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FLYWHEEL/DIESEL HYBRID POWER DRIVE: URBAN BUS VEHICLE SIMULATION

Glenn S. Larson
Harry Zuckerberg

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER
CAMBRIDGE MA 02142

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16. Abstract

A flywheel/diesel hybrid power drive configuration for urban transit bus application is investigated, using a computer simulation model. The hybrid uses continuously variable ratio transmissions and a control subsystem to optimize fuel consumption in an "on-off" mode of engine operation. The system is projected to use 50% less fuel than a diesel-alone in urban driving cycles having more than 4 stops per mile. Regenerative braking is used, contributing to fuel consumption improvement. The computer simulation model developed as a major tool for this investigation is described in detail.

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PREFACE

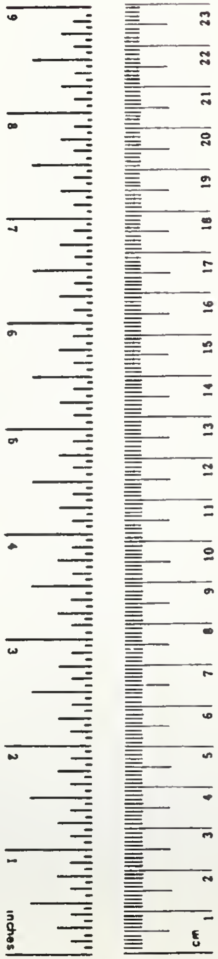
The work covered by this report is part of an Urban Mass Transportation Administration program which is concerned with fuel conservation in urban transit buses. The program is based on the use of a systems approach to develop propulsion design concepts consistent with environmental, safety, operational and economic objectives. This document reports on a Transportation Systems Center study of a flywheel/diesel hybrid power drive concept suitable for an urban transit bus. A primary tool of the investigation was a computer simulation model developed by the Center during the program and described in detail in this report. This model should be useful in further studies of flywheel/heat engine analyses for vehicle propulsion application over various drive cycles.

The authors are also indebted to Alan McDonald of Purdue University for helpful comments and suggestions, and to Detroit Diesel Engine personnel for valuable information regarding diesel on-off operation.

METRIC CONVERSION FACTORS

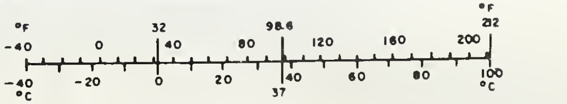
Approximate Conversions to Metric Measures

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	0.036	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	36	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



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SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The Transportation Systems Center has evaluated, as part of the Urban Mass Transportation Administration's fuel economy efforts, the practicality of a flywheel/diesel hybrid power drive concept for urban transit bus propulsion. A computer simulation model was developed as the major tool of this investigation.

The proposed subsystem is a moderately sized diesel engine in series with a relatively large flywheel. The model incorporated a friction clutch between the engine and the flywheel and a continuously variable ratio transmission between the flywheel and the rear axle drive wheels. This hybrid configuration shows considerable promise for fuel efficient propulsion of urban transit buses.

The flywheel/diesel power drive configuration, with the on-off engine operating mode, is projected to have a reduction in fuel consumption of at least 50% (in gallons per mile) below the diesel-alone fuel consumption for urban bus driving cycles having more than 4 stops per mile. This stems from the following:

- o The diesel engine, used in the hybrid, is operated (on-mode) in regions of minimum specific fuel consumption during a much greater portion of its operating time than in conventional drives. Also, the engine is not operating (off-mode) during the time the flywheel has sufficient stored energy to power the transit bus over a number of driving cycles. Transients in fuel consumption are minimized during the time the flywheel is used as an oversize starter in starting the engine up (on-mode). The on-off engine operation mode practically eliminates engine idling which is a major source of low fuel economy during city driving.
- o The flywheel power drive portion of the hybrid subsystem is used in a regenerative braking mode by storing the recoupped vehicle kinetic energy in the flywheel during deceleration. This recouping of energy is appreciable

during the multi-stop operations of transit buses. The recoupped energy also tends to increase the length of time the diesel engine is in the off-mode condition. This leads to additional fuel economy, as well as minimizing brake wear.

The required diesel engine in this application can, potentially, be rated at a lower horsepower than the conventional diesel transit bus engine, leading to further reductions in fuel consumption and weight.

A number of developments are needed to achieve an acceptable hybrid power drive, principally in the areas of continuously variable ratio transmissions (CVRT) design, improved bearings, and seal effectiveness.

RECOMMENDATIONS

A system design of a flywheel/diesel power drive (series configuration, on-off engine operation mode) should be conducted encompassing all the system elements in order to optimize the power transfer from power source to drive wheels with respect to minimizing fuel consumption within the constraints of safety, environmental effects, and acceptable driveability. This will entail engineering design of the diesel engine, CVRT, flywheel and gear train. An additional study should include life cycle cost analyses of the overall system and each of the subsystems.

1. INTRODUCTION

This report describes the results of a Transportation Systems Center investigation, conducted under Urban Mass Transportation Administration sponsorship, of the practicality of a flywheel/ diesel hybrid power drive for urban transit bus propulsion. A simulation model, developed in the program, was the major tool used in the investigation and is described in detail in the report.

1.1 BACKGROUND

A fundamental deficiency of the current urban transit bus diesel engine and transmission assembly is that the power unit is operated much of its time in the less-efficient regions of its performance envelope. During urban traffic use the diesel engines are operated in an intermittent mode or duty cycle, characterized by many cycles per mile consisting of acceleration, short cruise, deceleration, and idle segments. During the acceleration segment there is a large speed variation as well as a large variation in drive power required. In the cruise segment the speed is almost constant with sufficient engine power development to account for the air drag and ground rolling friction losses. During deceleration, the engine provides some form of braking to slow the bus vehicle. The idling segment is the most inefficient of all operating modes because fuel is wasted while doing no useful work. The fuel consumption for such a duty cycle is higher than desired.

The national fuel conservation effort has brought together the voluntary action of manufacturers and operators to promulgate fuel efficient or energy saving features for truck and bus vehicles. Typical of these, are the following:

- Weight reduction options;
- Aerodynamic design improvements that reduce the wind and ground effect drag of the buses;

- Use of radial ply tires that reduce rolling resistance;
- Redesign of diesel engines that develop rated power at reduced engine speeds;
- Use of turbochargers that improve the efficiency of diesel engines;
- Demand actuated fan clutches that disengage the engine cooling fan when it is not needed.

Case studies of major trucking operators reveal fuel savings ranging from 15 to 20% through the use of the above measures (References (1), (2). Similar fuel savings ranging from 10 to 15% may be estimated for the bus operators.

Additional fuel savings would be attainable with effective energy management and matching of the diesel engine to its duty cycle. This suggests that there are a number of potentials which can be considered for reducing urban bus fuel consumption. One potential is in the use of a Continuously Variable Ratio Power Drive Transmission (CVRT) concept which is capable of sustaining the diesel engine operation within its optimum performance envelope. A simulation study of such an approach has predicted that the use of an available CVRT in a present day urban bus would increase the bus fuel economy (in mpg) by as much as 30%.*

More improvement in fuel economy can be achieved with the alternate approach of using a hybrid power drive concept which will support deceleration energy recovery along with optimum engine operation.

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*H. Zuckerberg, "Performance Characteristics of a Diesel Powered Urban Bus Equipped with Sundstrand Hydromechanical Transmission," material on file with Kentron Hawaii, Limited, Transportation Systems Center, 55 Broadway, Cambridge MA 02142.

1.2 STUDY APPROACH

The objective of this study was to determine the potential of a flywheel/diesel power drive concept for urban transit bus propulsion. The approach taken to meet the objective was in accordance with the following tasks:

1. Provide information showing the potential viability of flywheel hybrid power drives for bus propulsion.
2. Estimate the improvement in fuel economy that could be achieved through use of flywheel hybrid propulsion.
3. Identify the problem areas which will be encountered in the development of flywheel hybrid power drives.
4. Delineate the initial phases necessary for an urban bus flywheel hybrid propulsion system development.

These tasks were performed within the following guidelines:

1. Engines designed to operate at peak efficiency;
2. Power transmissions designed for compatibility with peak engine efficiency;
3. Accessory power drives designed for compatibility with peak efficiency.

The most significant characteristic of the proposed flywheel/diesel power drive subsystem is a moderately sized engine in series with a relatively large flywheel. The interfaces between the engine and flywheel and between flywheel and rear axle drive wheels, are CVRTs and possibly fluid clutches. The use of CRVTs with flywheel/diesel hybrids permits the combining of the best features of the flywheel and the diesel to provide an attractive transit bus power drive subsystem.

Many "hotel" accessories (air conditioning, heating and ventilating) can provide optimum output within their peak efficiency regime when operated at near constant input speed. Within the time frame projected for the development of a prototype bus vehicle concept, (i.e., 1985), it is likely that an optimized package of "hotel" accessories having a constant input speed specification will be available for operation off the hybrid power drive or off a separate power source.

Because of the uncertainty in the characteristics of future "hotel" loads, comparisons between hybrid propulsion and standard diesel propulsion in this report are made on the basis of no air conditioning, heating or ventilation.

2. HYBRID SYSTEM CONSIDERATIONS

2.1 HYBRID SYSTEM SELECTION

In configuring a heat engine hybrid power drive, four major selections must be made:

Type of engine

Power drive configuration (series or parallel)

Type of energy storage

Operation mode of the engine

A discussion of these follows.

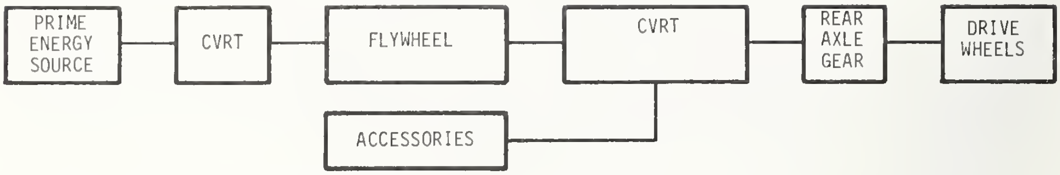
The diesel was chosen as the heat engine for this study because of its demonstrated superiority to other available engines in the areas of maintenance and fuel economy. Other engines such as the gas turbine or the Stirling may prove superior to the diesel at a later date when they are developed for bus operation.

Hybrid power drive configurations are often grouped into two broad classes, series and parallel, as illustrated in Figure 2-1. In the series configuration, the energy passes directly through the various energy conversion and energy storage devices as it flows from the prime source to the drive wheels. This permits a wide latitude in the degree of prime source decoupling from the drive wheels, which results in greater flexibility of diesel engine operation. In the parallel configuration of hybrids, the energy flow still has a path through energy conversion and storage devices but there is also a (parallel) path of mechanical power transmission to the drive wheels. The decoupling potential is less than in the series configuration, which limits the engine flexibility. However, the transmission losses in the mechnical drive path can be lower than those in the series configuration. Although the size and weight of some of the components can be less in parallel hybrid configurations there are more components.

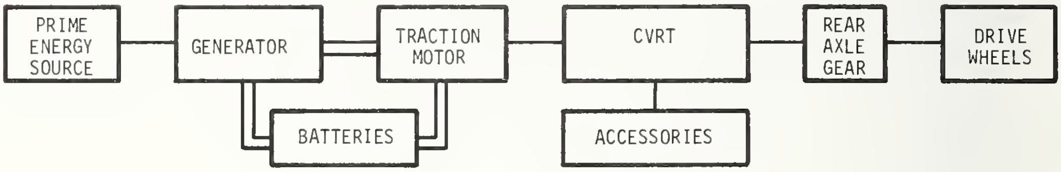
The series configuration was selected because, having less components it is less complex than the parallel. In addition, the

A. SERIES CONFIGURATION

(i) PRIME ENERGY SOURCE/FLYWHEEL HYBRID

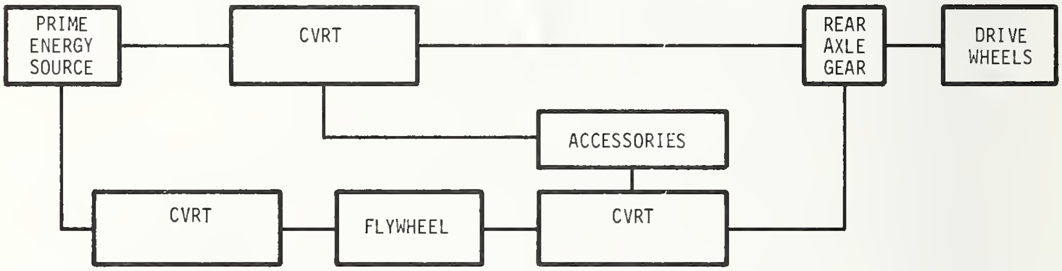


(ii) PRIME ENERGY SOURCE/BATTERY HYBRID



B. PARALLEL CONFIGURATION

(i) PRIME ENERGY SOURCE/FLYWHEEL HYBRID



(ii) PRIME ENERGY SOURCE/BATTERY HYBRID

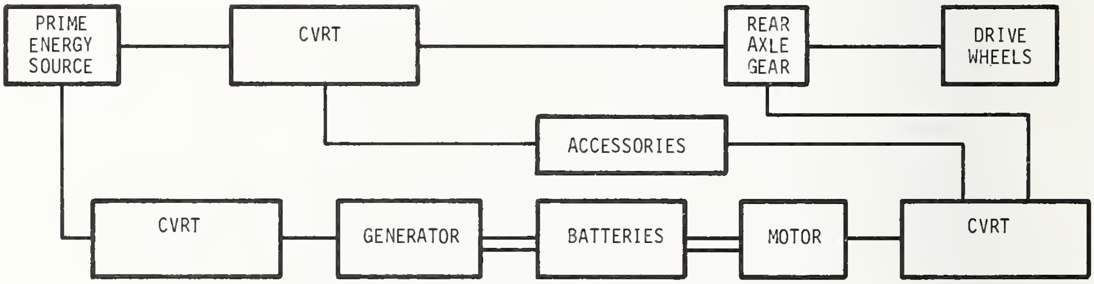


FIGURE 2-1. SCHEMATIC DIAGRAM OF HYBRID POWER DRIVE SUBSYSTEMS

particular series configuration chosen is more fuel efficient than a parallel configuration and allows on-off operation of the diesel engine, whereas the parallel configuration requires essentially continuous operation.

Continuous, constant speed operation of the heat engine is attractive because it provides the possibility of finding the best operating engine speed to minimize fuel consumption and/or exhaust emissions. However, a particular setting of constant speed operation is only applicable to a particular phase of a driving cycle. Because of this, the heat engine is sized to meet the maximum power requirement for the continuous operational mode, and the speed-power operation is adjusted to meet the lower power levels as required. The energy savings, if any, that are realized by this method of control, stem from the slow variations in engine speeds that are possible. The design challenge is to configure the control system so that the engine speed and power changes take place in such a manner that no vehicle acceleration demands are imposed upon the engine.

Another engine operational mode is possible in which the engine is turned on and off in response to the state-of-charge of the energy storage device. The energy storage device discharges as energy is extracted for propulsion. When the energy storage device has been discharged to its minimum operational level, the heat engine is turned on to charge it up. When the storage device reaches its maximum charge limit, the heat engine is turned off and disengaged. This on-off operation of the heat engine allows for essentially complete decoupling of the engine from the wheel loads and, therefore, minimum fuel consumption. For this reason, the on-off operation of the heat engine was chosen.

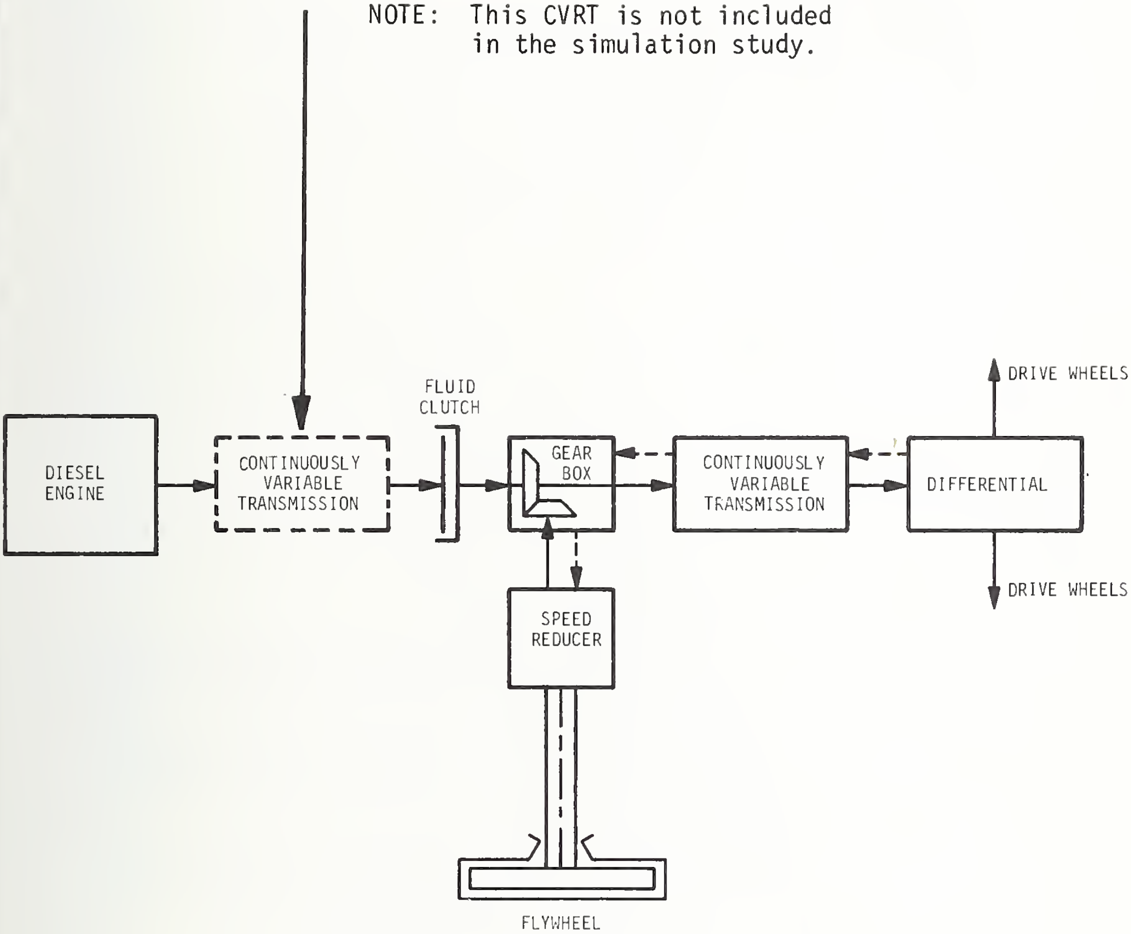
Energy can be stored in batteries, flywheels and hydraulic accumulators. A state-of-the-art review of these methods determined that only flywheels could be characterized well enough to be accurately modeled in a simulation program. In addition, flywheels are superior to the others in charge and discharge power densities and in cycle life.

A functional diagram of the selected hybrid power drive system is shown in Figure 2-2. This particular type of hybrid drive subsystem has not received extensive attention in prior studies. Only two previous studies and experimental trials are related. These are described in References 3 and 4. In this concept the flywheel/diesel hybrid drive train is dominated by the flywheel. The diesel engine is used only to charge up the flywheel. In terms of performance (acceleration, cruising speed and energy economy), the proposed subsystem can be a satisfactory substitute for currently manufactured transit bus power drive train subsystems. The flywheel can provide high power density levels to propel vehicles at the desired speeds and accelerations. With a bilateral transmission, a flywheel assembly can store vehicle kinetic energy developed during the deceleration phase which can be used during the next acceleration phase, thereby increasing the energy efficiency of the transit bus. In addition, the proposed systems should have the operating life compatible with service-life requirements of the complete bus vehicle drive system.

2.2 HYBRID POWER DRIVE OPERATION MODES

The proposed vehicle drive subsystem is shown schematically in Figure 2-2. The diesel engine is used primarily to charge the flywheel, when required. Power is supplied to the flywheel through a Continuously Variable Ratio Transmission (CVRT) which adjusts its ratio automatically to maintain the engine operation at its best power-speed profile while the flywheel speed varies between its minimum and maximum values. Figure 2-3 illustrates the optimum power-speed profile for a typical bus diesel engine.

Other modes of operation for the hybrid concept are illustrated in Figure 2-4. When the flywheel is fully charged, the engine is automatically turned off. Later, when the energy in the flywheel reaches a specified lower threshold level, the engine is started up by the flywheel. Once turned on, the engine brings the flywheel to full charge.



NOTE: This CVRT is not included in the simulation study.

FIGURE 2-2. SELECTED HYBRID POWER DRIVE - SERIES CONFIGURATION - ON-OFF ENGINE OPERATION

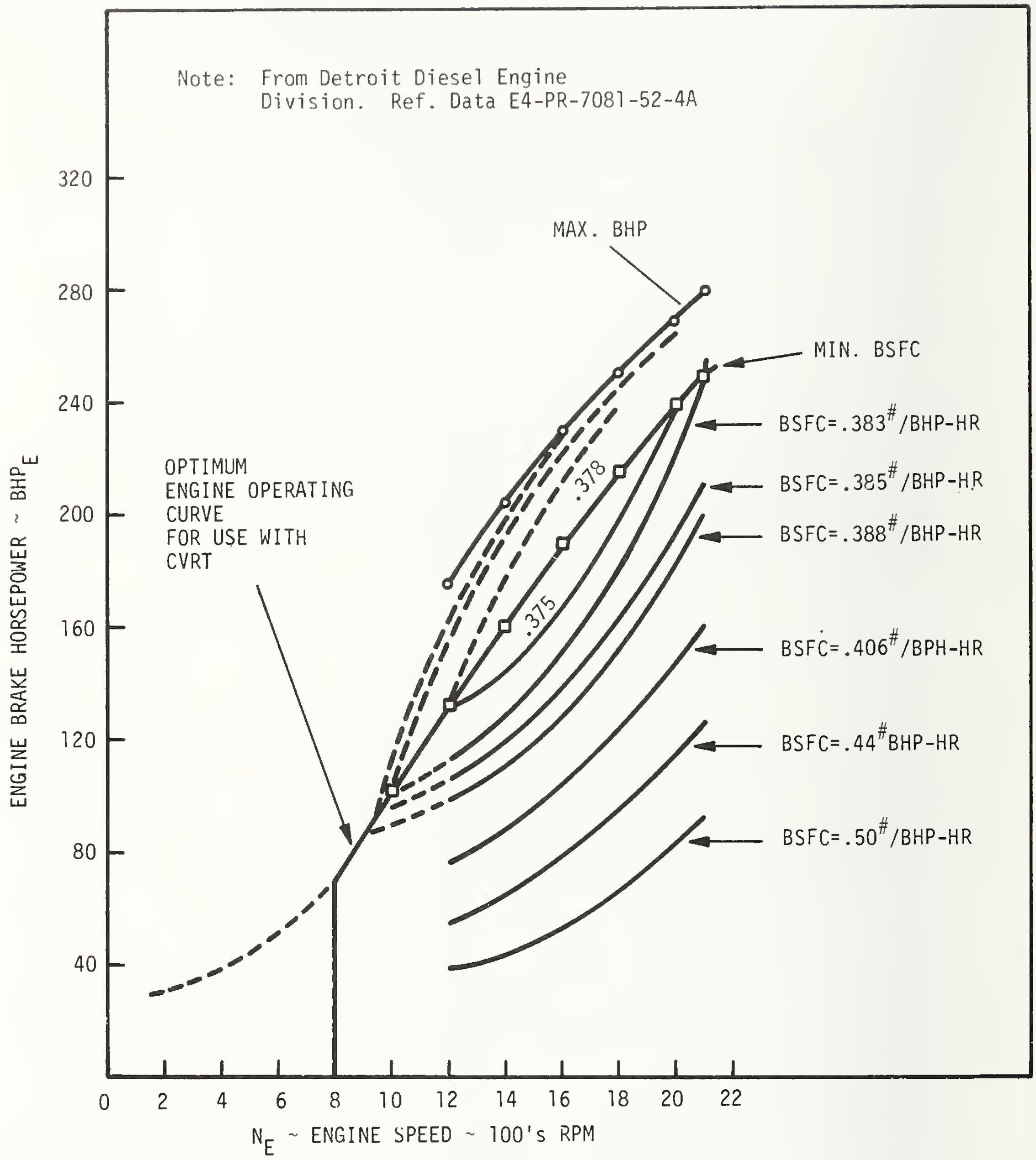
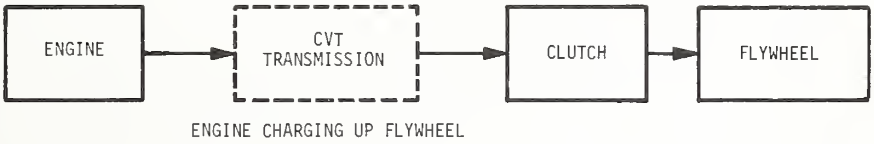
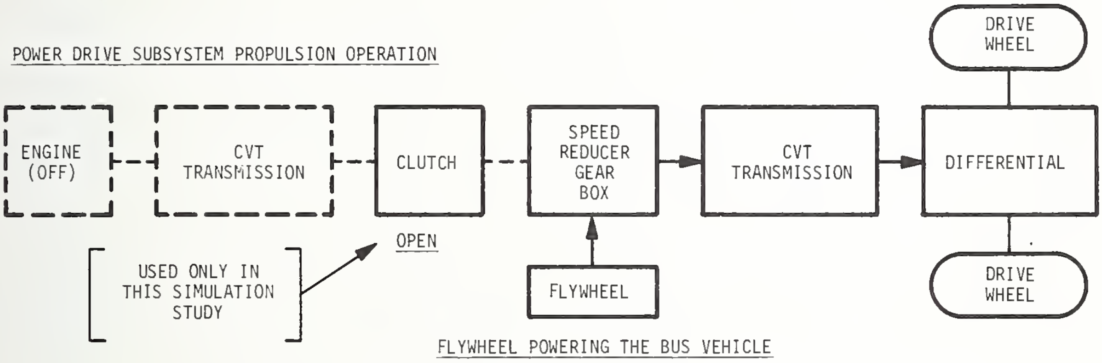


FIGURE 2-3. 8V-71N ENGINE PERFORMANCE CHARACTERISTICS

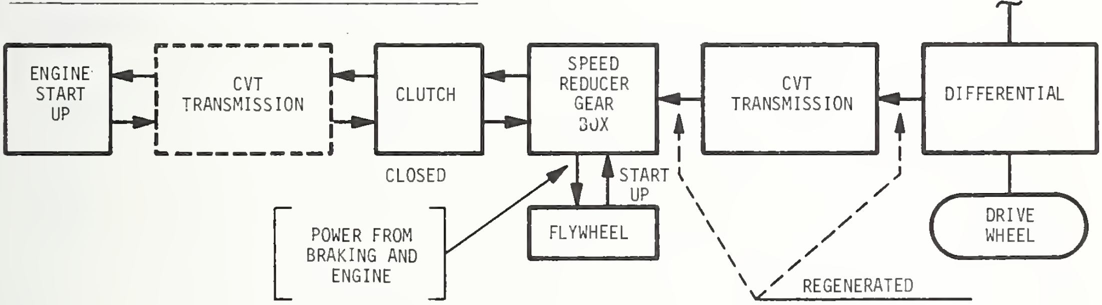
A - POWER DRIVE SUBSYSTEM STARTUP



B - POWER DRIVE SUBSYSTEM PROPULSION OPERATION



C - POWER DRIVE SUBSYSTEM - DECELERATION OPERATION



Note: For the simulation program the CVRT between the engine and the clutch was not included.

FIGURE 2-4. FLYWHEEL/DIESEL HYBRID POWER DRIVE MODE OF OPERATION

Another CVRT with reversing capabilities is used for transmitting power to the drive wheels from the flywheel. The need for a CVRT between the flywheel and the drive wheels is emphasized by the incompatibility of the flywheel and vehicle speed regimes. For example, at vehicle standstill, after charging, the flywheel speed is maximum while the vehicle speed is zero. As the urban bus begins to accelerate, the flywheel slows down. During the cruising phase with the bus travelling at steady speed, the flywheel gradually slows down due to the extraction of energy. During the deceleration phase, as the vehicle slows down, the flywheel speeds up because of the kinetic energy imparted to it.

The engine can be operated without CVRT coupling to the flywheel. In this case, a clutch must be used and the engine operation will not be optimal, resulting in higher fuel consumption.

To establish which approach is better, a trade-off analysis between the clutch and CVRT must be made, considering maintenance costs and power drive efficiency.

2.3 PRELIMINARY ENGINEERING ASSESSMENT OF THE FLYWHEEL/DIESEL HYBRID CONCEPT

The purpose of this section is to document the development of a "proof of principle" engineering assessment method for determining the fuel conservation potential of the selected flywheel/diesel hybrid concept. The method is based on the balance of energy flows from and to the flywheel energy storage subsystem. The analysis is predicated on the determination and use of average efficiency values of each of the drive components.

Upon completion and acceptance of this assessment method, a computer simulation model was used as a tool to develop component functional specifications of the selected power drive hybrid concept. In the computer simulation program, performance and efficiency maps of the power drive components are used. The accuracy of the simulation model output depends greatly upon the accuracy of these maps. The maps which have been used are considered to be the best available. A detailed computer listing of the simulation modeling is presented in Section 3 of this report.

The preliminary assessment, which follows, estimates the road load power requirement for a drive cycle considered to be realistic from an energy requirement viewpoint. Estimates are then made of the average efficiency of each component when operated over the chosen drive cycle. Then, through energy balance relationships, the fuel consumption per mile is calculated.

2.3.1 Dynamic Road Power Demand

The instantaneous dynamic power demand manifested at the drive wheels of an urban bus vehicle during any drive cycle is expressed by

$$P_i = P_A + P_D + P_F + P_G \qquad (2\text{-}1)$$

where

P_i = Instantaneous power at the drive wheels due to vehicle losses incurred while in motion.

P_A = Power loss or gain due to vehicle inertia effects - either during an acceleration or deceleration phase:

P_D = Power loss due to air resistance on the vehicle;

P_F = Power loss due to tire/ground resistance and wheel/axle bearing losses;

P_G = Power loss or gain due to vehicle negotiating an elevation change in the road profile - (in terms of grade slope in percent). During this study, this loss will be neglected.

The power loss in kilowatts for straight line motion, consists of the translational acceleration effects of the vehicle mass and the rotational acceleration effects of the rotating elements of the power drive train and is expressed by

$$P_A = K_A(GVWR)\ (ACC)\ (V) + K_{RA} \sum_{i=1}^{n} I_i \alpha_i \omega_i \qquad (2\text{-}2)$$

where K_A and K_{RA} are parameters to assure dimensional compatibility

GVWR = Rated Gross Vehicle Weight; lbs

ACC = Acceleration; mph/s

V = Velocity mph

I_i = Moment of inertia; slugs ft^2

α_i = Rotational acceleration; rad/sec^2

K_A = 9.07×10^{-5}

K_{RA} = 135×10^{-5}

For preliminary analyses the rotational effects are approximated as 10% of the translational effects. Thus

$$P_A = 1.10K_A\ (GVWR)\ (ACC)\ (V) \qquad (2\text{-}3)$$

where

GVWR = Normal Gross Rated, Vehicle weight; pounds.

ACC = Linear acceleration of vehicle; mph/sec.

V = Resultant vehicle velocity; mph.

K_A = Parameter to assure dimensional compatibility.

= $.0907 \times 10^{-3}$

The power loss in kilowatts due to the air resistance on the vehicle is expressed by

$$P_D = K_D C_D S V^3 \qquad (2\text{-}4)$$

where

C_D = Air drag coefficient

S = Vehicle frontal area; sq. ft.

V = Vehicle resultant velocity; mph

K_D = Parameter to assure dimensional stability

$K_D = 5.089 \times 10^{-6}$

Equation (2-4) is rewritten as follows:

$$P_D = 5.089 \times 10^{-6}\ C_D S V^3 \tag{2-5}$$

The power loss in kilowatts due to the drive wheel/ground rolling friction and wheel/axle bearing losses is expressed by

$$P_F = K_F\ (f)\ (GVWR)\ (V) \tag{2-6}$$

where

f = Wheel/ground rolling friction coefficient

K_F = Parameter to assure dimensional stability

$K_F = 1.9885 \times 10^{-3}$

Many values of the rolling friction and bearing loss coefficient have been quoted and measured under controlled conditions by various authors as noted in the technical literature. It would appear that during real life conditions many vehicles may not maintain the tire pressures consistent with those used in the tests, and there may not be compatibility of the route surface conditions with that of the tests and a host of other mismatches. Based on available data the following expression for f was developed:

$$f = .005 + 30 \times 10^{-6} V + .25 \times 10^{-6} V^2 \tag{2-7}$$

The resulting power loss in kilowatts due to rolling friction is expressed by

$$P_F = 1.99 \times 10^{-3} (.055 + 30 \times 10^{-6} V + .25 \times 10^{-6} V^2)\ (GVWR)\ (V) \tag{2-8}$$

The power loss in kilowatts due to the negotiating of a grade in the road profile, is expressed in terms of the slope in percent.

$$P_G = 1.99 \times 10^{-3} \Big((GVWR)\ \big(\sin(\tan^{-1}\gamma/100)\big)\Big) V \tag{2-9}$$

where γ = slope in percent.

2.3.2 Balance of Energy Flow

Figure 2-5 is a schematic of the drive chain of a flywheel/ diesel powered urban transit bus, equipped with a system for recovering energy when the vehicle is slowing down. The overall energy balance of the power drive subsystem during any kind of drive cycle and time interval is (see Figure 2-5):

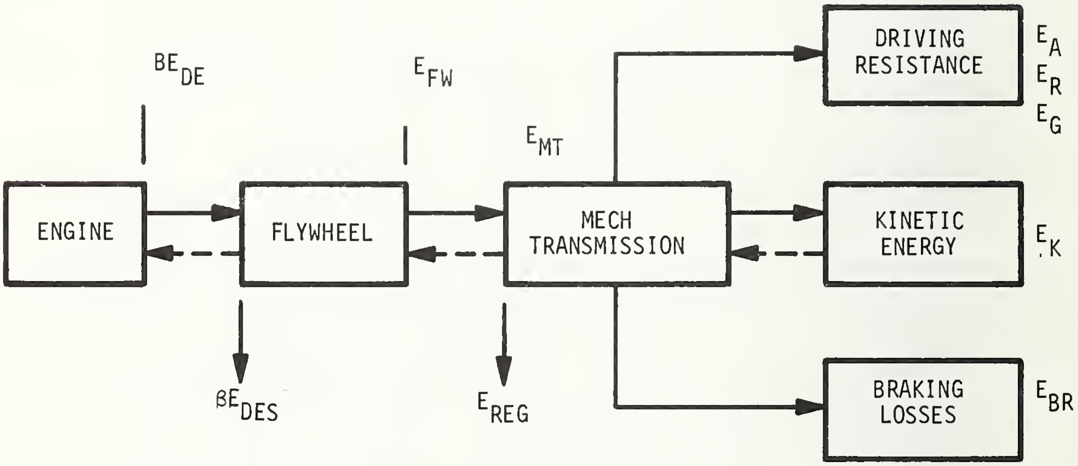


FIGURE 2-5. HYBRID FLYWHEEL PROPULSION SUBSYSTEM WITH REGENERATION

$$E_{FW} + E_{MT} + E_{PD} + E_{DES} + E_{BR} - BE_{DE} - E_{REG} = 0$$

where

E_{FW} = Net flywheel energy extracted

E_{MT} = Losses in mechanical transmission chain

E_{PD} = Energy consumption due to vehicle inertia acceleration, due to air drag, due to ground traction rolling resistance and due to road gradient = $E_A + E_R + E_G$

E_{DES} = Flywheel energy loss during diesel engine start up

E_{BR} = Energy wasted in friction braking

E_{DE} = Energy provided to flywheel from diesel engine; $\beta = 0$ if the engine is in the off mode and $\beta = 1$ during engine charging.

E_{REG} = Energy provided to flywheel from regenerated energy mechanism.

Estimates of Component Efficiencies

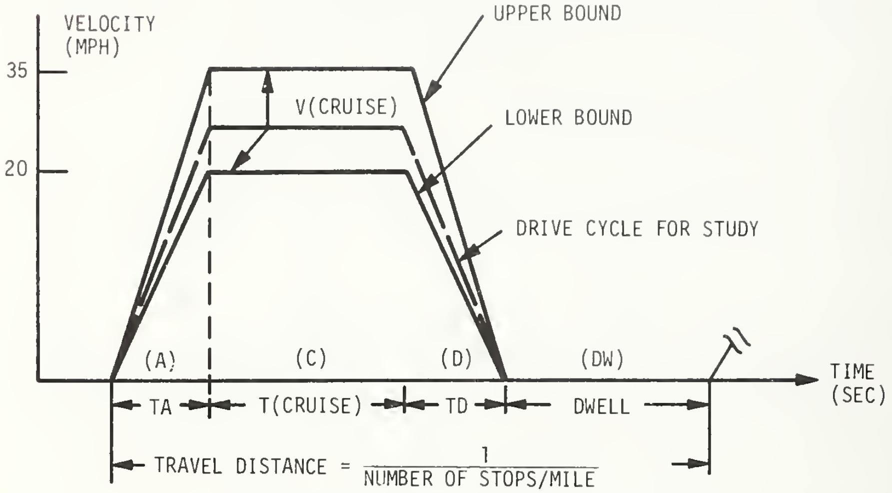
The efficiency of the mechanical transmission chain from the flywheel to drive wheels is based on the following engineering estimates:

γ(REAR AXLE) = .91

γ(CVRT) = .77

2.3.3 Drive Cycle Delineation

Power and energy relationships were determined with respect to a particular stop-and-go urban driving schedule. In order for the simulation model to provide reasonable values for the hybrid subsystem component specifications and for comparison with alternative concept approaches it was necessary to establish a reference drive cycle. Drive cycle candidates, (shown in Figure 2-6) were taken from the TRANSBUS and Small Bus Specifications (References 5 and 6), work by Renner (Reference 7), and measurements made by TSC in the Boston area. The limit drive cycles shown may be considered as the upper and lower bounds of national urban drive cycles when considered from an energy point of view. In real-world transit operations, buses are subjected to varying acceleration and/or cruising velocities within any one drive cycle as well as with



ITEM	NOMENCLATURE	UPPER BOUND	LOWER BOUND	STUDY DRIVE CYCLE
(A)	ACCELERATION MODE (CONSTANT ACCELERATION)	3.5 mphps	2.0 mphps	2.5 mphps
(C)	CRUISE MODE (CONSTANT VELOCITY)	35 mph	20 mph	25 mph
(D)	DECELERATION MODE (CONSTANT DECELERATION)	3.4 mphps	2.5 mphps	2.5 mph
(DW)	DWELL TIME AT BUS STOP	20 seconds	10 seconds	20.4 sec.

FIGURE 2-6. URBAN TRANSIT BUS DRIVING CYCLE

variation in the number of stops per mile. However, from the standpoint of determining the performance behavior and comparisons of different power drive subsystems such as a "standard transit bus" with a "hybrid bus", the use of simple repetitive drive cycles can provide data of sufficient accuracy for the purpose of the present study.

The simple trapezoidal-shaped drive cycle used in this study was taken as an average of the upper and lower bounds shown in Figure 2-6. This drive cycle was assumed repetitive over any number of stops. It should be noted that the dwell time in the stop region is 20.4 seconds to take into account exiting and entering passengers as well as traffic delays.

2.3.4 Determination of Fuel Usage

The fuel usage may be determined in the following manner: The typical high heat value (HHV) of diesel fuel (ranging from 18,500 to 20,000 BTU per lb, Reference 6) is estimated at 19,250 BTU per lb, or, (since 2511.5 BTU = 1 HPHR and 1 gallon = 6.8 lbs), 187,632 HP-SEC/GAL. Fuel usage was determined from

$$\text{mpg} = (\text{HHV})\xi_E/E_{DE}$$

where

ξ_E = Thermodynamic conversion efficiency of a diesel engine and is a function of the operating range of engine speed and power.

Average estimated values for component efficiencies were used in the determination of energy flows.

Since the diesel engine is to operate along its optimum fuel usage line (see Figure 2-3), it is estimated that the thermodynamic conversion efficiency is

$$\xi_E = .35$$

The efficiency of the standard bus transmission chain is based on the following average values (Abstracted from the technical literature):

η (rear axle) = .91

η (automatic transmission) = .85

η (torque converter) = .80

The process of estimating fuel consumption is as follows (Refer to the Energy Balance Diagram in Figure 2-7):

1. Determine the energy expended per cycle by integration of the power drive cycle. Any energy of regeneration is added to the flywheel energy.
2. Extract this energy expended from the flywheel. Track the flywheel rotational speed.
3. Determine when flywheel speed drops to minimum threshold level (a function of the velocity of the bus).
4. Turn engine on to recharge the flywheel. Determine the time for full flywheel charge. The start up energy of the engine must be taken into account.
5. Determine the fuel used during the on-cycle operation of the engine.
6. Repeat the process until the accumulated mpg levels out.

The preliminary estimates of fuel usage for an urban hybrid bus of 30,000 and 34,000 weights are illustrated in Figure 2-8.

The performance characteristics for a typical urban bus of similar size and weight are also estimated for comparison with those of the hybrid bus. The energy balance diagram for the diesel bus is illustrated in Figure 2-9, and the comparison is illustrated in Figure 2-8. The comparison of the preliminary assessments of fuel usage between the hybrid and standard transit buses showed sufficient promise for the hybrid to justify the development of an accurate computer performance simulation model.

Prof. A.T. McDonald had developed an Engineering Limit Performance of Transit Buses which is included herein as Appendix C. The results of the computer simulation program discussed in this report are consistent with the findings of Prof. McDonald.

