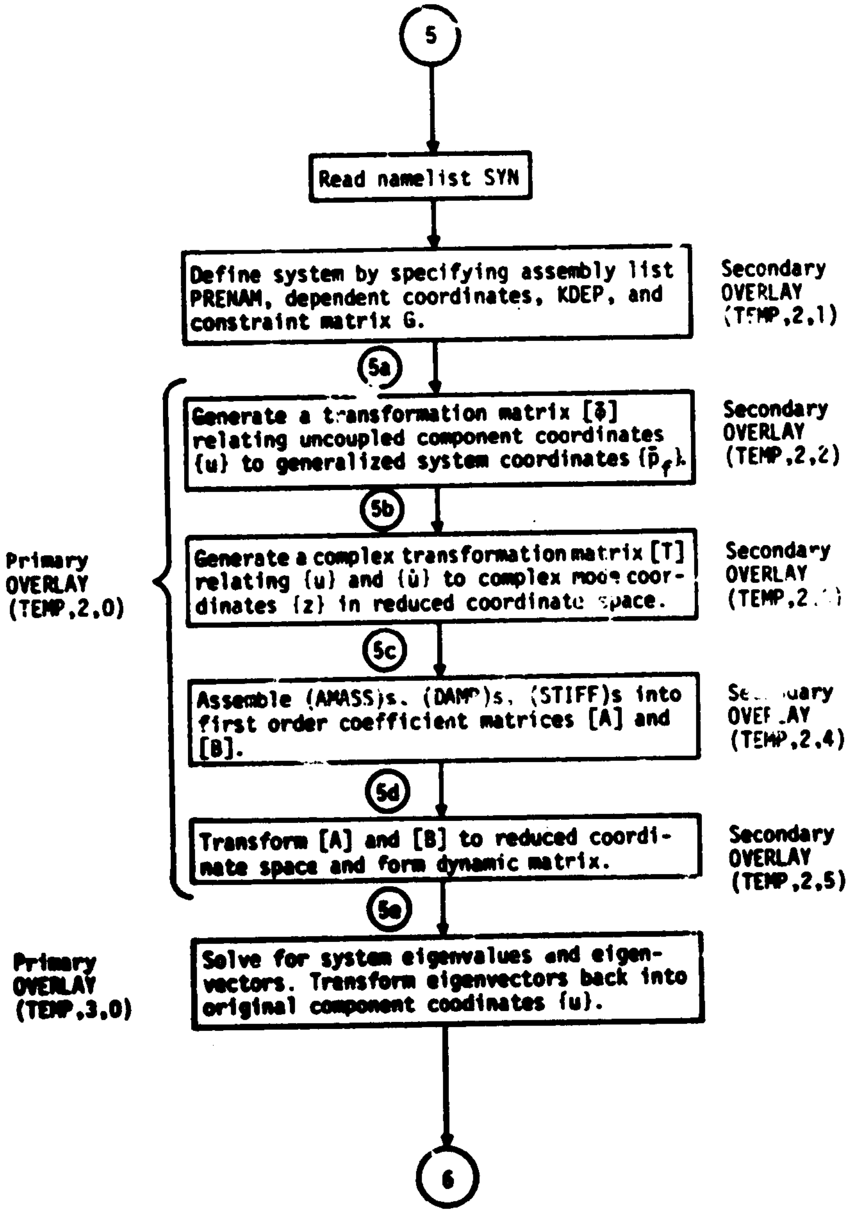


Figure D-6. Flow Diagram for Segment 3

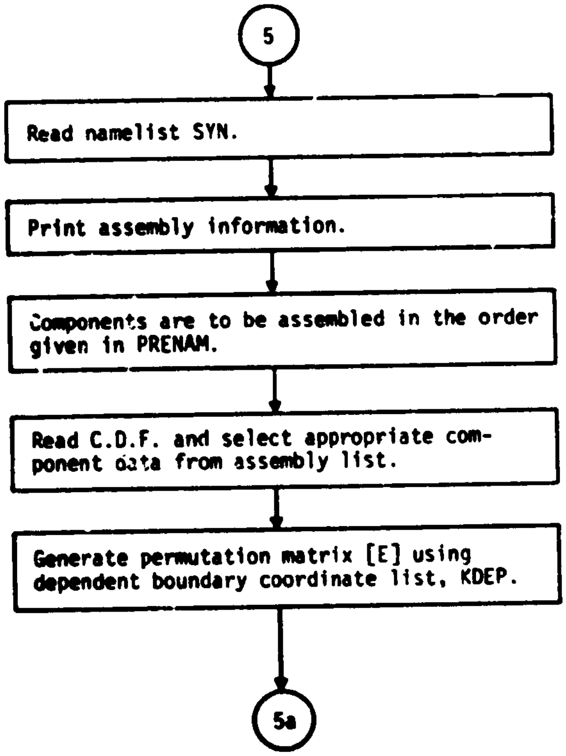


Figure D-7. Flow Diagram for OVERLAY (TEMP,2,1)