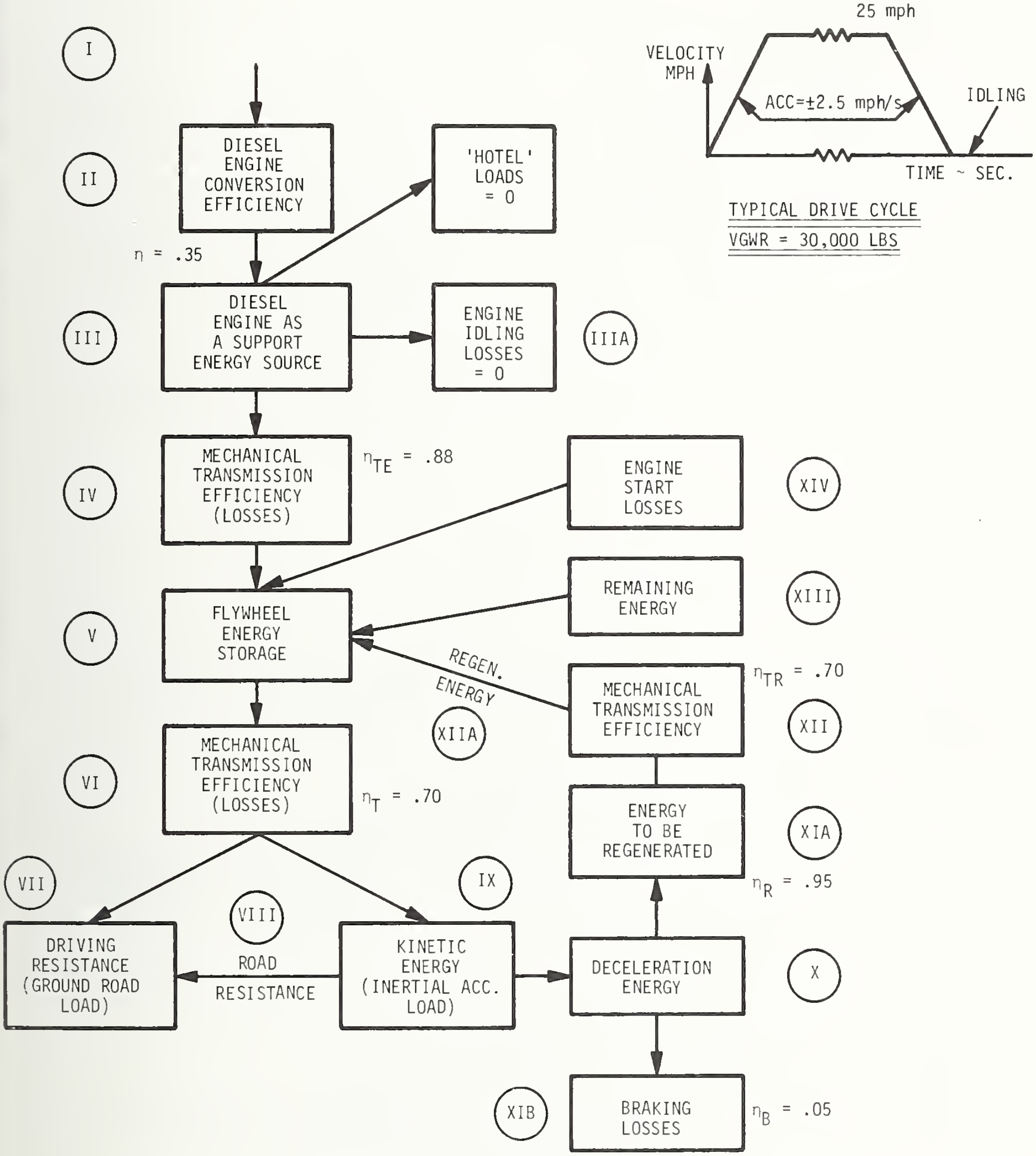


FIGURE 2-7. ENERGY BALANCE DIAGRAM - DIESEL/FLYWHEEL HYBRID BUS IN URBAN DRIVE CYCLE

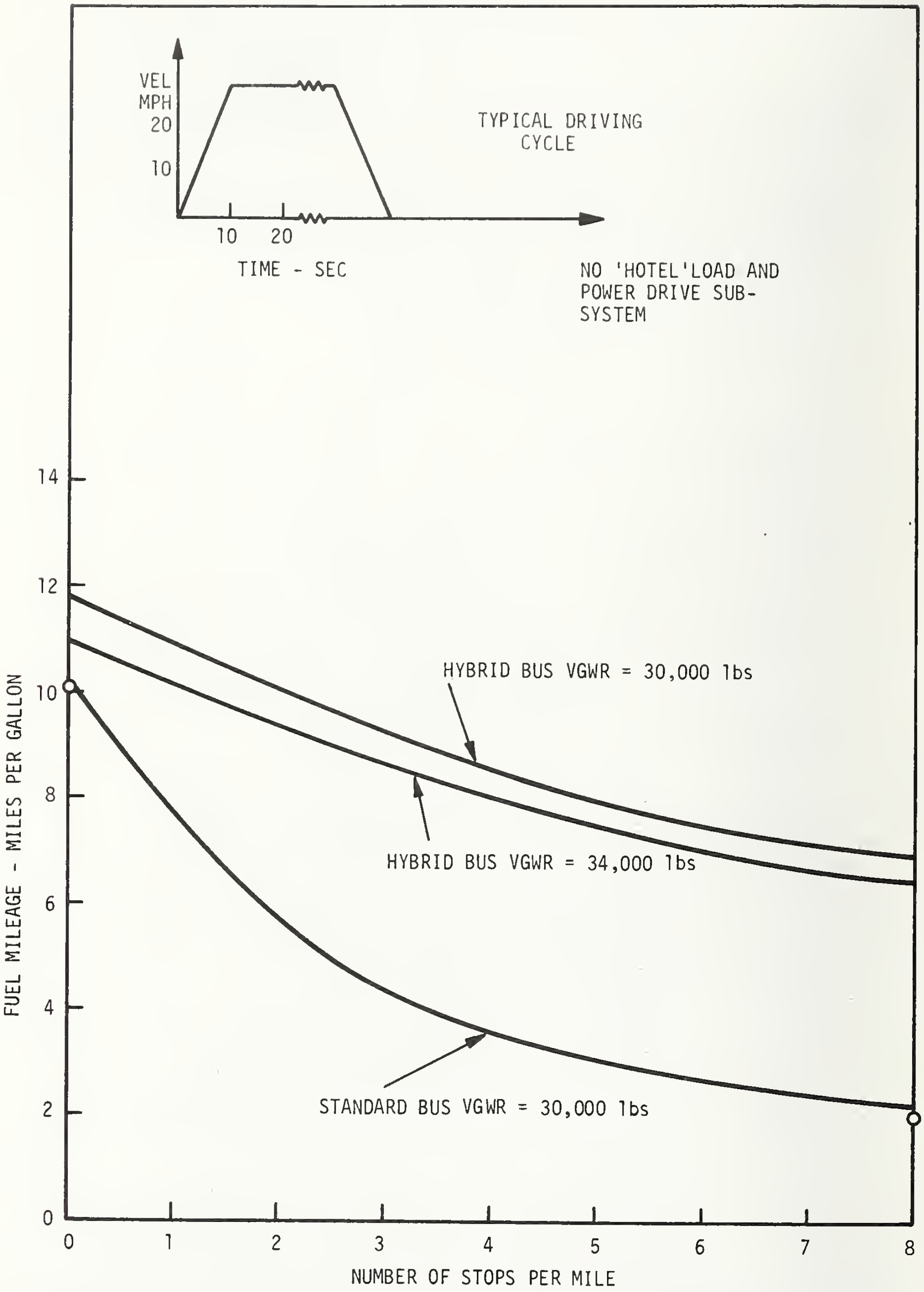


FIGURE 2-8. FUEL MILEAGE AS A FUNCTION OF STOPS PER MILE (ESTIMATED DATA USING ENERGY BALANCE ANALYSIS)

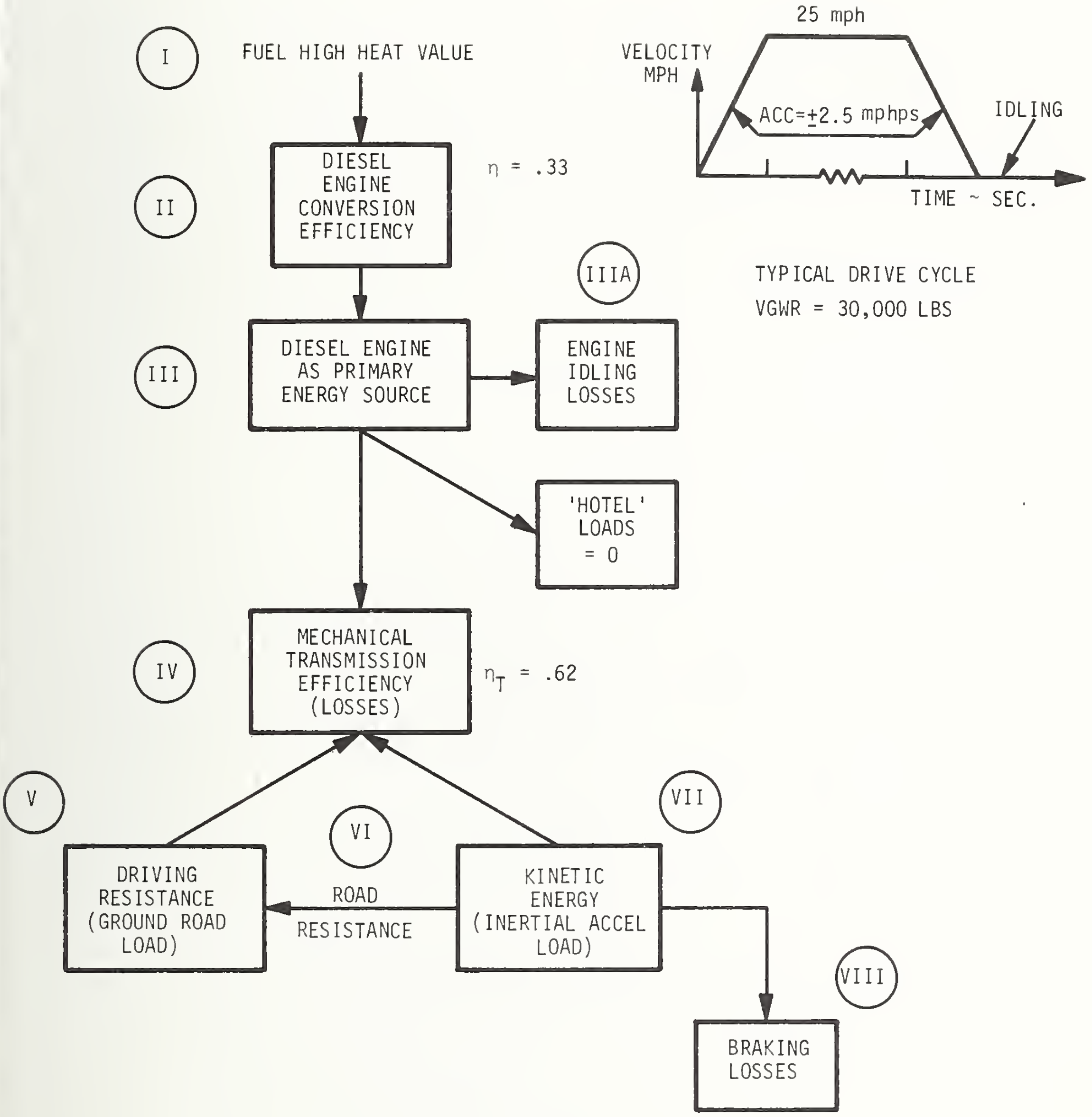


FIGURE 2-9. ENERGY BALANCE DIAGRAM - STANDARD BUS IN URBAN DRIVE CYCLE

3. COMPUTER SIMULATION PROGRAM

3.1 INTRODUCTION

The present study was initiated to compare the performance of hybrid power drive subsystems with a standard transit bus heat-engine power drive subsystem. The guidelines for the hybrid flywheel power drive subsystem include the following:

- Use the same baseline bus configuration and the same diesel power plant.
- Replace the torque converter and transmission with the following:

  A flywheel kinetic energy unit and engine/flywheel clutch

  A flywheel/transmission clutch

  A continuously variable ratio hydromechanical transmission.
- Select a flywheel size capable of storing enough energy to power the urban transit bus over a series of stop-and-go-drive cycles along a simulated scheduled route, with the diesel engine in the "OFF" mode.
- Engage the flywheel with the 'STOPPED' diesel engine to start the engine.
- Use the diesel engine to recharge the flywheel when required.

3.2 SYSTEM OPERATING PRINCIPLES

3.2.1 Configuration and Engine Operation Mode Options

The series hybrid concept was selected as the baseline configuration to be pursued for simulation and evaluation because of its simplicity of assembly and simple control system logic. There are a number of operation modes possible with the series hybrid. Two of the more interesting ones are:

(a) Continuous Engine Operation Mode

- Keep the diesel engine continuously running at constant speed and power except during braking.
- Use flywheel power to fulfill demand power.
- Regenerate to flywheel during braking.
- Balance over a selected number of cycles per bus route.

(b) On-Off Engine Operation Mode

- Operate the diesel engine in an on-off mode. Initially bring flywheel up to maximum rated speed, then shut off engine.
- Use flywheel energy to power the transit bus over its drive cycle. Limit the spin-down of the flywheel to a minimum threshold speed which will permit the engagement and start-up of the engine without the complete loss of flywheel energy and which should occur near the point of braking.
- Regenerate to the flywheel during braking.
- Use flywheel power to start engine and use engine power to bring flywheel speed up to maximum rated speed during stop segment of drive cycle.

Intuitively, the on-off mode operation should develop better fuel economy than the continuous mode. Therefore, the baseline concept of the initial study phase (the diesel engine/flywheel hybrid concept) employed the on-off mode of engine operation.

3.2.2 On-Off Engine Operation Mode

In this mode of operation the heat engine is started and warmed-up before initiating the route run. The engine clutch is engaged to "rev-up" the flywheel to its maximum operational speed. The engine operation control system logic will cause the engine clutch to disengage and the engine to be turned off when the flywheel reaches its maximum rpm. The transit bus is then ready to begin revenue operations. During the traverse of a number of driving cycles, energy is extracted from the flywheel causing it to spin-down. The control logic will sense the threshold minimum speed of the flywheel and cause the engine clutch to re-engage and, thus, cause the flywheel to turn the engine over and start-up. This will further extract energy from the flywheel and cause additional spin-down. The energy extracted from the flywheel during the 'powering' of the transit bus and engine restart, must not cause the flywheel speed to drop below its critical minimum speed where the flywheel will be ineffective. A schematic diagram of a typical series on-off engine power drive subsystem is shown in Figure 3-1.

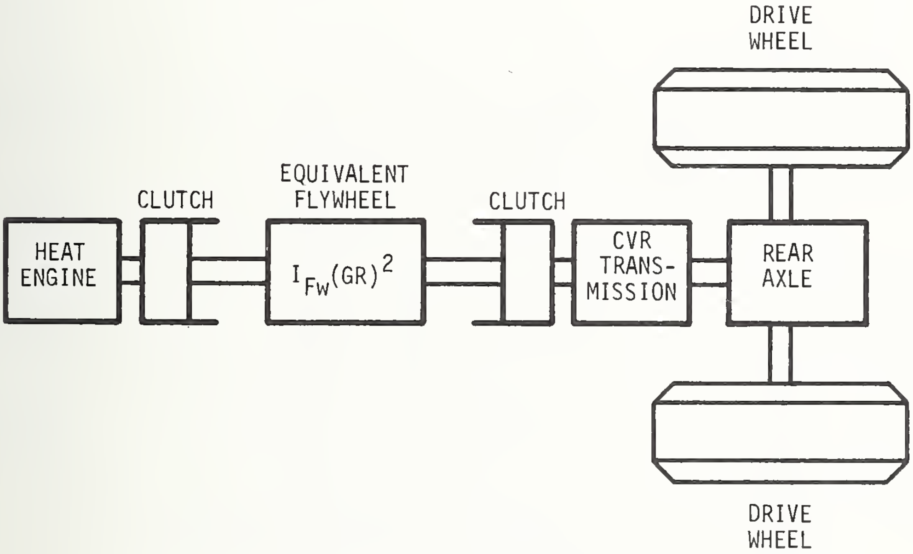


FIGURE 3-1. SERIES ON-OFF ENGINE OPERATION SCHEMATIC

3.3 PROGRAM

3.3.1 Subsystem Description

The computer simulation program used in this work is an adaptation of the University of Wisconsin hybrid vehicle computer program which was developed under the sponsorship of the U.S. Department of Transportation Office of University Research (Reference 3).

The TSC computer program is sufficiently flexible to permit any vehicle configuration to be simulated and to allow rapid evaluation of subsystem components as well as alternate configurations. Basically, the program consists of three parts; input, simulation and output.

The input element accepts the following information:

Vehicle configuration masses and moments of inertia.

Vehicle power drive subsystem component characteristics; e.g., heat engine data; gear box, flywheel, CVRT transmission, rear axle gearing and drive wheel characteristics.

Driving cycle characteristics for vehicle route; e.g., total length, number of stops, roadway grade, and wind conditions.

The simulation element of the program accepts input information controlling the simulation time step, time interval for storing simulation results, and operational control parameters. All simulation calculations and comparisons with necessary vehicle system operating constraints are performed within this element and the calculation results are output at the specified time intervals for the output element.

The output element accepts the simulation results and output specifications to produce printouts in a variety of formats. Summaries, tabular outputs and graphic plots of the desired simulation parameters are possible.

A flywheel hybrid vehicle power drive subsystem layout to be simulated for this study is shown in Figure 3-2. A schematic organization of the simulation program is illustrated in the block diagram of Figure 3-3. The equations of motion of the vehicle basic to the simulation program were delineated in Section 2-3. Representative input data are given in Figure 3-4.

The simulation program is started with an initialization step. After proper initialization, the reflected flywheel rotor element of the flywheel package is assumed spinning at 2,100 rpm (the basic flywheel is rotating at 11,000 rpm, and the engine and transmission "sees" the reflected rotor inertia at the gear box). The on-off mode of operation requires the engine to be turned off when the 'reflected' flywheel is fully charged; that is spinning the drive shaft at 2,100 rpm. Thus, after initialization, the heat engine is in the 'off' condition and the engine clutch disengaged.

The transmission clutch is engaged and the transit bus begins the driving cycle with calculations performed for time increments of 0.10 seconds. For each time increment, the 'automatic driver' compares the current vehicle speed (at the beginning of the time increment) with the required speed at the end of the time increment (from the driving schedule), and then determines the required drive shaft torque to bring the transit bus to the desired speed. The required torque is provided by the energy extracted from the flywheel. The extraction of energy from the flywheel causes the flywheel to slow down.

As previously noted, the engine is in the "off" mode when the flywheel is fully charged to 2,100 rpm drive shaft speed. When the reduction in flywheel speed due to energy extraction reaches the minimum threshold value (a function of vehicle speed, see Figure 3-5) the engine clutch is engaged and the engine operates in the "on" mode. Fuel is consumed only when the engine is in the "on" mode. Fuel consumption is calculated based on the fuel rate provided as input data.

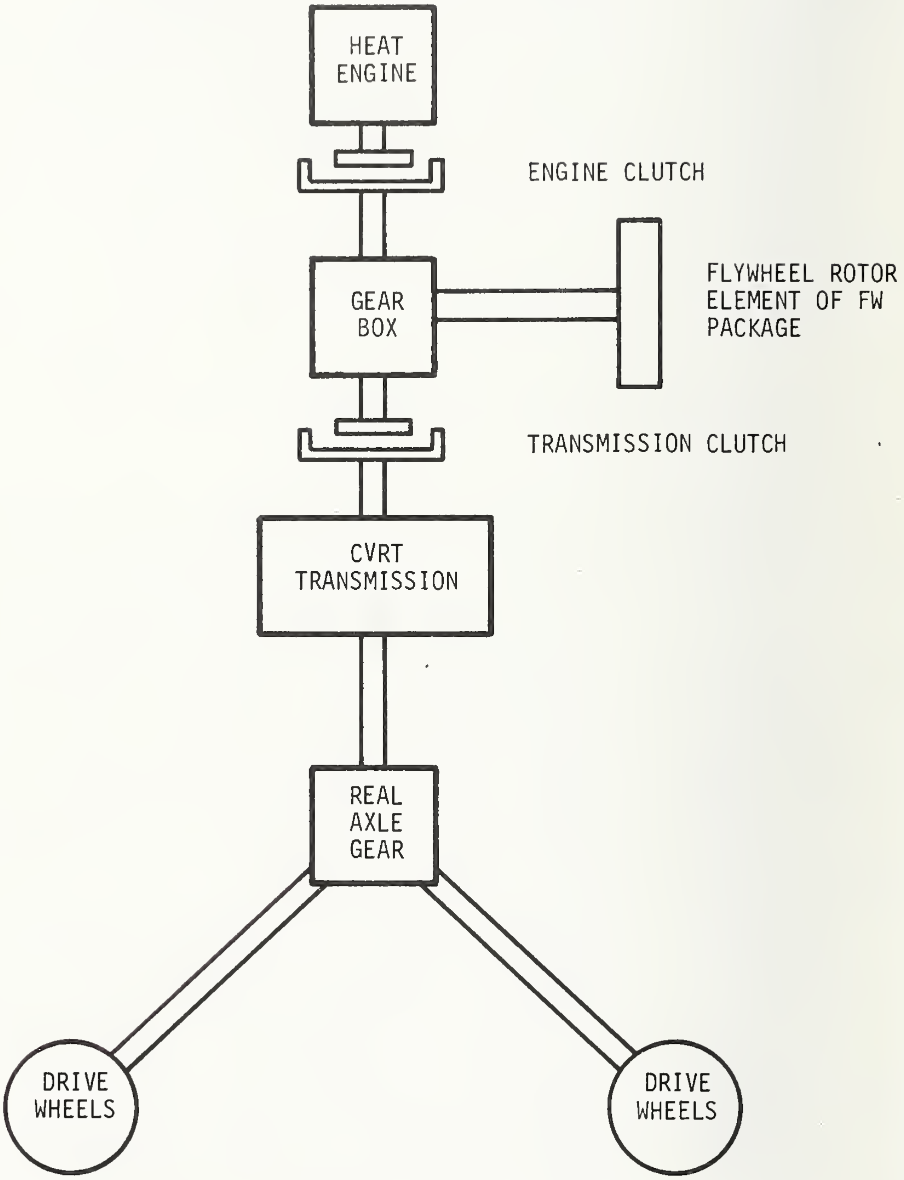


FIGURE 3-2. COMPONENT LAYOUT DIAGRAM OF HYBRID POWER DRIVE TRAIN SUBSYSTEM

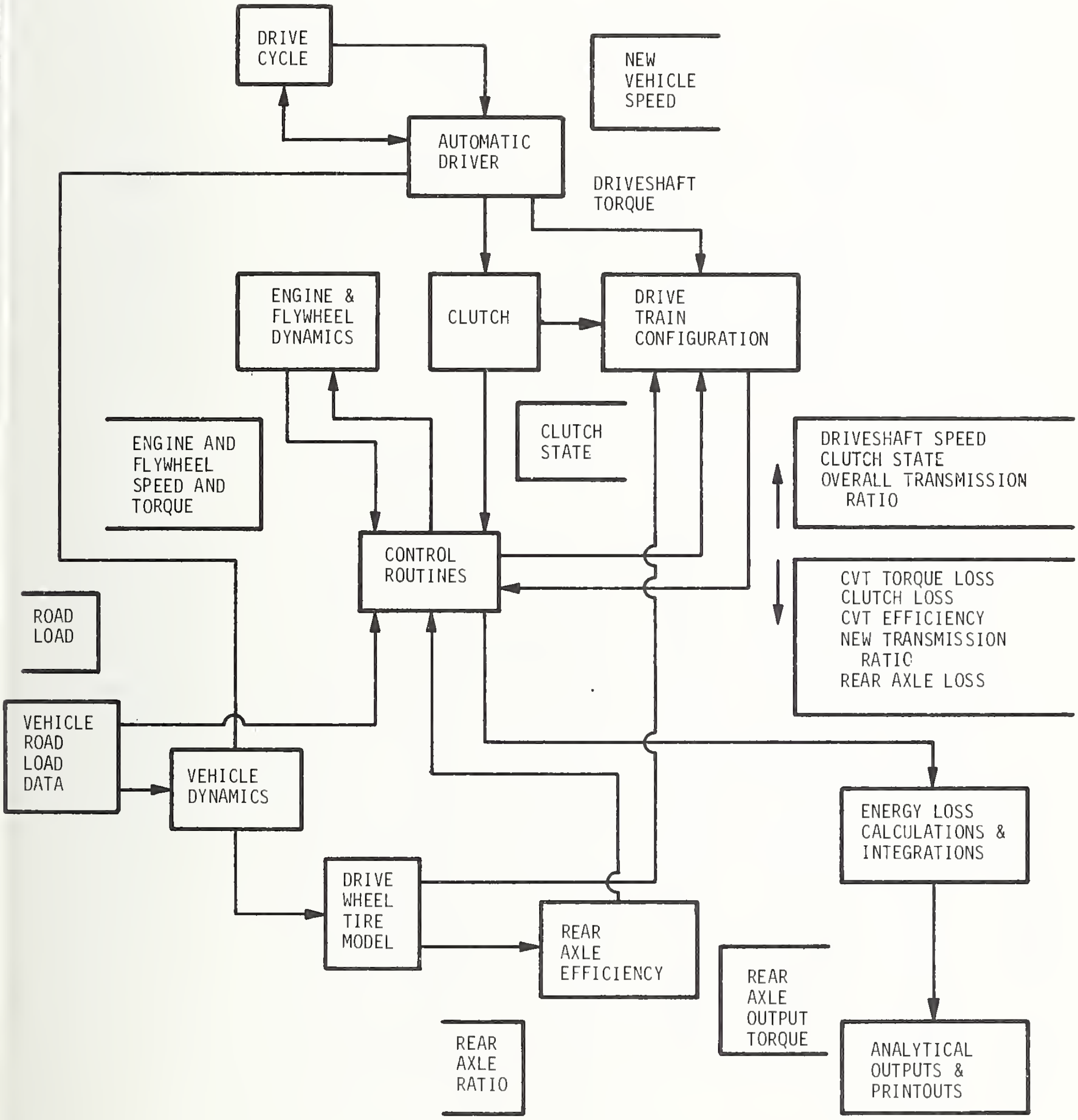


FIGURE 3-3. SIMPLIFIED SYSTEM BLOCK DIAGRAM

```
DIESEL WITH FLYWHEEL
                    DIGITAL SIMULATION OF A 30000 LB HYBRID
```

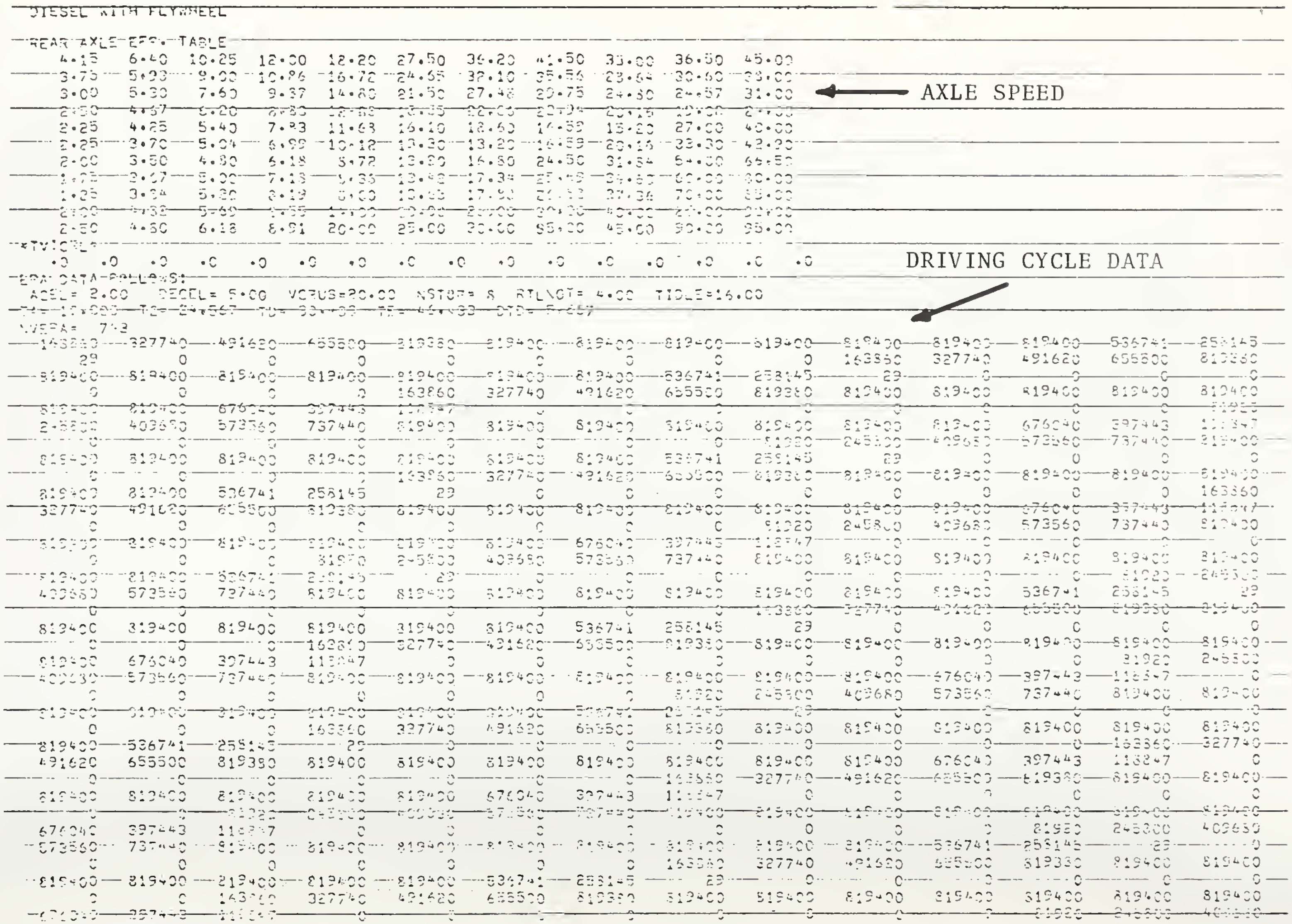
Typical Data

```
CVT EFF. TABLE
    12.13      22.03      22.39      22.39      22.39      22.39      22.39
    11.14      16.23      11.19      11.19      11.19      11.19      11.19
     7.12      13.69       5.60       5.60       5.60       5.60       5.60
     5.13      12.55       2.80       2.80       2.80       2.80       2.80
     3.24      11.45        .00        .00        .00        .00        .00
     6.17      11.60       5.60       5.60       5.60       5.60       5.60
     9.20      12.68      11.19      11.19      11.19      11.19      11.19
    15.30      14.91      22.39      22.39      22.39      22.39      22.39
    20.46      20.11      44.77      44.77      44.77      44.77      44.77
    12.13      19.58      19.79      29.29      29.29      29.29      29.29
    11.14      13.42      15.21      14.65      14.65      14.65      14.65
     7.12      10.23      13.36       7.32       7.32       7.32       7.32
     5.13       9.64      12.56       3.66       3.66       3.66       3.66
     3.24       8.45      11.80        .00        .00        .00        .00
     6.17       8.57      12.00       7.32       7.32       7.32       7.32
     9.20       9.72      12.77      14.65      14.65      14.65      14.65
    15.30      12.01      14.35      29.29      29.29      29.29      29.29
    20.46      17.19      18.17      58.58      58.58      58.58      58.58
    12.13      18.25      17.43      17.21      36.19      36.19      36.19
    11.14      11.56      12.27      13.13      18.10      18.10      18.10
     7.12       8.82       9.31      12.16       9.05       9.05       9.05
     5.13       7.64       8.85      11.31       4.52       4.52       4.52
     3.24       6.48       7.76      11.51        .00        .00        .00
     6.17       6.81       7.61      12.55       9.05       9.05       9.05
     9.20       7.59       8.67      12.35      18.10      18.10      18.10
    15.30       9.76      10.73      13.45      36.19      36.19      36.19
    20.46      14.84      15.14      15.58      72.39      72.39      72.39
    12.13      17.36      15.64      15.16      43.10      43.10      43.10
    11.14       9.98      10.08      10.90      21.55      21.55      21.55
     7.12       7.12       7.67       9.15      10.77      10.77      10.77
     5.13       5.85       6.56       8.41       5.39       5.39       5.39
     3.24       4.71       5.44       7.74        .00        .00        .00
     6.17       4.46       4.95       7.77      10.77      10.77      10.77
     9.20       5.42       5.94       8.43      21.55      21.55      21.55
    15.30       7.39       7.92       9.76      43.10      43.10      43.10
    20.46      11.74      11.91      12.75      86.19      86.19      86.19
    12.13      15.59       8.61       7.07       5.40      50.00      50.00
    11.14       9.50       6.30       5.44       5.47      25.00      25.00
     7.12       6.46       5.18       4.61       5.36      12.50      12.50
     5.13       4.94       4.85       4.20       5.38       6.25       6.25
     3.24       3.42       3.91       3.79       5.40        .00        .00
     6.17       5.93       5.60       5.24       6.42      12.50      12.50
     9.20       8.55       7.26       6.69       7.46      25.00      25.00
    15.30      13.57      10.43       9.81       9.54      50.00      50.00
    20.46      23.92      16.94      15.40      13.73     100.00     100.00
    12.13      11.57      11.78      12.13      12.82      56.90      56.90
    11.14       7.53       7.60       3.21       9.94      28.45      28.45
     7.12       5.59       5.64       6.17       8.61      14.23      14.23
     5.13       4.64       4.67       5.15       7.35       7.11       7.11
```

FIGURE 3-4. INPUT DATA - DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS (Sheet 1 of 6)
CVRT EFFICIENCY AS A FUNCTION OF SPEED AND TORQUE

```
DIESEL WITH FLYWHEEL
      3.24      4.89      4.95      5.77      7.83       .00       .00
      6.17      6.15      6.23      7.04      8.60     14.23     14.23
      9.20      7.56      7.56      8.26      9.46     28.45     28.45
     15.30     10.83     10.33     10.84     11.45     56.90     56.90
     20.46     19.41     17.36     16.60     16.28    113.81    113.81
     12.13     15.58     15.32     15.50     15.83     15.14     63.81
     11.14     10.37     10.10     10.59     11.68     13.31     31.90
      7.12      8.13      7.80      8.36      9.77     12.22     15.95
      5.13      7.03      6.55      7.23      8.81     11.69      7.98
      3.24      6.94      6.56      7.23      8.77     10.90       .00
      6.17      8.25      7.92      8.54      9.94     11.51     15.95
      9.20      9.62      9.31      9.65     10.93     12.17     31.90
     15.30     12.81     12.51     12.84     13.34     13.79     63.81
     20.46     20.98     19.93     19.35     19.12     18.93    127.61
     12.13     18.06     18.04     18.43     18.88     19.38     70.71
     11.14     12.54     12.35     12.89     13.74     15.21     35.35
      7.12     10.18      9.84     10.33     11.41     13.43     17.68
      5.13      8.98      8.59      9.03     10.27     12.56      8.84
      3.24      8.69      8.29      8.33     10.07     12.16       .00
      6.17     10.03      9.72     10.32     11.37     13.13     17.68
      9.20     11.40     11.19     11.80     12.72     14.15     35.35
     15.30     14.49     14.40     14.96     15.64     16.47     70.71
     20.46     22.40     22.05     21.96     22.11     22.09    141.42
     12.13     20.05     20.37     21.32     22.02     22.79     24.15
     11.14     14.36     14.46     15.24     16.27     17.73     19.37
      7.12     11.83     11.31     12.51     13.82     15.40     17.05
      5.13     10.66     10.53     11.15     12.64     14.28     15.93
      3.24     10.14     10.06     10.79     12.27     13.95     15.70
      6.17     11.48     11.52     12.32     13.61     15.23     16.98
      9.20     12.52     13.03     13.79     15.02     16.58     18.27
     15.30     16.02     16.25     17.27     18.13     19.42     20.79
     20.46     23.88     24.12     24.71     25.27     26.23     27.34
```

FIGURE 3-4. INPUT DATA - DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS (Sheet 2 of 6)



```
DIESEL WITH FLYWHEEL

REAR AXLE EFF. TABLE
    4.15    6.40   10.25   12.00   12.20   27.50   36.20   41.50   33.00   36.50   45.00
    3.75    5.23    9.00   10.96   16.72   24.65   32.10   35.56   23.64   30.60   33.00
    3.00    5.30    7.60    9.37   14.80   21.50   27.48   20.75   24.30   24.57   31.00
    2.50    4.57    6.20    8.80   12.88   18.35   22.05   22.94   20.15   19.00   27.00
    2.25    4.25    5.40    7.83   11.63   16.10   12.60   14.59   15.20   27.00   40.00
    2.25    3.70    5.04    6.99   10.12   13.30   13.20   16.59   20.16   33.30   42.30
    2.00    3.50    4.80    6.18    5.72   13.80   16.50   24.50   31.54   54.00   65.50
    1.75    3.17    5.00    7.13    5.35   13.48   17.34   25.49   34.67   60.00   80.00
    1.25    3.34    5.30    8.19    8.00   13.33   17.90   27.52   37.36   70.00   85.00
    2.00    4.32    5.69    7.55   11.00   20.94   25.00   30.30   40.00   21.00   [illegible]
    2.50    4.50    6.18    8.91   20.00   25.00   30.00   55.00   45.00   90.00   95.00
*TVICEL*
     .0     .0     .0     .C     .0     .0     .0     .C     .0     .0     .0     .C     .0     .0     .C     .0
EPA DATA FOLLOWS:
 ACEL= 2.00   DECEL= 5.00  VCRUS=20.00   NSTOP= 8   RTLNGT= 4.00   TIDLE=16.00
 T1= 10.000   T2= 24.567   T3= 33.833   T5= 46.833   DTD= 5.667
 NVEPA=  713
  163860  327740  491620  655500  819380  819400  819400  819400  819400  819400  819400  819400  536741  258145
      29       0       0       0       0       0       0       0       0  163860  327740  491620  655500  819380
  819400  819400  819400  819400  819400  819400  819400  536741  258145      29       0       0       0       0
       0       0       0       0  163860  327740  491620  655500  819380  819400  819400  819400  819400  819400
  819400  819400  676040  397443  118847       0       0       0       0       0       0       0       0   81920
  245800  409680  573560  737440  819400  819400  819400  819400  819400  819400  819400  676040  397443  118847
       0       0       0       0       0       0       0       0   81920  245800  409650  573560  737440  819400
  819400  819400  819400  819400  819400  819400  819400  536741  258145      29       0       0       0       0
       0       0       0       0  163860  327740  491620  655500  819380  819400  819400  819400  819400  819400
  819400  819400  536741  258145      29       0       0       0       0       0       0       0       0  163860
  327740  491620  655500  819380  819400  819400  819400  819400  819400  819400  819400  676040  397443  118847
       0       0       0       0       0       0       0       0   81920  245800  409680  573560  737440  819400
  819400  819400  819400  819400  819400  819400  676040  397443  118847       0       0       0       0       0
       0       0       0   81970  245800  409680  573560  737440  819400  819400  819400  819400  819400  819400
  819400  819400  536741  258145      29       0       0       0       0       0       0       0   81920  245800
  409680  573560  737440  819400  819400  819400  819400  819400  819400  819400  819400  536741  258145      29
       0       0       0       0       0       0       0       0  163860  327740  491620  655500  819380  819400
  819400  819400  819400  819400  819400  819400  536741  258145      29       0       0       0       0       0
       0       0       0  163860  327740  491620  655500  819380  819400  819400  819400  819400  819400  819400
  819400  676040  397443  118847       0       0       0       0       0       0       0       0   81920  245800
  409680  573560  737440  819400  819400  819400  819400  819400  819400  819400  676040  397443  118847       0
       0       0       0       0       0       0       0   81920  245800  409680  573560  737440  819400  819400
  819400  819400  819400  819400  819400  819400  536741  258145      29       0       0       0       0       0
       0       0       0  163860  327740  491620  655500  819380  819400  819400  819400  819400  819400  819400
  819400  536741  258145      29       0       0       0       0       0       0       0       0  163860  327740
  491620  655500  819380  819400  819400  819400  819400  819400  819400  819400  676040  397443  118847       0
       0       0       0       0       0       0       0  163860  327740  491620  655500  819380  819400  819400
  819400  819400  819400  819400  819400  676040  397443  118847       0       0       0       0       0       0
       0       0   81920  245800  409680  573560  737440  819400  819400  819400  819400  819400  819400  819400
  676040  397443  118847       0       0       0       0       0       0       0       0   81920  245800  409680
  573560  737440  819400  819400  819400  819400  819400  819400  819400  819400  536741  258145      29       0
       0       0       0       0       0       0       0  163860  327740  491620  655500  819380  819400  819400
  819400  819400  819400  819400  819400  536741  258145      29       0       0       0       0       0       0
       0       0  163860  327740  491620  655500  819380  819400  819400  819400  819400  819400  819400  819400
  676040  397443  118847       0       0       0       0       0       0       0       0   81920  245800  409680
```

FIGURE 3-4. INPUT DATA - DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS
(Sheet 3 of 6)

```
   DIESEL WITH FLYWHEEL                                                             DATE 25 JAN 1977      PAGE      0014
   573560    737440    819400    819400    819400    819400    819400    819400    819400    676040    397443    118847         0         0
        0         0         0         0         0         0     81920    245800    409680    573560    737440    819400    819400    819400
   819400    819400    819400    819400    819400    536741    258145        29         0         0         0         0         0         0
        0     81920    245800    409680    573560    737440    819400    819400    819400    819400    819400    819400    819400    819400
   536741    258145        29         0         0         0         0         0         0         0         0    163860    327740    491620
   655500    819380    819400    819400    819400    819400    819400    819400    819400    536741    258145        29         0         0
        0         0         0         0         0         0         0    163860    327740    491620    655500    819380    819400    819400
   819400    819400    819400    819400    676040    397443    118847         0         0         0         0         0         0         0
        0     81920    245800    409680    573560    737440    819400    819400    819400    819400    819400    819400    819400    676040
   397443    118847         0         0         0         0         0         0         0         0     81920    245800    409680    573560
   737440    819400    819400    819400    819400    819400    819400    819400    819400    536741    258145        29         0         0
        0         0         0         0         0         0    163860    327740    491620    655500    819380    819400    819400    819400
   819400    819400    819400    819400    536741    258145        29         0         0         0         0         0         0         0
        0    163860    327740    491620    655500    819380    819400    819400    819400    819400    819400    819400    819400    676040
   397443    118847         0         0         0         0         0         0         0         0    163860    327740    491620    655500
   819380    819400    819400    819400    819400    819400    819400    819400    676040    397443    118847         0         0         0
        0         0         0         0         0     81920    245800    409680    573560    737440    819400    819400    819400    819400
   819400    819400    819400    676040    397443    118847         0         0         0         0         0         0         0         0
        0
 END EPA DATA
```

END DRIVING CYCLE DATA

FIGURE 3-4. INPUT DATA - DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS
(Sheet 4 of 6)

```
 DIESEL WITH FLYWHEEL

      SCALEF     FUELWT     DELMIN
   .100E 01   .700E 01   .100E 00
      SPDINC    NSPEED
   .200E 03       11
ENGTRQ(I)
   .624E 03   .610E 03   .608E 03   .611E 03   .624E 03   .627E 03   .635E 03   .620E 03
   .620E 03   .620E 03   .620E 03
ENGTRQ(I)*SCALEF
   .624E 03   .610E 03   .608E 03   .611E 03   .624E 03   .627E 03   .635E 03   .620E 03
   .620E 03   .620E 03   .620E 03
ENGFUE(I)
   .330E 00   .330E 00   .330E 00   .330E 00   .388E 00   .361E 00   .332E 00   .300E 00
   .256E 00   .269E 00   .250E 00
     VELINC      NVEL
   .500E 01        8
ENGSTT(I)
   .900E 03   .900E 03   .107E 04   .125E 04   .142E 04   .159E 04   .176E 04   .194E 04
     TIMINC     NTIMES
   .000E 00        1
ENGSTP(I)
   .220E 04
     TRQIDL     FUIDL
   .223E 03   .130E 02
TRQIDL*SCALEF
   .223E 03   .130E 02
     CVTMAX
   .250E 04
ITSINV
      .0    303.0    606.0    909.0   1212.0        .0         .0         .0         .0         .0
    VMIN(1)    VMAX(1)    VINT(1)
   .000E 00   .640E 03   .200E 02
    VMIN(2)    VMAX(2)    VINT(2)
   .200E 03   .240E 04   .100E 03
**INERTIA UNITS: LB-FT-SEC/RPM    = (LB-FT*FT)*2*3.14159/60*32.174
        RIF
   .140E 02
        RIE
   .122E 00
      VVIMI     VVILFR     VVI2BR     VVI1CD       VVIM     VVIIRF     VVIMDR     VVIDRR
   .300E 05   .800E 02   .300E 05   .760E 00   .300E 05   .750E-02   .150E 05   .168E 01
       AVIU       AVIR     TSTIGR
   .142E 02   .600E 02   .370E 01
     VVIFUM     VVIFUS     VVISWE      VVISH     VVIICF
   .900E 00   .650E 00   .286E 03   .480E 02   .100E-01
     TVIUCT     TVIUTR     TVIURA     TVIUTX
   .360E 00   .205E 01   .336E 01   .405E 02
     TDOTMS      TDOTH  GAIN(FDT)
   .100E 00   .000E 00   .100E 00
```

FIGURE 3-4. INPUT DATA - DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS (Sheet 5 of 6) MISCELLANEOUS PARAMETERS: SEE APPENDIX D

```
  DIESEL WITH FLYWHEEL
          NGEAR
              4
GRATIO(I)
  .274E 00  .508E 00  .730E 00  .100E 01
RMINAS(I)
  .455E-01  .843E-01  .121E 00  .166E 00
RMAXAS(I)
  .127E 00  .236E 00  .339E 00  .464E 00
GEREFF(I)
  .925E 00  .935E 00  .945E 00  .975E 00
      PENDPS
  .100E-01
       A1CVT
  .750E 00
       RPMIN     RPMAX       EPS
  .189E 00  .467E 00  .900E 03
       FDPAS     ESMIN     FDRAG
  .247E-03  .100E 00  .300E-01
      RASCAL    CVTSCL
  .167E 01  .100E 01
        ISOT    LOADED
          10         1
          DT       DTF
  .100E 00  .200E-01
 CONSTANTS COMPUTED IN INCNHB
     NDIM(1)   NDIM(2)      AVIM        AVIS        RMIN        RMAX      RIEINV     RIEPIF
  .300E 02  .170E 02  .737E-01  .000E 00  .518E-01  .467E 00  .819E 01  .141E 02
      HPPSEC    VVIAMX     VVIAS        FNOT         NOT
  .278E-03  .462E 00  .365E 00  .500E 01         5.0
```

FIGURE 3-4. INPUT DATA - DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS (Sheet 6 of 6)

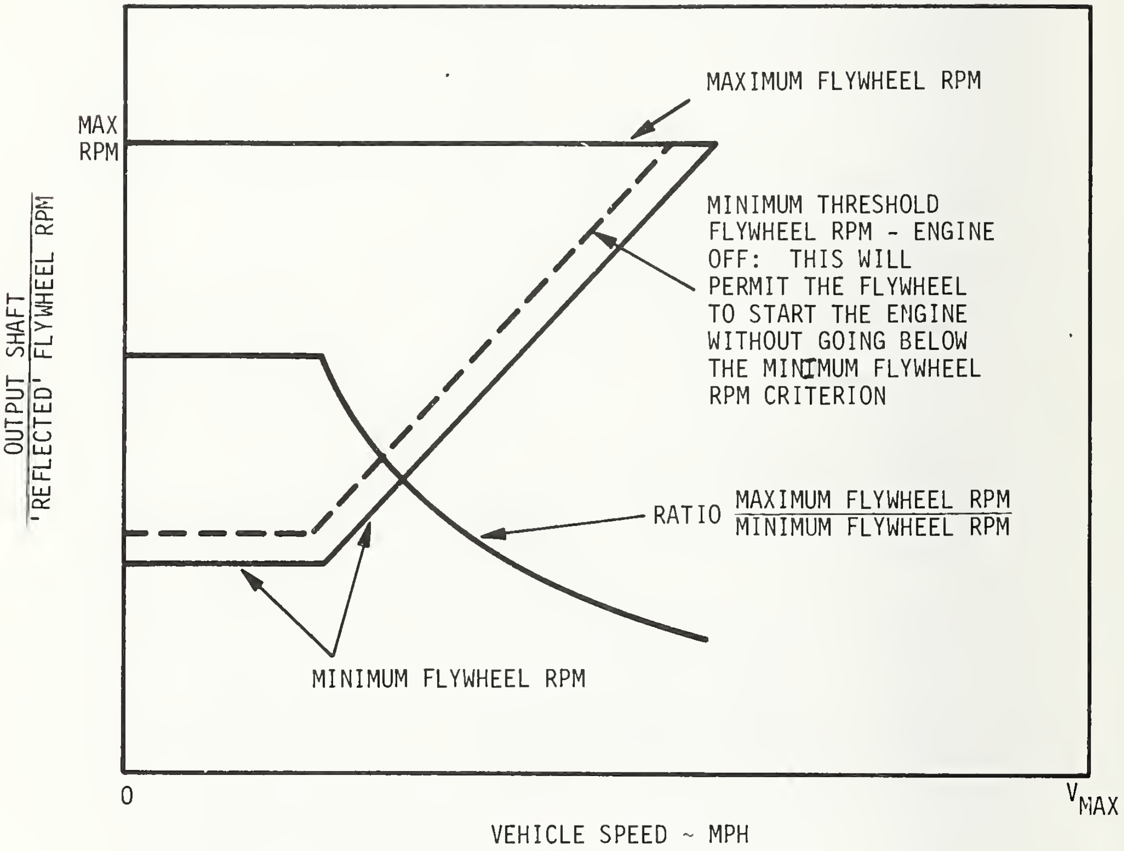


FIGURE 3-5. THRESHOLD LIMITS FOR FLYWHEEL SPEED

The calculations are carried through the drive shaft, CVRT transmission, rear axle and to the drive wheels. The dynamics of the vehicle are then determined and energy losses are integrated for each time increment of the driving cycle. The whole process then repeats until the end of the driving cycles constituting the route length.

Representative output data are illustrated in Figure 3-6.

The computer simulation program can be exercised for any drive cycle, any route length and/or any number of bus stops.

3.3.2 Hybrid Power Drive Simulation Results

The hybrid computer program was exercised for the series configuration with the engine operating in the on-off mode. In most of the cases the lower limit driving cycle illustrated in Figure 2-6 was used. The gross vehicle weight was 30,000 pounds. Enough variation in driving cycle and vehicle weight was studied to obtain an understanding of the effect of these variables. The computer runs were generated with variation in flywheel moment of inertia from 8 to 17 ft-lb-sec^2 (reflected to drive shaft) and for 6, 8 and 10 stops per mile.

When due consideration is given to fuel consumption, flywheel weight and frequency of on-off cycles, a flywheel moment of inertia of 14 lb-ft-sec^2 appears to be a reasonable initial design value.

Figure 3-7 illustrates the results of some simulation runs. The fuel consumption (gpm) decreases slowly with increasing values of flywheel moments of inertia over the entire range studied. For a fixed maximum flywheel rotational speed and fixed diameter, the flywheel weight varies linearly with moment of inertia. As shown in Appendix B, the flywheel system weight is approximately 2,200 pounds for a (reflected) inertia of 14 ft-lb-sec^2.

A comparison of fuel consumption performance of the hybrid power drive (inertia =14) with the baseline bus fuel consumption

```
DIESEL WITH FLYWHEEL

         ------VEHICLE-------- -------ENGINE------- ------FUEL RATE------ ACCUMU ------FLYWHEEL----- --DRIVETRAIN- GEAR
  TIME  DIST.  SPEED   ACCEL.   SPEED TORQUE POWER  (LB/  *INSTANTANEOUS* LATIVE  SPEED TORQUE OUTPUT  TR   RA  MO
 (SEC)  (MI)   (MPH) (MPH/SEC) (RPM) (FT-LB)  (HP) HP-HR)        (LB/HR)   (MPG)  (RPM) (FTLB)  (HP)  EFF. EFF. DE
  96.00  .249   7.98   2.112     0.      .0    .0     *              .00    4.21  1787.  -253.   86.  82.5 98.3 4.   2
  97.00  .251  10.21   1.999     0.      .0    .0     *              .00    4.25  1764.  -321.  102.  80.6 98.3 4.   2
  98.00  .254  12.20   1.999     0.      .0    .0     *              .00    4.31  1739.  -375.  124.  84.6 98.4 4.   2
  99.00  .258  13.98   2.113     0.      .0    .0     *              .00    4.37  1715.  -435.  158.  79.1 98.5 4.   3
 100.00  .262  16.21   1.999     0.      .0    .0     *              .00    4.44  1676.  -528.  168.  83.0 93.5 4.   3
 101.00  .267  18.20   1.999     0.      .0    .0     *              .00    4.52  1623.  -593.  186.  84.8 98.5 4.   3
 102.00  .272  20.13   -.001     0.      .0    .0     *              .00    4.61  1596.   -86.   26.  78.6 96.5 4.   4
 103.00  .278  19.99    .000     0.      .0    .0     *              .00    4.71  1593.   -79.   24.  78.2 96.3 4.   4
 104.00  .283  20.00   -.000     0.      .0    .0     *              .00    4.80  1587.   -80.   24.  78.3 96.4 4.   4
 105.00  .289  20.00    .000     0.      .0    .0     *              .00    4.89  1581.   -80.   24.  78.3 96.4 4.   4
 106.00  .294  20.00   -.000     0.      .0    .0     *              .00    4.99  1575.   -81.   24.  78.3 96.4 4.   4
 107.00  .300  20.00    .000     0.      .0    .0     *              .00    5.08  1569.   -81.   24.  78.2 96.4 4.   4
 108.00  .306  20.00   -.000     0.      .0    .0     *              .00    5.18  1562.   -81.   24.  78.2 96.4 4.   4
 109.00  .311  20.00    .000     0.      .0    .0     *              .00    5.27  1556.   -82.   24.  78.2 96.4 4.   4
 110.00  .317  20.00   -.000     0.      .0    .0     *              .00    5.36  1550.   -82.   24.  78.2 96.4 4.   4
 111.00  .322  20.00   -.000     0.      .0    .0     *              .00    5.46  1544.   -82.   24.  78.2 96.4 4.   4
 112.00  .328  20.00   -.000     0.      .0    .0     *              .00    5.55  1537.   -83.   24.  78.2 96.4 4.   4
 113.00  .333  20.00   -.000     0.      .0    .0     *              .00    5.65  1531.   -83.   24.  78.2 96.4 4.   4
 114.00  .339  20.00   -.000     0.      .0    .0     *              .00    5.74  1525.   -83.   24.  78.2 96.4 4.   4
 115.00  .344  20.00   -.000     0.      .0    .0     *              .00    5.84  1518.   -84.   24.  78.2 96.4 4.   4
 116.00  .350  20.00   -.000     0.      .0    .0     *              .00    5.93  1512.   -84.   24.  78.2 96.4 4.   4
 117.00  .356  19.82  -3.500     0.      .0    .0     *              .00    6.02  1511.  -687.  -198.  83.0 99.0 4.   4B
 118.00  .361  16.14  -3.398     0.      .0    .0     *              .00    6.11  1557.   513.  -152.  86.0 98.9 4.   4B
 119.00  .365  12.76  -3.399     0.      .0    .0     *              .00    6.18  1588.   353.  -116.  83.5 98.8 4.   4B
 120.00  .368   9.36  -3.399     0.      .0    .0     *              .00    6.23  1611.   278.   -85.  83.1 98.8 4.   4B
 121.00  .370   5.93  -3.403     0.      .0    .0     *              .00    6.26  1625.   179.   -55.  88.3 98.7 4.   3B
 122.00  .371   2.73  -3.172     0.      .0    .0     *              .00    6.29  1631.    89.   -23.  90.9 98.6 4.   1B
 123.00  .372    .41   -.229     0.      .0    .0     *              .00    6.29  1631.     0.     0.    .0 78.0 4.   1B
 124.00  .372    .22   -.189     0.      .0    .0     *              .00    6.30  1630.     0.     0.    .0 78.0 4.   1B
 125.00  .372    .03   -.159     0.      .0    .0     *              .00    6.30  1630.     0.     0.    .0 78.0 4.   1B
 126.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1630.     0.     0.    .0 78.0 4.   1
 127.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1629.     0.     0.    .0 78.0 4.   1
 128.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1629.     0.     0.    .0 78.0 4.   1
 129.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1628.     0.     0.    .0 78.0 4.   1
 130.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1628.     0.     0.    .0 78.0 4.   1
 131.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1628.     0.     0.    .0 78.0 4.   1
 132.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1627.     0.     0.    .0 78.0 4.   1
 133.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1627.     0.     0.    .0 78.0 4.   1
 134.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1626.     0.     0.    .0 78.0 4.   1
 135.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1626.     0.     0.    .0 78.0 4.   1
 136.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1626.     0.     0.    .0 78.0 4.   1
 137.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1625.     0.     0.    .0 78.0 4.   1
 138.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1625.     0.     0.    .0 78.0 4.   1
 139.00  .372    .00    .000     0.      .0    .0     *              .00    6.30  1624.    -1.     0.  36.2 78.0 4.   1
 140.00  .372   2.22   2.000     0.      .0    .0     *              .00    6.30  1615.  -108.   33.  76.2 98.1 4.   1
 141.00  .373   4.20   2.000     0.      .0    .0     *              .00    6.32  1607.  -138.   42.  82.2 98.1 4.   1
 142.00  .374   6.20   2.000     0.      .0    .0     *              .00    6.34  1594.  -201.   61.  85.9 98.2 4.   1
 143.00  .376   8.24   2.002     0.      .0    .0     *              .00    6.37  1578.  -274.   82.  84.3 98.2 4.   2
```

FIGURE 3-6. OUTPUT DATA – DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS WITH A MODIFIED EPA DRIVING CYCLE (Sheet 1 of 5)

```
DIESEL WITH FLYWHEEL

       -------VEHICLE--------  -------ENGINE-------- ------FUEL RATE------  ACCUMU  ------FLYWHEEL-----  -DRIVETRAIN-  GEAR
 TIME  DIST.  SPEED    ACCEL.   SPEED TORQUE POWER   (LB/   *INSTANTANEOUS* LATIVE  SPEED TORQUE OUTPUT  TR   RA   MO
 (SEC)  (MI)  (MPH) (MPH/SEC)  (RPM) (FT-LB)  (HP)   HP-HR)         (LB/HR)  (MPG)  (RPM) (FTLB)  (HP)  EFF. EFF. DE
144.00  .379  10.20    1.999       0.     .0    .0      *             .00    6.42   1555.  -351.  104.  84.0 98.3 4.    2
145.00  .382  12.20    1.999       0.     .0    .0      *             .00    6.47   1530.     0.    0.    .0   .0 4.    0
146.00  .386  14.22    1.999       0.     .0    .0      *             .00    6.53   1495.  -515.  146.  83.1 98.4 4.    3
147.00  .390  16.20    1.999       0.     .0    .0      *             .00    6.60   1455.  -592.  164.  85.2 98.5 4.    3
148.00  .395  18.22    1.999       0.     .0    .0      *             .00    6.68   1412.  -696.  187.  82.0 98.5 4.    4
149.00  .400  20.10    -.001     460.     .0    .0      *             .00    6.77   1380.  -193.   59.  78.7 96.5 3.    4
150.00  .405  19.99     .000     947.     .0    .0      *             .00    6.87   1351.  -135.   35.  78.2 96.3 3.    4
151.00  .411  20.00    -.000    1149.     .0    .0      *             .00    6.96   1342.  -115.   29.  78.2 96.4 3.    4
152.00  .417  20.00     .000    1351.  610.2 156.5    .330          51.66    6.97   1351.   512. -132.  78.2 96.4 2.    4
153.00  .422  20.00    -.000    1387.  610.7 160.9    .330          53.05    6.83   1387.   515. -136.  78.2 96.4 2.    4
154.00  .428  20.00     .000    1423.  612.3 165.5    .336          55.54    6.69   1423.   518. -140.  78.2 96.4 2.    4
155.00  .433  20.00    -.000    1460.  614.6 170.4    .343          59.00    6.54   1460.   523. -145.  78.2 96.4 2.    4
156.00  .439  20.00    -.000    1496.  617.0 175.4    .357          62.59    6.39   1496.   527. -150.  78.2 96.4 2.    4
157.00  .444  20.00    -.000    1534.  619.4 180.4    .368          66.34    6.24   1534.   532. -155.  78.2 96.4 2.    4
158.00  .450  20.00    -.000    1571.  621.9 185.6    .379          70.25    6.09   1571.   536. -160.  78.2 96.4 2.    4
159.00  .455  20.00    -.000    1609.  624.1 190.7    .387          73.67    5.93   1609.   540. -166.  78.3 96.4 2.    4
160.00  .461  20.00    -.000    1647.  624.6 195.4    .382          74.62    5.78   1647.   543. -170.  78.4 96.4 2.    4
161.00  .467  20.00    -.000    1685.  625.2 200.1    .377          75.46    5.64   1685.   545. -175.  78.0 96.4 2.    4
162.00  .472  20.00    -.000    1723.  625.8 204.8    .372          76.18    5.51   1723.   546. -179.  76.7 96.4 2.    4
163.00  .478  19.92   -3.500    1766.  626.4 209.6    .367          76.27    5.33   1766.  1194. -402.  86.5 99.0 2.    4B
164.00  .483  16.14   -3.398    1845.  628.5 220.0    .355          78.20    5.26   1845.  1021. -359.  81.5 98.9 2.    4B
165.00  .487  12.76   -3.399    1914.  631.3 229.3    .345          79.20    5.13   1914.   932. -340.  81.7 98.8 2.    4B
166.00  .490   9.52    -.251    1973.  633.7 237.5    .337          79.95    4.99   1973.   624. -234.  29.8 81.1 2.    3B
167.00  .492   6.10   -3.656    2029.  633.2 244.0    .325          80.08    4.86   2029.   792. -306.  86.8 98.8 2.    2B
168.00  .493   2.52   -2.903    2079.  629.4 248.6    .320          79.57    4.72   2079.   623. -247.    .0 98.4 2.    1B
169.00  .494    .00    -.228    2123.  625.1 252.5    .313          79.06    4.59   2123.   620. -251.    .0 78.0 2.    1B
170.00  .494    .00     .000    2166.  622.9 256.4    .306          78.49    4.46   2166.   617. -254.    .0 78.0 2.    1
171.00  .494    .00     .000       0.     .0    .0      *             .00    4.35   2200.     0.    0.    .0 78.0 4.    1
172.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2200.     0.    0.    .0 78.0 4.    1
173.00  .494    .00     .000       0.     .0    .0      *             .00    4.35   2199.     0.    0.    .0 78.0 4.    1
174.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2198.     0.    0.    .0 78.0 4.    1
175.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2198.     0.    0.    .0 78.0 4.    1
176.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2197.     0.    0.    .0 78.0 4.    1
177.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2197.     0.    0.    .0 78.0 4.    1
178.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2196.     0.    0.    .0 78.0 4.    1
179.00  .494    .00     .000       0.     .0    .0      *             .00    4.35   2195.     0.    0.    .0 78.0 4.    1
180.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2195.     0.    0.    .0 78.0 4.    1
181.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2195.     0.    0.    .0 78.0 4.    1
182.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2194.     0.    0.    .0 78.0 4.    1
183.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2194.     0.    0.    .0 78.0 4.    1
184.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2193.     0.    0.    .0 78.0 4.    1
185.00  .494    .00     .000       0.     .0    .0      *             .00    4.36   2192.    -1.    0.  36.2 78.0 4.    1
186.00  .494   2.22    2.000       0.     .0    .0      *             .00    4.36   2183.  -106.   44.  76.2 98.1 4.    1
187.00  .495   4.20    2.000       0.     .0    .0      *             .00    4.37   2175.  -109.   45.  76.9 96.1 4.    1
188.00  .496   6.20    2.000       0.     .0    .0      *             .00    4.38   2166.  -152.   63.  83.6 98.2 4.    1
189.00  .498   8.20    1.999       0.     .0    .0      *             .00    4.40   2152.  -200.   82.  85.4 98.2 4.    1
190.00  .501  10.21    2.078       0.     .0    .0      *             .00    4.42   2137.  -263.  107.  83.3 98.3 4.    2
191.00  .504  12.20    1.999       0.     .0    .0      *             .00    4.45   2116.  -326.  131.  79.9 98.4 4.    2
```

FIGURE 3-6. OUTPUT DATA – DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS WITH A MODIFIED EPA DRIVING CYCLE (Sheet 2 of 5)

DIESEL WITH FLYWHEEL

```
         ------VEHICLE--------  --------ENGINE--------  -------FUEL RATE------  ACCUMU  -------FLYWHEEL-----  -DRIVETRAIN-  GEAR
  TIME   DIST.  SPEED   ACCEL.   SPEED  TORQUE POWER    (LB/    *INSTANTANEOUS* LATIVE  SPEED TORQUE OUTPUT  TR   RA   MO
  (SEC)  (MI)   (MPH) (MPH/SEC)  (RPM)  (FT-LB)  (HP)   HP-HR)        (LB/HR)    (MPG)  (RPM) (FTLB)  (HP)   EFF. EFF. DE
1440.00 3.877   2.22   2.000       0.      .0      .0      *              .00    8.70   1600. -108.    33.   76.2 98.1 4.   1
1441.00 3.878   4.20   2.000       0.      .0      .0      *              .00    8.70   1592. -139.    42.   82.4 98.1 4.   1
1442.00 3.880   6.20   2.000       0.      .0      .0      *              .00    8.70   1579. -203.    61.   86.1 98.2 4.   1
1443.00 3.882   8.24   2.002       0.      .0      .0      *              .00    8.71   1562. -278.    83.   83.8 98.2 4.   2
1444.00 3.884  10.20   1.999       0.      .0      .0      *              .00    8.71   1539. -353.   104.   84.1 98.3 4.   2
1445.00 3.887  12.20   1.999       0.      .0      .0      *              .00    8.72   1514.    0.     0.     .0   .0 4.   3
1446.00 3.891  14.22   1.999       0.      .0      .0      *              .00    8.73   1479. -519.   146.   83.3 98.4 4.   3
1447.00 3.895  16.20   1.999       0.      .0      .0      *              .00    8.74   1439. -598.   164.   85.4 98.5 4.   3
1448.00 3.900  18.22   1.999       0.      .0      .0      *              .00    8.75   1395. -702.   187.   82.2 98.5 4.   4
1449.00 3.905  20.10   -.001     525.      .0      .0      *              .00    8.76   1342. -188.    46.   78.2 96.3 3.   4
1450.00 3.911  19.99    .000     965.      .0      .0      *              .00    8.77   1333. -132.    34.   78.2 96.3 3.   4
1451.00 3.916  20.00   -.000    1147.      .0      .0      *              .00    8.79   1324. -114.    29.   78.3 96.4 3.   4
1452.00 3.922  20.00    .000    1338.   610.0   155.0   .330          51.14    8.78   1338.  511.  -130.   78.3 96.4 2.   4
1453.00 3.927  20.00   -.000    1374.   610.6   159.3   .330          52.66    8.75   1374.  514.  -134.   78.2 96.4 2.   4
1454.00 3.933  20.00    .000    1410.   611.4   163.7   .332          54.32    8.72   1410.  517.  -139.   78.2 96.4 2.   4
1455.00 3.939  20.00   -.000    1446.   613.8   168.6   .342          57.72    8.69   1446.  521.  -144.   78.2 96.4 2.   4
1456.00 3.944  20.00   -.000    1483.   616.2   173.5   .353          61.00    8.66   1483.  526.  -148.   78.2 96.4 2.   4
1457.00 3.950  20.00   -.000    1520.   618.6   178.6   .364          64.56    8.63   1520.  530.  -153.   78.2 96.4 2.   4
1458.00 3.955  20.00   -.000    1557.   621.0   183.7   .375          68.80    8.59   1557.  535.  -159.   78.2 96.4 2.   4
1459.00 3.961  20.00   -.000    1595.   623.4   188.9   .385          72.80    8.55   1595.  539.  -164.   78.3 96.4 2.   4
1460.00 3.966  20.00   -.000    1633.   624.4   193.7   .384          74.39    8.51   1633.  542.  -168.   78.3 96.4 2.   4
1461.00 3.972  20.00   -.000    1671.   625.0   198.4   .379          75.18    8.46   1671.  544.  -173.   78.4 96.4 2.   4
1462.00 3.977  20.00   -.000    1709.   625.6   203.1   .374          75.92    8.42   1709.  545.  -177.   77.2 96.4 2.   4
1463.00 3.983  19.82  -3.500    1752.   625.2   207.9   .369          76.62    8.38   1752. 1202.  -401.   86.9 99.0 2.   4B
1464.00 3.988  16.14  -3.398    1832.   628.0   218.2   .357          77.98    8.34   1832. 1024.  -357.   81.6 98.9 2.   4B
1465.00 3.992  12.76  -3.399    1901.   630.8   227.5   .347          79.02    8.29   1901.  935.  -333.   81.8 98.8 2.   4B
1466.00 3.995   9.52   -.251    1960.   633.2   235.7   .338          79.79    8.24   1960.  624.  -233.   30.0 81.0 2.   3B
1467.00 3.997   6.10  -3.666    2018.   634.2   242.8   .330          80.20    8.20   2018.  794.  -305.   86.9 98.8 2.   2B
1468.00 3.998   2.52  -2.903    2066.   630.4   247.5   .322          79.71    8.14   2066.  634.  -248.     .0 98.4 2.   1B
1469.00 3.999    .00   -.223    2110.   627.1   251.4   .315          79.22    8.09   2110.  621.  -249.     .0 78.0 2.   1B
1470.00 3.999    .00    .000    2153.   623.9   255.2   .306          78.66    8.04   2153.  618.  -253.     .0 78.0 2.   1
1471.00 3.999    .00    .000    2196.   620.6   259.0   .301          78.04    7.99   2196.  614.  -257.     .0 78.0 2.   1
1472.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2200.    0.     0.     .0 78.0 4.   1
1473.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2199.    0.     0.     .0 78.0 4.   1
1474.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2199.    0.     0.     .0 78.0 4.   1
1475.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2198.    0.     0.     .0 78.0 4.   1
1476.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2198.    0.     0.     .0 78.0 4.   1
1477.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2197.    0.     0.     .0 78.0 4.   1
1478.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2197.    0.     0.     .0 78.0 4.   1
1479.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2196.    0.     0.     .0 78.0 4.   1
1480.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2195.    0.     0.     .0 78.0 4.   1
1481.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2195.    0.     0.     .0 78.0 4.   1
1482.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2194.    0.     0.     .0 78.0 4.   1
1483.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2194.    0.     0.     .0 78.0 4.   1
1484.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2193.    0.     0.     .0 78.0 4.   1
1485.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2193.    0.     0.     .0 78.0 4.   1
1486.00 3.999    .00    .000       0.      .0      .0      *              .00    7.99   2192.    0.     0.     .0 78.0 4.   1
```

FIGURE 3-6. OUTPUT DATA – DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS WITH A MODIFIED EPA DRIVING CYCLE (Sheet 3 of 5)

```
DIESEL WITH FLYWHEEL                    JOINT PROBABILITY DENSITY (PER CENT)

                              ENGINE STEADY STATE TORQUE VS. ENGINE SPEED

TORQUE                                              SPEED INTERVALS
INTERVALS
          800  900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300
          900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400

  0- 20   .11  .21  .27  .48  .01  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
 20- 40   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
 40- 60   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
 60- 80   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
 80-100   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
100-120   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
120-140   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
140-160   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
160-180   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
180-200   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
200-220   .00  .00  .00  .00  .00  .00 1.09 1.47  .82  .00  .00  .00  .00  .00  .00  .00
220-240   .00  .00  .00  .00  .00  .00  .00  .00  .82 1.41 1.17  .73  .90 1.04 1.25  .05
240-260   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
260-280   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
280-300   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
300-320   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
320-340   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
340-360   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
360-380   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
380-400   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
400-420   .21  .27  .48  .01  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
420-440   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
440-460   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
460-480   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
480-500   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
500-520   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
520-540   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
540-560   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
560-580   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
580-600   .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
600-620   .00  .00  .00  .00  .00 1.09 1.47  .82  .00  .00  .00  .00  .00  .00  .00  .00
620-640   .00  .00  .00  .00  .00  .00  .00  .82 1.41 1.17  .73  .90 1.04 1.25  .05  .00
TORQUE
INTERVALS

TOTALS    .32  .48  .75 [illegible] .01 1.09 2.56 2.91 2.35 2.58 1.90 1.62 1.94 2.29 1.31  .05
```

FIGURE 3-6. OUTPUT DATA - DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS WITH A MODIFIED EPA DRIVING CYCLE (Sheet 4 of 5)

```
         DIESEL WITH FLYWHEEL

            14860 ITERATIONS TOOK PLACE OVER THE CYCLE
                 ONE SAMPLE TAKEN DURING EACH PROGRAM ITERATION

                 0 SAMPLES FELL BELOW THE MINIMUM TORQUE
                 0 SAMPLES EXCEEDED THE MAXIMUM TORQUE
             13131 SAMPLES FELL BELOW THE MINIMUM SPEED
                 0 SAMPLES EXCEEDED THE MAXIMUM SPEED

                  VEHICLE WEIGHT: 30000.0 LBS
                  ACTUAL FLYWHEEL INERTIA:    172.05 LB-FT-SEC
                  STOPS PER MILE: 3
                  DISTANCE=  3.9990   MILES
                  VCRUS=20,00 MPH; ACCEL= 2.00 MPH/SEC; DECEL= 3.41 MPH/SEC

                  CUMULATIVE FUEL CONSUMPTION FOR EACH MILE:
                  MILE     UNCORRECTED                       CORRECTED
                    1         5.927 MPG = .16873 GPM;      25.040 MPG = .03993 GPM
                    2         7.160 MPG = .13966 GPM;      11.632 MPG = .08597 GPM
                    3         7.825 MPG = .12780 GPM;      10.447 MPG = .09572 GPM
                    4         7.985 MPG = .12523 GPM;       9.969 MPG = .10031 GPM

                  ENERGY GENERATED BY ENGINE: - - - - - - - 58188.66 HORSEPOWER SECONDS
                  ENERGY OUTPUT FROM SYSTEM POWERPLANT: - - 45083.62
                  ENERGY RECOVERED IN REGENERATIVE BRAKING: 18325.96
                  ENERGY LEFT IN FLYWHEEL: - - - - - - - -  6405.31

                  ROAD LOAD ENERGY: - - - - - - - - - - - - 12051.01

                  ENERGY LOST IN EXCESS BRAKING:  - - - - -  1451.15
                  ENERGY LOST IN REAR AXLE: - - - - - - - -   953.26
                  ENERGY LOST IN CVT: - - - - - - - - - - - 11764.29
                  ENERGY USED BY TRANSMISSION CHARGE PUMP:     44.81
                  ENERGY LOST IN TRANSMISSION GEARS:  - - -  2838.73
                  ENERGY LOST IN THE CLUTCH:  - - - - - - -   558.79
                  ENERGY LOST IN FLYWHEEL GEAR: - - - - - -   891.31
                  ENERGY LOST TO FLYWHEEL FRICTION: - - - -  3278.68
                  ENERGY LOST TO ENGINE INERTIA:  - - - - - -2152.97
                  ENERGY LOST IN STARTING THE ENGINE: - - -   319.84
```

FIGURE 3-6. OUTPUT DATA – DIGITAL SIMULATION OF A 30,000 LB HYBRID BUS WITH A MODIFIED EPA DRIVING CYCLE (Sheet 5 of 5)

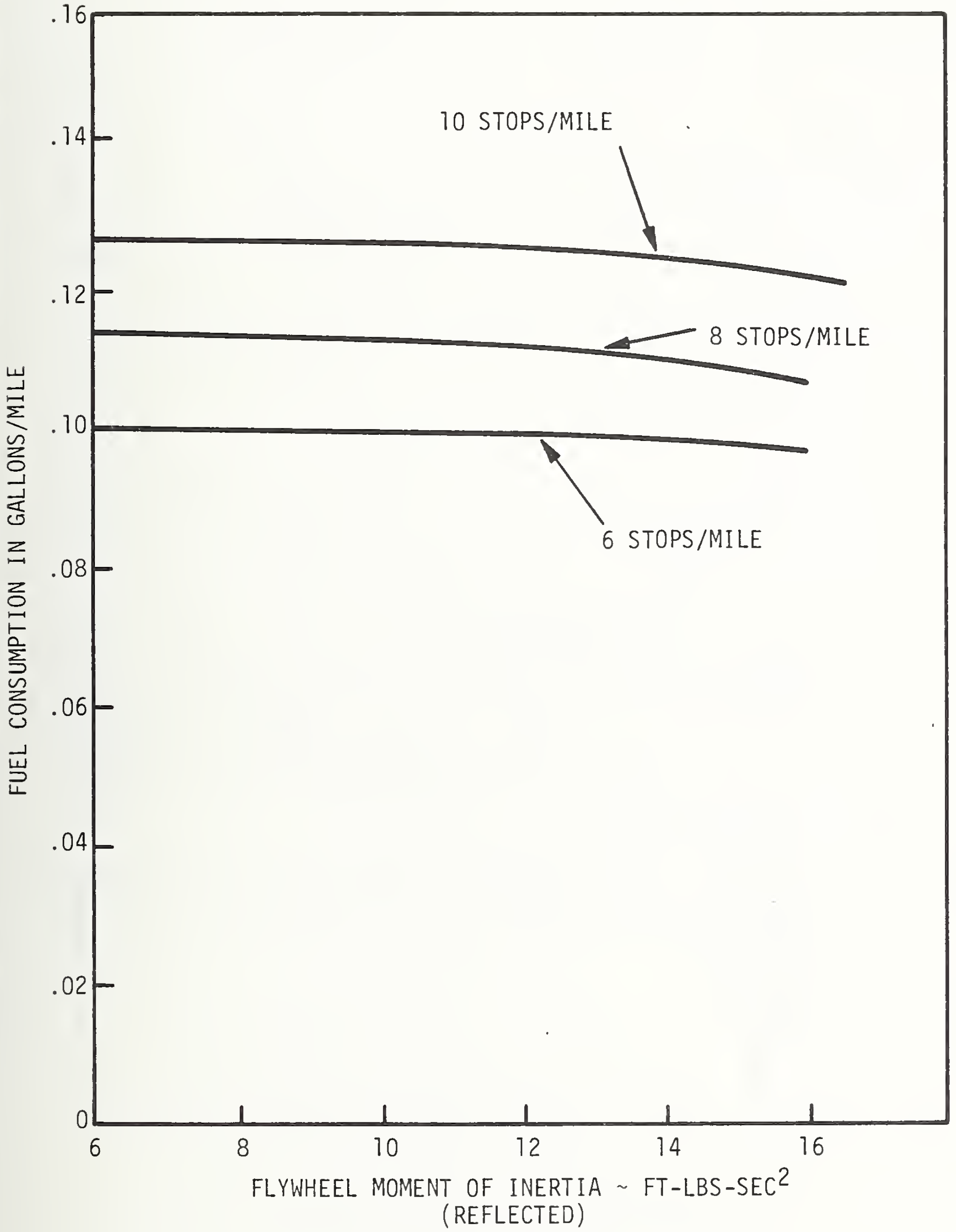


FIGURE 3-7. FUEL CONSUMPTION AS A FUNCTION OF FLYWHEEL MOMENT OF INERTIA

performance is shown in Figure 3-8. The hybrid bus shows sufficient improvement in fuel economy over the standard bus to warrant a design study culminating in an integrated hybrid power drive subsystem design.

Other analyses have been made using the computer simulation program from which the following can be predicted:

1. The diesel engine power may be reduced to approximately 100 horsepower (lower limit). This will result in a modest weight reduction of about 1,000 pounds in the hybrid propulsion subsystem, and a reduction in fuel consumption and exhaust emissions.
2. For other driving cycles representative of urban bus operation, the ratio of fuel consumption of the hybrid to fuel consumption of the baseline bus will not differ radically from the data shown in Figure 3-8.
3. A parallel hybrid configuration will show very little improvement in fuel economy (if any) over the series configuration. It will be less attractive because of its increased complexity and maintainability due to additional components.
4. The continuous mode of engine operation will not show any significant advantage over the on-off mode studied in this report.

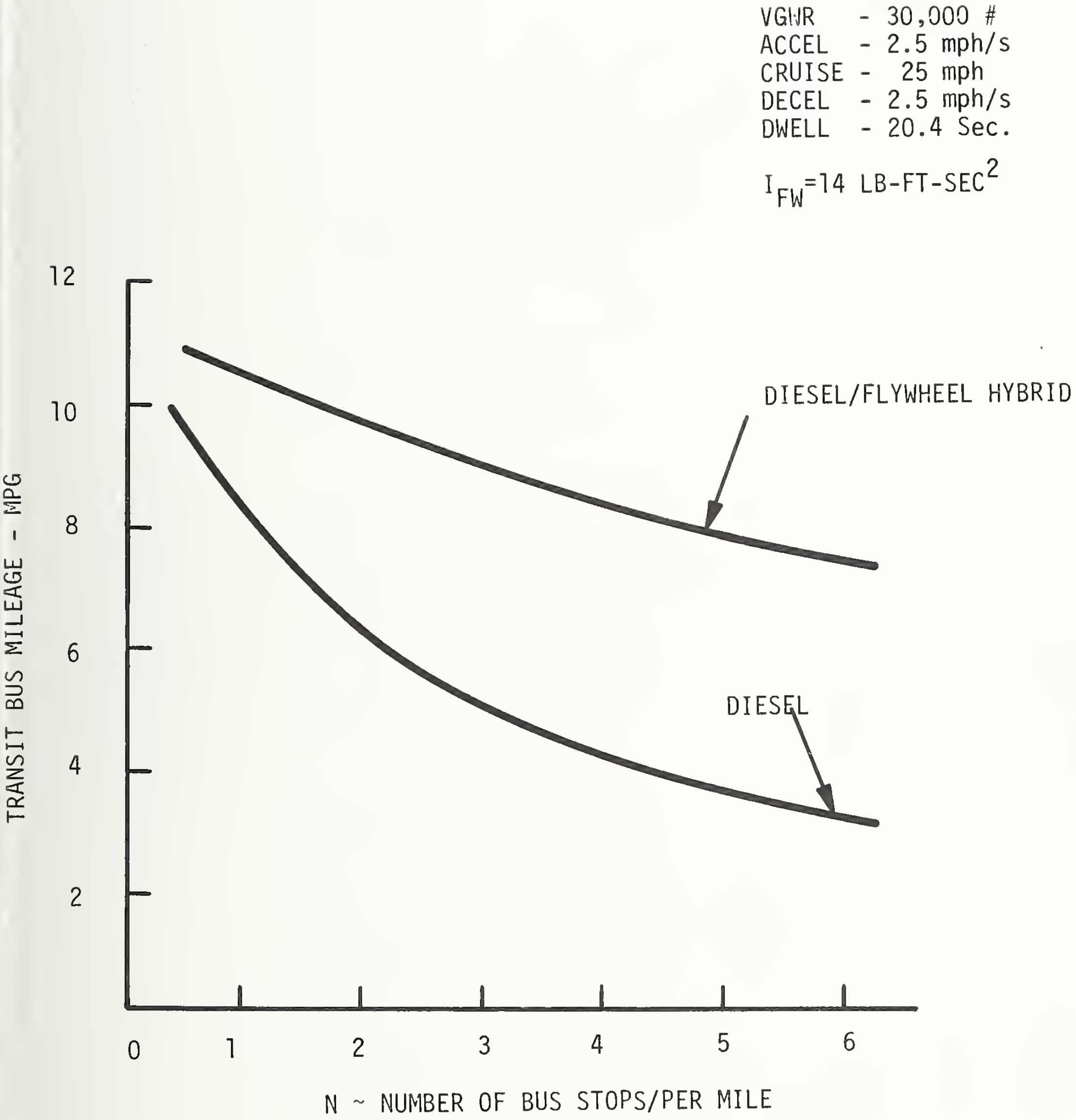


FIGURE 3-8. HYBRID TRANSIT BUS PERFORMANCE FROM COMPUTER SIMULATION

APPENDIX A
PREVIOUS FLYWHEEL AND HEAT ENGINE STUDIES

Flywheel Background

Robert Clerk (Reference 9) describes the early history of flywheel applicability to a number of vehicles including the flywheel-powered Howell Torpedo of 1885.

Most of these historical applications used steel flywheels. They illustrate the many advantages of flywheel energy storage even though the performance was very poor according to present technology. The advantages include:

1. Rapid charge/discharge capability;
2. Unlimited depth of discharge and number of cycles;
3. Simplicity, no maintenance, and infinite self life;
4. Flexibility, i.e., input/output can be electrical (AC or DC), hydraulic, or mechanical, or any combination; and
5. Autonomy from ambient environment.

But these early flywheels also had a number of very important disadvantages, which inhibited flywheel development until the present. Clerk described these disadvantages as:

1. Relatively poor energy storage per pound;
2. Poor efficiency, i.e., short rundown time, and
3. The ever-present hazard of catastrophic failure.

Although modern technology has provided an order of magnitude improvement in steel flywheel energy density and efficiency, the hazard problem has gotten proportionately worse. In spite of its present limitations, the flywheel is being introduced in an increasing number of applications throughout the world, including small road and non-road vehicles, buses, a variety of electrical power supplies, hoists, aircraft catapults, trains, and earth-moving vehicles.

The first major vehicular application of flywheels was the Oerlikon Electrogyro bus, used in European and African transit services in the 1950's. The buses were technically successful and economically feasible. However, long waits between recharges and difficulties imposed on the vehicle operators forced a gradual withdrawal of these buses from service.

Lockheed has worked on a program to demonstrate flywheel propulsion systems in San Francisco using a dual mode vehicle operating either from energy sypplied by the flywheel or from energy supplied by trolley wires (Reference 10). Initial analysis suggested an effective electric vehicle with increased route flexibility. Lockheed has also examined several flywheel and flywheel hybrid concepts in detail for the Environmental Protection Agency (Reference 11). These studies centered on the hybrid configuration of a small flywheel with a slightly reduced engine, e.g., about 50 percent of a normal power plant. This system was found to offer only minor advantages over the conventional automobile drive system in terms of economy and emissions. Furthermore, the high performance was limited to a small number of cycles because the small flywheel was quickly discharged. The study also found that a pure flywheel drive system was impractical for a conventional American automobile. The biggest drawback was the size of the drive system necessary to give a 5000-lb vehicle a 200-mile range. However, special purpose vehicles with a limited range were found to be excellent candidates for flywheel power systems.

Garrett Research* is currently testing flywheels as an element of a regenerative braking system for the New York subway system (Reference 12). Large flywheels absorb braking energy during stops and give it up upon demand during accelerations or emergencies. The Garrett tests indicate the regenerative system could reduce electrical energy demands by nearly 30 percent and, in addition, provide sufficient power for the trains to reach the next station in the event of a power failure.

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*Garrett Research and G.E. are presently involved in alternate flywheel storage systems studies for urban transit buses under UMTA sponsorship.

In addition to the flywheel power units just described, other variations of flywheel-driven vehicles are feasible as transportation alternatives. A more comprehensive look at the field of flywheel hybrids follows.

Aerospace Hybrid Study Review (1976 Draft)

The most recent study of hybrid propulsion was performed by the Aerospace Corporation (Reference 13). Both heat engine/battery and heat engine/flywheel propulsion systems were simulated, using a computerized model. The object of the study was to assess the potential of hybrid power drives in reducing energy consumption while still fulfilling Federal emission regulations. Only nickel-zinc batteries and steel flywheel storage means were considered sufficiently advanced to be included in a comparative study. Lead-acid batteries, hydraulic energy storage and composite flywheels were rejected as either inadequate or incompletely understood.

Three vehicles were considered: a 2,500 pound automobile; a 4,000 pound automobile; and a 6,000 pound van. The vehicles were configured to have the performance characteristics shown in Table A-1. In each case, the hybrid energy consumption was compared with published measurements of representative spark-ignition powered vehicles, manufactured to meet Federal emission standards of 1975/1976 model year.

TABLE A-1. PHYSICAL CHARACTERISTICS OF HYBRID VEHICLES

Vehicle Loaded Weight* (lb)	Tire Radius (ft)	Tire Pressure (psi)	Drag Area (ft^2)	Drag Coefficient (Dimensionless)
2500	0.98	25	19.0	0.45
4000	0.99	25	21.2	0.45
6000	1.22	40	35.0	0.76

*Loaded weight (includes 300 lb for occupants and luggage in cars, and 1000 lb for driver and payload in van).

Series and parallel power drive configurations were studied with the control routine depicted in Figure A-1. This is one example of a continuous, variable speed mode of engine operation.

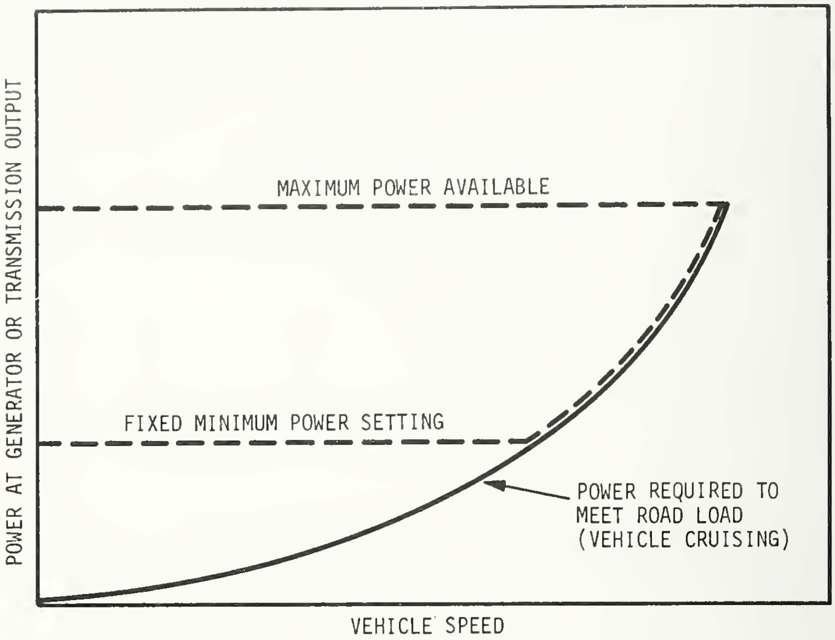

FIGURE A-1. Aerospace Study Control Routine

In this routine the power at the flywheel (or generator) is maintained at a fixed value up to a given vehicle speed. The shift from fixed power takes place only when the vehicle load (as determined at the engine transmission) exceeds the fixed power level. Then the power output is increased, following the increasing road load requirement. No other control routine was studied. The on-off type of heat engine operation, although considered attractive, was rejected because of unknown factors influencing the system lifetime and control system complexity.

Three types of driving cycles were selected for use in the comparative evaluation, namely, the EPA Urban, the EPA Highway and the U.S. Postal. Only the Postal is of interest for bus propulsion system evaluation. This is illustrated in Figure A-2.

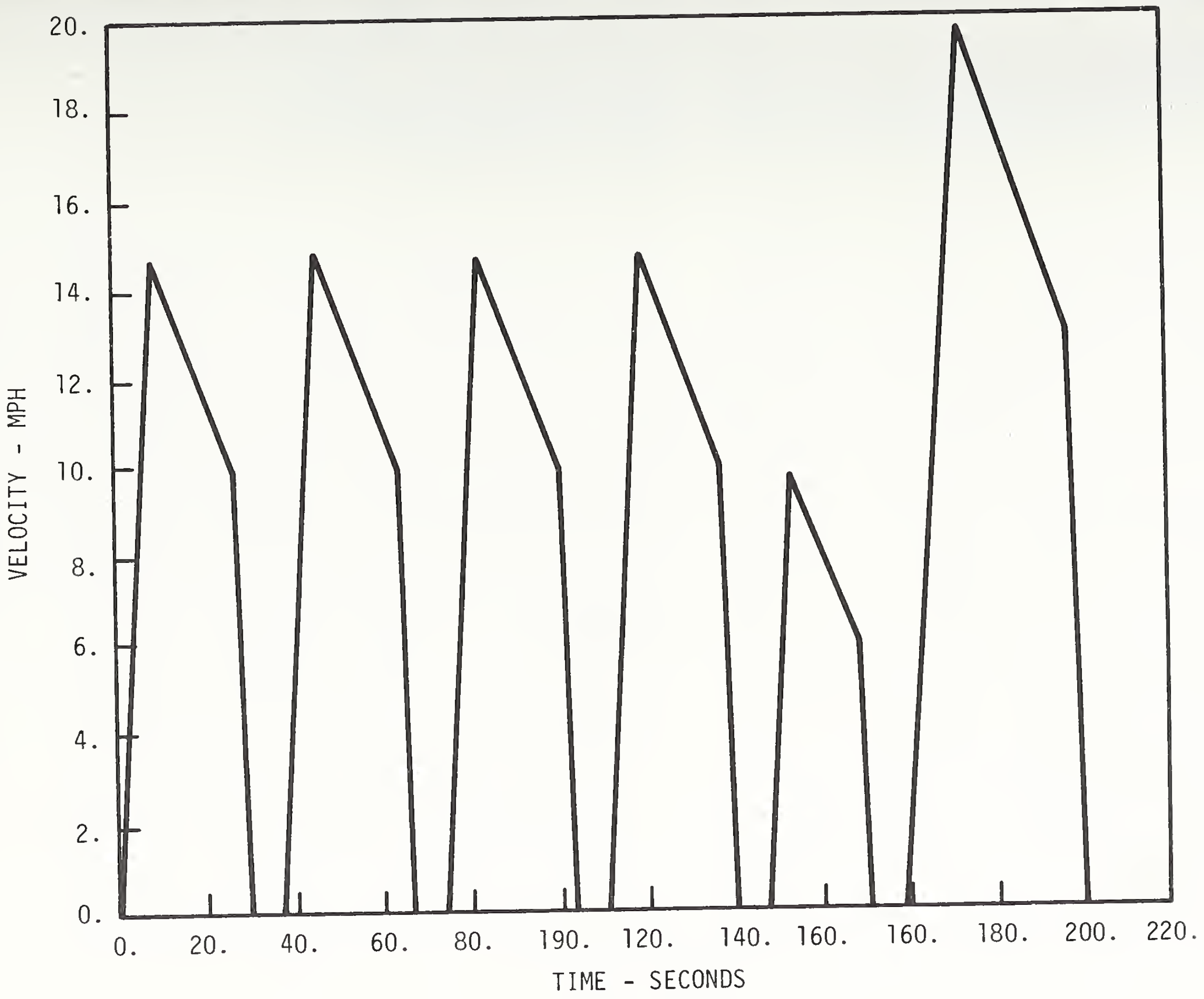

FIGURE A-2. POSTAL DRIVING CYCLE

The hybrid power drive examined in greatest detail was the series type configuration. For the heat engine/battery hybrid, it included: a conventional 1975 model year General Motors 140 CID, 4-cylinder, spark-ignition engine utilizing air injection, EGR, and oxidizing catalyst for emission control; nickel-zinc storage batteries with a specific energy density of 22 w-hr/lb;* an AC electric generator; a series-wound DC drive motor; and a solid-state chopper control to regulate battery power to the DC drive motor. For the heat engine/flywheel hybrid it included: a conventional 1975 model year General Motors 140 CID, 4-cylinder, spark-ignition engine; a 1.09 foot diameter, 25,600 rpm, steel flywheel; a continuously variable transmission; and a control system to regulate power flow. The flywheel system included a guard ring, vacuum housing and vacuum pump to support a pressure of 5 mm Hg.