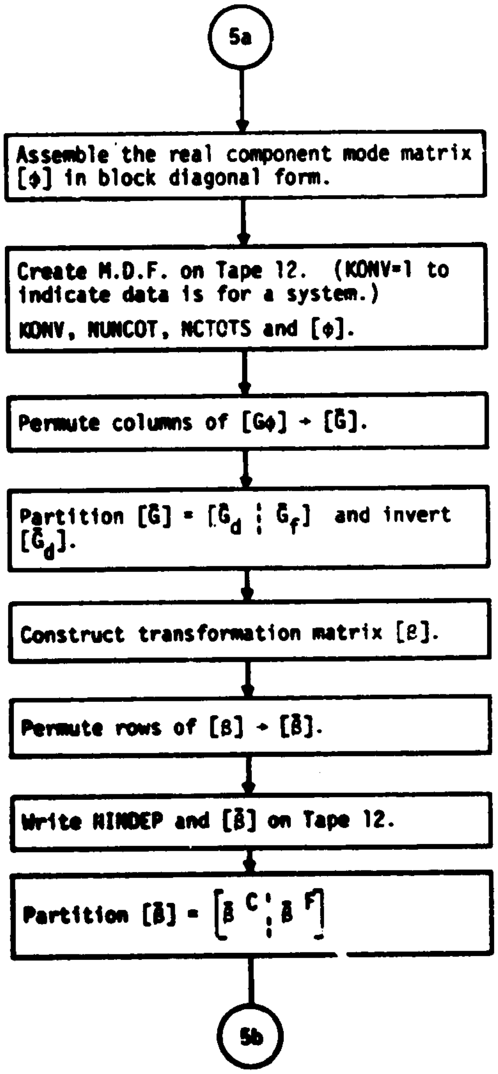


Figure D-8. Flow Diagram for OVERLAY (TEMP,2,2)

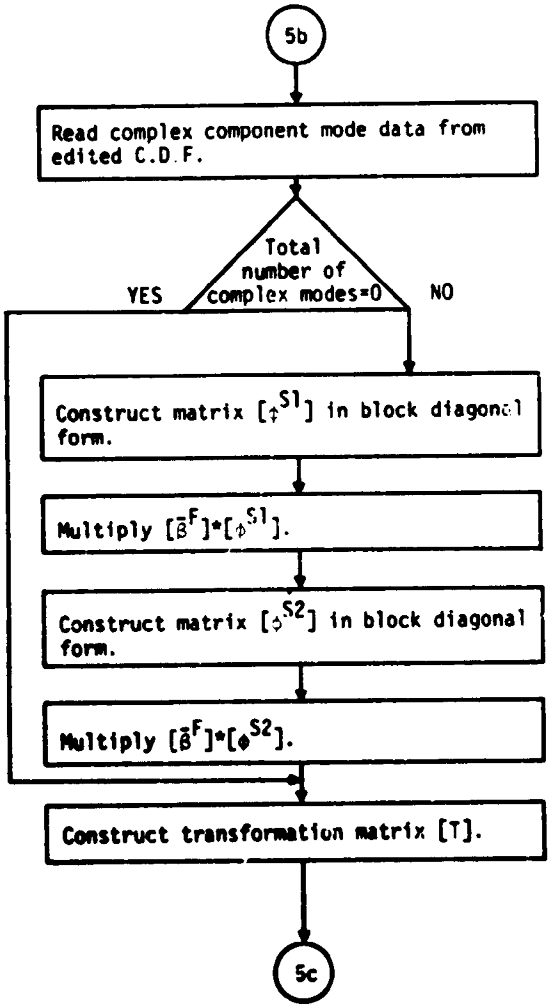


Figure D-9. Flow Diagram for OVERLAY (TEMP,2,3)