The effects of a parallel configuration and of regenerative braking were determined separately. For the hybrid heat engine/battery parallel configuration, it was estimated that the required heat engine output shaft energy (exclusive of battery recharge energy, and accessory/engine auxiliary drive energy) would be 70 percent of that required in the series configuration, regardless of driving cycle. This figure was based on the improved efficiency of an automatic mechanical transmission compared with the combined efficiencies of the generator/drive motor set. For the hybrid heat engine/flywheel parallel configuration, the automatic transmission efficiency was fixed at 90 percent.

Regenerative braking was treated parametrically. Ten and fifteen percent energy recovery values were used for comparative purposes for the Urban Driving Cycle, and fifteen and thirty

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*Lead-acid batteries were found to be too heavy for the requirements of the study. Nickel-zinc batteries were used in the expectation that they (or their equivalents) will be available.

percent for the Postal Driving Cycle. The percent energy recovery refers to the percent of total driving cycle energy recovered and delivered into the energy storage system by the regenerative braking system. This energy recovery amount was then used to reduce the energy required from the heat engine for recharging the energy storage system.

A brief examination was made of the type of performance that might be expected from an advanced design, high-speed plastic-reinforced composite flywheel.* The intention was to provide greater energy storage capability than was available with the metal rotor and, thereby, improve the vehicle operating range whenever the on-board heat engine was not providing full recharge energy to the flywheel.

It was assumed for purposes of rotor sizing that a guard ring was not required, thereby allowing a maximum possible rotor diameter for a vertical power shaft mounting of the flywheel in the hybrid vehicle. The resulting design for the Kevlar rotor was 2 feet in diameter with a speed of 42,000 rpm.

An initial evaluation showed totally unacceptable performance because of excessive parasitic losses related to aerodynamic drag, bearing drag, seal drag, and vacuum pump power requirements. Hence, a large amount of engine power was required to keep the wheel recharged, and this resulted in energy consumption much higher than that of a conventionally-powered car.

Lowering the pressure in the flywheel housing to reduce windage losses only caused a large increase in pump power requirements. Therefore, a further step was made: assuming improved seals to hold pressures in the rotor housing down to 10^{-3} mm Hg without requiring an increase in pump power requirements over those needed to sustain 5 mm Hg pressure. Even this liberal

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*This part on composite flywheels is copied essentially verbatim from the Aerospace report (Ref. 13).

assumption did not produce results equivalent to those for the case of a steel rotor. It appears that high-speed composite wheels are not viable for the heat engine/flywheel hybrid vehicle, unless parasitic losses can be reduced to much lower levels.

The results of the Aerospace study of interest to our present bus propulsion study are listed in Table A-2. This tables shows the energy consumptions of the hybrids as a percentage of the energy consumption of the conventional-powered vehicles for variations in regeneration energy. In all cases shown here all energy is supplied by the on-board fuel. For those cases in which utility energy is used, the reader is referred to the many plots in the Aerospace study.

Table A-2 shows energy consumption reductions of as much as 43% for heat engine/battery hybrids. In contrast, for the heat engine/flywheel hybrids, the comparable reductions were as large as 55%. The parallel mode always shows greater reductions in energy consumption, although, for the Multi-Stop Postal Cycle, the reductions of parallel over series are insignificant.

The Aerospace study considers hybrid vehicle data from the most significant government and privately sponsored investigations. A synopsis containing a brief description of major components of the power drive is given for each hybrid automotive vehicle system design that has been examined in recent years (11 systems). Only nickel-zinc battery and steel flywheel energy storage devices were considered for use in these designs. A tabular review of these systems is included at the end of this appendix as Table A-4.

A review of components which could be used in hybrid power drive sybsystems was made in the Aerospace study and by TSC, and is included in Appendix B.

The majority of the designs that was reviewed evolved from the work sponsored by EPA in the period 1970-1972 and was primarily aimed at achieving major reductions in exhaust emissions rather than reductions in fuel consumption. Only two of the studies had configurations and projected fuel economies that are

TABLE A-2. % ENERGY CONSUMPTION (GALLONS PER MILE) HYBRID RELATIVE TO CONVENTIONAL Postal Cycle

TYPE HYBRID	VEHICLE WEIGHT POUNDS	REGENERATION %	ENERGY CONSUMPTION % SERIES	PARALLEL
BATTERY	2500	0	75	69
		15	71	66
		30	67	63
	4000	0	70	65
		15	66	62
		30	62	58
	6000	0	71	66
		15	66	62
		30	62	57
FLYWHEEL	2500	0	60	57
		15	57	55
		30	54	52
	4000	0	58	55
		15	55	52
		30	52	50
	6000	54	54	51
		50	50	47
		47	47	45

Source: Ref. 13.

of interest to our present study. These are the studies of the University of Wisconsin and the Technical School at Aachen, West Germany. Descriptions of these systems and some of the results achieved follow.

University of Wisconsin Hybrid Automobile - Design and Simulation*

An automobile, based on a 3,000 pound chassis and equipped with a powerplant incorporating a high-speed energy-storage flywheel, has been analyzed, designed and built by the University of Wisconsin under contract to the U.S. Department of Transportation (Ref. 3). Design and fabrication of the vehicle have been augmented by computer simulation studies of fuel economy and emissions.

A reciprocating piston, spark ignition gasoline engine, calibrated for minimum emissions, is connected through a clutch to the flywheel. When the flywheel speed drops below a predetermined value, the engine is turned on and run at full throttle for maximum efficiency. The engine is shut off when the flywheel reaches a maximum design speed. A four-speed manual shift transmission is used in combination with a hydrostatic power-split, continuously-variable transmission to allow for proper matching of the flywheel. Power is transferred partly through a hydrostatic transmission (pump and motor) and partly through a mechanical gear train. The system is designed to absorb regenerative braking energy during vehicle deceleration.

Basic specifications for the flywheel are:

1. Usable energy storage of 2/3 hp-hr
2. Maximum windage loss of 1 hp
3. Overspeed protection
4. Locked bearing protection

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*Verbatim from Reference 13.

5. Alloy steel construction
6. 250 ft-lb torque capability.

Principal features of the CVRT are:

1. A ratio range of 3.5:1
2. Torque control
3. 400 ft-lb torque capability
4. Designed for 80 mph maximum vehicle speed

Vehicle acceleration and regenerative braking are controlled through the CVRT by varying the hydrostatic pressure. Although a production vehicle would have automatic controls, the demonstration vehicle will be manually controlled.

A computer simulation was developed by the University of Wisconsin to predict the fuel economy and other performance characteristics of the flywheel vehicle. Table A-3, based on 1976 emission standards, shows comparative predictions for three different types of 3,000 pound vehicles and includes a breakdown of energy disbursement in each case. A potential improvement of 58% (in mpg) over the conventional car is shown by the near-term flywheel car. This predicted improvement is based on the ability to operate the engine at a brake specific fuel consumption (BSFC) of 0.50 lb/hp-hr. The ability to shut the engine off when the flywheel is not being recharged and the use of regenerative braking also contribute to saving energy.

An examination of the calculated energy losses shows the greatest losses occur in the CVRT. The arrows in Table A-3 designate those components, including the transmission, that the University of Wisconsin feels can be significantly improved in efficiency.

Technical School at Aachen, West Germany Hybrid Van - Design and Test

Development of this hybrid drive system with flywheel energy storage has been sponsored by the West Germany Federal Ministry of

TABLE A-3. EPA CYCLE ENERGY CONSUMPTION BY UNIVERSITY OF WISCONSIN

ITEMS	STANDARD 1976 2.3 LITER VEHICLE (HP. SEC.)		1976 FLYWHEEL 2.3 LITER VEHICLE (HP. SEC.)	POTENTIAL FROM CONTINUED R & D (HP. SEC.)
Road Load	3700		3702	3702
Rear Axle	470		536	536
Transmission	648		648	200* ←
		Flywheel	855	400 ←
Deceleration and Brakes	2555	CVT	1809	900* ←
Total (+) Work	7373	FW Gears	172	172
		Charge Pump	634	100 ←
		Excess Brakes	50	50
Idle & Coast Fuel .25#	1111*	Engine Clutch	99	99
		Engine Inertia	93	93
		Engine Start	66	66
Total Work	8484		8664	6318
Fuel for (+) Work	1.655#		1.202#	0.876#
Fuel Total	1.905#		1.202#	0.876#
(+) BSFC	0.808#/HP-HR		0.50#/HP-HR	0.50#/HP-HR
Mileage	24.0 MPG		38.0 MPH	52.0 MPG
Improvement			58%	117%

*Equivalent Work
Computed at .808#/HP-HR

*A Single CVT Package
will Replace Both Units

Data Source: Reference 3.

Research and Technology since 1973. The ability to recover energy during vehicle braking and to operate the heat engine at improved efficiency account for the reduction in fuel consumption over that of a conventional power drive.

A schematic of the parallel configuration power drive is shown in Figure A-3. The major components are an electric-motor/generator, a heat engine, a differential gear train, a flywheel primary energy storage system, and a battery secondary energy storage system. Modulation of the speed and torque of the motor/generator controls the torque and speed of the drive shaft leading to the wheels during vehicle motion, as well as energy recharging of the battery and the flywheel when the vehicle is stationary. Power from the battery is only used for producing the necessary motor torque and speed. Power from the flywheel is used to augment heat engine power for vehicle acceleration.

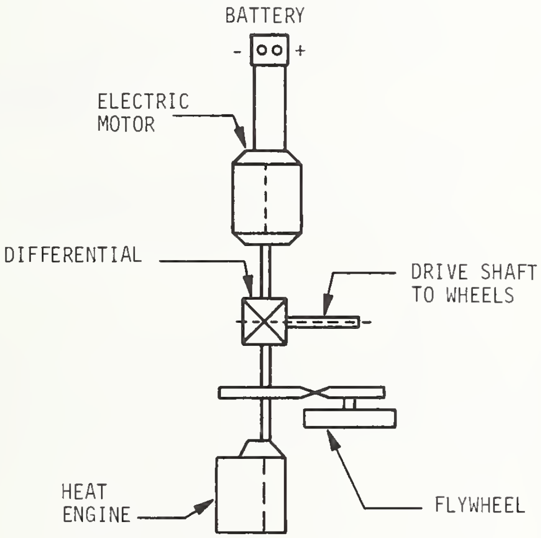

FIGURE A-3. SCHEMATIC OF THE TECHNICAL SCHOOL AT AACHEN HYBRID DRIVE WITH FLYWHEEL COMPONENT (Ref. 13)

A 2100 kilogram Volkswagen van was used for road tests on the installed hybrid drive train. The vehicle top speed is

70 km/hr; the system start-up time is about 20 seconds and the heat engine normally runs at about 3,500 rpm.

Road test results are shown in Figure A-4, which shows fuel consumption against the dynamic factor (a term developed to correlate the energy requirements of various types of driving cycles) for a conventional van and the hybrid van. The dynamic factors corresponding to various driving cycles are noted on the plot. A reduction in fuel consumption of about 40% is shown (with as much as 45% at the larger dynamic factors). Between 10% and 30% of the energy available for recovery during dynamic braking was actually recovered. For the case of 30% energy recovery efficiency, a 45% reduction in fuel consumption was achieved. Of this reduction, about 30% was attributed to recuperation of braking energy and 70% to improved operating efficiency of the heat engine.

Development work to optimize the system should reduce fuel consumption by 50% for a wide range in driving cycles.

The University of Florida Diesel/Battery Bus

The Mechanical Engineering Department of the University of Florida (Gainsville) has built a hybrid bus under the direction of Dr. Vern Roan (Reference 14). The basic vehicle is a modified Electrobus, Model 20. This bus is propelled by a 50 horsepower-electric motor and normally its energy source is a lead-acid battery pack. The batteries were resituated and a diesel engine and an ac generator were mounted in the normal battery position at the rear of the bus.

The diesel engine was sized so that it operates continuously at near rated load. The bus can be run on battery power alone, if desired. The sizing of the batteries and the diesel engine was accomplished with the aid of a computer simulation program. The total weight of the battery installation was quoted as 3,700 pounds.

Other elements of the system are the generator, the rectifiers and the controls. Two three-phase ac generators were chosen in order to minimize size and weight for a given power output.

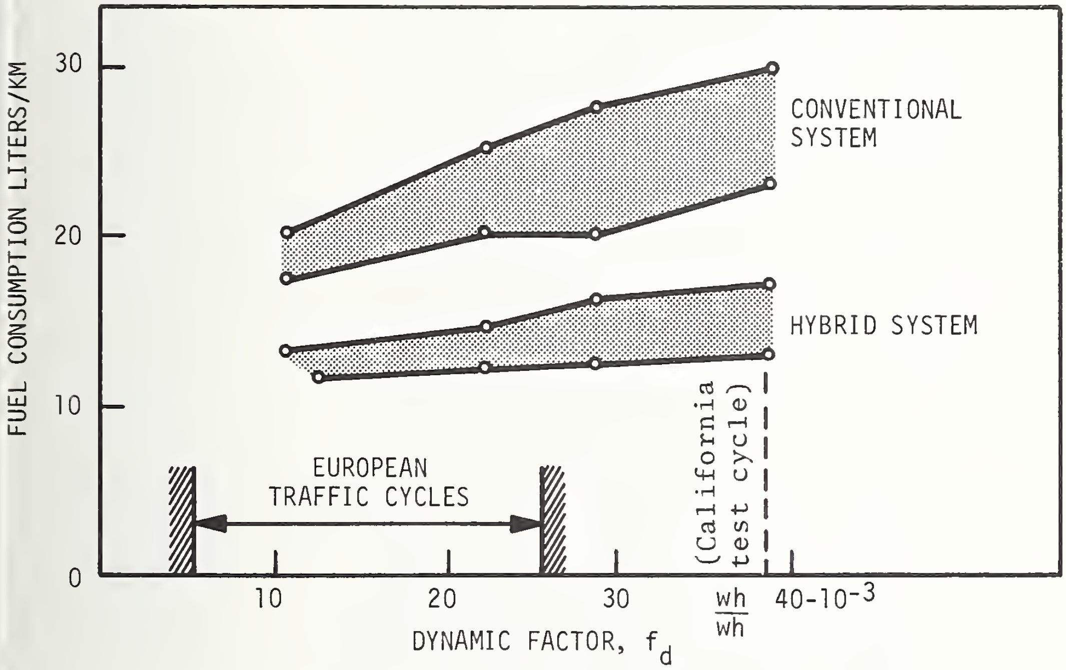

FIGURE A-4. FUEL CONSUMPTION FOR 2100 Kg VEHICLE AS A FUNCTION OF THE DYNAMIC FACTOR

Each generator charges a single battery pack weighing 1850 pounds. The total power output is 30 kW. Two bridge rectifiers are used to provide two independent voltage sources for charging the propulsion batteries. The control for the generator voltage is solid-state but the battery control system for the propulsion motor is composed of electromagnetic relays as in the normal Electrobus. There is controlled dynamic braking but no attempt was made to store energy through regeneration.

The computer simulation allowed study of the system response to various driving cycles. The generator output was varied and time of operation to discharge was analyzed. A typical analysis is shown in Figure A-5, which corresponds to the driving cycle of Figure A-6. On the pure electric mode the vehicle was predicted to travel 1.7 hours on this driving cycle (about 20 miles) but with increasing generator power the predicted time of operation increases until, at 28 kW, the simulation shows the bus running all day.

The hybrid bus of the University of Florida has gone through an initial road test program in which it closely followed the drive pattern of a diesel bus in revenue service on a transit route in Gainsville, Florida. Preliminary results from these tests indicate a 40% improvement in fuel economy over the standard bus.

Continuously Variable Ratio Transmission Devices

A very important component in the power drive connecting the flywheel energy storage device to the drive wheels is the transmission unit. It is necessary to match the energy required by the drive wheels to the energy extracted from the flywheel energy storage unit. There must be a smooth transition between the two to avoid excessive energy losses in the flywheel.

The Continuously Variable Ratio Transmission (CVRT) represents the most promising mechanical means to meet such transition requirements. A state-of-the-art review of CVRT's has been conducted at TSC.* Two primary CVRT types appeared to have the

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*Zuckerberg, H., "State-of-the-Art Review of Continuously Variable Ratio Transmissions (CVRT) Subsystems," KHL-TSC-76-1411, June 1976

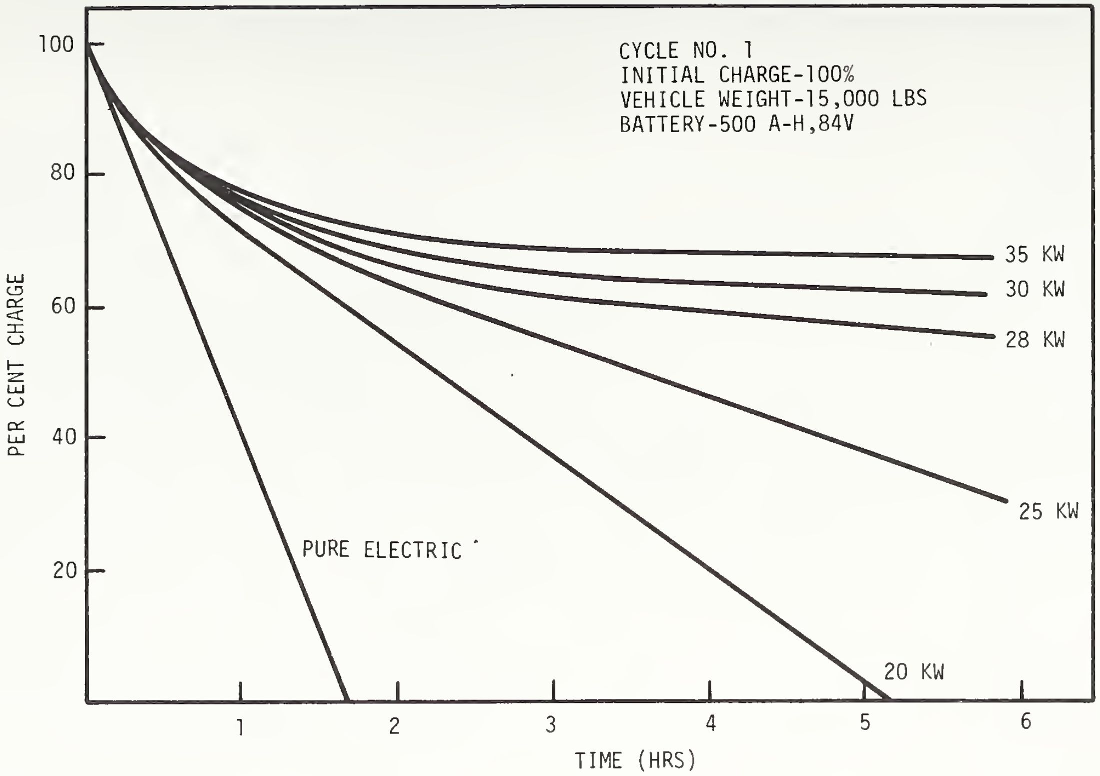

FIGURE A-5. PERCENT CHARGE AS A FUNCTION OF TIME FOR DIFFERENT GENERATOR SIZES, AND PURE ELECTRIC

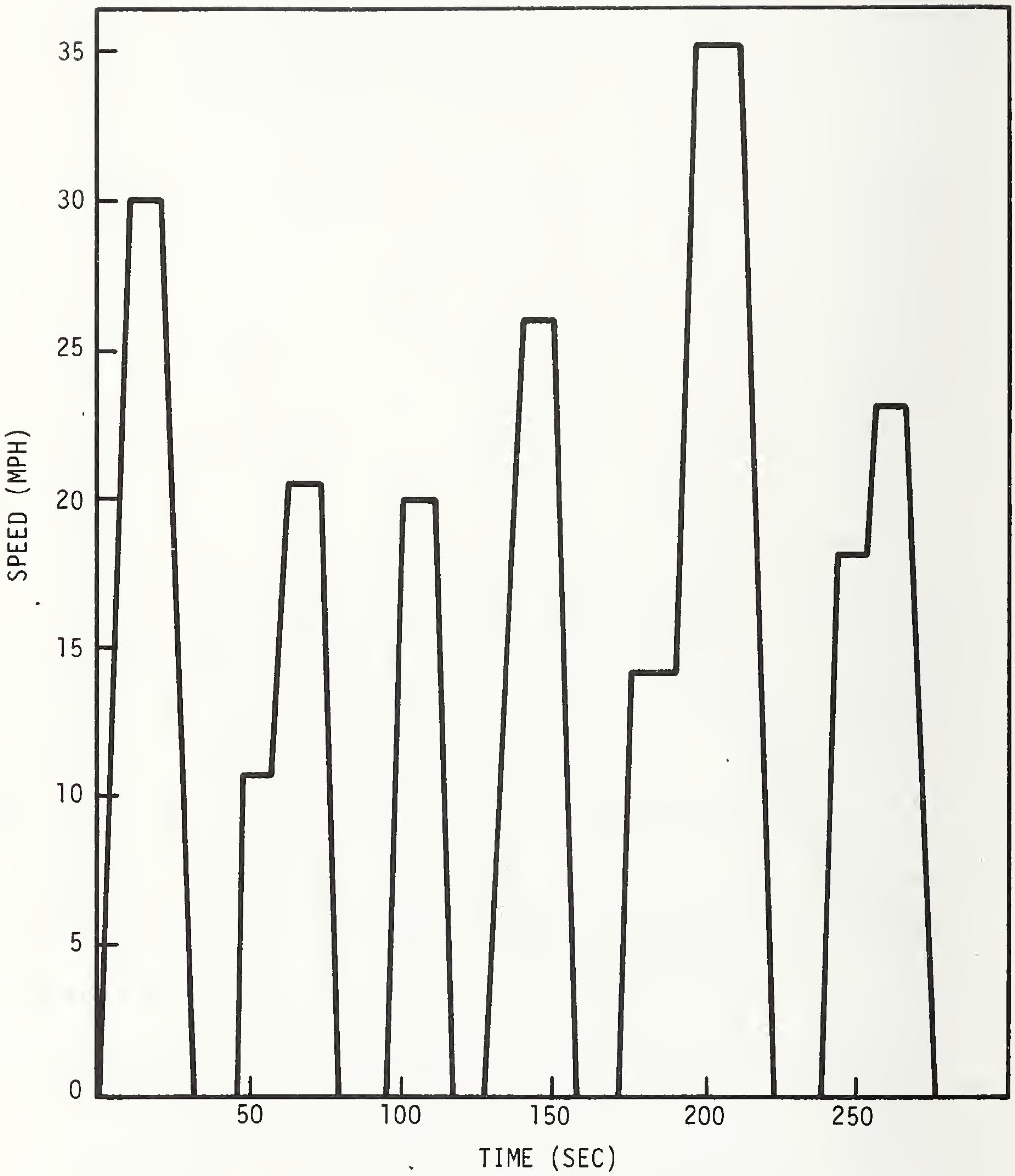

FIGURE A-6. SPEED AS A FUNCTION OF TIME CHART - DRIVING CYCLE #1, 6 STOPS PER MILE necessary viability; i.e., the hydromechanical and the traction drive types.

The hydromechanical transmission concept offers the best near-term (by 1980) CVRT for application with the hybrid power drive subsystem. The traction CVRT drive is considered to be the best long-term CVRT (by 1985) and beyond. An appreciable development effort will be necessary to bring the traction type CVRT to fruition.

Conclusions From Past Work

Very few of the hybrid drives that have been built to date show less fuel consumption than the heat engine-only drive when compared over the same drive cycle. In most cases, they have been developed for reasons other than enhanced fuel economy.

The multi-stop drive cycle, typified by urban bus operation, is a promising application of hybrids. This is especially true of the heat engine/flywheel because of its potential ability to use regenerated braking energy.

The parallel configuration requires more components and has more control complexity than the series configuration. In multi-stop operation the difference in energy efficiencies between the parallel and series configurations will be small (a few percent).

Regeneration can potentially reduce fuel consumption by 10% to 15% in multi-stop drive cycles.

Improvements in flywheel materials and fabrication technology promise weight reduction. However, since higher rotational speeds are required for such weight reduction, careful design studies must be made to determine the effect on parasitic losses, bearing life, seal effectiveness and safety.

Present lead-acid batteries when operated at the power levels required in automotive and bus driving, would have a cycle lifetime that is probably too short from an operational cost standpoint. On-going developments on these and other battery types project significantly better performance within five years.

Present knowledge of hydraulic energy storage and re-use is not sufficient to generate a heat engine/hydraulic simulation comparable to that with flywheel energy storage.

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 1 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	Petro-Electric, Ltd.	Mercedes-Benz
Objectives and Goals	Develop standard-size prototype car which meets FCCIP requirements	Develop a hybrid diesel electric bus
Power Train Elements		
Configuration	Parallel	Series
Heat Engine	Continuous operation, variable power, Mazda rotary, 70 cu.in., 9.4/1 compression ratio, 4-barrel carburetor, 130 HP max @ 7000 rpm, 115 ft-lb max torque @ 4000 rpm, weight 273 lb	OM 314 diesel engine, 232 cu.in., 4-cylinder, 65 HP @ 2200 rpm, operated for range extension of vehicle during highway driving
Emission Control System	Thermal reactor and EGR	Information not provided (INP)
Electric Traction Motor	DC shunt, separately excited motor, 120 volts, 115 amps continuous or 600 amps surge, 20 HP continuous rating, 60 HP max @ 5500 rpm, 190 ft-lb max torque, weight 240 lb	DC shunt, separately excited motor, 120 HP continuous rating, 201 HP max, 4800 rpm max motor speed, motor weight with driving gear, 1330 lb
Electric Power Conditioning and Control	INP*	Combined pulse width and pulse frequency modulation max pulse frequency, 250 Hz min pulse duration 1 ms, max current - 600 amps
Electric Power Generator	INP	3-phase generator with rectifier
Batteries	8 Gould, 12-volt, lead-acid batteries; voltage 48 or 96; 90 amp hours at 10-hr rate; 600 amps max current; weight 300 lb	Supplied by VARTA; rated voltage 380 volts; 5-hour cap city discharge 275 A-hr; storage capacity 104 kw-hr, weight 3.86 tons
Transmission	Manual 1973 Vega - 1st gear ratio 3.0/1.0 2nd gear ratio 1.85/1.0 3rd gear ratio 1.0/1.0	None

Data Source: Reference 13

*INP = Information not present.

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 2 of 15)

I. HEAT ENGINE/BATTERY SYSTEM (continued)

Organization	Petro-Electric, Ltd. (continued)	Mercedes-Benz (continued)
Objectives and Goals		
Differential	Gear ratio 5.0/1.0	Single reduction gear between electric traction motor & wheels
Performance		
Emissions		
HC	0.38 gr/mi, 40 mi, EPA test	INP
CO	2.42 gr/mi, 40 mi, EPA test	
NO_x	0.76 gr/mi, 40 mi, EPA test	
Acceleration	0-60 mph, 17.5 sec @ 4950 lb	≤ 2.25 mph/second from stop due to standees
Fuel Economy	8.75 mi/gal, EPA Urban Cycle	INP
Noise	70 db (A) max	INP
Max Speed	INP	43.5 mpg
Gradeability	INP	11% @ 13.7 mph
Range	INP	34.2 mi with stops every 0.25 mi on batteries only. All-day operation in hybrid mode
Payload	INP	66 - 110 passengers

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 3 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

ORGANIZATION	TRW Systems, Inc.	
Objectives and Goals	(1) Select and analyze performance of hybrid vehicle designs, (2) Define relative weights and costs, (3) Get data on catalysts, (4) Develop an accumulator, (5) Meet 75/76 emission goals.	
Power Train Elements		
Configuration	Parallel	Series
Heat Engine	Continuous operation, variable power, 71 Chevrolet Vega, 2300 cc (140 CID), 90 HP (max), aluminum block	INP
Emission Control System	Hydrocarbon accumulator of activated carbon catalytic converter with copper oxide on aluminum pellets	INP
Electric Traction Motor	Series DC, 30 HP at 7200 rpm, 180 terminal volts, 145 amps at 22.5 ft-lb continuous duty, 9-inch diameter frame GE BT 2338, 15-1/2 inches long, 150 lb	Series DC, 65 HP at 4650 rpm, 235 terminal volts, 235 amps at 74 ft-lb continuous duty, 12-1/2 inch diameter frame GE CD 280/2508, 21 inches long, 325 lb
Electric Power Conditioning and Control	200 VDC rectifier	240 VDC rectifier
Electric Power Generator	Salient pole alternator with slip rings, 10 kw @ 12,000 rpm, 95% efficient, rpm range 1200-12,000, 3-phase continuous duty, 40 lb, 8-in. diameter, 4 in. long, 400 Hz base speed	Salient pole alternator with slip rings, 58 kw @ 4000 rpm, 95% efficient, rpm range 4000-12,000, 3-phase, continuous duty, 160 lb, 10-in. diameter, 19 in. long, 400 Hz top speed
Batteries	INP	INP
Transmission	Electromechanical transmission; 2:1, 0 to 42.5 mph; 1.5:1, 42.5 to 55 mph; 1:1, 55 to 85 mph; planetary geartrain	INP

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 4 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

<table>
<tr><td>Organization</td><td colspan="2">TRW Systems, Inc.
(continued)</td><td></td></tr>
<tr><td>Objectives and Goals</td><td colspan="2"></td><td></td></tr>
<tr><td>Differential</td><td colspan="2">INP</td><td>INP</td></tr>
<tr><td><u>Performance</u></td><td colspan="2"></td><td></td></tr>
<tr><td>Emissions</td><td colspan="2">EPA Urban Cycle, gr/mi</td><td>INP</td></tr>
<tr><td></td><td><u>Cold</u></td><td><u>Hot</u></td><td></td></tr>
<tr><td>HC</td><td>2.84</td><td>.29</td><td></td></tr>
<tr><td>CO</td><td>46.8</td><td>3.26</td><td></td></tr>
<tr><td>NO_x</td><td>3.84</td><td>.32</td><td></td></tr>
<tr><td>Acceleration</td><td colspan="2">Designed for 440 ft in 10 sec</td><td>INP</td></tr>
<tr><td>Fuel Economy</td><td colspan="2">INP</td><td>INP</td></tr>
<tr><td>Noise</td><td colspan="2">INP</td><td>INP</td></tr>
<tr><td>Max Speed</td><td colspan="2">85 mph calculated at dry weight</td><td>85 mph calculated at dry weight</td></tr>
<tr><td>Gradeability</td><td colspan="2">INP</td><td>INP</td></tr>
<tr><td>Range</td><td colspan="2">INP</td><td>INP</td></tr>
<tr><td>Payload</td><td colspan="2">INP</td><td>INP</td></tr>
</table>

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 5 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	Minicars, Inc.	General Motors Corp.
Objectives and Goals	Determine relative reduction in exhaust emissions obtainable from a heat engine/battery hybrid car compared to same vehicle powered by heat engine alone.	Basic in-house research to explore use of low emission Stirling engine in a hybrid car.
Power Train Elements		
Configuration	Series hybrid, elements in line	Series, 1189 pounds
Heat Engine	Continuous operation, variable power Corvair engine, 6-cylinder opposed, clock-wise rotation, 164 cu.in. displacement, 8/1 compression ratio, single venturi carburetor with idle, main, and power jets, and an accelerator pump, heat air intake and manifold legs	Continuous operation, fixed power, Stirling engine (GPU-3), converted Army design with hydraulic controls single-cylinder, 8 HP at 3000 rpm, hydrogen working fluid at 1000 psi using combustion air blower.
Emission Control System	INP	INP
Electric Traction Motor	Lear-Siegler G22-3, 24V, 300 amp, 9.7 HP rated, shunt motor-generator, 94 lb, 2000-6500 rpm range	AC induction motor, 3-phase 24 VDC, 20 HP over 3:1 speed ratio
Electric Power Conditioning and Control	Modulated with both shunt field control and variable armature voltage, throttle delay mechanism	Variable frequency and voltage, all solid state, modulating inverter frequency and amplitude control
Electric Power Generator	(see Electric Traction Motor)	3-phase alternator, 19 kv nominal, 5500 rpm
Batteries	24 VDC or 48 VDC controlled by parallel-series relay (based on throttle depression) 12-12 volt batteries in different parallel-series configurations	14 series-connected lead-acid, SLI batteries, 44 A-hr at 20-hr discharge rate, 6.6 kw

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 6 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	Minicars, Inc. (continued)	General Motors Corp. (continued)
Objectives and Goals		
Transmission	Automatic transmission, 2.0/1 stall ratio at 1400 rpm, 1.82/1 low and reverse, 1/1 high gear	Planetary gear set
Differential	3.57 axle gear ratio	3.45/1.0
Performance		
Emissions	DHEW Cycle, Constant Volume Sampling (engine air-fuel ratio set at 16.5 to 1.0)	With 25 to 1 air-fuel ratio, and 1200°F heated combustion air
HC	3.15 gr/mi	HC (c6) 0.03 gr/hp-hr
CO	29.6 gr/mi	CO 0.5 gr/hp-hr
	1.0 gr/mi	NO_x 3.3 gr-hp-hr
Acceleration	0-60 mph, 23.2 sec on 3000-lb car (5.64 mph/sec peak); 32.1 sec on 4000-lb car (4.20 mph/sec peak)	0 - 30 mph in 10 sec
Fuel Economy	Internal combustion engine: 14.5 mpg at 15 mph, 10.3 mpg at 30 mph, 12.6 mpg at 50 mph; hybrid: 11.8 mpg at 15 mph, 8.8 mpg at 30 mph, 12.4 mpg at 50 mph; no all-electric mode possible	30-40 mpg at 30 mph, engine-only operation
Noise	INP	INP
Max. Speed	75 mph	55 mph with heat engine and batteries, 30 mph with heat engine alone

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 7 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	Minicars, Inc. (continued)	General Motors Corp. (continued)
Gradeability	INP	INP
Range	≈ 200 miles on heat engine; believed 2-5 miles on batteries only	Heat engine: 30-40 miles at 55 mph; electric power only: 15-30 miles at 30 mph
Payload	INP	3200 lb, with 2 passengers

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 8 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	The Aerospace Corporation	
Objectives and Goals	(1) Establish through computerized analysis and hardware data the design feasibility and potential for major reductions in exhaust emissions through use of hybrid heat engine/battery vehicles, (2) Establish general design goals for components & subsystems in the vehicle power train.	
Power Train Elements		
Configuration	Series	Parallel
Heat Engine	Continuous operation, variable power, 93 HP spark ignition engine operating at best brake specific fuel consumption of 0.5 and weighing 335 lb, for powering 4000-lb full-size hybrid family car	Continuous operation, variable power, 84 HP spark ignition engine operating at best brake specific fuel consumption of 0.5 and weighing 319 lb for powering 4000-lb full-size hybrid family car
Emission Control System	Lean carburetion (A/F=22), oxidizing catalyst, exhaust gas recirculation	Lean carburetion (A/F=22), oxidizing catalyst, exhaust gas recirculation
Electric Traction Motor	Forced-air cooled, 8000 rpm, 64 HP, DC, shunt-wound with step voltage and field control weighing 337 pounds. 90% peak efficiency, 80% average efficiency	Forced-air cooled, 8000 rpm, 35 HP, DC, shunt-wound with step voltage and field control weighing 250 lb. 90% peak efficiency, 80% average efficiency and capability of 3:1 short-term overload
Electric Power Conditioning and Control	Step voltage augmented with field control and armature current sensing, 12.5 lb motor controller, 18 lb AC rectifier, 3 lb generator controller, 99.5% control system efficiency	Step voltage augmented with field control and armature current sensing, 12.5 lb motor controller, 9 lb AC rectifier, 2 lb generator controller, 99% control system efficiency
Electric Power Generation	12,000 rpm alternator, rated at 51 kw, weighing 80 lb with rated efficiency of 90% and average efficiency of 80%	12,000 rpm alternator rated at 7 kw weighing 18 lb with rated efficiency of 90% and average efficiency of 80%

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 9 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	The Aerospace Corporation (continued)	
Objectives and Goals		
Batteries	38 amp-hr lead-acid or nickel-zinc with capacity of 8.36 kw-hr, weighing 398 lb and required to deliver 92.5 kw, 10 shallow charge-discharge cycles (3.5% of capacity max) per vehicle mile	38 amp-hr lead-acid or nickel zinc, with capacity of 8.36 kw weighing 460 lb and required to deliver 92.5 kw, 10 shallow charge-discharge cycles (3.5% of capacity max) per vehicle mile
Transmission	transmission not necessary	Modified conventional 3-speed automatic, rated at 64 HP, 90% efficiency, weighing 59 lb
Differential	95% efficiency, total rear axle drive weighing 80 lb	95% efficiency, total rear axle drive weighing 80 lb
Performance		
Emissions	Calculated for DHEW* Urban Driving Cycle	Calculated for DHEW* Urban Driving Cycle
HC	0.361 gr/mi	0.323 gr/mi
CO	0.494 gr/mi	0.442 gr/mi
NO_x	0.504 gr/mi	0.451 gr/mi
Acceleration	0-60 mph in 13 sec, peak acceleration of 5 mph/sec	0-60 mph in 13 sec, peak acceleration of 5 mph/sec
Fuel Economy	Calculated 11 mpg over DHEW Urban Driving Cycle	Calculated 12.5 mpg over DHEW Urban Driving Cycle
Noise	INP	INP
Max Speed	80 mph	80 mph
Gradeability	40 mph on 12% grade for 8 miles	40 mph on 12% grade for 8 miles
Range	200 miles	200 miles
Payload	Min. of 300 lb, passengers and luggage	Min. of 300 lb, passengers and luggage

*U.S. Department of Health, Education & Welfare, forerunner of EPA cycle.

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 10 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	University of Wisconsin
Objectives and Goals	Urban Vehicle Design Competition - 1972 - High fuel economy, low emissions
Power Train Elements	
Configuration	Parallel
Heat Engine	Continuous operation, variable power, Wankel, 53 HP (power train also functions in other modes with engine off)
Emission Control System	INP
Electric Traction Motor	DC, continuous rating of 18 HP
Electric Power Conditioning and Control	manual control
Electric Power Generator	INP
Batteries	Lead-acid, run between 50% and 90% full charge, 450 lb, 36 volts
Transmission	1:1 gear ratio
Differential	Gear ratio 1:1 to 1:2 depending on drive mode
Performance	
Emissions	Simulated LA4-1370 sec driving cycle, 60% efficient power train, no emission controls or devices
HC	.559 gr/mi
CO	27.7 gr/mi
NO_x	1.26 gr/mi

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 11 of 15)

I. HEAT ENGINE/BATTERY SYSTEM

Organization	University of Wisconsin (continued)
Objectives and Goals	
Acceleration	0.3 g (11 ft/s^2)
Fuel Economy	Simulated LA4-1370 sec, 60% efficient power train, 21.6 mpg
Noise	INP
Max Speed	INP
Gradeability	INP
Range	Mode 1, 5-10 miles (simulated); Modes 2, 3 INP (probably limited by gas tank size only)
Payload	INP

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 12 of 15)

II. HEAT ENGINE/FLYWHEEL SYSTEM

Organization	Lockheed Missiles and Space Company	Johns Hopkins University Applied Physics Laboratory
Objectives and Goals	(1) Determine through analysis feasibility of flywheel system as a low-emission propulsion system, (2) Demonstrate and evaluate performance of full-size flywheels	Conduct proof-of-principle tests of the "superfly-wheel" concept and evaluate through analysis the use of such flywheels to reduce automotive emissions.
<u>Power Train Elements</u>		
Configuration	Series	Series
Heat Engine	Continuous operation, variable power, medium-size V-8, 350 CID engine characteristics scaled from 176 HP for full-size 4300-lb car	On-off operation, 94 HP, 357 spark ignition engine for 4300-lb car, characteristics derived from literature sources
Emission Control System	Exhaust recirculation and Engelhard oxidizing catalyst	INP
Transmission	Hydrostatic power-splitting, 238-lb Sundstrand Version 8C	Hydrostatic power-splitting
Control System	INP	INP
Flywheel	Tapered steel disk with rim flange, 6.52-inch radius, 24,000 rpm, 86 lb weight for rotor only; usable energy storage of 0.5 HP-hr (max of 1.0 HP-hr), shaft mounted in-line with engine, total flywheel system weight of 187 lb.	Reinforced plastic composite, 5.3-inch-thick bar with spin diameter of 24 inches, 32,000 rpm, 163-lb rotor weight, 7.1 HP-hr energy storage, 3.5 min. recharge time, system weight of 255 lb.
Differential	INP	INP
Batteries	NA	NA

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 13 of 15)

II. HEAT ENGINE/FLYWHEEL SYSTEM

Organization	Lockheed Missiles and Space Company (cont.)	Johns Hopkins University APL (cont.)
Objectives and Goals		
Performance		
Emissions	Calculated for 4300-lb car over EPA Urban Cycle, hot start	Calculated for 4300-lb car over EPA Urban Cycle, hot start
HC	0.378 gr/mi	0.127 gr/mi
CO	1.12 gr/mi	1.97 gr/mi
NO_x	1.21 gr/mi	0.692 gr/mi
Acceleration	*	*
Fuel Economy	Calculated 10 mpg over EPA Urban Driving Cycle	Calculated 14.4 mpg over EPA Urban Driving Cycle
Max Speed	*	*
Gradeability	*	*
Range	*, 200 mi	*, 200 mi
Payload	*, 1700 lb max	*, 1700 lb max

*Specified in "Vehicle Design Goals - Six Passenger Automobile," EPA Advanced Automotive Power Systems Program, Revision C, May 28, 1971.

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 14 of 15)

II. HEAT ENGINE/FLYWHEEL SYSTEM

Organization	University of Wisconsin	Technical School at Aachen, West Germany
Objectives and Goals	(1) Study & evaluate methods for improving fuel utilization efficiency in autos emphasizing advanced power plant concepts, (2) Complete a demonstration flywheel vehicle and test its fuel consumption and emission characteristics	Development and demonstration of vehicle power train designed to reduce fuel consumption in urban traffic
<u>Power Train Elements</u>		
Configuration	Parallel	Parallel
Heat Engine	2.3 liter, Spark ignition engine operating on-off at wide-open throttle and calibrated for low emissions and fuel consumption. Clutch connects engine to flywheel for recharging	Continuous operation, Wankel rotary, max power of 15 kw, max speed of 523 rad/sec, weight of 28 kg, operates normally at 366 rad/sec
Emission Control System	INP	INP
Transmission	Four-speed manual - in conjunction with University of Wisconsin designed CVT hydrostatic power splitting unit with 400 ft-lb capability and 3.5 to 1.0 speed ratio range	INP (Direct mechanical link to vehicle drive wheels via differential controlled by electric motor torque.)
Control System	Hydrostatic system linked to CVT transmission and sensitive to position of accelerator pedal and use of brake pedal	INP (Electric motor torque and speed are mechanical input to control of drive shaft output torque and speed.)
Flywheel	AiResearch steel design with 2/3 HP-hr energy storage and 250 ft-lb torque capability	Moment of inertia of 0.621 kg-m^2, max speed of 1832 rad/sec, weight of 50 kg

TABLE A-4. DETAIL REVIEW OF HYBRID SYSTEMS BY AEROSPACE CORPORATION (Sheet 15 of 15)

II. HEAT ENGINE/FLYWHEEL SYSTEM

Objectives and Goals	University of Wisconsin (continued)	Technical School at Aachen, West Germany (continued)
Objectives and Goals		
Differential	INP	INP
Batteries	NA	Energy content of 4.1 kwh, weight of 150 kg
Electric Motor		Power output of 11 kw, max speed of 701 rad/sec, weight of 65 kg
<u>Performance</u>		
Emissions	Designed to meet model year 1976 emission standards of HC = 1.5 gr/mi CO = 1.5 gr/mi NO_x = 3.1 gr/mi	INP
Acceleration	INP	Max. acceleration of 1.2 m/sec, max. deceleration of 1.4 m/sec reaches 50 km/hr in 10.8 sec (with flywheel operating, up to 100 kw can be delivered to drive shaft)
Fuel Economy	Calculated 38 mpg for 3000-lb car	0.11 ltr/km (reduced fuel consumption up to 45% compared to conventional vehicle)
Max Speed	80 mph	70 km/hr*
Gradeability	INP	INP
Range	INP	INP
Payload	INP	INP

*By road test for 2100 kg vehicle, test cycle not specified

APPENDIX B
SELECTED POWER DRIVE SUBSYSTEM COMPONENT REVIEW AND FLYWHEEL SIZING

B.1 COMPONENT REVIEW

B.1.1 Aerospace Review of Components

Aerospace Corporation made a review of components which could be used in hybrid power drives (Ref. 13). It was found that state-of-the-art heat engines, electric motors, electric generators and controls are satisfactory for hybrid propulsion. However, cost and weight reductions are possible with development and higher levels of production. On the other hand, substantial development is needed in batteries, flywheels and continuously variable transmissions.

B.1.2 Batteries

Specific power, specific energy, cycle life and cost are the most important parameters in battery selection. Power and energy parameters are plotted in Figure B-1 along with performance requirements for various vehicles configured for hybrid operation. Lead-acid batteries do not meet the specific energy or power requirements of any of the hybrid vehicles shown. Nickel-cadmium batteries are better adapted but are too expensive and use materials that are too scarce. Nickel-zinc batteries are very promising provided they can be developed in the time-frame desired. It does not appear that development of molten salt batteries is crucial for practical hybrid power trains. The development of molten salt batteries does not appear to be as important to future hybrid power trains as the battery types described above.

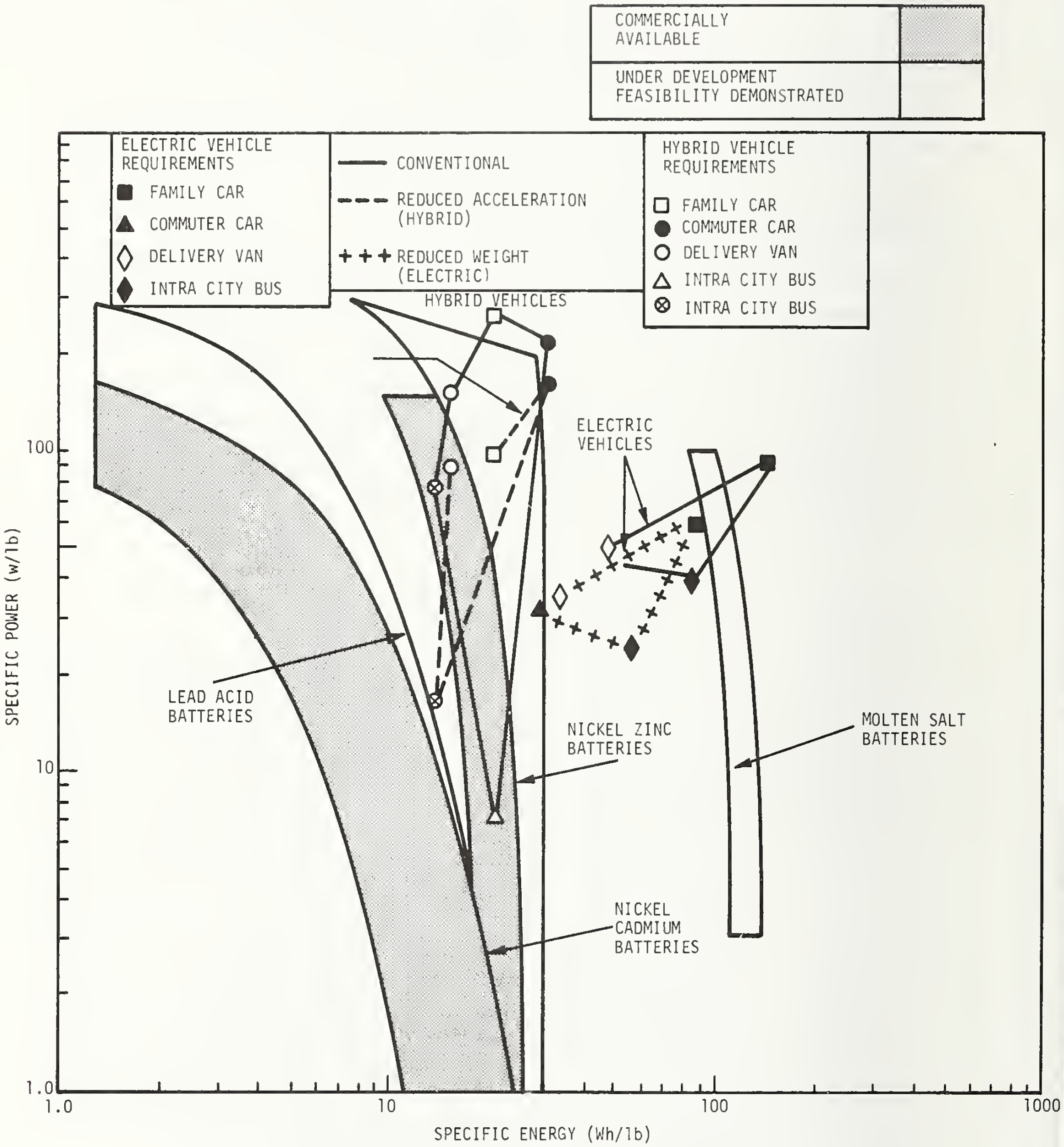

FIGURE B-1. COMPARISON OF BATTERY PERFORMANCE CAPABILITIES AND VEHICLE REQUIREMENTS

B.1.3 Transmission*

Several types of continuously variable transmissions were investigated for possible application in the heat engine/flywheel vehicle power train. Included in these are the mechanical (straight gear ratio), the hydrostatic, the multiple V-belt (variable pitch sheaves), the traction drive and the hydromechanical transmission. Because of numerous limitations (size, weight cost, durability and/or efficiency), the most promising candidates appear to be either the traction drive or the hydromechanical transmissions.

B.2 TSC REVIEW OF COMPONENTS

TSC findings are similar to those of the Aerospace Corporation. The areas where the most development is needed are batteries, flywheels, continuously variable transmissions and hydraulic accumulators.

B.2.1 Battery Energy Storage

In contrast to the need for high energy density batteries for electric vehicles, the emphasis in hybrid battery design is on high power density to handle the high peak power involved in acceleration, regenerative braking, grade climbing, and high-speed passing maneuvers. The heat engine supplies the primary energy requirements but displaces space and weight that is otherwise available for batteries in the battery-powered vehicle. Therefore, the hybrid battery must provide the same or greater power delivery capability as the electric vehicle battery at half or less than half its weight. The energy storage requirements for the hybrid battery are less severe than those for electric vehicles.

Experimental car experience has demonstrated that conventional aqueous storage batteries can marginally meet hybrid vehicle power and energy density requirements, and battery studies have indicated

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*Verbatim from the Aerospace study.

that further improvements in each of these parameters are possible. Cycle life under the high charge/discharge rates of hybrid operation poses the largest technical problem remaining to be solved for all battery systems.

Lead-acid, nickel-cadmium and nickel-zinc batteries have been used in experimental and analytical hybrid vehicle designs to date, with limited success. A brief summary of the different types of batteries that can be considered as potential candidates for powering transit vehicles is presented herein. Much of the information was obtained from certain of the References,* and the various proceedings of the Intersoc Energy Conversion Engineering conferences as well as the Electric Vehicle Conference Proceedings.

The lead-acid battery is considered promising on the basis of cost and materials availability but is marginal from a weight point of view. The lead-acid type has an open circuit potential of approximately 2 V, a theoretical energy density of 76 Whr/lb, and achieved energy densities of 10-24 Whr/lb and power densities of 40 to 90 W/lb. This battery type has a high current capability, can operate over a wide temperature range, has good charge retention, high efficiency, long life, and low cost for materials and manufacturing.

The attainable energy density of lead-acid batteries is dependent on the discharge rate as illustrated in Figure B-2. This rate dependency is caused primarily by mass transport and ionic diffusion limitations.

Present cycle life of the lead-acid batteries is of the order of 300-500 for high energy density designs at deep depths of discharge. Further developments promise cycle lives up to 1000 in the near term. It is possible to increase life by compromising on energy density. One question which should be addressed is the

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*H. Zuckerberg and C. Salmi, "A Bibliography on Hybrid Power Drive Subsystems," material on file with Kentron Hawaii, Limited, Transportation Systems Center, 55 Broadway, Cambridge MA 02142.

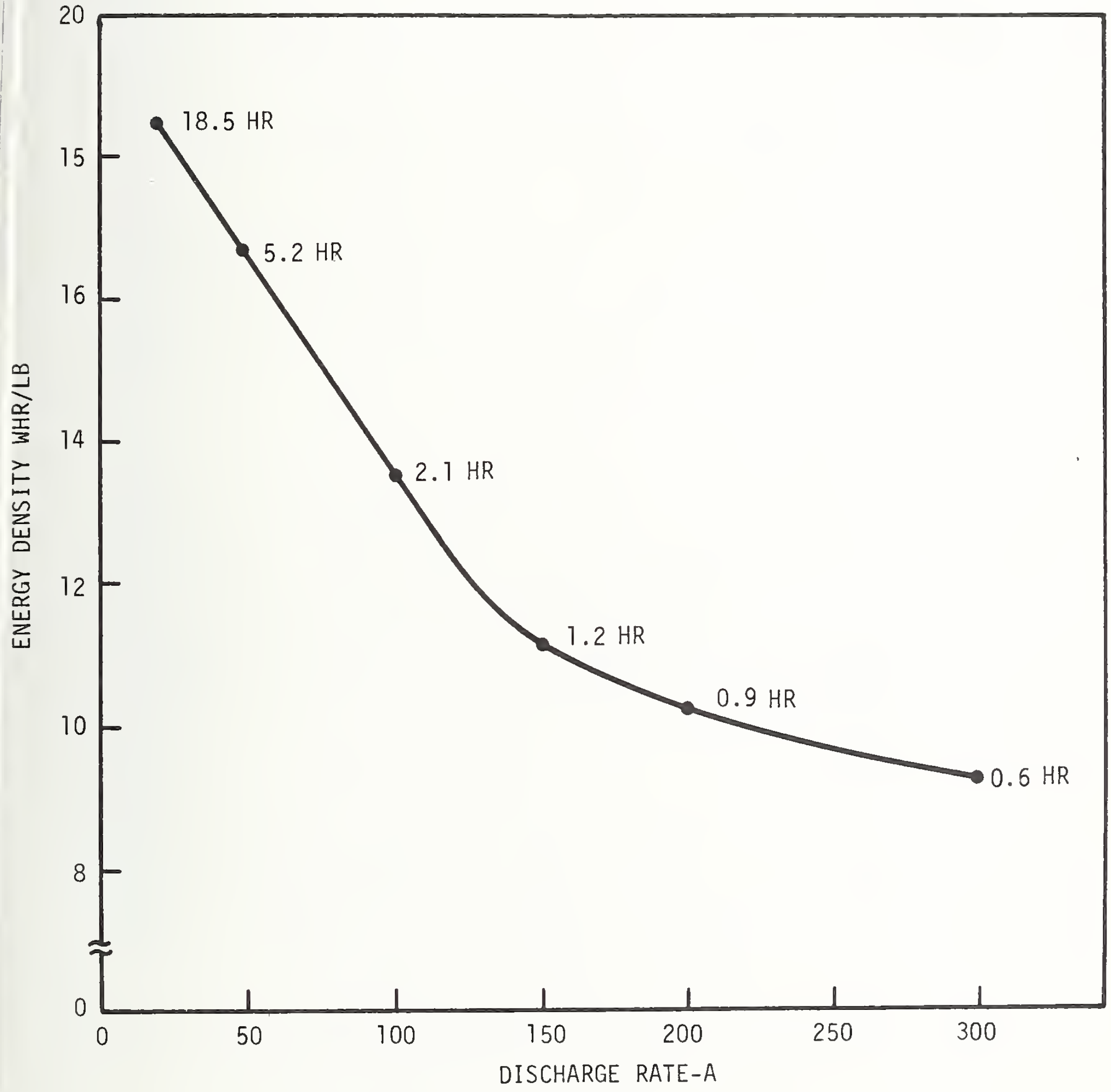

FIGURE B-2. EFFECT OF DISCHARGE RATE ON ENERGY-DENSITY OF LEAD-ACID BATTERIES economic trade-offs between the use of light, high energy-density batteries with short life and the use of heavier, longer-life designs.

As can be deduced from the information in the technical press, a substantial effort is in progress to develop better lead-acid batteries.[15] Typical avenues for improvements include:

a. Lightweight cases with shortened intercell connector path lengths;

b. New laminar grid design where the active material is sandwiched between grid segments which may meet the high charge and discharge current needs of electric power drives for longer cycles; there may not be any improvement in energy density.

c. The use of other types of grid alloys, such as using lead with calcium and tin, and fabricated by wrought processes instead of casting. (Wrought processes will develop a better microstructure which should be stronger and more corrosion resistant. This should lead to thinner and lighter grids and thus a higher energy density.).

d. Further development and improvement of the automotive maintenance-free lead-acid batteries. With the newer lead-calcium-tin grids, the oxygen over-voltage is low enough that gassing is negligible at normal charging voltages.

e. The use of potassium perchlorate as the electrolyte instead of sulphuric acid in order to improve the energy density.

It is possible that energy densities of at least 50 Whr/lb for long distance duration may be achieved within the next 5 years along with power densities of the order of 100 watts/lb.

Nickel-Zinc Battery

The nickel-zinc battery unit has an open circuit potential of 1.7 V, a theoretical energy density of 140 Whr/lb and an achieved energy density of over 30 Whr/lb. This battery unit is of great interest since:

a. The theoretical and practical energy density is considerably better than the lead-acid battery unit;

b. It has good high-rate capability;

c. It can be sealed;

d. The cost of materials is reasonable.

Much research is needed to improve the cycle life of this type of battery unit. One possible direction is the development of improved separators which are essential to long life.

Nickel-Cadmium (Ni-Cad) Battery

The Ni-Cad battery has an open circuit potential of 1.3 V and a theoretical energy density of at least 100 Whr/lb depending on state of charge. Ni-Cad cells permit very high power drain, and have satisfactory cycle life. Though the Ni-Cad system has excellent potential, the main drawback to its use is the limited world supply of cadmium and its high cost.

Metal-Air Batteries

Metal-air batteries use a metal for the negative electrode and a gas electrode, using oxygen from the air, for the positive side. High energy-density metal-air batteries have severe thermal problems since this type of battery system overheats quite readily.

Research has concentrated on the zinc-air types. The many problems surrounding this concept, including passivation of the electrodes, thermal problems, etc., are discouraging further application of this type.

Iron-air, aluminum-air and lead-air systems have been looked at. Iron-air seems to be one of the more promising types but it still has not reached the stage which is encouraging.

High Temperature Batteries

High temperature batteries offer both high power density and high energy density ratings. High energy is achieved by using reactants of low equivalent weight and high electron difference. High power capability is achieved by use of low resistance electrolyte materials such as fused salts and, by operating at elevated temperature which increases the exchange current density.

Research efforts have been applied toward the development of the following types among others:

Sodium-sulfur system

Potassium-sulfur system

Lithium-sulfur system

The above types show excellent promise, especially if they can be made to operate in the vicinity of 70°-100°C. However, severe engineering problems must be solved to achieve the necessary confidence and safety for public use.

B.2.2 Flywheel Energy Storage

The very high power densities and moderate energy densities achievable with flywheels provide a good match to the requirements of hybrid vehicles. In separate tests, Lockheed determined that the power density of a steel flywheel rotor could exceed 5000 W/lb, and the Johns Hopkins Applied Physics Laboratory (APL) obtained 28 W-hr/lb rotor energy density in subscale experiments with bar-type filamentary flywheels. It should be recognized that the weight added by the housing, power coupling system, bearings and ancillary components detracts from the overall energy and power density of the complete storage system assembly. Since the rotor is the most critical component, most work done to date has concentrated on improving its performance.

The Lockheed work concentrated on metal flywheels of various materials and configurations. Pierced and solid disk and conical and constant stress exponential cross-section designs were examined. Materials considered included maraging steel, 1020 and 1040 steel, 4340 steel, and 2021-T81 and 2024-T851 aluminum. Several experiments were also conducted with E-glass and S-glass bar type composite wheels. On the basis of minimum weight and cost, Lockheed selected 4340 steel in a modified exponential constant-stress disk configuration as the best among the combinations analyzed. Two 46-lb wheels designed to operate at 24,000 rpm were built and tested. One of these was tested to destruction after spindown and acoustic tests were conducted. Disintegration occurred at a speed in excess of 35,000 rpm at a stored kinetic energy level of 1.1kW-hr which represents an energy density of 26.1 W-hr/lb for the 20.4-in. diam., 42.4-lb wheel.

Work at APL was confined to an investigation of composite wheels using boron, graphite, E-glass, and R-glass filaments. A large number of early tests were performed on small rod configurations using epoxy, RTV, acrylic and tube-supported mounting systems to evaluate the ultimate performance of the materials and to verify the operation of the test instrumentation. In these tests, a 0.004-in. diameter boron filament weighing 0.00035 lbs/in displayed the highest energy density of all the materials tested at 48 W-hr/lb without failing. For reasons of lower ultimate cost, subsequent 1-lb bar tests were limited to graphite/polyester, graphite/epoxy, and S-glass/epoxy composites. In the best of a series of five tests, a 30-in. diam. S-glass epoxy wheel exhibited a 28 W-hr/lb energy density. APL found that flywheel failures occurred at 71% of the static tensile stress failure levels measured for S-glass/epoxy composites and at 81% of those measured for graphite/epoxy systems. The premature failure stress is attributed to fabrication practices used in the preparation of the experimental specimens which resulted in fiber misalignment and cut surface fibers.

The containment ring required for the metal rotors will probably be much heavier than that for composite rotors in order to resist the large chunks which are characteristic of the failure of homogeneous rotors. Lockheed found that a 192-lb steel ring was required to contain a 0.86-hp-hr steel rotor burst and that a 167-lb composite ring could contain a 0.46-hp-hr burst. APL did not perform burst containment tests of full-scale wheels, but found that the 1/4"-thick rings used in their bar test series successfully contained the bursts of the experimental composite wheels. They concluded that the very low energy which apparently transfers to the containment ring is due to the fact that the composite rotors dissipate a significant portion of their kinetic energy by microfracture of vaporization of the matrix material. As part of their test series, APL observed that bursts of the graphite/epoxy composite rotors produced greater deformation of the containment ring than did bursts of S-glass epoxy composites. This difference was attributed to the rate at which disintegration occurs in the two materials.

The sustaining power required to maintain the rotor within its operational speed range also detracts from the overall performance of flywheel energy storage systems. Both Lockheed and APL system designs use a mechanical coupling between the rotor and drive system; both rotor housings are evacuated to a vacuum of 10^{-2} - 10^{-3} torr to reduce windage losses to a negligible level. However, the required support bearings and vacuum seals can be responsible for sustained power losses up to 3 hp at the maximum stored energy level, according to Lockheed calculations and measurements. These parasitic losses are similar in effect to, but much higher than, the self-thermal losses of high-temperature battery systems.

Many other investigators (Reference 16) have been studying the use of various materials and design concepts to maximize the utility of the flywheel energy storage subsubsystem.

Sizing of Flywheels

Discussion

The hybrid power drive subsystem concept considered herein uses the series on-off engine operation mode. This concept requires that the flywheel, for efficient subsystem operation, serve a double duty:

Case I - Oversize Starter

Case II - Energy Storage Accumulator

The sizing of the flywheel should include the above cases with the higher value being selected for use in the design concept.

Case I - Flywheel as Engine Starter

The flywheel is to be used as a starter for the engine in the on operation mode.

Flywheel Inertia Criteria in On-Off Operation Mode

Let Engine Speed = N_E in rpm

Engine Torque = T_E in ft-lbs

Gear Ratio to Reflect Flywheel Inertia to Drive Shaft = $(GR_{FW/E})$

Flywheel Speed = N_{FWD} at drive shaft in rpm

Flywheel Torque = T_{FW} in ft-lbs

Engine Inertia = I_E in lb-ft-sec/rpm

Flywheel Inertia = I_{FW} in lb-ft-sec/rpm

Assume Engine to be Started by Flywheel

Engine acceleration due to clutch torque, T_C

$$\dot{N}_E = T_C/I_E \text{ in rpm/sec} \tag{B-1}$$

Flywheel deceleration due to clutch torque, T_C

$$\dot{N}_{FWD} = T_C/I_{FW}(GR_{FW/E})^2 \text{ in rpm sec} \qquad \text{(B-2)}$$

Assume Synchronizing Speed = N_S

$$\text{Synchronizing time } t_S = \frac{N_S}{\dot{N}_E} = \frac{N_S \cdot I_E}{T_C} \qquad \text{(B-3)}$$

Solving for N_S by Combining Equations (B-1) through (B-3)

$$N_S = N_{FWD}[I_{FW}(GR_{FW/E})^2]/[I_E + I_{FWD}(GR_{FW/E})^2] \qquad \text{(B-4)}$$

Let the Energy Originally Stored in the Flywheel be:

$$(ENERGY)_{FW} = \frac{1}{2} I_{FW}(GR_{FW/E} \cdot N_{FWD})^2 \qquad \text{(B-5)}$$

After Clutch Engagement and Subsequent Engine Start-Up

$$\text{The final energy} = \frac{1}{2} [I_E + I_{FW}(GR_{FW/E})^2](N_S)^2 \qquad \text{(B-6)}$$

$$(ENERGY)_{FW} = \frac{1}{2}[I_{FW}(GR_{FW/E})^2][N_{FWD}{}^2] \left\{\frac{I_{FW}(GR_{FW/E})^2}{I_E+I_{FW}(GR_{FW/E})^2}\right\} \qquad \text{(C-7)}$$

Energy Lost in Synchronization:

$$\text{LOST ENERGY}_{FW} = (ENERGY)_{FW} - (ENERGY)_{FINAL} \qquad \text{(B-8)}$$

$$\text{Ratio to original} = \left[\frac{I_E}{I_E+I_{FW}(GR_{FW/E})^2}\right] \qquad \text{(B-9)}$$

$$\text{To minimize loss, } I_{FW}(GR_{FW/E})^2 > I_E \qquad \text{(B-10)}$$

Let

Minimum drive shaft speed for engine-flywheel clutch engagement = N_{DSTS}

Critical minimum drive shaft speed = N_{DSMS}

(Below this speed, flywheel will not have sufficient energy stored to accomplish anything.)

From Equations (B-7) through (B-9):

$$I_{FW}(GR_{FW/E})^2 = I_E/[(\frac{N_{DSTS}}{N_{DSMS}})^2 - 1] \qquad \text{(B-11a)}$$

The maximum rated flywheel speed (at the flywheel) is set at:

$$N_{FW} = 11{,}000 \text{ rpm}$$

The following limiting values are established for this study:

$$N_{DSTS} = 1{,}200 \text{ rpm}$$

$$N_{DSMS} = 1{,}050 \text{ rpm}$$

Thus

$$I_{FW}(GR_{FW/E})^2 = 3.267\ I_E \qquad \text{(B-11b)}$$

For the types of engines used in this program:

$$I_E = 14 \text{ lb-in-sec}^2$$

typical of current Detroit Diesel engines.

Then from Equation (B-11):

$$I_{FW}(GR_{FW/E})^2 = .1222 \text{ lb-ft-sec/rpm} \qquad \text{(B-12)}$$

Case II - Sizing of Flywheel as an Energy Storage Accumulator During Driving Cycle(s)

Drive Wheel Power Requirements

Let P_{WH} = drive wheel power in lb-ft/sec

P_{ACCE} = power required for vehicle acceleration in lb-ft/sec

P_{DRAG} = power loss due to air drag in lb-ft/sec

P_{RDRES} = power loss due to road resistance in lb-ft/sec

VGW = vehicle gross weight in lb

ACC = initial vehicle acceleration in mph/s

g = gravity constant = 32.1739 ft/sec^2

C_D = air drag coefficient - non dimensional

A_F = vehicle frontal area in square feet

V = vehicle velocity in mph

μ = road resistance coefficient - non dimensional

Air Drag Power

$$P_{DRAG} = .002556\ (C_D)(A_F)(V^3) \quad \text{(B-13)}$$

Road Resistance Power

$$\begin{aligned} P_{RDRES} &= \mu(VGW)(V) \\ &= [.005+5.45(1.466V)^{2.5}](10^{-7})(VGW)(V) \quad \text{(B-14)} \end{aligned}$$

Acceleration Power

$$P_{ACCE} = (VGW/G)(1.4667(ACC))(V) \quad \text{(B-15)}$$

Drive Wheel Power

$$P_{WH} = P_{ACCE} + P_{DRAG} + P_{RDRES} \quad \text{(B-16)}$$

Let

Net engine power at engine flywheel = P_{ENG}

P_{ENG} = GROSS ENGINE POWER - ENGINE ACCESS. POWER

Flywheel charging power = P_{FWIN}

Power extracted from flywheel = P_{FWOUT}

Transmission efficiency involved in charging = η_C

Flywheel power drive efficiency = η_D

Engine on-off coefficient = β

β = 0 engine off

β = 1 engine on

The net horsepower P_{FWOUT} extracted from the flywheel shaft is the difference between the vehicle power requirement and the power supplied by the engine:

$$P_{FWOUT} = (P_{WH}/\eta_D) + P_{A/C} - \beta(P_{ENG} \times \eta_C) \qquad \text{(B-17)}$$

$P_{A/C}$ = power requirement for air conditioning, etc.

During deceleration the power regenerated at the flywheel shaft is defined by:

$$P_{REG} = (P_{DECEL})(\eta_R) \qquad \text{(B-18)}$$

where η_R is the average regeneration transmission efficiency.

The change in β from 0 to 1 is set to occur when the flywheel speed drops to a minimum of 50% of maximum rated speed.

Let

Total time during which power is expended = t_E sec

Energy expended, $E_{EXP} = (P_{FWOUT})(t_E)(3.766 \times 10^{-7})$ (B-19)

in kW-hr

Energy Storage

$$E_{EXP} = \frac{1}{2} I_{FW}(W_0^2 - W_1^2)\ (K) \qquad \text{(B-20)}$$

where W_0 = flywheel speed fully charged in rpm

W_1 = minimum flywheel threshold speed in rpm

Assume $W_1/W_0 = .50$

Let I_{FW} = flywheel moment of inertia in lb-ft-sec^2

$K = (2\pi/60)^2$

Then $E_{EXP} = (.004112)(I_{FW})(W_0^2)$ (B-21)

Equating Equations (B-19) and (B-21) and solving for I_{FW} yields:

$$I_{FW} = (7.825x10^3)(P_{FWOUT})(t_E)W_0^2 \text{ in lb-ft}^2 \qquad \text{(B-22)}$$

Correcting for flywheel installation losses, $\phi_{LOSS} = .707$

$$I_{FW} = (1.105x10^4)(P_{FWOUT})(t_E)/W_0^2 \text{ in lb-ft}^2 \qquad \text{(B-23)}$$

Assume Δt_E = time increment wherein power is expended

N_{CY} = number of cycles during time t_E

Then $$t_E = (N_{CY})(\Delta t_E) \qquad \text{(B-24)}$$

Finally $$I_{FW} = (1.105x10^4)[(P_{FWOUT})(\Delta t_E)/W_0^2]\ (N_{CY}) \qquad \text{(B-25)}$$

Correcting Equation (B-25) to be reflected at the drive shaft

$$I_{FW} = (36)[(P_{FWOUT})(\Delta t_E)/W_{DS}^2](GR_{FW/E})(N_{CY}) \text{ in lb-ft-sec/rpm} \qquad \text{(B-26)}$$

where W_{DS} = drive shaft rpm

$GR_{FW/E}$ = gear ratio between engine and flywheel

The weight of the flywheel rotor corresponding to the moment of inertia calculated from Equation (B-25), can be determined using the following empirical relationship.

$$W_{ROTOR} = K_W(I_{FW}) \qquad \text{(B-27)}$$

where

$$K_W = .70$$

For the Case I driving cycle, and assuming

$N_{CY} = 3$

$E_{EXP}/CYCLE = .628 \times 10^6$

TOTAL $E_{EXP} = 1.884 \times 10^6$

$W_0 = 11{,}000$ rpm

From Equation (B-25)

$$I_{FW} = (1.105 \times 10^4)(1.884 \times 10^6)/121 \times 10^6 = 172.05 \text{ lb-ft}^2$$

From Equation (B-26)

$$I_{FW} = 14 \text{ lb-ft-sec/rpm}$$

From Equation (B-27)

$$W_{ROTOR} = 172.05/.70 = 246 \text{ lbs}$$

The miscellaneous hardware weight consisting of shafting, bearings, housing, containment ring, etc. is estimated at 5 times W_{ROTOR}.

The miscellaneous installation weight consisting of transmission between engine and flywheel, housing, supports, etc. is estimated as a fixed quantity at 724 pounds.

The total flywheel installation subsystem weight is estimated as follows:

Rotor weight	=	246 lbs
Miscellaneous hardware weight	=	1,230 lbs
Miscellaneous installation weight	=	724 lbs
TOTAL		2,200 lbs

APPENDIX C
ENGINEERING LIMIT PERFORMANCE OF TRANSIT BUSES OVER URBAN DRIVE CYCLES

This appendix consists of an Engineering Limit Performance of Transit Buses developed by Professor A.T. McDonald, Purdue University, School of Engineering

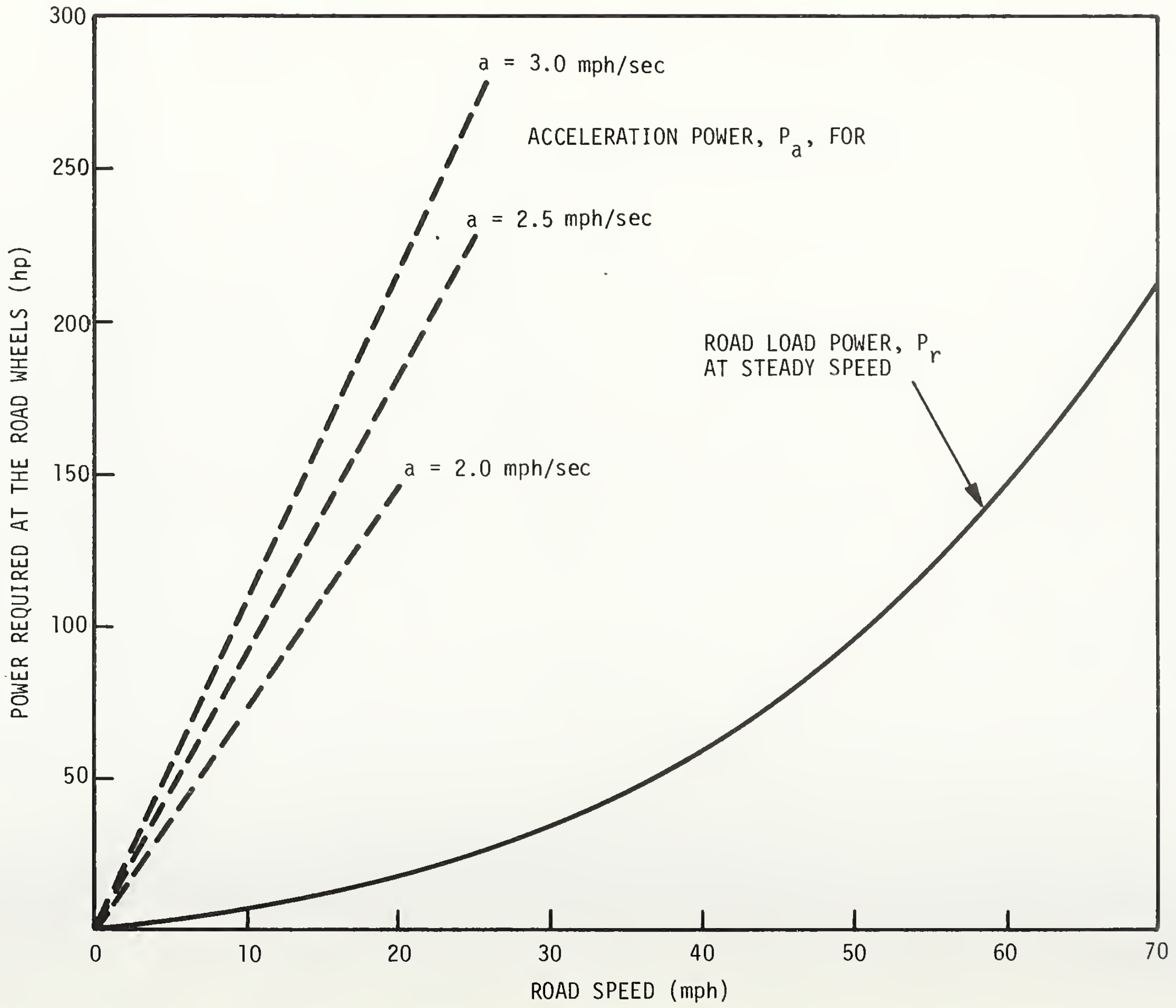

FIGURE C-1. TRACTIVE POWER REQUIREMENTS FOR TRANSIT COACH

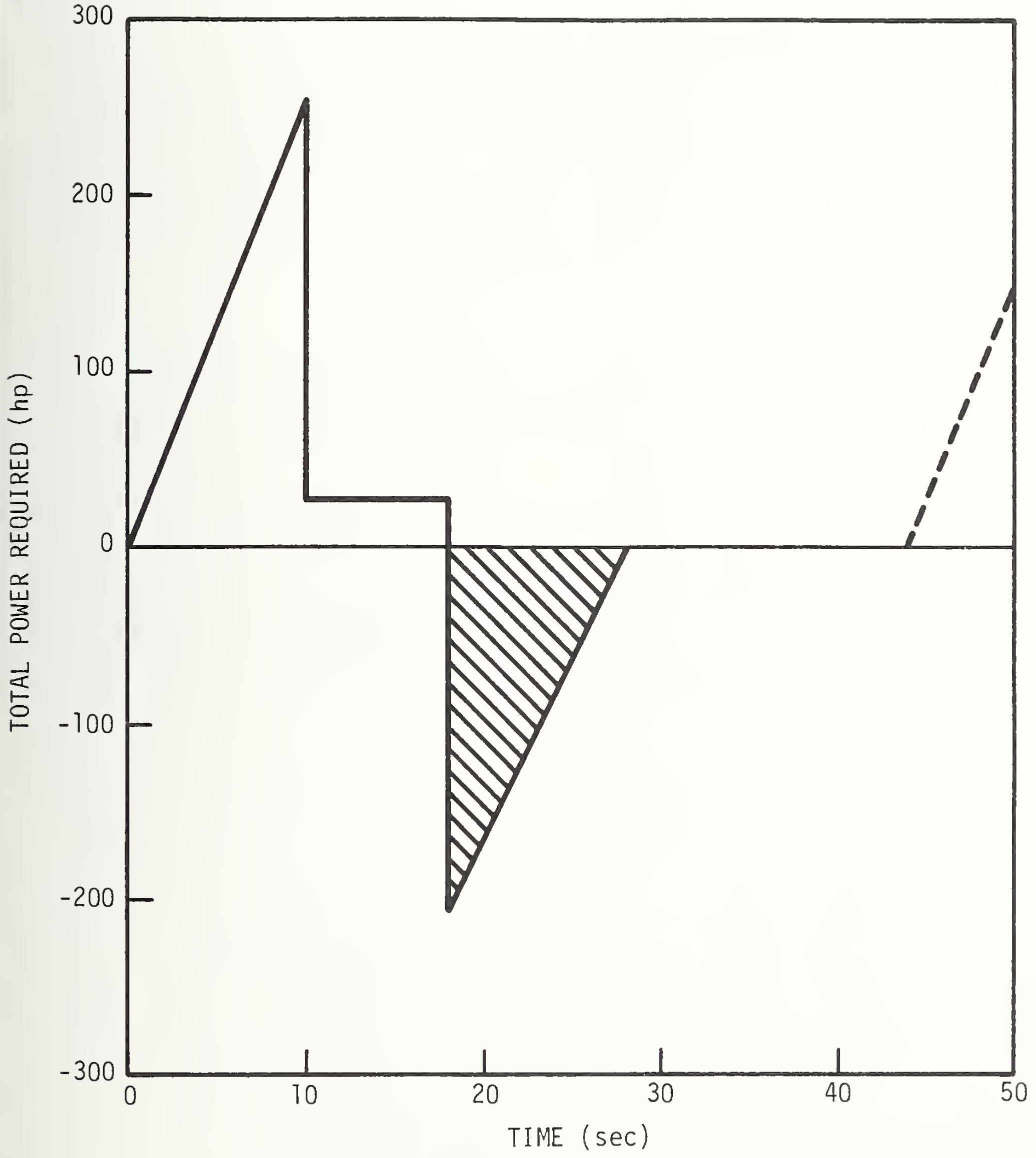

FIGURE C-2. PROFILE OF TRACTION POWER AS A FUNCTION OF TIME FOR CYCLE C AT 8 STOPS PER MILE

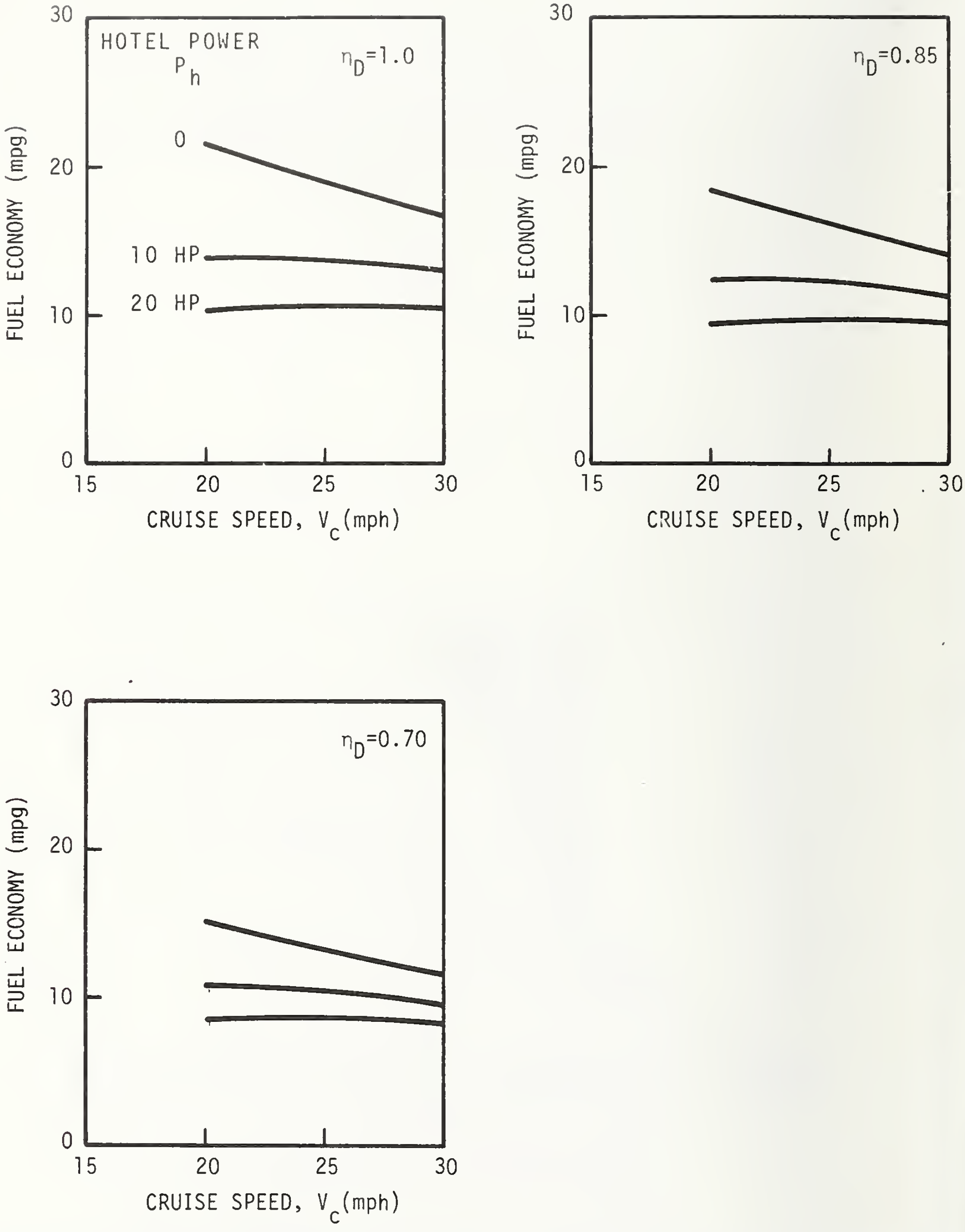

FIGURE C-3. MAXIMUM PRACTICAL FUEL ECONOMY LIMIT FOR OPERATION WITHOUT STOPS AS A FUNCTION OF CRUISE SPEED

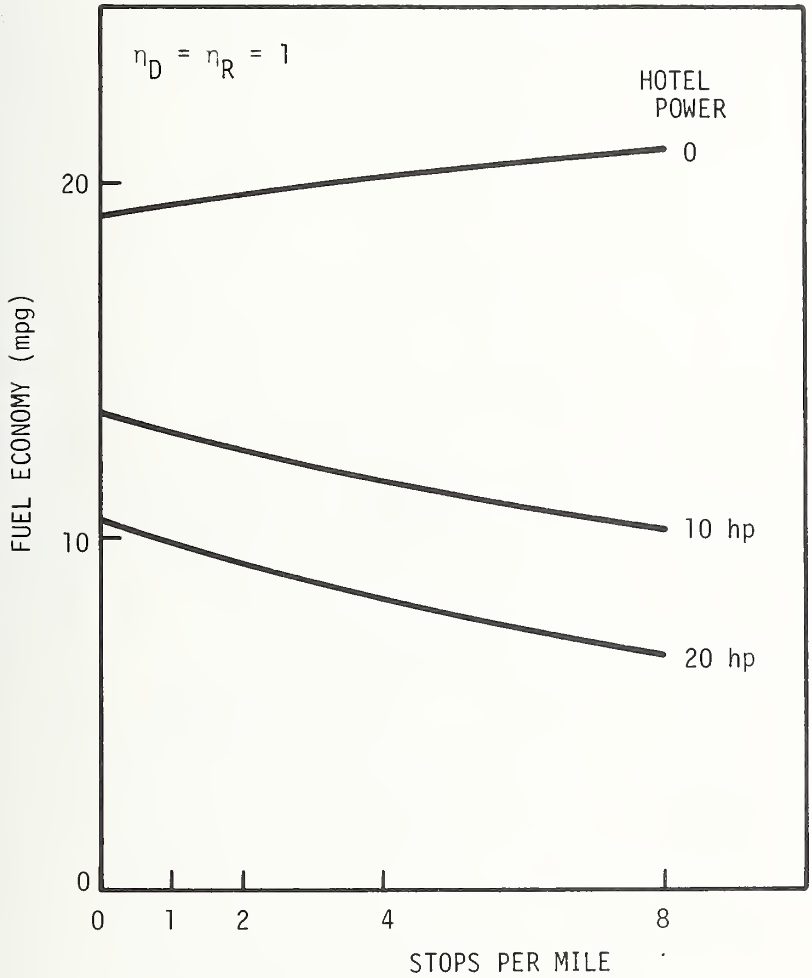

FIGURE C-4. ENGINEERING LIMIT FUEL ECONOMY WITH REGENERATION FOR TRANSIT COACH OPERATING ON CYCLE C AS A FUNCTION OF NUMBER OF STOPS PER MILE (1 of 2)

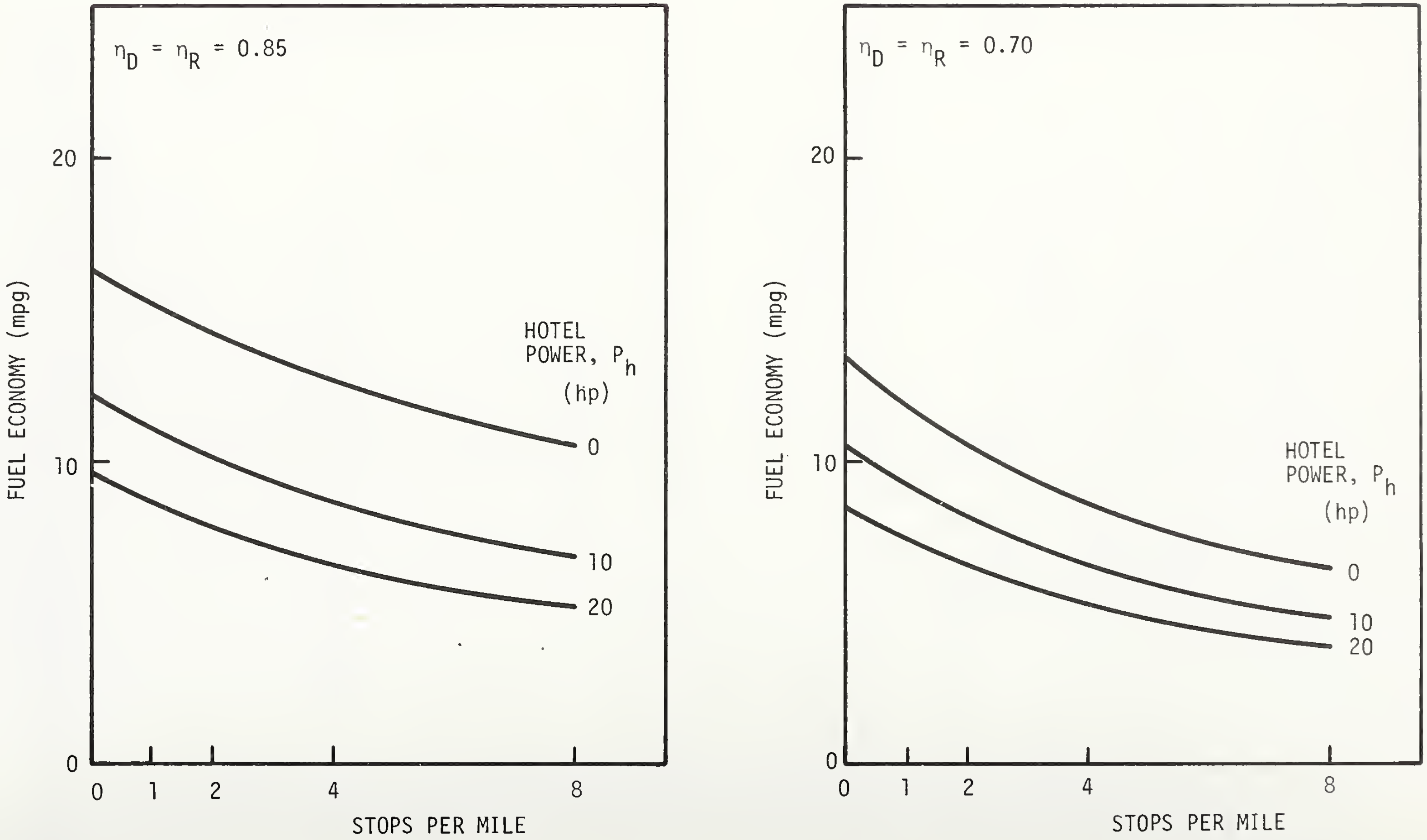

FIGURE C-4. ENGINEERING LIMIT FUEL ECONOMY WITH REGENERATION FOR TRANSIT COACH OPERATING ON CYCLE C AS A FUNCTION OF NUMBER OF STOPS PER MILE (2 of 2)