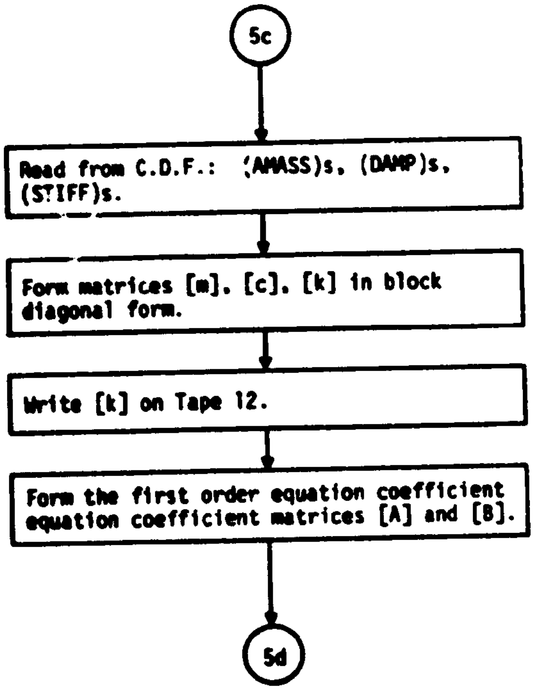


Figure D-10. Flow Diagram for OVERLAY (TEMP,2,4)

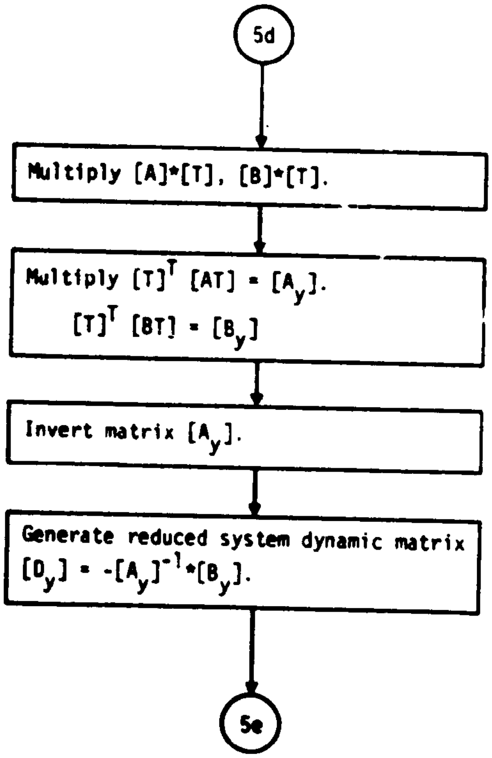


Figure D-11. Flow Diagram for OVERLAY (TEMP,2,5)

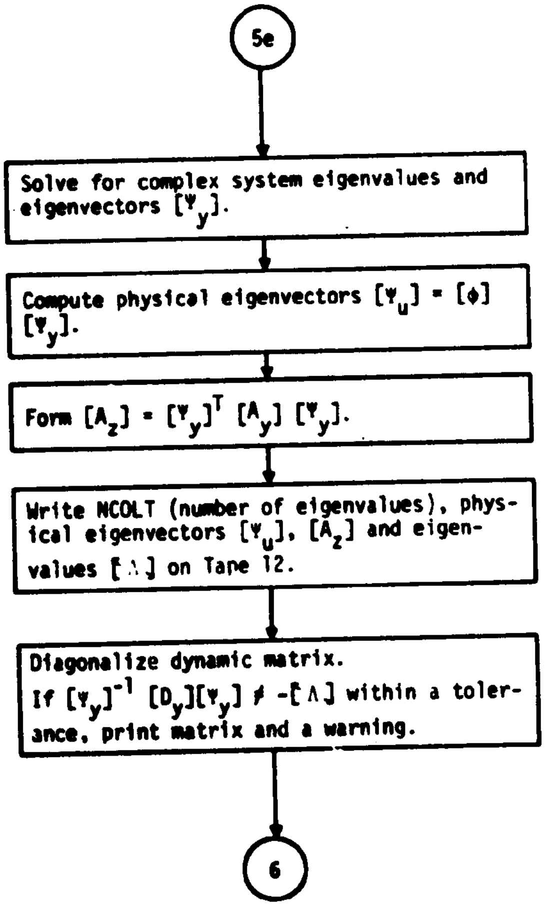


Figure D-12. Flow Diagram for OVERLAY (TEMP,3,0)

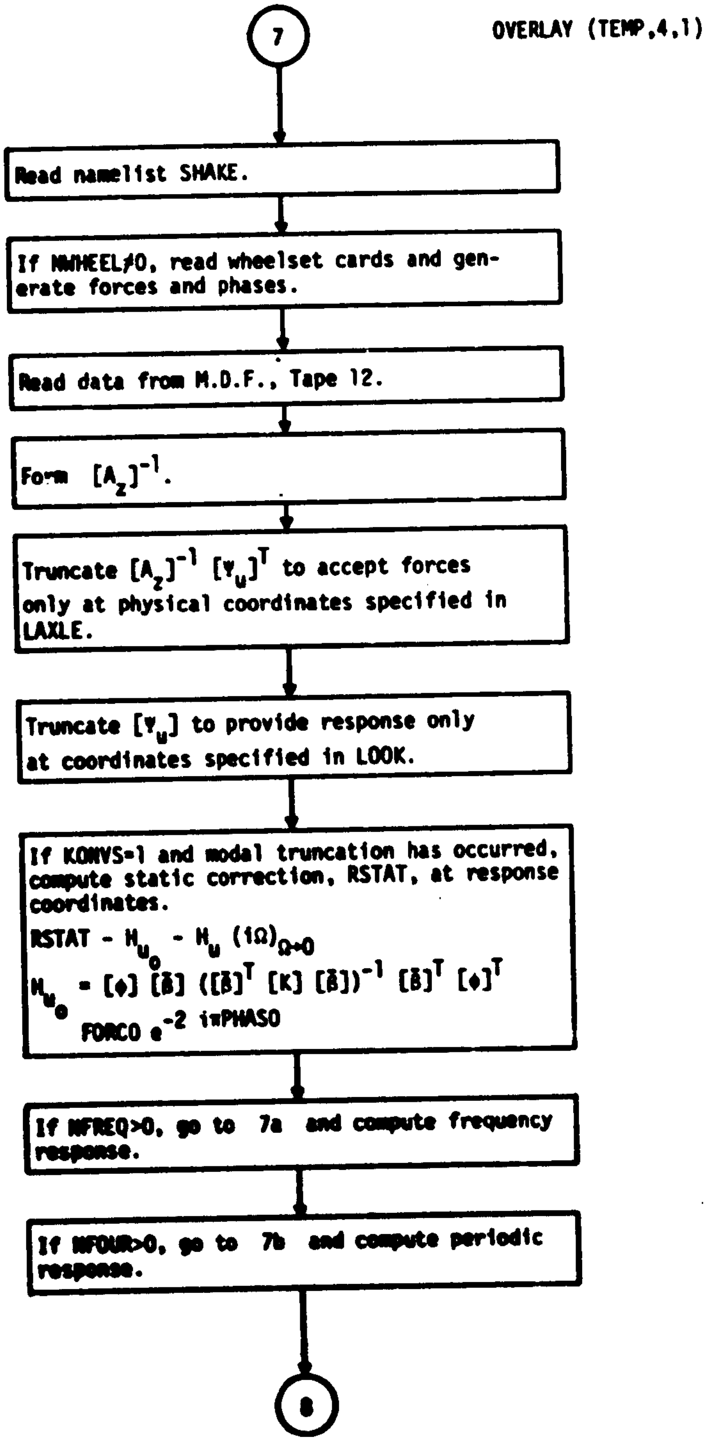


Figure D-13. Flow Diagram for Segment 4

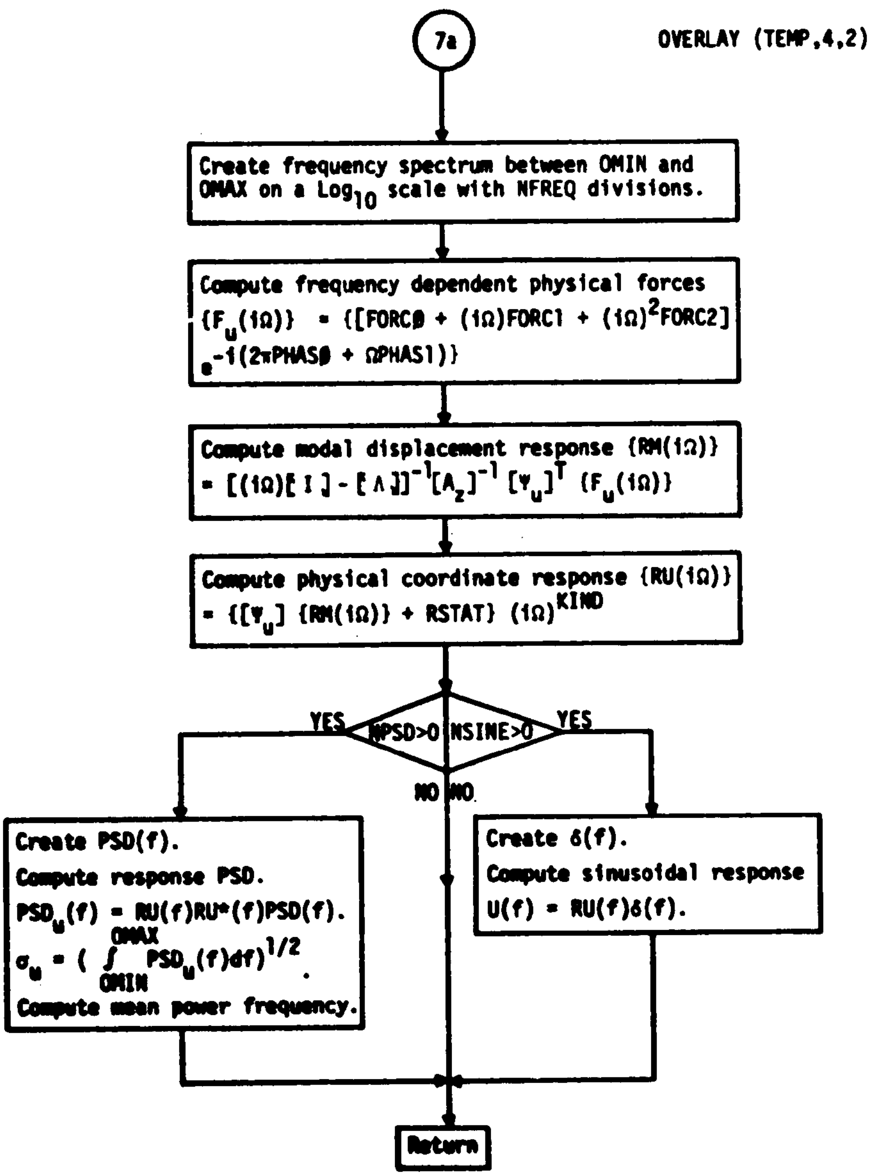


Figure D-14. Flow Diagram for Frequency Response

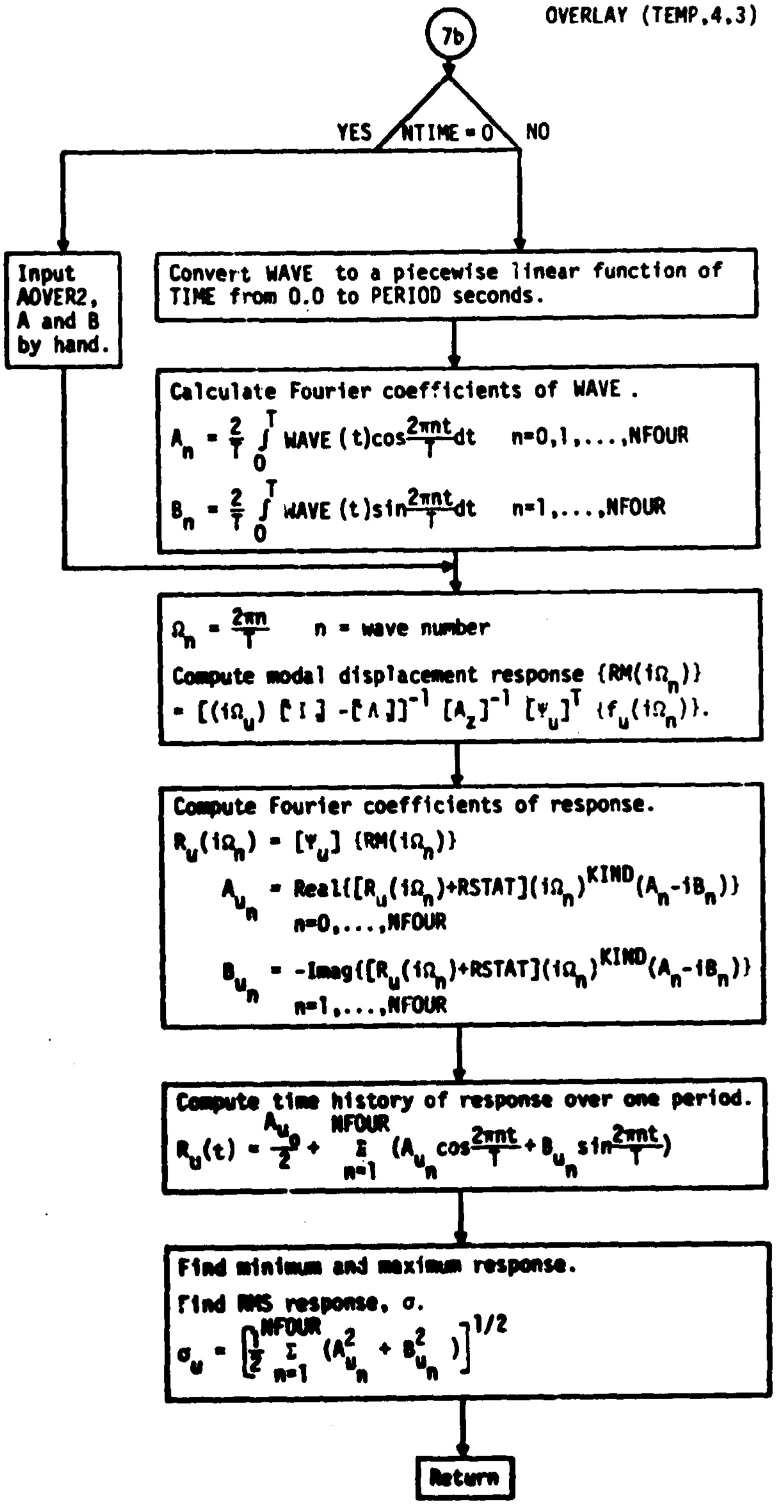


Figure D-15. Flow Diagram for Periodic Response

APPENDIX E

REPORT OF INVENTIONS

In accordance with the patent rights clause of the terms and conditions of this contract, and after comprehensive review of the work performed, it was found that no new patentable items were produced under this contract. However, significant innovations and improvements were made relative to the DYNALIST computer program and its documentation, as summarized in Section 1 of Volume III. In particular these include: (1) a component