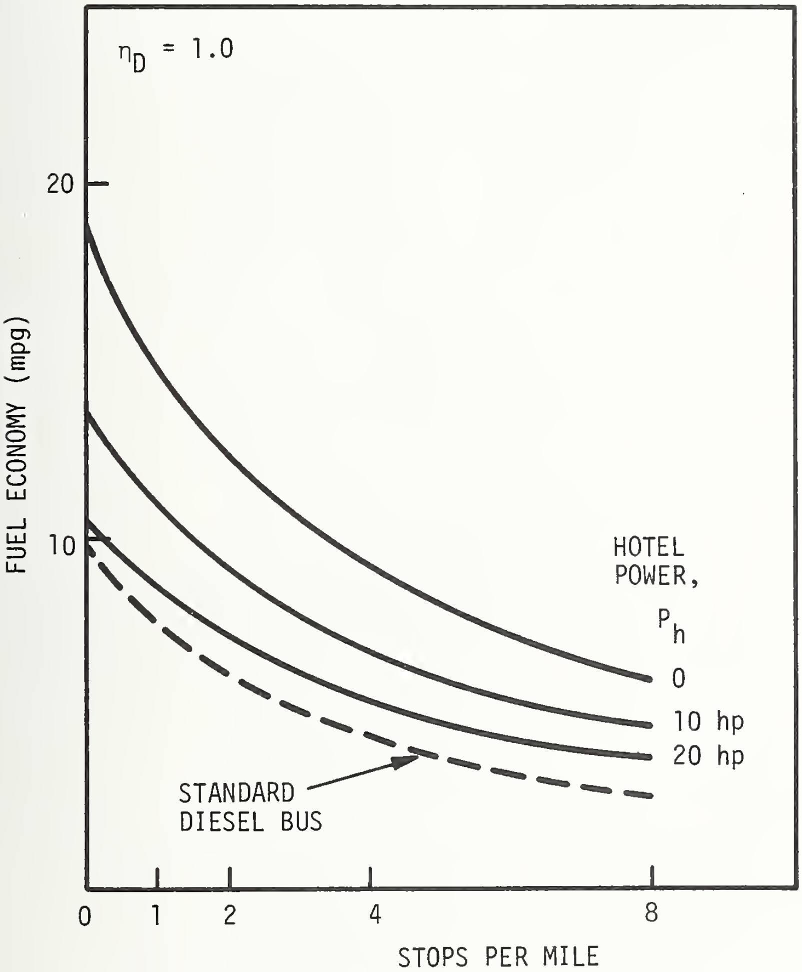

FIGURE C-5. ENGINEERING LIMIT FUEL ECONOMY WITHOUT REGENERATION FOR TRANSIT COACH OPERATING ON CYCLE C AS A FUNCTION OF NUMBER OF STOPS PER MILE (1 of 2)

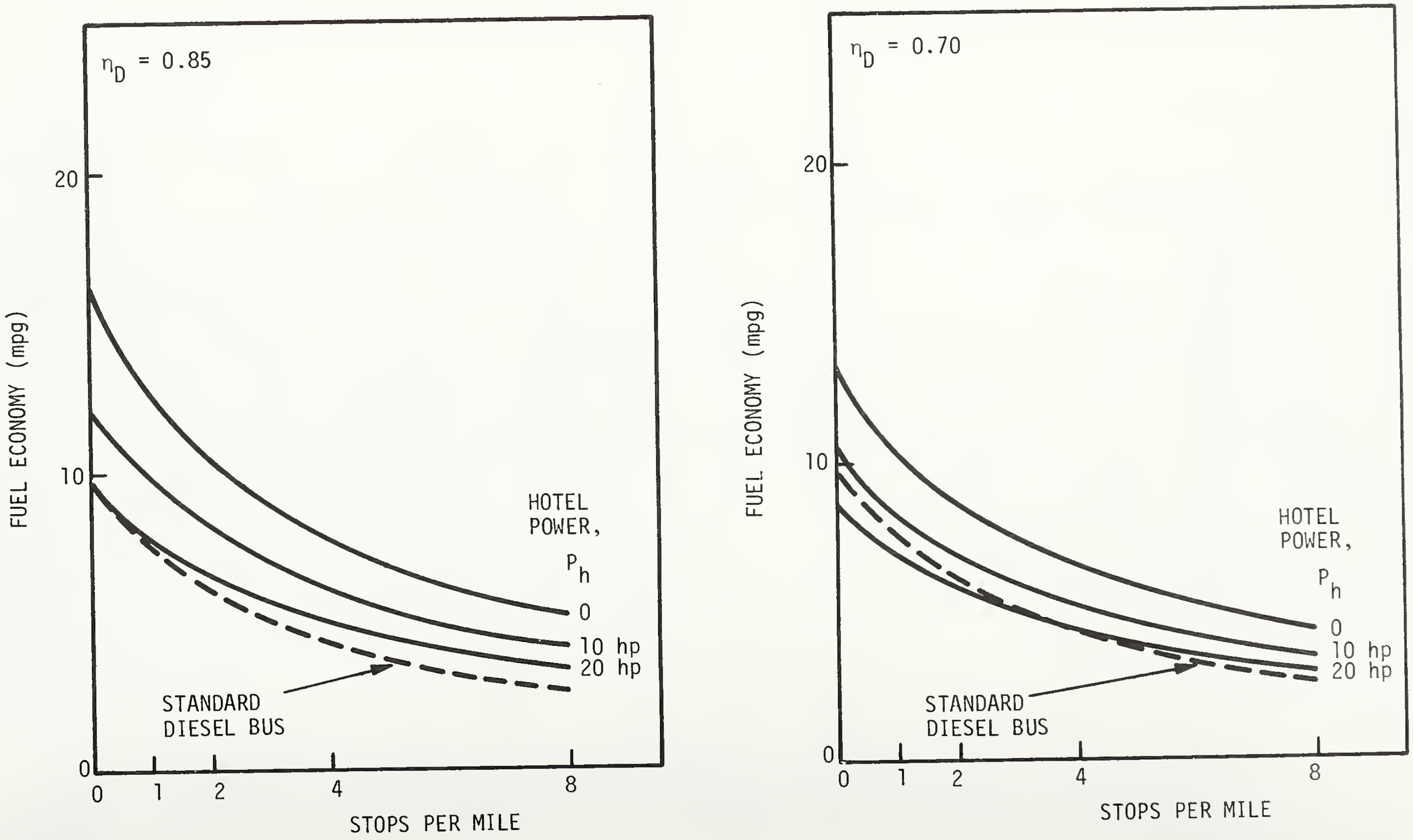

FIGURE C-5. ENGINEERING LIMIT FUEL ECONOMY WITHOUT REGENERATION FOR TRANSIT COACH OPERATING ON CYCLE C AS A FUNCTION OF NUMBER OF STOPS PER MILE (2 of 2)

APPENDIX D
COMPUTER PROGRAM NOMENCLATURE

Subroutine name: AUTOHB

Type of subroutine: Component subroutine

Description: Subroutine to simulate the driver and to determine new vehicle velocity and the new desired driveshaft torque for the next point in the driving cycle.

AEPA - acceleration required to reach next cycle velocity
DELT - time difference between next cycle point and current time
GR - gear ratio from engine to rear wheels
RATKLS - rear axle torque loss
TMAX - maximum steady state engine torque
T9ICDN - new required driveshaft torque
T9I1GR - equivalent rear axle gear ratio
VEPA - required cycle velocity
VVDF - vehicle road load
VVDFD - vehicle road load
VVDMI - inertial vehicle mass
VVIDRR - time radius
VVOS - vehicle velocity

Subroutine name: CONTHB

Type of subroutine: control subroutine

Description: Subroutine to control the engine and flywheel torque depending on the operating modes of the hybrid car.

DF - flywheel speed

DFSTOP - flywheel speed at which engine shuts off

DFSTRT - flywheel speed at which engine starts

ENGSTP(1) - maximum flywheel speed

FINTRQ - torque from engine (or starter motor) to flywheel

IENGIN - mode of operation of engine-flywheel system

2. Engine charging flywheel
3. Flywheel starting engine
4. Engine off

ISW1 - engine on-off. 0-off, -1-on.

ISW2 - torque flow from flywheel to engine. 0-no, -1-yes

PAON - engine speed (rpm)

RFINR - system inertia (1/RIF or 1/RIEPIF)

VVOS - vehicle speed (mph)

Subroutine name: CVTGNU

Type of subroutine: Component subroutine

Description: Subroutine to calculate flywheel torque losses in the CVT, clutch, and driveshaft.

A1CVT - ratio of hydraulic pump input speed to CVT input speed.

CVTLS - torque loss in CVT

CVTSCL - CVT scale

CVTTRQ - torque at driveshaft which will be transmitted to flywheel

GNU - CVT efficiency

ICLUCH - clutch indicator, 0 if open, 1 if closed or slippin

IGEAR - shift indicator. 0 if neutral

R - ratio of driveshaft speed to flywheel speed

RMIN - minimum system ratio

RP - the CVT ratio

RPP - the new transmission ratio

SPDIN - driveshaft speed

SPUMP - input speed of hydraulic pump

TC - output torque of CVT

TCLULS - torque loss in clutch at flywheel

TCVTLS - equivalent torque loss in CVT at flywheel

TLPUMP - charge pump loss at flywheel

TMAX - maximum engine torque

TTRIN - torque in shaft between the 4-speed transmission and CVT

T9IC - driveshaft torque

T9IN - driveshaft speed

Subroutine name: DSTORQ

Type of subroutine: Component subroutine

Description: Subroutine to calculate driveshaft torque and the next desired torque command and brake setting

BS - brake setting

ICLUCH - clutch indicator, 0 if open, 1 if closed or slipping

IGEAR - gear shift indicator

RP - CVT ratio

TMAX - maximum steady state engine torque

TNUM - rear axle torque

TS - throttle setting

T8I1GR - nominal rear axle ratio

T9IC - driveshaft torque

T9ICDN - new required driveshaft torque

T9ON - rear axle speed

VVI2BR - brake constant

Subroutine name: ENGINI

Type of subroutine: Initialization

Description: Subroutine used for initializing engine.

FINTRQ - torque from engine (or starter motor) to flywheel.

ISW1 - engine on-off. 0 - off, -1 - on.

ISW2 - torque flow from flywheel to engine. 0 - no, -1 - yes.

PAOC - engine shaft torque

PAOFR - fuel consumption rates (lb. l hr.)

PPOB - engine vacuum (in -Hg)

SSTORQ - STEADY STATE TORQUE

Subroutine name: ENGWHL

Type of subroutine: Component subroutine

Description: Subroutine to integrate flywheel speed and engine speed.

Input variables:

CVTTRQ - torque at driveshaft which will be transmitted to the flywheel

DT - time increment (= .05 sec.)

EDRAG - engine drag coefficient

EGAIN - engine gain

ENGTORQ - torque supplied by engine at a given speed and throttle setting. Taken from throttle map.

FINTRQ - torque from engine (or starter motor) to flywheel.

IENGIN - Mode of operation of engine flywheel system.

2. Engine charging flywheel
3. Flywheel starting engine
4. Engine off

ISW1 - engine on-off. 0-off, -1-on.

ISW2 - torque flow from flywheel to engine. 0-no, -1-yes.

PAOC - engine shaft torque

PAON - engine speed

PERLOS - % loss in flywheel gears

R - ratio of driveshaft speed to flywheel speed

RFINR - System inertia (1/RIF or 1/RIEPIF)

RIEINV - inverse of engine inertia

TCLSS - torque loss in four speed transmission reflected to the flywheel

TCLULS - torque loss in the clutch at the flywheel

TCVTLS - equivalent torque loss in CVT at flywheel

TLPUMP - charge pump loss at flywheel

T9IN - Driveshaft speed (between CVT & rear axle) corrected for tire growth

Output Variables:

A(1) - power generated by engine

A(2) - power required by road load

A(3) - power lost in CVT

A(4) - power lost in clutch

A(5) - power lost in excess braking

A(6) - power output from system

A(7) - power lost in rear axle

A(8) - power lost in starting the engine

A(9) - power lost to flywheel friction

A(10) - power lost in flywheel gear

AA(1) - power lost in transmission gears

AA(2) - power used by transmission charge pump

Other program variables:

DFINT - change in flywheel speed over the integration period

DFDOT - flywheel acceleration

DTF - time increment for integrating flywheel acceleration

ENTORQ - torque on flywheel to accelerate engine

ESDOT - derivative of engine speed

FLYGRL - flywheel gear loss

NDT - number of times flywheel power out is calculated before average is taken and integrated for energy out.

RGNTRQ - regenerative braking torque

TFTORQ - torque on flywheel demanded by drivetrain - also includes torque for accelerating engine

Subroutine name: EPAVEL

Type of subroutine: System computation

Description: EPAVEL retrieves the appropriate velocity as a function of time and supplies it to the automatic driver.

Input variables:

IVEPA (I) - cycle velocities at 1 second intervals

TIME - time from start of driving cycle (sec.)

Output variables:

DELT - time difference between next cycle point and current time.

ICYEND - used as a flag to indicate the end of the cycle.

VEPA - next required cycle velocity

Other program variables:

DELMIN - automatic drive minimum lead time

DT - time of one clock pulse

FLOAT(I) - treat the integer variable I as a real variable

NVEPA - number of velocities specified in driving cycle

IVEL
KPLACE variables used to pack and unpack two cycle
KREM velocities per word of core

Subroutine name: FSPEED

Type of subroutine: Interpolation

Description: Subroutine to provide interpolation for engine parameters.

Subroutine name: GRSHFT

Type of subroutine: Component subroutine

Description: Subroutine to simulate gear shift

AEPA - acceleration required to reach next cycle velocity

DT - time of one clock pulse

ICLUCH - clutch indicator, 0 if open, 1 if closed or slipping

IGEAR - current gear zero if neutral

INEXT - the next transmission gear

NGEAR - number of gears

R - ratio of driveshaft speed to flywheel speed

RMAX - maximum allowable transmission system ratio

RMIN - minimum allowable transmission system ratio

RP - the CVT ratio

RPMAX - maximum allowable CVT ratio.

RPMIN - minimum allowable CVT ratio

RPP - the new transmission ratio

STIME - time interval between checks for shift

TIMINT - time interval

TRMAX - maximum overall gear ratio (flywheel to driveshaft) for the current gear

TRMIN - minimum overall gear ratio (flywheel to driveshaft) for the current gear.

T9ICDN - new required driveshaft torque

Subroutine name: HYBLSS

Type of subroutine: Computing Subroutine

Description: Subroutine to calculate energy losses in the hybrid car.

Input variables:

A (1)

↓ same as ENGWHL

AA (6)

CVTTRQ - torque at driveshaft which will be transmitted to the flywheel

DELTA - integration time increment (sec.)

RATKLS - rear axle torque loss

T9IC - driveshaft torque (between CVT and rear axle)

T9IN - driveshaft speed

VVDF - vehicle road load force at the road interface (lb)

VVOS - vehicle speed (mph)

Output variables:

C (1)

↓ same as ENGWHL but substitute energy for power.

C (6)

Other variables:

DELCON - 2 DELTA/5252

RACON - vehicle speed (ft/sec)

Subroutine name: INCNHB

Type of subroutine: Initialization

Description: This subroutine reads in all maps and tables needed by the system computation routines. It reads in all constants that are required and calculates other constants as necessary. It sets the ADC and DAC conversion constants. It also calculates acceleration limits of the vehicle, accounting for weight transfer.

ADDCON(9) - ADC conversion constants

AVIB - air pressure (psi)

AVIM - air density (lb/ft^3)

AVIR - air temperature (°F)

A1CVT - ratio of hydraulic pump input speed to CVT input speed.

COMM(I) - title cards

CVTSCL - CVT scale

DACCON(10) - DAC conversion constants

DELMIN - automatic drive minimum lead time (sec)

DT - value of one clock pulse (sec)

EDRAG - engine internal drag coefficient

EFFTAB(I,J,K) - CVT torque loss table (ft-lb)

EGAIN - engine gain

ENGFUL(I) - engine fuel consumption map (BSFC vs. rpm)

ENGSTP(1) - maximum flywheel speed (rpm)

ENGSTT(I) - minimum flywheel speed vs. vehicle speed (rpm vs. mph)

ENGTRQ(I) - engine torque map (ft-lb vs. rpm)

ENGVAC(I) - manifold vacuum map (in Hg vs. rpm)

EPS - used to test for constant engine speed (rpm)

FDRAG - flywheel drag

FUELWT - weight of 1 gallon of fuel (lb)

FUIDL - fuel consumption at idle (lbm/hr)

GAIN - gain for VEDYNH

GEREFF(I) - table of gear efficiencies for each gear of the manual transmission

GRATIO(I) - table of gear ratios for the manual transmission

HRPSEC - hours per second

IOUT - number of clock pulses allowed between outputs

IVEPA - driving cycle velocities at 1 second intervals

LOADEQ - road load calculation control

MAXLIN - lines per page

NDIM(2) - number of variables used in joint probability density

NGEAR - number of gears

NSPEED - number of speed increments in throttle map

NTIMES - number of velocities

NVEL - number of velocities

NVEPA - number of velocities specified in driving cycle

PERLOS - % loss in flywheel gears

PMAX(1) - maximum torque for PRBDHB (ft-lb)

PMAX(2) - maximum engine speed for PRBDHB (rpm)

RAEFTB(I,J) - rear axle efficiency table

RASCAL - rear axle scale

RIE - rotary engine inertia (lbm-ft^2)

RIEINV - inverse engine inertia

RIEPIF - engine inertia plus flywheel inertia

RIF - flywheel inertia

RMAX - maximum allowable transmission system ratio

RMAXAS(I) - maximum overall gear ratio (from flywheel to driveshaft) for gear I

RMIN - minimum allowable transmission system ratio

RMINAS(I) - minimum overall gear ratio (from flywheel to driveshaft) for gear I

RPMAX - maximum allowable CVT ratio

RPMIN - minimum allowable CVT ratio

SPDING - speed increment for reading throttle map (rpm)

TIMING - not used

TMAX - maximum steady state engine torque (ft-lb)

TRQIDL - engine torque at idle (ft-lb)

TVICRL - road load torque at driveshaft (ft-lb)

TVIJCT - polar moment of torque converter turbine (lbm-ft^2)

TVIJRA - polar moment of rear axle gears (lbm-ft^2)

TVIJTR - polar moment of transmission gears (lbm-ft^2)

JVIJTW - polar moment of tires and wheels (lbm-ft^2)

T8INV(10) - driveshaft speed as a function of vehicle speed (rpm vs. mph)

T8I1GR - nominal rear axle ratio

VACIDL - manifold vacuum at idle (in-Hg)

VACMAX - maximum manifold vacuum (in-Hg)

VELINC - velocity increment (mph)

VINT(1) - increment in torque for PRBDHB (ft-lb)

VINT(2) - increment in engine speed for PRBDHB (rpm)

VMIN(1) - minimum torque for PRBDHB (ft-lb)

VMIN(2) - minimum engine speed for PRBDHB (rpm)

VVIAMX - maximum vehicle acceleration accounting for weight transfer without tire slippage

VVIAS - maximum vehicle acceleration accounting for weight transfer with tires slipping.

VVIDRR - tire rolling radius (ft)

VVIFUM - coefficient of static tire friction (g's)

VVIFUS - coefficient of slipping tire friction (g's)

VVILFR - frontal area (ft^2)

VVIM - vehicle mass (lb)

VVIMDR - weight on drive wheels (lb)

VVIMI - inertial mass of vehicle (lb). The read in value of VVIMI is not used - it is calculated instead.

VVISH - height of vehicle center of gravity (in)

VVISWB - wheel base (in)

VVI1CD - drag coefficient

VVI1CF - tire constant friction coefficient

VVI1RF - rolling friction coefficient

VVI2BR - brake constant (usually static weight of vehicle)

Subroutine name: INGRHB

Type of subroutine: Initialization

Description: Subroutine to initialize the hybrid car after the engine is in steady state.

AVIO - grade angle (rad)

AVIS - windspeed (mph)

EMISE - emissions (not used)

EMISF - emission rate (not used)

FUELE - cumulative fuel consumed (lb)

ICLOCK - cumulative number of clock pulses

ICLOKO - time at previous output of variables

ICLOK1 - ICLOCK at completion of last integration

ICLUCH - clutch indicator, 0 if open, 1 if closed or slipping

ICYCLE - number of times the program has iterated

IENGIN - mode of operation of engine - flywheel system

2. Engine charging flywheel
3. Flywheel starting engine
4. Engine off

IGEAR - current gear

INDIC - output indicator

INEXT - the next transmission gear

IPDX(I,J) - integer table of probability density distribution

ISEQ - shift indicator

ITICYC - ICLOCK at start of driving cycle

NGI - current gear number

NGIOLD - gear at previous iteration

NGT(1) - number of samples above maximum engine speed

NGT(2) - number of samples above maximum torque

NLINE - number of lines on current page

NLT(1) - number of samples below minimum engine speed

NLT(2) - number of samples below minimum torque

PAOFR - fuel consumption rate (lb/hr)

PAOFRO - previous value of PAORR

RP - the CVT ratio

RPP - the new transmission ratio

TIMAVG(I) - timer averages

TIME - time from start of driving cycle (sec.)

TIMLEN(I) - timer lengths

TIMMAX(I) - timer maximum

T8DN - uncorrected driveshaft speed

T9ICDO - old desired driveshaft torque

T9IN - driveshaft speed

T9I1GR - effective rear axle ratio

T9ON - rear axle speed

VEPA - next driving cycle velocity

VVOA - vehicle acceleration

VVOAO - previous value of VVOA

VVOD - vehicle distance traveled

VVOS - vehicle speed (mph)

VVOSO - previous value of VVOS

WHLOLD - previous value of wheel slip indicator

Subroutine name: INGRTH

Type of subroutine: Computing subroutine

Description: This subroutine integrates vehicle acceleration, vehicle speed and fuel rate to get vehicle velocity, distance traveled and fuel expended respectively. Velocity is set to zero if it becomes negative in this subroutine.

Input variables:

FUELE - fuel expended
ICLOCK - value of system clock
ICLOK1 - last value of system clock
PAOFR - new fuel rate
PAOFRO - old fuel rate
VVOA - new vehicle acceleration
VVOAO - old vehicle acceleration
VVOD - last distance traveled
VVOS - last vehicle speed

Output variables

FUELE - new fuel consumed
ICLOK1 - current value of system clock
PAOFRO - old fuel rate for next iteration
VVOAO - old acceleration for next iteration
VVOD - new distance
VVOS - new velocity
VVOSO - old speed for next iteration

INGRTH Subroutine

Other variables:

DELTA - integration time factor

HPPSEC - hours per second

Subroutine name: INVRHB

Type of subroutine: Initialization

Description: Subroutine to initialize the variables for the hybrid car simulation.

BS - brake setting

CVTTRQ - torque at driveshaft which will be transmitted to flywheel

DELMIN - automatic drive minimum lead time

DF - flywheel speed (rpm)

DFDOT - flywheel acceleration (rpm/sec)

ESDOT - engine acceleration (rpm/sec)

ESDOTO - previous value of engine acceleration

FINTRQ - torque from engine (or starter motor) to flywheel

GNU - CVT efficiency

ICLOCK - cumulative number of clock pulses

ICLOK1 - ICLOCK at completion of last integration

ICYEND - end of driving cycle indicator

IENGIN - mode of operation of engine-flywheel system

2. Engine charging flywheel
3. Flywheel starting engine
4. Engine off

IENGNO - state of engine on last iteration

IOLD1 - old value of switch 1

IOLD2 - old value of switch 2

ISHIFT - ICLOCK at start of last shift

ISW1 - engine on-off. 0 - off, -1 - on.

ISW2 - torque flow from flywheel to engine. 0-no, -1-yes

INVRHB Subroutine
Page 2

NGI - current gear number

NGIOLD - gear at previous iteration

NREC - output record number

R - ratio of driveshaft speed to flywheel speed

RIEINV - inverse of engine inertia

RIF - flywheel inertia

RFINR - system inertia (1/RIF or 1/RIEPIF)

TB01GI - transmission gear index

TB01GR - transmission gear ratio

TCLULS - torque loss in clutch at flyweel

TCVTLS - equivalent torque loss in CVT at flywheel

TIMAVG(I) - timer averages

TIME - time from start of driving cycle (sec.)

TIMLEN(I) - timer lengths

TIMMAX(I) - timer maximums

TS - throttle setting

TVEPAO - time of previous driving cycle speed

T9IN - driveshaft speed

VANALG - analog car speed

VAR(10) - extra space for variables

VEPAO - previous driving cycle speed

VVOA - vehicle acceleration (ft/sec^2)

VVOS - vehicle speed (mph)

Subroutine name: JPBHYB

Type of subroutine: Output

Description: Subroutine to printout gross results of the simulation for a complete run of the driving cycle.

CFMPG - corrected fuel consumption - connected for energy left in the flywheel (mpg)

EFRIC - The sum of ELENIN and energy lost to flywheel friction

ELEFT - energy left in the flywheel

ELENIN - energy lost to engine inertia

FUMPG - fuel consumption (mpg)

INT - increment in torque intervals for printout

INSPEED(I) - interval storage for printout of speed for joint probability density

ITORQ1 - start of torque interval (for printout)

ITORQ2 - end of torque interval (for printout)

N2 - number of speed intervals (for printout)

SUMJ(I) - totals of joint probability distribution for each speed interval

X(J) - dummy array for tape or disc output

Subroutine name: MONKEY

Type of subroutine: Interpolation

Description: Subroutine to interpolate input torque loss of a hydrostatic power split transmission.

ABS(I) - absolute value

R - ratio of driveshaft speed to flywheel speed

RMAX - maximum allowable transmission system ratio

RMIN - minimum allowable transmission system ratio

RP - the CVT ratio

S - driveshaft speed

STAR(9,7,9) transmission torque loss for specific driveshaft torque driveshaft speed and transmission ratio.

T - output torque of CVT

TLOS - torque loss in CVT

Subroutine name: NUTRAL

Type of subroutine: Component subroutine

Description: Subroutine to calculate torque in rear axle due to drivetrain spin losses with transmission in neutral.

CVTR - ideal CVT ratio

RAR - effective rear axle ratio

RAS - rear axle speed

TAXLE - rear axle torque

Subroutine name: OTCNHB

Type of subroutine: Output

Description: Subroutine to output constants for hybrid car on a disc for performance analysis.

Subroutine name: OTPTHB

Type of subroutine: Output

Description: Subroutine to output hybrid system variables on a line printer for evaluation.

BSFC - brake specific fuel consumption
FMPGC - accumulative fuel consumption (mpg)
FOBHP - flywheel output horsepower
NLINE - number of lines on current page
OBHP - observed brake horsepower
RIENG - mode of operation of engine - flywheel system

2. Engine charging flywheel
3. Flywheel starting engine
4. Engine off

TBD1EF - overall transmission efficiency
T9D1 - rear axle efficiency

Subroutine name: OTVRHB

Type of subroutine: Output

Description: Subroutine to output variables for the hybrid car on a disc for performance analysis.

Subroutine name: PRBDHB

Type of subroutine: Computing subroutine

Description: This subroutine calculates the joint probability density distribution of engine speed versus steady state torque over a given driving cycle.

Input variables:

VAL(1) - current steady state torque

VAL(2) - current engine speed

Output variables:

IPDX(20,20) - new probability distribution

NGT(1) - number of samples above maximum engine speed

NGT(2) - number of samples above maximum torque

NLT(1) - number of samples below minimum engine speed

NLT(2) - number of samples below minimum torque

Other varialbes:

INT1 - torque index

INT2 - engine speed index

VINT(1) - size of torque interval

VINT(2) - size of engine speed interval

VMAX(1) - maximum torque

VMAX(2) - maximum engine speed

VMIN(1) - minimum torque

VMIN(2) - minimum engine speed

Subroutine name: RAEFFH

Type of subroutine: component subroutine

Description: Subroutine to calculate rear axle torque loss.

IGEAR - gear shift indicator
RASCAL - rear axle scale
RATKLS - rear axle torque loss
T9IC - driveshaft torque
T9Il - rear axle efficiency
T9IlGR - rear axle ratio equivalent
T90C - rear axle output torque.

Subroutine name: RAXLOS

Type of subroutine:	Interpolation
Description:	Subroutine to interpolate rear axle torque losses

RALS - rear axle torque loss

STRA (11, 11) - rear axle torque loss table

Subroutine name: RDEPA

Type of subroutine: Input

Description: RDEPA reads and stores the driving cycle velocities at one second intervals.

Input variables:

IVEPA(I) - cycle velocities at one second intervals

ITEMP - intermediate variable for reading the cycle points from the cards (26 points per card)

N - number of cycle points

NREAD - number of cards to read in cycle velocities

NREM - number of points to read from last card

IDATA
ITEMP
ITEMP1 - variables used to pack and unpack two cycle
KPLACE velocities per word of core
KREM

Subroutine name: READRA

Type of subroutine: Input

Description: Subroutine to read in the rear axle efficiency table STRA (I,J) - rear axle torque loss table.

Subroutine name: SIMHBD

Type of subroutine: Control

Description: Mainline of the simulation, including a proper calling sequence for the rest of the routines.

ATORQS(NFUEL) engine torque used in performance analysis

DF - flywheel speed

EPS - used to test for constant engine speed

ESPEED(NFUEL) engine speed used in performance analysis

FINTRQ - torque from engine (or starter motor) to flywheel

FOBHP - flywheel output horsepower

FTIME(NFUEL) time used in performance analysis

ICLOCK - cumulative number of clock pulses

ICLOKO - time at previous output of variables

ICLOK1 - ICLOCK at completion of last integration

ICYCLE - number of times the program has iterated

ICYEND - end of driving cycle indicator

INDIC - output indicator

INISWT - logic variable 0 - initialization of engine speed complete. Car in first.
1 - engine being initialized. Car in neutral.

IREADY - logic variable 0 - engine not in steady state
1 - engine in steady state

NTIMEP - time since last printout

OBHP - observed brake horsepower

PAOC - engine shaft torque

PAOFR - fuel consumption rate (lb/hr)

PAON - engine speed (rpm)

PPOB - engine vacuum (in Hg)

RATE - flywheel speed

RATKLS - rear axle torque loss

SSTORQ - steady state engine torque

TFTORQ - total flywheel input torque

TIME - time from start of driving cycle

T9IC - driveshaft torque

T9I1GR - effective rear axle ratio

T9OC - rear axle output torque

VAL(1) - current steady state torque

VAL(2) - current engine speed

Subroutine name: TGG15H

Type of subroutine: Component subroutine

Description: Subroutine to determine the effective rear axle ratio and driveshaft speed taking into account tire growth.

Input variables:

VVOS - vehicle speed

Output varialbes:

T9IN - actual driveshaft speed

T9I1GR - equivalent rear axle ratio

Other variables:

DIFF - difference between current vehicle speed and vehicle speed at lower interpolation points

T8DN - uncorrected driveshaft speed

T8DNHI - upper interplation point

T8DNLO - lower interpolation point

T8INV(J) - table of driveshaft speeds

T8I1GR - Nominal rear axle ratio

VVIDRR - time radius

Subroutine name: TREFFH

Type of subroutine: Component subroutine

Description: This subroutine calculates the torque loss in the 4 speed transmission.

GRATIO(I) - table of gear ratios of the manual transmission

GEREFF(I) - table of gear efficiencies for each gear of the manual transmission

IGEAR - current gear

TCLSS - torque loss in the 4 speed transmission reflected to the flywheel

TORQ - torque in shaft between 4 speed transmission and CVT.

Subroutine name: TURKEY

Type of subroutine: Input

Description: Subroutine to read in hydrostatic power-split transmission efficiency table.

STAR(I,J,K) - transmission torque loss for specific driveshaft torque, driveshaft speed and transmission gear ratio

I	Input Torque ft-lbf	J	Input Speed rpm	K	Transmission Gear Ratio
1	-200	1	0	1	.224
2	-100	2	600	2	.293
3	- 50	3	1200	3	.362
4	- 25	4	1800	4	.431
5	0	5	2400	5	.500
6	25	6	3000	6	.569
7	50	7	3600	7	.638
8	100			8	.707
9	200			9	.776

Subroutine name: VAL

Type of subroutine:	Interpolation
Description:	Function subroutine to evaluate by 2-dimensional linear interpolation the value of a point bounded by four points of known values.

Subroutine name: VEDYNH

Type of subroutine: System computation

Description: This subroutine determines the vehicle acceleration based on the difference between the force driving the vehicle and the resistive forces. It also tests for conditions of tire spinning or skidding.

Input variables:

AVIO - wind speed (mph)

TB01GI - gear index

TB01GR - transmission gear ratio

T9I1GR - equivalent rear axle ratio

T9OC - rear axle output torque (ft-lb)

VVIBBR - brake setting

VVOS - vehicle speed (mph)

Output variables:

VVDF - vehicle road load force at tire road interface (lb)

VVOA - vehicle acceleration (mph/sec)

Other program variables:

AVIM - air density (lb/ft^3)

AVIS - wind speed (mph)

LOADEQ - used in a logical manner to determine whether road load equation or D.S. torque table is used

R - ratio of driveshaft speed to flywheel speed

SINAVO - sine approximation for grade angle

TVICRL(16) - road load torque at driveshaft

TVIJCT - polar movement of inertia of torque converter turbine (lbm-ft^2)

TVIJRA - polar moment of inertia of rear axle (lbm-ft^2)

TVIJTR - " " " transmission (lbm-ft^2)

TVIJTW - " " " rear wheels (lbm-ft^2)

TVIMJ - total rotary inertia of drivetrain reflected to rear wheels.

VVDFBR - total resistive force acting on vehicle including brakes

VVDFN - net force available to accelerate the vehicle

VVDMI - total inertial mass of vehicle

VVIAMX - maximum acceleration based on maximum coefficient of tire friction (g's)

VVIAS - maximum acceleration based on sliding coefficient of tire friction (g's)

VVIDRR - tire radius

VVIFUM - coefficient of static tire friction

VVIFUS - coefficient of slipping tire friction

VVILFR - frontal area (ft^2)

VVIM - vehicle mass (lb)

VVIMAX - maximum vehicle acceleration

VVIlCD - drag coefficient

VVIlCF - tire coulomb friction coefficient

VVIlRF - coefficient of rolling friction

WHLSLP - used in R.T. simulation to control tire slip noise generator.

APPENDIX E
PROGRAM LISTING OF COMPUTER SIMULATION

```
* * * * * * *
*                              **** SIMHBD ****
      SUBROUTINE SIMHBD
C---- DIGITAL MAINLINE FOR HYBRID CAR
C**** R.R.RADTKE 2/18/75
*     MODIFIED ON 12 NOV 1976
*  MODIFIED 8 APRIL 1977 TO PUT RUN NUMBER ON OUTPUT TAPE
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF      COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,TOI1GR,AVIM,VVIFUM,VVUFUS           COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA       COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                        COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ      COMMON05
      DIMENSION TOINV(11),IVEPA(3000)                                    COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                          COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                    COMMON08
      DIMENSION TVICRL(16)                                               COMMON09
      COMMON TOINV                                                       COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL              COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ    COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                       COMMON13
      COMMON T9IC,T9IN,TODN,T9OC,T9ON                                    COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOO,AVIO,AVIS,TVIMJ,VVOF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                    COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRD,VVOAD     COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                      COMMON18
      EQUIVALENCE (DIST,VVOO),(BS,VVIBBR)                                COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPOX(20,20),ISPEED(20),TIMMAX(5)    COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                      COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPOX,ISPEED,TIMMAX,TIMLEN,TIMAVG    COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN              COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFOOT,GNU,FGNU,TRQIDL,T9ICO,R,DF    COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)     COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                   COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB              COMMON29
      DIMENSION A(10),C(10)                                              COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPOINC,VELINC,TIMINC    COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO         COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF             COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF           COMMON34
      DIMENSION GRATIO(10)                                               COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                              COMMON36
      DIMENSION GEREFF(10)                                               COMMON
      COMMON /EFFGER/GEREFF                                              COMMON
      COMMON /FLYEFF/PERLOS                                              COMMON
      DIMENSION CC(10),AA(10)
      COMMON /SUMVAR/CC,AA                                               COMMON
      COMMON /GRLOSS/TCLSS,TTRIN                                         COMMON
      COMMON /PUMPCG/TLPUMP
      COMMON/MPG/FMPG(15),CFMP(15),RN,CFMPG,RWEN,RWHP
*
*  SENSE SWITCH INFORMATION
```

```
* * * * * *
*       1. PRINTV OUTPUT
*       2. ENGWHL OUTPUT
*       3. WINDUP OPERATION
*       6. AUTOMATIC RUNNING
*
C---- RUNINDICATOR
      NRUN = 0
    1 CONTINUE
*     INITIALIZE ALL CONSTANTS AND TABLES
      CALL INCNHB
C---- INITIALIZE VARIABLES
      CALL INVRHB
      NRUN=NRUN+1
      WRITE(16) NRUN
      INDIC=0
      ICYEND=0
      FUELE = 0.0
      RN = 1.0
      GO TO 60
*
   10 CONTINUE
      IF(SENSE SWITCH 1) 11,12
   11 CALL PRINTV
   12 CONTINUE
C---- UPDATE SYSTEM CLOCK
      ICLOCK=ICLOCK+1
      TIME=ICLOCK*DT
C---- AUTOMATIC DRIVER
      CALL EPAVEL
      CALL AUTOHB
C---- CALCULATE ACTUAL DRIVESHAFT TORQUE
      CALL DSTORQ
      CALL CONTHB
C---- HORSEPOWER
      OBHP = FINTRQ*PAON/5252.0
      PAOC = SSTORQ * FINTRQ
      PAOFR = 0.0
      IF(FINTRQ) 30,50,30
   30 CONTINUE
C---- CALCULATE FUEL CONSUMPTION
*  ENGFUL(I) STARTS AT PAON = 800 RPM
      PAOFR=OBHP*FSPEED(ENGFUL,NSPEED,SPDINC,PAON-800.0)
   50 CONTINUE
      T9OC=(T9IC-RATKLS)*T9I1GR
C---- VEHICLE DYNAMICS
      CALL VEDYNH
C---- SUBROUTINE TO SHIFT GEARS
      CALL GRSHFT
C---- TRANSMISSION EFFICIENCY
      CALL CVTGNU
      CALL TREFFH(TTRIN,T9IC,IGEAR,TCLSS,GRATIO)
C---- INTEGRATION SUBROUTINE
      CALL ENGWHL
```

```
* * * * * *
          CALL INGRTH
          CALL HYBLSS
C---- TIRE GROWTH SUBROUTINE
          CALL TGG15H
          T9ON = T9IN/T9I1GR
C---- REAR AXLE EFFICIENCY
          CALL RAEFPH
C---- JOINT PROBABILITY DISTRIBUTION
          VAL(1)=SSTORQ
          VAL(2)=PAON
          CALL PRBDHB
          ICYCLE=ICYCLE+1
          NTIMEP = ICLOCK-ICLOKO
C---- CHECK FOR END OF DRIVING CYCLE
*  ICYEND IS SET IN EPAVEL
          IF(ICYEND-1)55,90,90
C---- CHECK FOR OUTPUTS
     55 IF(NTIMER-IOUT)10,85,85
*
*                          * INITIALIZATION SECTION *
     60 CONTINUE
          CALL ENGINI
*
          REPEAT 75, WHILE DF < EPS
          CALL ENGWHL
     75 CONTINUE
*
          IF(SENSE SWITCH 3) 77,78
     77 CONTINUE
*  DF(0) IS INCREASED FROM 900 TO 2200 RPM IN WINDUP
          CALL WINDUP
          PAON = OBHP = PAOFR = 0.0
     78 CONTINUE
          CALL ENGINI
          CALL INGRHB
*
*                          * END OF INITIALIZATION *
*
*                          * OUTPUT SECTION *
*
     85 CONTINUE
          CALL OTPTHB
          CALL OTVRHB
          ICLOKO=ICLOCK
*
*                          * END OF OUTPUT SECTION *
*
          GO TO 10
*
*                          * BEGIN TERMINATION SECTION *
*
     90 CONTINUE
          CALL OTPTHB
```

```
* * * * * *
            CALL JPBHYB
 *
            CALL OTVRHB
            END FILE 16
 *
 *                              * END TERMINATION SECTION *
 *
            IF(SENSE SWITCH 6) 1,100
        100 CONTINUE
            END FILE 16
            REWIND 16
 *
            RETURN
            END
```

```
* * * * * *
*                               **** AUTOHB ****
      SUBROUTINE AUTOHB
C---- R.R.RADTKE 1/29/75
*     MODIFIED ON 14 OCT 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF      COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS           COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA       COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                        COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ      COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                    COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                          COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                    COMMON08
      DIMENSION TVICRL(16)                                               COMMON09
      COMMON T8INV                                                       COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL              COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,OBHP,TORQ    COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                       COMMON13
      COMMON T9IC,T9IN,T8ON,T9OC,T9ON                                    COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVOF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                    COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO     COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                      COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                                COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)    COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                      COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG    COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN              COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF    COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)     COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                   COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB              COMMON29
      DIMENSION A(10),C(10)                                              COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC    COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO         COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF             COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF           COMMON34
      DIMENSION GRATIO(10)                                               COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                              COMMON36
      COMMON /ACCELN/AEPA                                                COMMON
      COMMON/CVTTORQ/CVTMAX
*
*  DETERMINE VEHICLE ACCELERATION REQUIRED TO REACH NEXT CYCLE VELOCITY.
      AEPA = (VEPA-VVOS)/DELT
*
      VVDFD=VVDF
      IF(VEPA < 0.1 > VVOS)  VVDFD = 0.0
*
      GR=VVIDRR/T9I1GR
      TNUM=AEPA*VVDMI*1.4667+VVDFD
*
      T9ICDN=TNUM*GR*RATKLS
      IF(T9ICDN < CVTMAX) RETURN
      T9ICDN = CVTMAX
*
      RETURN
      END
```

```
* * * * * * *
*                               **** CGPUMP ****
      SUBROUTINE CGPUMP(SPEED,TLOS)
C*****SUBROUTINE TO COMPUTE TORQUE LOSS ON CVT INPUT SHAFT DUE TO
C         FIFTY CUBIC INCH PER REVOLUTION HYDROSTATIC TRANSMISSION
C         CHARGE PUMP
C*****TOM HAUSENBAUER  8/1975
*  UPDATED 19 JAN 77
      DIMENSION HPLOSS(9)
      DATA HPLOSS/0.0,0.14,0.29,0.47,0.68,0.89,1.10,1.37,1.80/
*
      IF(SPEED .EQ. 0.0) TLOS = 0.245166; RETURN
      I=(SPEED/500.)+1
      IF(I < 1) I = 1
      IF(I > 8) I = 8
      IP=I+1
      SM=500.*(I-1)
      PLOS = HPLOSS(I) + 0.002*(SPEED-SM)*(HPLOSS(IP)-HPLOSS(I))
      TLOS = 875.333*PLOS/SPEED
      RETURN
      END
```

```
* * * * * *
*                            **** CONTHB ****
      SUBROUTINE CONTHB
C---- SUBROUTINE TO CONTROL ENGINE AND FLYWHEEL TORQUE
C---- R.R.RAOTKE 1/29/75
*
*   17 NOV 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,OELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOAOEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),AOCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,AOCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESOOT,PAOC,PAON,PPOS,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVOMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLO,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSD,OELTA,DELT,ISEQ,IGO,ESOOTO,IGEAR                     COMMON18
      EQUIVALENCE (OIST,VVOO),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEEO(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPOX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      OIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPOX,ISPEEO,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLO1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,OFOOT,GNU,FGNU,TRQIOL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      OIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIOL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICON,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FORAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      COMMON /SPASH/VCRUS,OUM(8)
*
      IF(IENGIN-3)5,15,25
    5 CONTINUE
      OFSTOP=ENGSTP(1)
      IF(VVOS .GT. VCRUS-0.1) DFSTOP = 2080.0
      IF(OF-DFSTOP)10,30,30
   10 IENGIN=2
      ISW1 = 0; ISW2 = -1
      FINTRQ=FSPEED(ENGTRQ,NSPEED,SPDINC,PAON-800.0)
```

```
* * * * *
      RFINR=1./RIEPIF
      RETURN
*
   15 CONTINUE
      IF(PAON/DF-.90)20,10,10
   20 IENGIN=3
      ISW1 = ISW2 = -1
      FINTRQ=0.0
      RFINR=1./RIF
      RETURN
*
   25 CONTINUE
      DFSTRT = FSPEED(ENGSTT,NVEL,VELINC,VVOS)
      IF(DF-DFSTRT)20,20,30
   30 IENGIN=4
      ISW1 = ISW2 = 0
      FINTRQ=0.0
      RFINR=1./RIF
      RETURN
      END
```

```
* * * * * *
*                                  **** CVTGNU ****
      SUBROUTINE CVTGNU
C---- SUBROUTINE TO CALCULATE CVT EFFICIENCY
C---- R.R.RADTKE 1/28/75
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILER,VVI2OR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEO     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOKI,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAD    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      COMMON /GRLOSS/TCLSS,TTRIN
      COMMON /PUMPCG/TLPUMP
      COMMON /GEARA1/A1CVT
      COMMON/CVTTORQ/CVTMAX
*
C---- INPUT VARIABLES
C---- IGEAR--GEAR CAR IS IN.  ZERO IF NEUTRAL.
C---- ICLUCH--CLUTCH INDICATOR 0 IF OPEN.  1 IF CLOSED OR SLIPPING.
C---- T9IN----DRIVE SHAFT SPEED
*     T9IC    DRIVESHAFT TORQUE
*     RMIN    MINIMUM SYSTEM RATIO
C---- R-------RATIO OF DRIVESHAFT SPEED TO FLYWHEEL SPEED
C---- THE OUTPUTS ARE
```

```
* * * *                                                                  DAT
C---- CVTTRQ--TORQUE AT DRIVESHAFT WHICH WILL BE TRANSMITTED TO FLYWHEEL
C---- TCVTLS--EQUIPMENT TORQUE LOSS IN CVT AT FLYWHEEL
C---- TCLULS TORQUE LOSS IN CLUTCH AT FLYWHEEL
C---- GNU-----CVT EFFICIENCY
*---- CVTLS---TORQUE LOSS IN CVT
*
      IF (IGEAR) 60,60,3
    3 CONTINUE
      IF(ICLUCH) 40,40,5
    5 IF(R-RMIN)50,50,10
   10 CONTINUE
C---- CLUTCH CLOSED, NOT SLIPPING
      CVTTRQ=T9IC
      TCLULS=0.0
      IF(CVTTRQ + CVTMAX < 0.0) CVTTRQ = -CVTMAX
      GO TO 20
*
   50 CONTINUE
C---- CLUTCH SLIPPING
      CVTTRQ=T9IC
      TCLULS=(RMIN-R)*CVTTRQ
   20 CONTINUE
      SPDIN=T9IN
      TC=CVTTRQ*CVTSCL
      CALL MONKEY(TC,SPDIN,RP,RRMIN,RPMAX,EFFTAB,CVTLS)
      SPUMP=(T9IN/RP)*A1CVT
      CALL COPUMP(SPUMP,TLPUMP)
      TLPUMP=TLPUMP*RPP*A1CVT
      CVTLS=CVTLS/CVTSCL
      TCVTLS=CVTLS*RPP
      TTRIN=T9IC*RP+CVTLS
      TEMP = ABS(T9IC*RP)
      GNU=TEMP/(TEMP+CVTLS)
      RETURN
*
   60 CONTINUE
C---- GEAR BOX IN NEUTRAL
      CVTLS=0.0
   40 CONTINUE
C---- CLUTCH NOT ENGAGED
      CVTTRQ = GNU = TCLULS = TCVTLS = TLPUMP = TTRIN = 0.0
      RETURN
      END
```

```
* * * * * *
*                                  **** DSTORQ ****
      SUBROUTINE DSTORQ
C---- SUBROUTINE TO CALCULATE DRIVESHAFT TORQUE AND NEXT THROTTLE AND BRAKE
C---- R.R.RADTKE 1/28/75
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF      COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS           COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA       COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                        COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ      COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                    COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                          COMMON07
      DIMENSION DACCON(15],ADCCON(15)                                    COMMON08
      DIMENSION TVICRL(16)                                               COMMON09
      COMMON T8INV                                                       COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL              COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,BBHP,TORQ    COMMON12
      COMMON SSTORQ,ESOOT,PAOC,RAON,PPOB,TAOC,TAON                       COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                    COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVOF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                    COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAD     COMMON17
      COMMON VVOSD,DELTA,DELT,ISEQ,IGO,ESOOTD,IGEAR                      COMMON18
      EQUIVALENCE (DIST,VVOO),(BS,VVIBBR)                                COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPOX(20,20),ISPEED(20),TIMMAX(5)    COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                      COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPOX,ISPEED,TIMMAX,TIMLEN,TIMAVG    COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN              COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFOOT,GNU,FGNU,TRQIDL,T9ICD,R,DF    COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)     COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                   COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB              COMMON29
      DIMENSION A(10),C(10)                                              COMMON30
      COMMON AIC,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC    COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICON,T9ICOO         COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF             COMMON33
      COMMON RASCAL,ENTORQ,FORAG,EGAIN,EDRAG,RAEFTB,RATKLB,DTF           COMMON34
      DIMENSION GRATIO(10)                                               COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                              COMMON36
*
C---- SET ACTUAL DRIVESHAFT TORQUE
      T9IC=T9ICON
*     CALCULATE BRAKE SETTING
      BS = 0.0
      IF(T9ICON .LE. 0.0) BS = -T9ICON/VVI2BR
*
      IF(IGEAR > 0 < ICLUCH) RETURN
C---- CAR IN NEUTRAL OR CLUTCH OPEN.
      IF(BS > 0.2) RETURN
C---- EXCESS BRAKING NOT REQUIRED. VEHICLE COASTS.
      CALL NUTRAL(T9ON,1.0,RP,TNUM)
      T9IC = TNUM
      RETURN
      END
```

```
* * * *
*                                **** ENGINI ****
      SUBROUTINE ENGINI
C**** SUBROUTINE USED FOR INITIALIZING ENGINE
C**** R.R.RADTKE 1/29/75
*     MODIFIED ON 14 OCT 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMOR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8ON,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOKI,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB              COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICON,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLB,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
*
      OBHP=PAON*TRQIDL/5252.
      FINTRQ=TRQIDL
      PAOFR=FUIDL
*  SPECIAL
      PPOB = 0.0
***   PPOB = VACIDL
*
      ISW1=0
      ISW2=1
       PAOC = SSTORQ = 0.0
      RETURN
      END
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*                                 **** ENGWHL ****
      SUBROUTINE ENGWHL
C---- SUBROUTINE TO INTEGRATE FLYWHEEL SPEED AND ENGINE SPEED
C---- R.R.RADTKE 2/19/75
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVUFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T80N,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAD    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMO521
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RF,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,TCLUCH,CVTSCL                             COMMON36
      DIMENSION CC(10),AA(10)
      COMMON /SUMVAR/CC,AA
      COMMON /FLYEFF/PERLOS
      COMMON /GRLOSS/TCLSS,TTRIN
      COMMON /PUMPCG/TLPUMP
      COMMON /ENGW/FNDT,NDT
      COMMON/HOTEL/THOTEL
*
*
*  T9IN IS THE SHAFT VELOCITY AFTER THE CVT
*
 1000 FORMAT(/19H**INPUT TO ENGWHL**,2X,5HTIME=,F.2)
 1010 FORMAT(6X,4HISW1,6X,4HISW2,5X,6HFINTRQ,5X,6HTCVTLS,5X,6HTCLULS,
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* * * * *
     1 6X,5HTCLSS,6X,5HRFINR,7X,4HSUM1,7X,4HSUM2,5X,6HCVTTRQ)
 1020 FORMAT(2(7X,I3),8E11.3)
 1030 FORMAT(5X,6HENTORQ,5X,6HTFTORQ,5X,6HRGNTRQ,6X,5HESDOT,6X,5HDFDOT,
     1 7X,4HPAON,9X,2HDF)
 1040 FORMAT(7E11.3)
 1050 FORMAT(/)
*
      A(1)=A(6)=A(8)=A(9)=A(10)=AA(1)=AA(2)=AA(6)=DFINT=0.0
      EGIS = (-ISW2)*EGAIN
      SUM1 = TCVTLS + TCLULS + TCLSS + TLPUMP + THOTEL
      SUM2 = FINTRQ + SUM1
      PER1 = PERLOS = 1.0
*
      IF(SENSE SWITCH 2) 100,110
  100 CONTINUE
      PRINT 1000,TIME
      PRINT 1010
      PRINT 1020,ISW1,ISW2,FINTRQ,TCVTLS,TCLULS,TCLSS,RFINR,SUM1,SUM2,
     1 CVTTRQ
      PRINT 1030
  110 CONTINUE
*
      OO 50 I = 1,FNDT
      ENTORQ = EGIS*(DF-PAON)
      TFTORQ = SUM2 - R*CVTTRQ + ENTORQ*(-ISW1)
*
*  IF TFTORQ < 0, THEN
*
      TFTORQ = -TFTORQ/PER1
      FLYGRL = -TFTORQ*PERLOS
*
*  OTHERWISE, FOR POSITIVE TFTORQ
*
      IF(TFTORQ .GE. 0.0) TFTORQ = TFTORQ*PER1*PER1; FLYGRL = FLYGRL*PER1
*
      OFDOT=TFTORQ*RFINR-DF*FDRAG
      OF=DF+OFDOT*DTF
      R = T9IN/OF
      IF(IENGIN-2)20,30,20
*
   20 ESDOT=ENTORQ*RIEINV-EORAG*PAON
      PAON=PAON+ESDOT*DTF
      IF(IENGIN .EQ. 4) PAON = 0.0
      IF(PAON)25,40,40
   25 PAON=0.0
      GO TO 40
   30 CONTINUE
      PAON=DF
      ESDOT=DFDOT
   40 CONTINUE
      A(1)=A(1)+PAON
      A(6)=A(6)+(TFTORQ-FINTRQ)*DF
      A(8)=A(8)+ENTORQ*OF
```

```
* * * * * *
      A(9)=A(9)+DF*DF
      A(10)=A(10)+DF*FLYGRL
      DFINT = DFINT + DF
      IF(SENSE SWITCH 2) 200,210
  200 CONTINUE
*
*  RGNTRQ VALUE IS FROM THE PREVIOUS DT INTERVAL
*
      PRINT 1040,ENTORQ,TFTORQ,RGNTRQ,ESDOT,DFDOT,PAON,DF
  210 CONTINUE
   60 CONTINUE
*
      RGNTRQ = (R*CVTTRQ + SUM1)*PER1
      IF(RGNTRQ < 0.0) RGNTRQ = 0.0
      IF(SENSE SWITCH 2) 300,310
  300 CONTINUE
      PRINT 1050
  310 CONTINUE
*
      DFF  = DFINT/FNDT
*  ADD BACK INTO FINTRQ THE ACCESSORY LOAD; SEE SUBROUTINE ACCESS.
      A(1) = A(1)*1.08*FINTRQ/FNDT
*
      A(3) = DFF*TCVTLS
      A(4) = DFF*TCLULS
      A(6) = A(6)/FNDT
      A(8) = A(8)*(-ISW1)/FNDT
      A(9) = A(9)*FDRAG/(RFINR*FNDT)
      A(10) = A(10)/FNDT
      AA(1) = DFF*TCLSS
      AA(2) = DFF*TLPUMP
      AA(6) = DFF*RGNTRQ
      RETURN
      END
```

```
* * * * *
*                                **** EPACALC ****
      SUBROUTINE EPACALC(RVEL,TUTIME)
*
*   17 NOV 1976
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,TOI1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION TOINV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON TOINV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,TODN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOO,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLO                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON AIC,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON /EPAOH/ VCRUS,ACEL,DECEL,TA,TC,TD,DUM(2),RTLNGT
C
C**** RETURNS THE VELOCITY THE VEHICLE MUST REACH IN T+1 SEC.
C**** INPUT FROM RDEPA IN COMMON IS VCRUS=CRUISING SPEED
C**** ACEL=ACCELERATION
C**** DECEL=DECELERATION
C**** TA=TIME THE ACCELERATION CYCLE ENDS
C**** TC=TIME THE CRUISING CYCLE ENDS
C**** TD TIME THE DECELERATION CYCLE ENDS
*     TIDLE=TIME AT BUS STOP
*     TE=TIME FOR ONE CYCLE  =TD + TIDLE
*     TUTIME = PTIME - TU FROM RDEPA
*
*  ACCELERATION PHASE
      IF(TUTIME < TA) RVEL = RVEL + ACEL;NVEL = RVEL*10.0;RETURN
*  CRUISE PHASE
      IF(TUTIME < TC) RVEL = VCRUS;NVEL = RVEL*10.0;RETURN
*  BUS STOP PHASE
      IF(TUTIME .GE. TD) NVEL = RVEL = 0.0;RETURN
*  DECELERATION PHASE
      RVEL=RVEL-DECEL
      IF(RVEL ≤ 0.0) NVEL = RVEL = 0.0;RETURN
      NVEL=RVEL*10.0
      RETURN
      END
```

```
*                                            **** EPAVEL ****
      SUBROUTINE EPAVEL
*  16 NOV 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
*
      I=TIME
      II=I+1
   16 CONTINUE
      DELT=FLOAT(II)-TIME
      IF(DELT-DELMIN) 15,10,10
   15 II=II+1
      IF(II - NVEPA) 16,16,6
    6 CONTINUE
      II=NVEPA
      ICYEND=1
   10 CONTINUE
      KPLACE=II/2
      KREM=II-2*KPLACE
*
      IF(KREM .EQ. 0) VEPA = 0.1*IDATA2,RETURN
*
      ITEMP1=IVEPA(KPLACE+1)
      IDATA2 = ITEMP1/4096
*** IDATA1 = IVEL = ITEMP1 - IDATA2*4096
      VEPA =(ITEMP1 - IDATA2*4096)*0.1
      RETURN
      END
```

```
* * * *
*                                  **** GRSHFT ****
      SUBROUTINE GRSHFT
C----- SUBROUTINE TO SHIFT GEARS
C*****TOM HAUSENBALER  9/1975
*     MODIFIED ON 14 OCT 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF      COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVUFUS           COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA       COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                        COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ      COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                    COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                          COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                    COMMON08
      DIMENSION TVICRL(16)                                               COMMON09
      COMMON T8INV                                                       COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL              COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,OBHP,TORQ    COMMON12
      COMMON SSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                       COMMON13
      COMMON T9IC,T9IN,T8ON,T9OC,T9ON                                    COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOO,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOKI,ISHIFT,WHLSLP,WHLOLD                    COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO     COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                      COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                                COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)    COMMO521
      DIMENSION TIMLEN(5),TIMAVG(5)                                      COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG    COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN              COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF    COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)     COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                   COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB              COMMON29
      DIMENSION A(10),C(10)                                              COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC    COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO         COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF             COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF           COMMON34
      DIMENSION GRATIO(10)                                               COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                              COMMON36
      COMMON /SHIFT/ RMINAS(10),RMAXAS(10)
      COMMON /GRINIT/INEXT
      COMMON /ACCELN/AEPA
      COMMON /DELAY/TBDTMS,TBDTW
*
C----- THE INPUTS TO THIS SUBROUTINE ARE
C----- R-------RATIO OF DRIVESHAFT SPEED TO FLYWHEEL SPEED
C----- IGEAR---CURRENT GEAR. ZERO IF NEUTRAL.
C----- RPMIN---MINIMUM ALLOWABLE CVT RATIO
C----- RPMAX---MAXIMUM ALLOWABLE CVT RATIO
C----- RMIN----MINIMUM ALLOWABLE TRANSMISSION SYSTEM RATIO
```

```
C---- RMAX----MAXIMUM ALLOWABLE TRANSMISSION SYSTEM RATIO
C---- THE OUTPUTS ARE
C---- IGEAR---THE NEW TRANSMISSION GEAR
C---- RP------THE CVT RATIO
C---- RPP-----THE NEW TRANSMISSION RATIO
*
      IF (IGEAR) 10,10,20
C*****GEAR BOX IN NEUTRAL
*
  5   STIME=0.
 10   STIME=STIME+DT
      IF(STIME .LE. TBDTMS) RETURN
*
      IGEAR = INEXT
      IF(IGEAR .GT. NGEAR) IGEAR = INEXT = NGEAR
      ICLUCH=1
 20   IF (R-RMIN) 55,55,25
 25   IF (R-RMAX) 30,30,60
 30   CONTINUE
C*****CALCULATE RATIO LIMITS IN CURRENT GEAR
      TRMIN=RMINAS(IGEAR)
      TRMAX=RMAXAS(IGEAR)
      IF (R-TRMIN) 35,35,40
 35   CONTINUE
C*****DOWNSHIFT
      INEXT=IGEAR-1
      ICLUCH = IGEAR = 0
      GO TO 5
*
 40   CONTINUE
      IF (R-TRMAX) 50,50,45
C*****UPSHIFT
 45   INEXT=IGEAR+1
      ICLUCH = IGEAR = 0
      GO TO 5
*
 50   CONTINUE
C*****CALCULATE TRANSMISSION GEAR RATIO
      RPP=GRATIO(IGEAR)
C*****CALCULATE CVT RATIO
      RP=R/RPP
      RETURN
*
 55   CONTINUE
C*****R IS LESS THAN MINIMUM RATIO
      IGEAR=1
      RPP=GRATIO(1)
      RP=RPMIN
      IF (AEPA) 56,56,59
C*****ACCELERATION NOT REQUIRED; OPEN CLUTCH)
 56   ICLUCH=0
      IF(T9ICDN > 0.0) T9ICDN = 0.0
      RETURN
```

```
* * * * *
*
 59   CONTINUE
C*****ACCELERATION REQUIRED.  SLIP CLUTCH.
      ICLUCH = 1
      RETURN
*
 60   CONTINUE
C*****R GREATER THAN MAXIMUM RATIO (SHOULD BE IMPOSSIBLE)
      IGEAR=NGEAR
      RPP=GRATIO(NGEAR)
      RP=RPMAX
      RETURN
      END
```

```
* * * * *
*                           **** FSPEED ****
      FUNCTION FSPEED(ARRAY,N,VALINC,VAL)
C---- SUBROUTINE TO PROVIDE INTERPOLATION FOR ENGINE PARAMETERS
C---- R.R.RADTKE 1/29/75
      DIMENSION ARRAY(1)
      I=VAL/VALINC
      REM=VAL-VALINC*I
      I=I+1
*
      IF(I .GE. N) FSPEED = ARRAY(N); RETURN
*
      FSPEED=ARRAY(I)+REM*(ARRAY(I+1)-ARRAY(I))/VALINC
      RETURN
      END
```

```
* * * * *
*                             **** HYBLSS ****
      SUBROUTINE HYBLSS
C---- SUBROUTINE TO CALCULATE HYBRID ENERGY LOSSES
*     THIS VERSION OF HYBLSS IS ONLYFOR THE DIGITAL SIMULATION
C---- R.R.RADTKE 1/30/75
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILER,VVI2OR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,TOI1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWO,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMOND3
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION TOINV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMOND8
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON TOINV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOKI,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSD,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(2D,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(1D6)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(2D),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON AIC,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      DIMENSION CC(10),AA(1D)
      COMMON /SUMVAR/CC,AA                                              COMMON
      COMMON /EPASH/VCRUS,DUM(8)
      COMMON /RR/VVDFN
*
      DATA CONST/0.00533333/
*
*  DELTA = DT/2
      DELCON = DELTA/2626.0
*  CONST = 22/15/275
      RACON = VVOS*CONST
```

```
* * * * * *
      A(1)=A(1)*DELCON
      A(2)=VVDF*RACON*DELTA
      A(3)=A(3)*DELCON
      A(4)=A(4)*DELCON
*
      A(5) = -T9IN*DELCON*(T9IC-CVTTRQ)
      IF(T9IC > 0.0) A(5) = 0.0
*
      A(6)=A(6)*DELCON
      A(7)=RATKLS*T9IN*DELCON
      A(8)=A(8)*DELCON
      A(9)=A(9)*DELCON
      A(10)=A(10)*DELCON
      AA(1)=AA(1)*DELCON
      AA(2)=AA(2)*DELCON
*
      IF(AEPA > 0.01)
     1   AA(7) = VVDFN*RACON*DELTA;
     2   AA(3) = VVDF *RACON*DELTA
      IF(VVOS $ VCRUS*0.02)
     1   AA(4) = VVDF *RACON*DELTA
      IF(AEPA < -0.01)
     1   AA(5) = VVDF *RACON*DELTA
*
      AA(6)=AA(6)*DELCON
      DO 20 I=1,10
       C(I)= C(I)+ A(I)
      CC(I)=CC(I)+AA(I)
   20 CONTINUE
      RETURN
      END
```

```
* * * *
*                                 **** INCNHB ****
      SUBROUTINE INCNHB
C---- SUBROUTINE TO INITIALIZE CONSTANTS FOR SIMULATION OF HYBRID CAR
C---- R.R.RADTKE 1/28/75
*   MODIFIED FOR DIESEL ON 13 OCT 1976
*  MODIFIED FOR PRODUCTION RUNNING ON 1 MAR 1977
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T80N,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSD,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB              COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,E,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICON,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      EQUIVALENCE (VAR(3),GAIN)
      COMMON /SHIFT/ RMINAS(10),RMAXAS(10)
      DIMENSION GEREFF(10)                                              COMMON
      COMMON /EFFGER/GEREFF                                             COMMON
      COMMON /FLYEFF/PERLOS                                             COMMON
      DIMENSION CC(10),AA(10)
      COMMON /SUMVAR/CC,AA                                              COMMON
      COMMON /GEARA1/A1CVT
      COMMON /DELAY/TBDTMS,TBDTH
      COMMON /ENGW/FNDT,NDT
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* * * * * *
      COMMON/CVTTORQ/CVTMAX
      DIMENSION ICOMM(52)
      EQUIVALENCE (ICOMM,COMM)
      DIMENSION ENGTR(20)

  104 FORMAT(8E10.3)
  105 FORMAT(8I10)
  106 FORMAT(16F5.1)
  109 FORMAT(12F6.1)
  110 FORMAT(13A6)
  112 FORMAT(E10.3,I10)
  204 FORMAT(3E10.3,F10.1,I10)
  209 FORMAT(12F8.1)
  990 FORMAT(H1)
 1000 FORMAT(4X,6HSPDINC,2X,6HNSPEED)
 1005 FORMAT(E10.3,I8)
 1010 FORMAT(9HENGTRQ(I))
 1015 FORMAT(16HENGTRQ(I)*SCALEF)
 1030 FORMAT(9HENGFUL(I))
 1040 FORMAT(4X,6HVELINC,4X,4HNVEL)
 1050 FORMAT(9HENGSTT(I))
 1052 FORMAT(4X,6HTIMINC,4X,6HNTIMES)
 1054 FORMAT(9HENGSTP(I))
 1060 FORMAT(4X,6HTRQIDL,5X,5HFUIDL)
 1062 FORMAT(13HTRQIDL*SCALEF)
 1065 FORMAT(4X,6HCVTMAX)
 1070 FORMAT(5HTOINV)
 1080 FORMAT(14HCVT EFF. TABLE)
 1090 FORMAT(21H REAR AXLE EFF. TABLE)
 1100 FORMAT(8H*TVICRL*)
 1110 FORMAT(3X,7HVMIN(1),3X,7HVMAX(1),3X,7HVINT(1))
 1120 FORMAT(3X,7HVMIN(2),3X,7HVMAX(2),3X,7HVINT(2))
 1125 FORMAT(30H**INERTIA UNITS: LB-FT-SEC/RPM)
 1126 FORMAT(H+,32X,32H= (LB-FT*FT)*2*3.14159/60*32.174)
 1130 FORMAT(7X,3HRIF)
 1140 FORMAT(7X,3HRIE)
 1150 FORMAT(5X,5HVVIMI,4X,6HVVILFR,4X,6HVVI2BR,4X,6HVVI1CD,
     1 6X,4HVVIM,4X,6HVVI1RF,4X,6HVVIMDR,4X,6HVVIDRR)
 1160 FORMAT(6X,4HAVIB,6X,4HAVIR,4X,6HTOI1GR)
 1170 FORMAT(4X,6HVVIFUM,4X,6HVVIFUS,4X,6HVVISWB,5X,5HVVISH,4X,6HVVI1CF)
 1180 FORMAT(4X,6HTVIJCT,4X,6HTVIJTR,4X,6HTVIJRA,4X,6HTVIJTW)
 1190 FORMAT(4X,6HSCALEF,4X,6HFUELWT,4X,6HDELMIN)
 1200 FORMAT(4X,6HTBDTMS,5X,5HTBDTH,6X,9HGAIN(=DT))
 1210 FORMAT(5X,5HNGEAR)
 1220 FORMAT(9HGRATIO(I))
 1230 FORMAT(9HRMINAS(I))
 1240 FORMAT(9HRMAXAS(I))
 1250 FORMAT(9HGEREFF(I))
 1260 FORMAT(4X,6HPERLOS)
 1270 FORMAT(5X,5HA1CVT)
 1280 FORMAT(5X,5HRPMIN,5X,5HRPMAX,7X,3HEPS)
 1290 FORMAT(5X,5HFDRAG,5X,5HEGAIN,5X,5HEDRAG)
 1300 FORMAT(4X,6HRASCAL,4X,6HCVTSCL)
```

```
* * * * * *
 1310 FORMAT(6X,4HISOUT,4X,6HLOADEQ)
 1320 FORMAT(8X,2HOT,7X,3HOTF)
 1325 FORMAT(10HTBDTMS=DT=F5.3)
 1330 FORMAT(28HCONSTANTS COMPUTED IN INCNHB)
 1340 FORMAT(3X,7HNDIM(1),3X,7HNDIM(2),6X,4HAVIM,6X,4HAVIS,
     1 6X,4HRMIN,6X,4HRMAX,4X,6HRIEINV,4X,6HBIEPIF)
 1350 FORMAT(4X,6HHRPSEC,4X,6HVVIAMX,5X,5HVVIAS 5X,4HFNDT,7X,3HNDT)
 1360 FORMAT(14H*COMMENT CARD*)
*
      IF(SENSE SWITCH 6) 2,1
    1 CONTINUE
*  ZERO-OUT COMMENT ARRAY
      DO 6,I = 1,52
         ICOMM(I) = 0H
    6    CONTINUE
C**** READ CVT EFFICIENCY TABLE
      PRINT 1080
      CALL TURKEY(EFFTAB)
*  TOP OF PAGE
      PRINT 990
C**** READ IN REAR AXLE EFFICIENCY TABLE
      PRINT 1090
      CALL READRA(RAEFTB)
C**** DRIVESHAFT RESISTIVE TORQUE ROAD LOAD DATA
      READ  106,TVICRL
      PRINT 1100
      PRINT 106,TVICRL
C**** READ THROTTLE MAP
      READ  112,SPDINC,NSPEED
      PRINT 1000
      PRINT 1005,SPDINC,NSPEED
      READ  104,(ENGTR (I),I=1,NSPEED)
      PRINT 1010
      PRINT 104,(ENGTR (I),I=1,NSPEED)
C**** READ FUEL CONSUMPTION MAPS
      READ  104,(ENGFUL(I),I=1,NSPEED)
      PRINT 1030
      PRINT 104,(ENGFUL(I),I=1,NSPEED)
C**** ENGINE CONTROL PARAMETERS
      READ  112,VELINC,NVEL
      PRINT 1040
      PRINT 1005,VELINC,NVEL
      READ  104,(ENGSTT(I),I=1,NVEL)
      PRINT 1050
      PRINT 104,(ENGSTT(I),I=1,NVEL)
*
*  SAVE NVEL
      NVELSAVE = NVEL
      READ  112,TIMINC,NTIMES
      PRINT 1052
      PRINT 1005,TIMINC,NTIMES
      READ  104,(ENGSTP(I),I=1,NTIMES)
      PRINT 1054
```

```
* * * * * *
              PRINT 104,(ENGSTP(I),I=1,NTIMES)
      C----   ENGINE TORQUE AT IDLE
              READ  104,TRQID ,FUIDL
              PRINT 1060
              PRINT 104,TRQID ,FUIDL
      *       READ MAX CVT OUTPUT TORQUE
              READ  104,CVTMAX
              PRINT 1065
              PRINT 104,CVTMAX
      C----   DRIVE SHAFT SPEED AS A FUNCTION OF VEHICLE SPEED
              READ  109,T8INV
              PRINT 1070
              PRINT 209,T8INV
      C----   READ IN DEFINITION OF CROSS CORRELATION
              READ  104,VMIN(1),VMAX(1),VINT(1)
              PRINT 1110
              PRINT 104,VMIN(1),VMAX(1),VINT(1)
              READ  104,VMIN(2),VMAX(2),VINT(2)
              PRINT 1120
              PRINT 104,VMIN(2),VMAX(2),VINT(2)
              NDIM(1)=(VMAX(1)-VMIN(1))/VINT(1)+1
              NDIM(2)=(VMAX(2)-VMIN(2))/VINT(2)+1
      *       ENGINE INERTIA UNITS SAME AS FLYWHEEL
      *       ENGINE INERTIA
              READ  104,RIE
              PRINT 1140
              PRINT 104,RIE
      C----   INVERSE ENGINE INERTIA
              RIEINV = 1.0/RIE
      C----   AIR PRESS.,AIR TEMP,REAR AXLE RATIO
              READ  104,AVIB,AVIR,T8I1GR
              PRINT 1160
              PRINT 104,AVIB,AVIR,T8I1GR
      C----   CALCULATE AIR DENSITY
              AVIM=2.702912*AVIB/(459.67+AVIR)
      C----   SET THE WIND SPEED TO ZERO
              AVIS=0
      C----   TIRE PARAMETERS
              READ  104,VVIFUM,VVIFUS,VVISWB,VVISH,VVI1CF
              PRINT 1170
              PRINT 104,VVIFUM,VVIFUS,VVISWB,VVISH,VVI1CF
      C----   POLAR MOMENTS
              READ  104,TVIJCT,TVIJTR,TVIJRA,TVIJTW
              PRINT 1180
              PRINT 104,TVIJCT,TVIJTR,TVIJRA,TVIJTW
      C----   LENGTH OF TIME FOR SHIFTING, TIME BETWEEN SHIFTS IN SECONDS
              READ  104,TBDTMS,TBDTH,GAIN
              PRINT 1200
              PRINT 104,TBDTMS,TBDTH,GAIN
      *    TOP OF PAGE
              PRINT 990
              READ  105,NGEAR
              PRINT 1210
```

```
      PRINT 105,NGEAR
      READ  104,(GRATIO(I),I=1,NGEAR)
      PRINT 1220
      PRINT 104,(GRATIO(I),I=1,NGEAR)
      READ  104,(RMINAS(I),I=1,NGEAR)
      PRINT 1230
      PRINT 104,(RMINAS(I),I=1,NGEAR)
      READ  104,(RMAXAS(I),I=1,NGEAR)
      PRINT 1240
      PRINT 104,(RMAXAS(I),I=1,NGEAR)
      READ  104,(GEREFF(I),I=1,NGEAR)
      PRINT 1250
      PRINT 104,(GEREFF(I),I=1,NGEAR)
      READ  104,PERLOS
      PRINT 1260
      PRINT 104,PERLOS
      READ  104,A1CVT
      PRINT 1270
      PRINT 104,A1CVT
      READ  104,RPMIN,RPMAX,EPS
      PRINT 1280
      PRINT 104,RPMIN,RPMAX,EPS
      READ  104,FDRAG,EGAIN,EDRAG
      PRINT 1290
      PRINT 104,FDRAG,EGAIN,EDRAG
      READ  104,RASCAL,CVTSCL
      PRINT 1300
      PRINT 104,RASCAL,CVTSCL
      READ  105,IOUT,LOADEQ
      PRINT 1310
      PRINT 105,IOUT,LOADEQ
      RMIN = RPMIN*GRATIO(1)
      RMAX = RPMAX*GRATIO(NGEAR)
C---- TIME INCREMENT
      READ  104,DT,DTF
      PRINT 1320
      PRINT 104,DT,DTF
      FNDT = NDT = DT/DTF + 0.5
*     CORRECT TBDTMS IF LESS THAN DT
      IF(TBDTMS < DT)  TBDTMS = DT;  WRITE(108,1325) TBDTMS
C---- HOURS PER SECOND
      HRPSEC=1./3600.
C---- LINES PER PAGE
      MAXLIN=48
*
*  PRODUCTION RUNS START HERE
*
    2 CONTINUE
C---- READ IN COMMENT CARDS
      READ  110,(COMM(I),I = 1,13)
      PRINT 1360
      PRINT 110,(COMM(I),I = 1,13)
C---- READ IN DRIVING CYCLE
```

```
* * * * * *
          CALL RDERA
*     TOP OF PAGE
          PRINT 990
*
*     RESTORE NVEL
          NVEL = NVELSAVE
*         READ FLYWHEEL INERTIA--UNITS: LB-FT-SEC/RPM
          READ  104,RIF
          PRINT 1125
          PRINT 1126
          PRINT 1130
          PRINT 104,RIF
          RIEPIF = RIE + RIF
C**** DRAG CONSTANTS
          READ  104,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF,VVIMDR,VVIDRR
          PRINT 1150
          PRINT 104,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF,VVIMDR,VVIDRR
*         ENGINE SCALE,FUEL WEIGHT,
          READ  104,SCALEF,FUELWT,DELMIN
          PRINT 1190
          PRINT 104,SCALEF,FUELWT,DELMIN
*
*     MULTIPLY TORQUE VALUES BY THE SCALE FACTOR.
*
          DO 10 I = 1,NSPEED
             ENGTRQ(I) = ENGTR (I)*SCALEF
       10    CONTINUE
          PRINT 1015
          PRINT 104, (ENGTRQ(I),I = 1,NSPEED)
          TRQIDL = TRQID *SCALEF
          PRINT 1062
          PRINT 104, TRQIDL
*
          VVIAMX=VVIFUM*VVIMDR*VVISWB/(VVIM*(VVISWB*VVIFUM*VVISH))
          VVIAS =VVIFUS*VVIMDR*VVISWB/(VVIM*(VVISWB*VVIFUS*VVISH))
          PRINT 1330
          PRINT 1340
          PRINT 104,NDIM(1),NDIM(2),AVIM,AVIS,RMIN,RMAX,RIEINV,RIEPIF
          PRINT 1350
          PRINT 204,HRPSEC,VVIAMX,VVIAS,FNDT,NDT
*
          IF(NDIM(1) > 20 .OR. NDIM(2) > 20)
         1 OUTPUT(102), 'NDIM(1) AND/OR NDIM(2) EXCEED 20 IN INCNHB',
         2 PAUSE
*
*         TMAX NOT USED IN PROGRAM, BUT IS SET TO ZERO.
          TMAX = 0.0
*
          RETURN
          END
```

```
* * * * * *
*                                 **** INGRHB ****
      SUBROUTINE INGRHB
C**** SUBROUTINE TO INITIALIZE CAR AFTER ENGINE IS IN STEADY STATE
C**** R.R.RADTKE 1/30/75
*
*  18 NOV 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIO,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INOIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8ON,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLO                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAD    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOO),(BS,VVIBOR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON AIC,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RF,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      DIMENSION CC(10),AA(10)
      COMMON /SUMVAR/CC,AA                                              COMMON
      COMMON /GRLOSS/TCLSS,TTRIN                                        COMMON
      COMMON /GRINIT/INEXT                                              NEW
*
      AVIO = AVIS = 0.0
      EMISE = EMISF = 0.0
      ICLOKO=-(IOUT+1)
      ICLOK1 = ICLOCK = 0
      ICYCLE = ISEQ = ITICYC = 0
```

```
* * * * * *
      ICLUCH = 0
      IENGIN=2
      IGEAR = 0
      INOIC=0
      INEXT = 1
      NGI = NGIOLD = 1
      NGT(1) = NGT(2) = NLT(1) = NLT(2) = 0
      NLINE=MAXLIN+5
      PAOFRO = PAOFR = FUIDL
      RP = RPMIN
      RPP = GRATIO(1)
      TIME = 0.0
      T8ON = T9IN = T9ON = 0.0
      T9I1GR=T8I1GR
      T9ICDO = 0.
      VEPA = 0.0
      VVOA = VVOAO = VVOD = VVOSO = 0.0
      VVOS = 0.0
      WHLOLD = 0.0
      DO 6 M=1,10
         A(M) = AA(M) = C(M) = CC(M) = 0.0
    6    CONTINUE
      DO 10 I=1,20
      DO 10 J=1,20
         IPDX(I,J) = 0
   10    CONTINUE
      DO 15 I=1,5
         TIMAVG(I) = TIMLEN(I) = TIMMAX(I) = 0.0
   15    CONTINUE
      CALL CONTHB
      CALL CVTGNU
      CALL TREFFH(TTRIN,T9IC,IGEAR,TCLSS,GRATIO)
      CALL RAEFFH
      CALL VEDYNH
*
      IGEAR = 1
*
      RETURN
      END
```

```
* * * * * *
*                         **** INGRTH ****
      SUBROUTINE INGRTH
C---- SUBROUTINE TO INTEGRATE SYSTEM VARIABLES
C---- R.R.RADTKE 3/5/74
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILER,VVI2BR,VVI1CD,VVIM,VVI1RF       COMMON01
      COMMON VVIMDR,VVIORR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS            COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA        COMMON03
      COMMON TVIJTW,SCALEF,OELMIN,FUELWT,TIOLE,OT                         COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOAOEQ       COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                     COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NOIM(2)                           COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                     COMMON08
      DIMENSION TVICRL(16)                                                COMMON09
      COMMON T8INV                                                        COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NOIM,DACCON,ADCCON,TVICRL               COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ     COMMON12
      COMMON SSTORQ,ESOOT,PAOC,PAON,PPOB,TAOC,TAON                        COMMON13
      COMMON T9IC,T9IN,T8ON,T9OC,T9ON                                     COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOO,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                     COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLO,VEPA,VANALG,PAOFRO,VVOAO      COMMON17
      COMMON VVOSO,OELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                       COMMON18
      EQUIVALENCE (OIST,VVOD),(BS,VVIOBR)                                 COMMON19
      DIMENSION FTIME(60),ESPEEO(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      OIMENSION VAL(2),NLT(2),NGT(2),IPOX(20,20),ISPEED(20),TIMMAX(5)     COMMON21
      OIMENSION TIMLEN(5),TIMAVG(5)                                       COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEEO,TIMMAX,TIMLEN,TIMAVG     COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLO2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN               COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,OFDOT,GNU,FGNU,TRQIDL,T9ICO,R,DF     COMMON26
      OIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)      COMMON27
      OIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                    COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB               COMMON29
      DIMENSION A(10),C(10)
      COMMON A,C,FUIOL,VACIDL,NSPEEO,NVEL,NTIMES,SPDINC,VELINC,TIMINC     COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICON,T9ICOO          COMMON32
      COMMON RR,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF              COMMON33
      COMMON RASCAL,ENTORQ,FORAG,EGAIN,EORAG,RAEFTB,RATKLS,DTF            COMMON34
      OIMENSION GRATIO(10)                                                COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                               COMMON36
*
      NTIMEP=ICLOCK
      DELTA=(NTIMEP-ICLOK1)*OT*.5
      VVOS=VVOS+(VVOAO+VVOA)*DELTA
      IF(VVOS < 0.0) VVOS = 0.0
      VVOO=VVOD+(VVOSO+VVOS)*OELTA*HRPSEC
      FUELE=FUELE+(PAOFRO+PAOFR)*OELTA*HRPSEC
      VVOAO=VVOA
      VVOSO=VVOS
      PAOFRO=PAOFR
      ICLOK1=NTIMEP
      RETURN
      END
```

```
* * * * * ,
*                                    **** INVRHB ****
      SUBROUTINE INVRHB
C---- SUBROUTINE TO INITIALIZE VARIABLES FOR SIMULATION HYBRID CAR
C----R.R.RADTKE 1/30/75
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIORR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,OT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      OIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      OIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESOOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIOBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      OIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      OIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOL02,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      OIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON AAC,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EORAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      EQUIVALENCE (VAR(4),TVEPAO),(VAR(5),VEPAO)
*
      BS=0.
      ICLOCK = ICLOK1 = ICYEND = ISHIFT = 0
      IOLD1 = IOL02 = IOLD3 = 0
      NGI = NGIOLD = NREC = 0
      TIME = TS = VANALG = VEPAO = VVOA = 0.0
      VVOS=0.
      DO 5 I=1,5
         TIMMAX(I) = TIMLEN(I) = TIMAVG(I) = 0.0
    5    CONTINUE
      VAR(2)=50.
      TVEPAO=-DELMIN
```

```
• • • • • •
      RFINR=1./RIF
      FINTRQ=TRQIDL
      PAON = 0.
      ESDOT=TRQIDL*RIEINV
      ISW1=0
      ISW2=-1
      IENGIN=1
      IENGNO=1
      T9IN = T9ON = 0.0
      DF   = 775.0
      DFDOT = 0.0
      CVTTRQ = TCLSS = TCLULS = TCVTLS = TLPUMP = GNU = R = 0.0
      RETURN
      END
```

```
* * * * * * *
*                         **** JPBHYB ****
      SUBROUTINE JPBHYB
C**** TERMINATION SUBROUTINE
C**** R.R.RADTKE 3/5/74
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTB,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,OBHP,TORQ   COMMON12
      COMMON BSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8ON,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOKI,ISHIFT,WHLSLP,WHLOLO                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION ETIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFOOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      DIMENSION SUMJ(20)
      DIMENSION CC(10),AA(10)
      COMMON /SUMVAR/CC,AA                                              COMMON
      COMMON/STOPS/NSTOP
      COMMON /EPASH/ VCRUS,ACEL,DECEL,D(3),TIDL,DD,RTLNGT
      COMMON/MPG/FMPG(15),CFMP(15),RN,CFMPG,RWEN,RWHP
*
  199 FORMAT(/,20X,13A6,//,20X,13A6,/)
  200 FORMAT(    41X,36HJOINT PROBABILITY DENSITY (PER CENT))
  201 FORMAT(//,39X,43HENGINE STEADY STATE TORQUE VS. ENGINE SPEED)
  202 FORMAT(2/,1X,6HTORQUE,44X,15HSPEED INTERVALS,/,1X,9HINTERVALS)
  203 FORMAT(H0)
  204 FORMAT(8X,20I6)
```

```
, * * * *
  205 FORMAT(1X,6HTORQUE,/,1X,9HINTERVALS)
  206 FORMAT(1X,I3,1H-,I3,20F6.2)
  207 FORMAT(/,5X,I5,38H SAMPLES FELL BELOW THE MINIMUM TORQUE,
     1 /,5X,I5,36H SAMPLES EXCEEDED THE MAXIMUM TORQUE,
     2 /,5X,I5,37H SAMPLES FELL BELOW THE MINIMUM SPEED,
     3 /,5X,I5,35H SAMPLES EXCEEOED THE MAXIMUM SPEEO)
  208 FORMAT(5X,I7,37H ITERATIONS TOOK PLACE OVER THE CYCLE)
  209 FORMAT(8H TOTALS ,20F6.2)
  210 FORMAT(10X,42HCUMULATIVE FUEL CONSUMPTION FOR EACH MILE:)
 2100 FORMAT(10X,4HMILE,5X,11HUNCORRECTED,17X,9HCORRECTED)
 2110 FORMAT(8X,F6.3,5X,F6.3,X,5HMPG =,F7.5,X,4HGPM),4X,F6.3,X,5HMPG =,
     1 F7.5,X,3HGPM)
  211 FORMAT(10X,9HOISTANCE=,F7.4,2X,5HMILES)
  212 FORMAT(12X,46HONE SAMPLE TAKEN OURING EACH PROGRAM ITERATION)
  213 FORMAT(10X,17HROAD LOAO ENERGY:,12(2H =),F9.2)
  214 FORMAT(10X,19HENERGY LOST IN CVT:,11(2H =),F9.2)
  215 FORMAT(10X,26HENERGY LOST IN THE CLUTCH:,X,7(2H =),F9.2)
  216  FORMAT(10X,30HENERGY LOST IN EXCESS BRAKING:,X,5(2H =),F9.2)
  217 FORMAT(10X,27HENERGY GENERATEO BY ENGINE:,7(2H =),F9.2,X,
     1   18HHORSEPOWER SECONDS)
  218 FORMAT(10X,24HENERGY LEFT IN FLYWHEEL:,X,8(2H =),F9.2)
  219 FORMAT(10X,33HENERGY LOST TO FLYWHEEL FRICTION:,4(2H =),F9.2)
  220 FORMAT(10X,37HENERGY OUTPUT FROM SYSTEM POWERPLANT:,2(2H =),F9.2)
  221 FORMAT(10X,25HENERGY LOST IN REAR AXLE:,8(2H =),F9.2)
  222 FORMAT(10X,35HENERGY LOST IN STARTING THE ENGINE:,3(2H =),F9.2)
  225 FORMAT(10X,30HENERGY LOST TO ENGINE INERTIA:,X,5(2H =),F9.2)
  226 FORMAT(10X,29HENERGY LOST IN FLYWHEEL GEAR:,6(2H =),F9.2)
  227 FORMAT(10X,34HENERGY LOST IN TRANSMISSION GEARS:,X,3(2H =),F9.2)
  228 FORMAT(10X,40HENERGY USED BY TRANSMISSION CHARGE PUMP:,X,F9.2)
  230 FORMAT(10X,15HVEHICLE WEIGHT:,F8.1,X,3HLBS)
  260 FORMAT(10X,41HENERGY RECOVEREO IN REGENERATIVE BRAKING:,F9.2)
  262 FORMAT(10X,24HACTUAL FLYWHEEL INERTIA:,F9.2,X,9HLB-FT SQO)
  300 FORMAT(H1)
 1000 FORMAT(5X,5HACCEL,4X,6HCRUISE,5X,5HDECEL,12X,8HBUS STOP,2X,
     1 8HNO STOPS,4X,6HLENGTH)
 1002 FORMAT(3X,9H(MPH/SEC),3X,5H(MPH),4X,9H(MPH/SEC),11X,5H(SEC),2X,
     1 10H(PER MILE),3X,7H(MILES))
 1003 FORMAT(3F10.3,F20.3,I10,F10.3)
*
        PRINT 300
        PRINT 199,(COMM(I),I=1,26)
        PRINT 200
        PRINT 201
        PRINT 202
        ISPEEO(1)=YMIN(2)
        INT=VINT(2)
        NLIM=NOIM(2)
        OO 5 I=2,NLIM
        ISPEED(I)=ISPEEO(I-1)+INT
      5 CONTINUE
        N2=NDIM(2)-1
        PRINT 204,(ISPEED(I),I=1,N2)
        PRINT 204,(ISPEEO(I),I=2,NLIM)
```

```
      PRINT 203
      ITORQ1=VMIN(1)
      INT=VINT(1)
      N1=NDIM(1)-1
      DO 10 I=1,NLIM
   10 SUMJ(I)=0
      DO 20 I=1,N1
      ITORQ2=ITORQ1+INT
      DO 15 J=1,N2
      X(J)=FLOAT(IPDX(I,J))*100./FLOAT(ICYCLE)
      SUMJ(J)=SUMJ(J)+X(J)
   15 CONTINUE
      PRINT 206,ITORQ1,ITORQ2,(X(J),J=1,N2)
      ITORQ1=ITORQ2
   20 CONTINUE
      PRINT 205
      PRINT 203
      PRINT 209,(SUMJ(J),J=1,N2)
      PRINT 300
      PRINT 203
      PRINT 208,ICYCLE
      PRINT 212
      PRINT 207,(NLT(I),NGT(I),I=1,2)
      PRINT 203
      PRINT 230,VVIM
*  COMPUTE ACTUAL FLYWHEEL INERTIA IN LB*FT*FT
      RI  = RIF*32.174*60.0/(6.28318*25.0)
      PRINT 262,RI
      PRINT 203
      PRINT 211,VVOD
      PRINT 1000
      PRINT 1002
      PRINT 1003,ACEL,VCRUS,DECEL,TIDL,NSTOP,RTLNGT
      PRINT 203
      PRINT 210
      PRINT 2100
*
*  OUTPUT FUEL CONSUMPTION
*
      DO 25 N = 1,RN
      VN = N
      IF(N .EQ. RN) VN = VVOD
      PRINT 2110,VN,FMPG(N),1.0/FMPG(N),CFMP(N),1.0/CFMP(N)
   25 CONTINUE
*
      PRINT 203
      ELEFT = DF*DF*RIF/10504.0
      EFRIC=C(1)-C(6)-ELEFT
      ELENIN=EFRIC-C(9)
      PRINT 217,C(1)
      C(6)=C(6)+CC(6)
      PRINT 220,C(6)
      PRINT 260,CC(6)
```

```
      PRINT 218,ELEFT
      PRINT 203
      PRINT 213,C(2)
      PRINT 203
      PRINT 216,C(5)
      PRINT 221,C(7)
      PRINT 214,C(3)
      PRINT 228,CC(2)
      PRINT 227,CC(1)
      PRINT 215,C(4)
      PRINT 226,C(10)
      PRINT 219,C(9)
      PRINT 225,ELENIN
      PRINT 222,C(8)
      PRINT 300
      RETURN
      END
```

```
* * * * * *
*                                  **** MONKEY ****
      SUBROUTINE MONKEY(T,S,R,RMIN,RMAX,STAR,TLOS)
C*****TOM HAUSENBAUER   5/1975
      DIMENSION STAR(9,7,9)
      DIMENSION TLT(2),TS(2)
      TA=ABS(T)
      IF(TA-25.) 11,11,12
   11 ID=1
      TMD=0.
      TPD=25.
      GO TO 20
   12 IF (TA-50.) 13,13,14
   13 ID=2
      TMD=25.
      TPD=50.
      GO TO 20
   14 IF (TA-100.) 15,15,16
   15 ID=3
      TMD=50.
      TPD=100.
      GO TO 20
   16 ID=4
      TMD=100.
      TPD=200.
   20 CONTINUE
      IF (T) 25,21,21
   21 I=ID+4
      TM=TMD
      TP=TPD
      GO TO 30
   25 I=5-ID
      TM=-TPD
      TP=-TMD
   30 CONTINUE
      IPP=I+1
      J=1+(S/600.)
*
      IF(J < 1) J = 1
      IF(J > 6) J = 6
*
      SP=600.*J
      SM=SP-600.
      RINT=(RMAX-RMIN)/8.
      K=((R-RMIN)/RINT)+1
*
      IF(R < RMIN) K = 1
      IF(R > RMAX) K = 8
*
      RP=(K*RINT)+RMIN
      RM=RP-RINT
      DO 46 LL=1,2
      L=K+LL-1
      DO 45 MM=1,2
```

```
* * * * * *
           M=J+MM-1
           TLT(MM) = STAR(I,M,L) + (T-TM)*(STAR(IPP,M,L)-STAR(I,M,L))/(TP-TM)
        45 CONTINUE
        46 TS(LL) = TLT(1) + (S-SM)*(TLT(2)-TLT(1))/(SP-SM)
           TLOS = TS(1) + (R-RM)*(TS(2)-TS(1))/(RP-RM)
           RETURN
           END
```

```
* * * * * *
*                             **** NUTRAL ****
           SUBROUTINE NUTRAL(RAS,RAR,CVTR,TAXLE)
C*****TOM HAUSENBAUER  9/1975
C*****SUBROUTINE TO CALCULATE TORQUE IN REAR AXLE DUE TO DRIVETRAIN
C            SPIN LOSSES WITH TRANSMISSION IN NEUTRAL
*
*          GBTLS = 0.
*          CVTTLS = 2.
*          TT = GBTLS + CVTTLS
*          IF(CVTR) 10,5,10
*        5 TDST = 0.
*          GO TO 15
*       10 TDST = TT/CVTR
*       15 RATLS = 2.
*          TAXLE = -RAR*(TDST+RATLS)
*
           TDST = 0.0
           IF(CVTR .NE. 0.0) TDST = 2.0/CVTR
           TAXLE = -RAR*(TDST + 2.0)
           RETURN
           END
```

```
* * * * * *
*                                     **** OTPTHB ****
      SUBROUTINE OTPTHB
C---- SUBROUTINE TO OUTPUT HYBRID SYSTEM VARIABLES
C---- R.R.RADTKE 1/30/75
*  11 FEB 1977
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2OR,VVIICD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUG          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8ON,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRD,VVOAD    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      COMMON/FUEL/FMPGC
      COMMON/MPG/FMPG(15),CFMP(15),RN,CFMPG,RWEN,RWHP
      COMMON/ERASH/DUM(8),RTLNGT
*
   90 FORMAT(1H1,20X,13A6,/,21X,13A6)
  102 FORMAT(/19X,6(H=),7HVEHICLE,8(H=),2X,6(H=),6HENGINE,6(H=),X,2H==,
     1 4HFUEL,B=,2X,6HACCUMU,X,5HCORR=,X,6(H=),8HFLYWHEEL,5(H=),X,
     2 6H=REAR=,2X,13H=DRIVE TRAIN=,X,2HGE,X,2HBR)
  103 FORMAT(3X,4HTIME,2X,5HDIST.,2X,5HSPEED,3X,6HACCEL.,2X,5HSPEED,X,
     1 6HTORQUE,X,5HPOWER,X,7HINSTANT,2X,6HLATIVE,X,5HECTED,X,5HSPEED,X,
     2 6HTORQUE,X,6HOUTPUT,X,6HWHEELS,4X,2HTR,3X,2HRA,2X,2HMO,X,2HAR,
     3 X,2HAK)
```

```
  104 FORMAT(2X,5H(SEC),2X,4H(MI),3X,5H(MPH),X,9H(MPH/SEC),X,5H(RPM),X,
     1 6H(FTLB),2X,4H(HP),X,7H(LB/HR),3X,5H(MPG),X,5H(MPG),X,5H(RPM),X,
     2 6H(FTLB),2X,4H(HP),3X,4H(HP),3X,4HEFF.,X,4HEFF.,2X,2HDE,4X,2HE.)
  105 FORMAT(X,F6.1,F7.3,F7.2,F9.3,I7,F7.1,F6.1,F8.2,F8.2,F6.2,I6,F7.1,
     1 2F7.1,F6.1,F5.1,I3,I4, X,A)
*
*   IF BRAKE APPLIED, OUTPUT LETTER B.
      IB = 4H
      IF(BS > 0.0) IB = 4HB
*
      RWEN = T90N*T90N*TVIJTW/ 3227396.0
*  3227396.0 = 2*33000*60*32.174/(2*PI * 2*PI)
      RWHP = T90C*T90N/5252.0
*
      TB01EF=100.*GNU
      T901=100.*T9I1
      FOBHP=-TFTORQ*DF/5252.
      RIENG=IENGIN
      FMPGC=0.0
      IF(FUELE)4,4,3
    3 FMPGC=VV60*FUELWT/FUELE
    4 CONTINUE
      ELEFT = OF*DF*RIF/10504.0
      CFMPG = FMPGC*C(1)/(C(1)+ELEFT)
      IF(CFMPG < 0.0) CFMPG = 0.0
      IF(CFMPG > 50.0) CFMPG = 50.0
*
      IF(VV6D ≥ RN)
     1                FMPG(RN) = FMPGC;
     2                CFMP(RN) = CFMPG;
     3                RN = RN + 1.0
*
      IF(ICYEND > 0)
     1                FMPG(RN) = FMPGC;
     2                CFMP(RN) = CFMPG
*
      NLINE=NLINE+1
      IF(NLINE-MAXLIN)20,20,5
    5 CONTINUE
      PRINT 90,(COMM(I),I=1,26)
      PRINT 102
      PRINT 103
      PRINT 104
      NLINE=1
   20 CONTINUE
      PRINT 105,TIME,VV60,VV6S,VV6A,PA6N,SSTORQ,OBHP,PA6FR,FMPGC,
     1 CFMPG,OF,TFTORQ,FOBHP,RWHP,TB01EF,T901,IENGIN,IGEAR,IB
      RETURN
      END
```

```
* * * * * * *
*                                  **** OTVRHB ****
      SUBROUTINE OTVRHB
C---- SUBROUTINE TO OUTPUT HYBRID VARIABLES
C---- R.R.RADTKE 1/30/75
*
*  1/3/77  L. SOMERS.
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMOR,VVIORR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIOLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION OACCON(15),AOCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,OACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INOIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESOOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOO,AVIO,AVIS,TVIMJ,VVOF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYENO,NLINE,ICYCLE,NGI,NGIOLO,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSO,OELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOO),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEEO(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
*
*     EQUIVALENCE (FTIME(1),X(46)),(ESPEEO(1),X(106)),(ATORQS(1),X(166))COMMON24
*
      COMMON IOLD1,IOLO2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      OIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIOL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EORAG,RAEFTB,RATKLG,DTF          COMMON34
      OIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      DIMENSION B(25)
      EQUIVALENCE (B(1),X(1))
      COMMON/FUEL/FMPGC
      OIMENSION CC(10),AA(10)
      COMMON /SUMVAR/CC,AA                                              COMMON
      COMMON/MPG/FMPG(15),CFMP(15),RN,CFMPG,RWEN,RWHP
*
      PULSE = 0.0
```

```
* * * * * *
          IF(IENGIN .EQ. 2) PULSE = 1.0
*
          GPM = 0.0
          IF(FMPGC > 0.0) GPM = 1.0/FMPGC
*    CORRECTED MPG
          CGPM = 0.0
          IF(CFMPG > 0.0) CGPM = 1.0/CFMPG
*
          B( 1) = TIME
*    VEHICLE DATA
          B( 2) = VVOD
          B( 3) = VVOS
          B( 4) = VVOA
*    ENGINE DATA
          B( 5) = PAON
          B( 6) = PAOC
          B( 7) = OBHP
*    FLYWHEEL DATA
          B( 8) = DF
          B( 9) = TFTORQ
          B(10) = FOBHP
*
          B(11) = VEPA
          B(12) = VVDF
*    REAR WHEEL DATA
          B(13) = RWHP
          B(14) = RWEN
*    ENGINE ON/OFF PULSE
          B(15) = PULSE
*    FUEL DATA
          B(16) = FMPGC
          B(17) = GPM
          B(18) = CFMPG
          B(19) = CGPM
          B(20) = PAOFR
*
          B(21) = CC(6)
          B(22) = T9IN
*
*    UNUSED  LOCATIONS
          B(23) = B(24) = B(25) = 0.0
*
          WRITE(16) B
*
          RETURN
          END
```

```
* * * * * *
*                              **** PRODHB ****
      SUBROUTINE PRODHB
C---- SUBROUTINE TO CALCULATE THE JOINT PROBABILITY DENSITY OF TWO VARIABLES
C---- DAN KAPELLEN 2/74
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
C*****************************************************************
C---- THIS SUBROUTINE CALCULATES THE JOINT PROBABILITY DENSITY OF TWO
C---- SPECIFIED FUNCTIONS DURING THE DRIVING CYCLE.  THE PROGRAM
C---- VARIABLES ARE AS FOLLOWS,
C-----------------INPUT VARIABLES---------------------------------
C---- VAL(1)----CURRENT VALUE OF FIRST SPECIFIED VARIABLE.
C-----VAL(2)----CURRENT VALUE OF SECOND SPECIFIED VARIABLE.
C-----------------OUPUT VARIABLES---------------------------------
C---- NLT(I)---NUMBER OF SAMPLES BELOW SPECIFIED MINIMUM FOR EACH VARIABLE,
C---- NGT(I)---NUMBER OF SAMPLES ABOVE SPECIFIED MAXIMUM FOR EACH VARIABLE.
C---- IPDX(I,J)-INTEGER TABLE OF PROBABILITY DENSITY DISTRIBUTION.
C-----------------OTHER PROGRAM VARIABLES---------------------------------
C---- VMIN(I)--SPECIEFIED MINIMUM FOR EACH VARIABLE.
```

```
* * * * * *
C---- VMAX(I)--SPECIFIED MAXIMUM FOR EACH VARIABLE.
C---- VINT(I)--SPECIFIED INTERVAL LENGTH FOR EACH VARIABLE.
C---- INT1----TABLE INDEX FOR FIRST VARIABLE.
C---- INT2----TABLE INDEX FOR SECOND VARIABLE.
C---- THE JOINT PROBABILITY DENSITY IS DETERMINED AS A PERCENTAGE AT THE
C---- END OF THE CYCLE IN JPBHYB.
*
*  DETERMINE RANGE OF VALUES
      IF(VAL(1) .LT. VMIN(1)) NLT(1) = NLT(1) + 1
      IF(VAL(1) .GT. VMAX(1)) NGT(1) = NGT(1) + 1
      IF(VAL(2) .LT. VMIN(2)) NLT(2) = NLT(2) + 1; RETURN
      IF(VAL(2) .GT. VMAX(2)) NGT(2) = NGT(2) + 1; RETURN
*
C---- DETERMINE THE TABLE INDICES FOR EACH OF THE VARIABLES AS DETERMINED
C---- BY THE INTERVAL IN WHICH THE VALUES FALL.
      INT1=(VAL(1)-VMIN(1))/VINT(1)+1.
      INT2=(VAL(2)-VMIN(2))/VINT(2)+1.
C---- UPDATE THE PROPER ARRAY ELMENT IN THE TABLE.
      IPDX(INT1,INT2)=IPDX(INT1,INT2)+1
      RETURN
      END
```

```
* * * * *
*                                **** PRINTV ****
      SUBROUTINE PRINTV
* MOOIFIED 2 NOV 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIORR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,OT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEO     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      OIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,AOCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,T8,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLO                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLO,VEPA,VANALG,PAOFRO,VVOAD    COMMON17
      COMMON VVOSD,DELTA,DELT,ISEQ,IGO,ESOOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOO),(BS,VVIOBR)                               COMMON19
      OIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NOT(2),IPOX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NOT,IPOX,ISPEEO,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFOOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      OIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      OIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      OIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIOL,VACIDL,NSPEEO,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICOO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EORAG,RAEFTB,RATKLS,OTF          COMMON34
      OIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      EQUIVALENCE (VAR(3),GAIN)
      COMMON /SHIFT/ RMINAS(10),RMAXAS(10)
      DIMENSION GEREFF(10)                                              COMMON
      COMMON /EFFOER/GEREFF                                             COMMON
      COMMON /FLYEFF/PERLOS                                             COMMON
      DIMENSION CC(10),AA(10)
      COMMON /SUMVAR/CC,AA                                              COMMON
      COMMON /GEARA1/A1CVT
      COMMON /DELAY/TBDTMS,TBDTW
      COMMON/ACCELN/AEPA
      COMMON /PR/VVDFN
      COMMON /GRINIT/INEXT
*
```

```
* * * * * *
  980 FORMAT(HO)
  990 FORMAT(5HTIME=,F.2,2X,7HT9I1GR=,F6.3,2X,6HIGEAR=,I2,2X,6HINEXT=,
     1 I2,2X,7HICLUCH=,I2)
 1000 FORMAT(5HPAON=,F5,4X,5HT8DN=,F5,2X,5HT9IN=,F5,2X,5HT9IL=,F5.3)
 1020 FORMAT(5HPAOC=,F5,2X,7HT9ICON=,F5,2X,5HT9IC=,F5,2X,5HT98C=,F5)
 1030 FORMAT(H+,48X,3HDF=,F6)
 1050 FORMAT(6HVVDMI=,F7,2X,6HVVIMI=,F6,2X,6HTVIMJ=,F6.1,2X,
     1 7HSSTORQ=,F5,2X,7HENTORQ=,E12.5,2X,7HTFTORQ=,E12.5,2X,
     2 7HCVTTRQ=,E12.5)
 1070 FORMAT(4HGNU=,F4.3,2X,5HVEPA=,F5.1,2X,3HRP=,F5.2,
     1 2X,4HRPP=,F5.2,2X,2HR=,F5.2,2X,5HAEPA=,E9.3,2X,
     2         5HVVDF=,E11.4,2X,6HVVDFN=,E11.4,2X,7HRATKLS=,E10.3)
*
      PRINT 980
      PRINT 990,TIME,T9I1GR,IGEAR,INEXT,ICLUCH
      PRINT 1000,PAON,T8DN,T9IN,T9IL
      PRINT 1020,PAOC,T9ICON,T9IC,T98C
      PRINT 1030,DF
      PRINT 1050,VVDMI,VVIMI,TVIMJ,SSTORQ,ENTORQ,TFTORQ,CVTTRQ
      PRINT 1070,GNU,VEPA,RP,RPP,R,AEPA,VVDF,VVDFN,RATKLS
      RETURN
      END
```

```
*                             **** RAEFFH ****
      SUBROUTINE RAEFFH
C---- SUBROUTINE TO COMPUTE REAR AXLE TORQUE LOSS
C---- R.R.RADTKE 3/3/75
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILER,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,BSHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOKI,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAD    COMMON17
      COMMON VVOSD,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICON,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
*
*
C---- CAR IN NEUTRAL
      T9I1 = 0.
      IF(IGEAR < 1)    T9OC = T9IC/T9I1GR; RETURN
*
*  CAR NOT IN NEUTRAL
      TRF=ABS(T9IC)
      TR=TRF*RASCAL
      IF(TR  >   1000.0) TR = 1000.0
      T9INL = T9IN
      IF(T9IN  >   4000.0) T9INL = 4000.0
      CALL RAXLOS(TR,T9INL,RAEFTB,RATKLS)
```

```
* * * * *
        RATKLS=RATKLS/RASCAL
C----   COMPUTE EFFICIENCY
        TEMP=TRF-RATKLS
*
        IF(TEMP > 0.0) T9I1 = TEMP/TRF
*
        T90C=(T9IC-RATKLS)*T9I1GR
        RETURN
        END
```

```
* * * * *
*                                     **** RAXLOS ****
        SUBROUTINE RAXLOS(T,S,STRA,RALS)
        DIMENSION TS(2),STRA(11,11)
*
        I=(T/100)+1
*
        IF(I > 10) I = 10
*
        IP=I+1
        TP=100*I
        TM = TP-100.0
        J=(S/400)+1
*
        IF(J > 10) J = 10
*
        SP=400*J
        SM = SP-400.0
        DO 1 MM=1,2
        M=J+MM-1
      1 TS(MM)=VAL(T,TM,TP,STRA(I,M),STRA(IP,M))
        RALS=VAL(S,SM,SP,TS(1),TS(2))
        RETURN
        END
```

```
* * * * * *
*                        **** RDEPA ****
      SUBROUTINE RDEPA
*
*     READS IN EPA DATA
*  17 NOV 1976
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2OR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIB,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,DUMMY,DT                       COMMON 4
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,OS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T80N,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAD    COMMON17
      COMMON VVOSD,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(OS,VVIBOR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON AIC,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON /EPASH/ VCRUS,ACEL,DECEL,TA,TC,TD,TIDLE,TE,RTLNGT
      COMMON/STOPS/NSTOP
      REAL ILNGTH,ITIME,LTA,LTC,LTD
*
*     ACEL=ACCELERATION(MPH/SEC)
*     VCRUS=CRUISING VELOCITY MPH
*     DECEL=DECELERATION FT/SEC**2 ON INPUT; MPH/SEC ON OUTPUT IN EPASH
*     NSTOP=NUMBER OF STOPS PER MILE
C     RTLNGT=ROUTE LENGTH(MILES)
*
C     TA TIME ACCELERATION STOPS
C     TC TIME CRUISING STOPS
C     TD TIME DECELERATING STOPS
*     TIDLE=TIME AT BUS STOP
*     TE=TIME FOR ONE CYCLE  =TIDLE+TD
*     DLNGTH=LENGTH OF EACH CYCLE(MILES)
```

```
* * * *
*
  100 FORMAT(3F8.3,I8,2F8.3)
  980 FORMAT(/)
  990 FORMAT(17HEPA OATA FOLLOWS:)
 1000 FORMAT(5X,5HACCEL,4X,6HCRUISE,5X,5HDECEL,12X,8HBUS STOP,2X,
     1 8HNO STOPS,4X,6HLENGTH)
 1002 FORMAT(3X,9H(MPH/SEC),3X,5H(MPH), 3X,10HFT/SEC/SEC,11X,5H(SEC),2X,
     1 10H(PER MILE),3X,7H(MILES))
 1003 FORMAT(3F10.3,F20.3,I10,F10.3)
 1004 FORMAT(8X,2HTA,8X,2HTC,8X,2HTD,7X,3HDTO,8X,2HTE,2X,8HNO STOPS)
 1005 FORMAT(5(5X,5H(SEC)),3X,7H(TOTAL))
 1006 FORMAT(6F10.3)
 1007 FORMAT(7X,3HLTA,7X,3HLTC,7X,3HLTO,4X,6HILNGTH,5X,5HITIME,5X,
     1 5HTIMAX)
 1008 FORMAT(6F10.3)
 1010 FORMAT(X,13(I7,2X),I7)
 1015 FORMAT(6HNVEPA=,I5)
 1020 FORMAT(16H**ENO EPA DATA**)
 1025 FORMAT('RDEPA: EXCEEOS 3000 VALUES')
*
      REAO 100,ACEL,VCRUS, OECEL,NSTOP,RTLNGT,TIOLE
      PRINT 980
      PRINT 990
      PRINT 980
      PRINT 1000
      PRINT 1002
      PRINT 1003, ACEL,VCRUS,OECEL,TIDLE,NSTOP,RTLNGT
      NTOTAL = TSTOPS = NSTOP*RTLNGT
      OLNGTH = 1.0/FLOAT(NSTOP)
C     CONVERTS OECEL TO MPH/SEC
      DECEL = DECEL*15.0/22.0
      TA=VCRUS/ACEL
      DTD=VCRUS/OECEL
      TC = 0.5*(DTD*OTD*DECEL + TA*TA*ACEL)
      TC = (3600.0*OLNGTH -TC)/VCRUS + TA
      TO=TC+OTD
      TE = TD + TIDLE
      PRINT 980
      PRINT 1004
      PRINT 1005
      PRINT 1006, TA,TC,TD,OTD,TE,TSTOPS
*
      ILNGTH = NTOTAL*OLNGTH
      ITIME  = NTOTAL*TE
      TIMAX = TSTOPS*TE
      LTA = 0.5*ACEL*TA*TA/3600.0
      LTC = LTA + VCRUS*(TC-TA)/3600.0
      LTO = LTC + 0.5*OECEL*DTO*DTD/3600.0
      PRINT 980
      PRINT 1007
      PRINT 1008, LTA,LTC,LTD,ILNGTH,ITIME,TIMAX
      PRINT 980
*
```

```
* * * * * * *
      RVEL = 0.0
      PTIME = 0.0
      DO 5 I = 1,3000
         IVEPA(I) = 0
    5 CONTINUE
*
      DO 32 I = 1,NTOTAL+1
      TR = FLOAT(I)*TE
      TU = TR - TE
   10 CONTINUE
      IPTIME = PTIME = PTIME + 1.0
      TUTIME = PTIME + TU
*
*  TERMINATE IF PTIME EXCEEDS TIMAX
      IF(PTIME > TIMAX) GO TO 33
*
      CALL EPACALC(RVEL,TUTIME)
      KPLACE = IPTIME/2
      KREM = IPTIME - 2*KPLACE
      IF(KREM < 1) IVEPA(KPLACE) = NVEL*4096 + ITEMP1
      ITEMP1 = NVEL
      IF(PTIME + 1.0 < TR) GO TO 10
   32 CONTINUE
*
   33 CONTINUE
*
      IF(KREM ≠ 0) IVEPA(KPLACE) = ITEMP1
*
      NVEPA = PTIME + 1.0
      NN = NVEPA/2
      PRINT 1015,NN
      PRINT 980
      IF(NN > 3000) WRITE(102,1025);WRITE(108,1025);PAUSE
      K = 0
      DO 60 J = 1,NN,14
         K = K + 14
         IF(K > NN) K = NN
         PRINT 1010,(IVEPA(I),I=J,K)
   60    CONTINUE
      PRINT 980
      PRINT 1020
      RETURN
      END
```

```
* * * * * *
   *                                   **** READRA ****
            SUBROUTINE READRA(STRA)
            DIMENSION STRA(11,11)
       1000 FORMAT(11F7.2)
       1001 FORMAT(1X,11F7.2)
            DO 1 J=1,11
            READ  1000,(STRA(I,J),I=1,11)
            PRINT 1001,(STRA(I,J),I=1,11)
          1 CONTINUE
            RETURN
            END
```

```
* * * * * *
   *                                   **** TREFFH ****
            SUBROUTINE TREFFH (TORQ,SPEED,IGEAR,TCLSS,GRATIO)
            DIMENSION GEREFF(10)
            COMMON /EFFGER/GEREFF
            DIMENSION GRATIO(10)
            IF (IGEAR) 4,4,11
         11 CONTINUE
            EFF=GEREFF(IGEAR)
            IF(TORQ)1,2,2
          1 TCLSS=(TORQ-(TORQ/EFF))*GRATIO(IGEAR)
            GO TO 3
          2 TCLSS=TORQ*(1-EFF)*GRATIO(IGEAR)
          3 CONTINUE
            TORQ=TORQ-TCLSS
            RETURN
          4 TCLSS=0
            RETURN
            END
```

```
* * * * * *
   *                                   **** TURKEY ****
            SUBROUTINE TURKEY(STAR)
      C*****SUBROUTINE TO READ THE ARRAY 'STAR' FROM HYDROSTATIC POWER SPLIT
      C              TRANSMISSION TORQUE LOSS DATA CARDS
      C*****TOM HAUSENBAUER   5/1975
            DIMENSION STAR(9,7,9)
      C*****READ TORQUE LOSS DATA CARDS
            DO 1 K = 1,9
            DO 1 I = 1,9
            READ  2, (STAR(I,J,K),J=1,7)
            PRINT 2, (STAR(I,J,K),J=1,7)
          1 CONTINUE
          2 FORMAT(7F10.2)
            RETURN
            END
```

```
* * * * * *
   *                                   **** VAL ****
            FUNCTION VAL(X,X1,X2,Y1,Y2)
            VAL=(X-X1)*(Y2-Y1)/(X2-X1)+Y1
            RETURN
            END
```

```
* * * * * * *
*                             **** TGG15H ****
      SUBROUTINE TGG15H
C---- SUBROUTINE TO DETERMINE EFFECTIVE REAR AXLE RATIO AND D.S. SPEED
C---- DAN KAPELLEN 10/73
*  MODIFIED  21 DEC 1976
*  MAX RANGE OF T8INV: 40 MPH
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKD,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T80N,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVBS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAD    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTD,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMON21
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      EQUIVALENCE (V,VVOS)
*
C---- THIS SUBROUTINE DETERMINES A 'CORRECTED' DRIVESHAFT SPEED AND AN
C---- 'EQUIVALENT' REAR AXLE RATIO BASED ON A TABLE OF DRIVESHAFT SPEED
C---- AS A FUNCTION OF VEHICLE SPEED OBTAINED FROM EXPERIMENTAL DATA.
*
C---- THE PROGRAM VARIABLES ARE AS FOLLOWS,
*                   INPUT VARIABLES
C---- VVOS----VEHICLE SPEED.
*                   OUTPUT VARIABLES
```

```
* * * *
C-----T9IN-----'CORRECTED' DRIVESHAFT SPEED TAKING INTO ACCOUNT TIRE GROWTH.
C---- T9I1GR---EQUIVALENT REAR AXLE RATIO.
*                    PROGRAM CONSTANTS
C---- T8INV(J)-TABLE OF DRIVESHAFT SPEEDS AS A FUNCTION OF VEHICLE SPEED.
C---- T8I1GR--NOMINAL REAR AXLE RATIO.
C---- VVIDRR---TIRE RADIUS.
*                   .OTHER PROGRAM VARIABLES
C---- T8DN----UNCORRECTED DRIVESHAFT SPEED.
C---- T8DNHI--UPPER INTERPOLATION DRIVESHAFT SPEED.
C-----T8DNLO--LOWER INTERPOLATION DRIVESHAFT SPEED.
C---- DIFF-----DIFFERENCE BETWEEN CURRENT VEHICLE SPEED AND VEHICLE
C---- SPEED AT LOWER INTERPOLATION POINT.
*
C---- CALCULATE THE UNCORRECTED DRIVESHAFT SPEED.
*  CONVERT FROM MPH TO RPM
*  14.00565 = (5280/60)*(1.0/2PI)
      T8DN=14.00565* V  *T8I1GR/VVIDRR
C---- TEST IF THE VEHICLE SPEED EXCEEDS THE RANGE OF THE TABLE.
*
      IF( V   .GT. 40.0) T9IN = T9I1GR*T8DN/T8I1GR; RETURN
*
      JJ = V*0.1
C---- DETERMINE THE DRIVESHAFT SPEEDS AT THE UPPER AND LOWER INTERPOLATION POINT
      J=JJ+1
      T8DNHI=T8INV(J+1)
      T8DNLO=T8INV (J)
      DIFF = V - 10.0*JJ
C---- INTERPOLATE TABLE FOR CORRECTED DRIVESHAFT SPEED.
      T9IN=T8DNLO+.1*DIFF*(T8DNHI-T8DNLO)
*
      IF(T9IN .LE. 0.1) T9I1GR = T8I1GR; RETURN
*  OTHERWISE;
      T9I1GR = T8I1GR*T9IN/T8DN; RETURN
      END
```

```
* * * * * *
      *                      **** VEDYNH ****
            SUBROUTINE VEDYNH
      C---- SUBROUTINE TO SIMULATE VEHICLE ACCELERATION AND BRAKING DYNAMICS
      C---- DAN KAPELLEN 10/73
      *
            COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
            COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
            COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CE,TVIJCT,TVIJTR,TVIJRA      COMMON03
            COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
            COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
            DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
            DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
            DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
            DIMENSION TVICRL(16)                                              COMMON09
            COMMON T8INV                                                      COMMON10
            COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
            COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
            COMMON SSTORQ,ESOOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
            COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
            COMMON T9I1,T9I1GR,VVOS,VVOA,VVOO,AVIO,AVIS,TVIMJ,VVOF,VVOMI,PAOFRCOMMON15
            COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
            COMMON ICYENO,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFRO,VVOAO    COMMON17
            COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESOOTO,IGEAR                     COMMON18
            EQUIVALENCE (DIST,VVOO),(BS,VVIBBR)                               COMMON19
            DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
            DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMO521
            DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
            COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
            EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
            COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
            COMMON EINTRQ,FINTRQ,RIF,RFINR,OFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
            DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
            DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
            COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
            DIMENSION A(10),C(10)                                             COMMON30
            COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
            COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICOB        COMMON32
            COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
            COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
            DIMENSION GRATIO(10)                                              COMMON35
            COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
            EQUIVALENCE(VAR(3),GAIN,DELTAT)
            COMMON /PR/VVOFN
            EQUIVALENCE (V,VVOS)
      *
      C---- THIS SUBROUTINE DETERMINES THE VEHICLE ACCELERATION BASED ON THE
      C---- DIFFERENCE BETWEEN THE FORCE DRIVING THE VEHCLE AND THE RESISTIVE
      C---- FORCES.  IT ALSO TESTS FOR CONDITIONS OF TIRE SPINNING OR SKIDDING.
      * ' --INPUT VARIABLES--
      C---- VVOS- VEHICLE SPEED (MPH).
      C---- T9OC-REAR AXLE OUTPUT TORQUE (FT-LB).
      C---- VVIBBR OR BS-BRAKE SETTING (0 TO 1)
      C---- T8I1GR-TRANSMISSION GEAR RATIO SQUARED.
```