matrix generator which operates as a [illegible]-D finite element modeling program where elements consist of rigid bodies, flexural bodies, wheelsets, suspension elements, and point masses assembled on a nodal skeleton; (2) a periodic and transient time-history response capability; (3) a component update capability for parametric studies; (4) an orthogonality check on component and system complex eigenvectors; (5) an option for improving low-frequencey convergence under modal truncation; (6) a more general sine-amplitude forcing function capability; (7) automatic phase lag generation; (8) user controlled scaling options on all response plots; and a number of additional minor improvements. The overall utility of the program has been enhanced accordingly.

REFERENCES

1. Hasselman, T. K., Bronowicki, Allen, Hart, Gary C., "DYNALIST II - A Computer Program for Stability and Response Analysis of Rail Vehicle Systems, Volume I: Technical Report," Report No. FRA-OR&D-75-22.I, prepared for the U. S. Department of Transportation, Federal Railroad Administration, Office of Research and Development, February 1975.

2. Bronowicki, Allen and Hasselman, T. K., "DYNALIST II - A Computer Program for Stability and Dynamic Response Analysis of Rail Vehicle Systems, Volume III: Technical Report Addendum," Report No. FRA-OR&D-75-22.III, prepared for the U. S. Department of Transportation, Federal Railroad Administration, Office of Research and Development, July 1976.