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* * * * *
C----- T9I1GR=EQUIVALENT REAR AXLE RATIO.
C----- AVIS=WIND SREED (MPH)
C----- GRADE ANGLE (RAD)
*     --OUTPUT VARIABLES--
C----- VVOA=VEHICLE ACCELERATION (MPH/SEC)
C----- VVDF=VEHICLE ROAD LOAD FORCE AT TIRE ROAD INTERFACE (LB).
C----- WHLSLP= USED IN R. T. SIMULATION TO CONTROL TIRE SLIP NOISE GENERATOR.
*     --PROGRAM CONSTANTS--
C----- VVIM=VEHICLE MASS (LB).
C----- VVILFR=FRONTAL AREA (SQ. FT.).
C----- VVI1CD=DRAG COEFFICIENT.
C----- VVI1RF=COEFFICIENT OF ROLLING FRICTION.
C----- VVIFUM=COEFFICIENT OF STATIC TIRE FRICTION (G'S).
C----- VVIFUS=COEFFICIENT OF SLIPPING TIRE FRICTION (G!S).
C----- VVIMAX=MAX VEHICLE ACCEL (G'S).  CALCULATED IN INCNHB
C----- VVIAS=MAX VEHICLE ACCEL WITH WHEEL SPIN(G'S). CALC. IN INCNHB
C----- VVI2BR=BRAKE CONSTANT. (LB).
C----- TVIJCT,TVIJTR,TVIJRA,TVIJTW= POLAR MOMENT OF INERTIA OF TORQUE
C----- CONVERTER TURBINE, TRANSMISSION, REAR AXLE, AND REAR WHEELS
C----- RESPECTIVELY(LBM-FT**2).
C----- LOADEQ=A USED IN A LOGICAL  MANNER TO TO DETERMINE WHETHER
C----- LOADEQ= USED TO DETERMINE IF ROAD LOAD EQUATION IS OF TABLE IS USED.
C----- OTHER PROGRAM VARIABLES------------------------------------------------.
C----- SINAVO=SINE APPROXIMATION FOR GRADE ANGLE.
C----- TVIMJ=TOTAL ROTARY INERTIA OF DRIVETRAIN REFLECTED TO REAR WHEELS.
C----- VVDFBR= TOTAL RESISTIVE FORCE ACTING ON VEHICLE INCLUDING BRAKES.
C----- VVDFN=NET FORCE AVAILABLE TO ACCELERATE VEHICLE.
C----- VVDMI=TOTAL INERTIAL MASS OF VEHICLE (G'S).
*
C----- APPROXIMATE GRADE ANGLE TO AVOID USE OF SINE FUNCTION.
      SINAVO=AVIO*(1.-AVIO*AVIO/6.)
      WHLSLP=0.
   40 CONTINUE
C----- IF LOADEQ IS 1, USE ROAD LOAD EQUATION.  IF ZERO USE D.S. TORQUE TABLE.
      IF(LOADEQ)45,45,46
   45 I = V/10.0 + 1.0
      T9I2=.97
      REM = V-(I-1)*10.0
      DRTORK=TVICRL(I)+(TVICRL(I+1)-TVICRL(I))*REM/10.
      VVDF=DRTORK*T9I1GR*T9I2/VVIDRR
      GO TO 47
   46 CONTINUE
      VVAV = V + AVIS
      VVDF=.033+294*VVI1CD*VVILFR*AVIM*VVAV*VVAV +
     2 VVI1RF*VVIM*(1.+VVI1CF*V)+VVIM*SINAVO
   47 CONTINUE
C----- ADD RESISTIVE FORCE TO BRAKING FORCE TO OBTAIN TOTAL RESISTIVE FORCES.
C----- FOR THE HYBRID CAR THE BRAKING FORCE IS INCLUDED IN T90C
      VVDFBR=VVDF
C----- OBTAIN NET FORCE AVAILABLE TO ACCELERATE THE VEHICLE.
      VVDFN=T90C/VVIDRR-VVDFBR
C----- CALCULATE TO TOTAL ROTARY INERTIA OF THE DRIVETRAIN AS SEEN AT THE
C----- REAR WHEELS.
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* * * * * *
*                               **** VEDYNH ****
      SUBROUTINE VEDYNH
C---- SUBROUTINE TO SIMULATE VEHICLE ACCELERATION AND BRAKING DYNAMICS
C---- DAN KAPELLEN 10/73
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2OR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISW,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLSKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,RAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,T8DN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PABFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,YANALG,PABFRC,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
      DIMENSION VAL(2),NLT(2),NGT(2),IPDX(20,20),ISPEED(20),TIMMAX(5)   COMMO521
      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFOOT,GNU,FGNU,TRQIDL,T9ICO,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)                                             COMMON30
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
      COMMON RP,RPP,FOBHP,TCVTLS,TCLULS,RPMIN,RPMAX,TT,TC,TF            COMMON33
      COMMON RASCAL,ENTORQ,FDRAG,EGAIN,EDRAG,RAEFTB,RATKLS,DTF          COMMON34
      DIMENSION GRATIO(10)                                              COMMON35
      COMMON GRATIO,RMIN,RMAX,ICLUCH,CVTSCL                             COMMON36
      EQUIVALENCE(VAR(3),GAIN,DELTAT)
      COMMON /PR/VVOFN
      EQUIVALENCE (V,VVOS)
*
C---- THIS SUBROUTINE DETERMINES THE VEHICLE ACCELERATION BASED ON THE
C---- DIFFERENCE BETWEEN THE FORCE DRIVING THE VEHCLE AND THE RESISTIVE
C---- FORCES.  IT ALSO TESTS FOR CONDITIONS OF TIRE SPINNING OR SKIDDING.
* ' **INPUT VARIABLES**
C---- VVOS= VEHICLE SPEED (MPH).
C---- T9OC=REAR AXLE OUTPUT TORQUE (FT-LB).
C---- VVIBBR OR BS=BRAKE SETTING (0 TO 1)
C---- T8O1GR=TRANSMISSION GEAR RATIO SQUARED.
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* * * * *
C---- T9I1GR-EQUIVALENT REAR AXLE RATIO.
C---- AVIS-WIND SREED (MPH)
C---- GRAOE ANGLE (RAD)
*   --OUTPUT VARIABLES--
C---- VVOA-VEHICLE ACCELERATION (MPH/SEC)
C---- VVDF-VEHICLE ROAD LOAD FORCE AT TIRE ROAD INTERFACE (LB).
C---- WHLSLP- USED IN R. T. SIMULATION TO CONTROL TIRE SLIP NOISE GENERATOR.
*   --PROGRAM CONSTANTS--
C---- VVIM-VEHICLE MASS (LB).
C---- VVILFR-FRONTAL AREA (SQ. FT.).
C---- VVI1CD-ORAG COEFFICIENT.
C---- VVI1RF-COEFFICIENT OF ROLLING FRICTION.
C---- VVIFUM-COEFFICIENT OF STATIC TIRE FRICTION (G'S).
C---- VVIFUS-COEFFICIENT OF SLIPPING TIRE FRICTION (G!S).
C---- VVIMAX-MAX VEHICLE ACCEL (G'S).  CALCULATED IN INCNHB
C---- VVIAS-MAX VEHICLE ACCEL WITH WHEEL SPIN(G'S). CALC. IN INCNHB
C---- VVI2BR-BRAKE CONSTANT. (LB).
C---- TVIJCT,TVIJTR,TVIJRA,TVIJTW- POLAR MOMENT OF INERTIA OF TORQUE
C---- CONVERTER TURBINE, TRANSMISSION, REAR AXLE, AND REAR WHEELS
C---- RESPECTIVELY(LBM-FT**2).
C---- LOADEQ-A USED IN A LOGICAL  MANNER TO TO DETERMINE WHETHER
C---- LOADEQ- USED TO OETERMINE IF ROAD LOAD EQUATION IS OF TABLE IS USED.
C---- OTHER PROGRAM VARIABLES------------------------------------------
C---- SINAVO-SINE APPROXIMATION FOR GRADE ANGLE.
C---- TVIMJ-TOTAL ROTARY INERTIA OF DRIVETRAIN REFLECTED TO REAR WHEELS.
C---- VVOFBR- TOTAL RESISTIVE FORCE ACTING ON VEHICLE INCLUDING BRAKES.
C---- VVDFN-NET FORCE AVAILABLE TO ACCELERATE VEHICLE.
C---- VVDMI-TOTAL INERTIAL MASS OF VEHICLE (G'S).
*
C---- APPROXIMATE GRADE ANGLE TO AVOID USE OF SINE FUNCTION.
      SINAVO=AVIO*(1.-AVIO*AVIO/6.)
      WHLSLP=0.
   40 CONTINUE
C---- IF LOADEQ IS 1, USE ROAD LOAD EQUATION.  IF ZERO USE D.S. TORQUE TABLE.
      IF(LOADEQ)45,45,46
   45 I = V/10.0 + 1.0
      T9I2=.97
      REM = V-(I-1)*10.0
      DRTORK=TVICRL(I)+(TVICRL(I+1)-TVICRL(I))*REM/10.
      VVDF=DRTORK*T9I1GR*T9I2/VVIDRR
      GO TO 47
   46 CONTINUE
      VVAV = V + AVIS
      VVDF=.0334294*VVI1CO*VVILFR*AVIM*VVAV*VVAV +
     2 VVI1RF*VVIM*(1.+VVI1CF*V)+VVIM*SINAVO
   47 CONTINUE
C---- ADD RESISTIVE FORCE TO BRAKING FORCE TO OBTAIN TOTAL RESISTIVE FORCES.
C---- FOR THE HYBRID CAR THE BRAKING FORCE IS INCLUDED IN T9OC
      VVDFBR=VVDF
C---- OBTAIN NET FORCE AVAILABLE TO ACCELERATE THE VEHICLE.
      VVDFN=T9OC/VVIDRR-VVDFBR
C---- CALCUCATE TO TOTAL ROTARY INERTIA OF THE DRIVETRAIN AS SEEN AT THE
C---- REAR WHEELS.
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* * * * *
      T9I = T9I1GR*T9I1GR
      T801GR = R*R ,
      TVIMJ=(TVIJCT+TVIJTR)*T801GR*T9I + TVIJRA*T9I + TVIJTW
C---- DETERMINE THE INERTIAL MASS OF THE VEHICLE.
      VVIDRRSQ = VVIDRR*VVIDRR
      VVDMI = (VVIM + TVIMJ/VVIDRRSQ)/32.1739
C-----DETERMINE VEHICLE ACCELERATION.
      VVOA=VVDFN /VVDMI
*
C---- DETERMINE IF THERE ARE ANY CONSTRAINTS ON THE CALCULATED ACCELERATION
*
      IF(VVOA) 51,50,52
C---- IF ACCEL IS NEGATIVE CHECK IF TIRES ARE SKIDDING.
   51 IF (VVOA/32.1739+VVIFUM) 55,56,56
   55 CONTINUE
      WHLSLP=-1.
      VVOA=-VVIFUS*32.179
C---- IF TIRES ARE SKIDDING SET DECEL TO THAT OCCURRING UNDER SLIDING CONDITIONS
   56 CONTINUE
C---- ENSURE VELOCITY WILL NOT BECOME NEGATIVE DURING NEXT TIME STEP.
      IF(V   +VVOA*DELTAT*.681818)59,59,50
   59 VVOA = -V/DELTAT
      RETURN
C---- FOR POSITIVE ACCEL DETERMINE IF WHEELS ARE SPINNING.
   52 IF (VVOA-VVIAMX*32.1739) 50,50,62
   62 CONTINUE
      WHLSLP=-1.
C---- IF WHEELS ARE SPINNING SET ACCEL TO MAX POSSIBLE UNDER SLIP.
      VVOA=VVIAS*32.1739
   50 CONTINUE
C---- CHANGE VEHICLE ACCLERATION FROM FT/SEC/SEC TO MPH/SEC.
      VVOA=VVOA*.681818
      RETURN
      END
```

```
*                                  **** WINDUP ****
      SUBROUTINE WINDUP
*
*  9 FEBRUARY 1977
*
      COMMON RIE,TMAX,VACMAX,VVIMI,VVILFR,VVI2BR,VVI1CD,VVIM,VVI1RF     COMMON01
      COMMON VVIMDR,VVIDRR,AVIB,AVIR,T8I1GR,AVIM,VVIFUM,VVIFUS          COMMON02
      COMMON VVISWB,VVISH,VVIAMX,VVIAS,VVI1CF,TVIJCT,TVIJTR,TVIJRA      COMMON03
      COMMON TVIJTW,SCALEF,DELMIN,FUELWT,TIDLE,DT                       COMMON04
      COMMON NVEPA,RIEINV,HRPSEC,MAXLIN,EPS,NGEAR,IOUT,IPRNT,LOADEQ     COMMON05
      DIMENSION T8INV(11),IVEPA(3000)                                   COMMON 6
      DIMENSION VMIN(2),VMAX(2),VINT(2),NDIM(2)                         COMMON07
      DIMENSION DACCON(15),ADCCON(15)                                   COMMON08
      DIMENSION TVICRL(16)                                              COMMON09
      COMMON T8INV                                                      COMMON10
      COMMON IVEPA,VMIN,VMAX,VINT,NDIM,DACCON,ADCCON,TVICRL             COMMON11
      COMMON TIME,NRUN,INDIC,NREC,NFUEL,ICLOCK,ICLOKO,TS,BS,OBHP,TORQ   COMMON12
      COMMON SSTORQ,ESDOT,PAOC,PAON,PPOB,TAOC,TAON                      COMMON13
      COMMON T9IC,T9IN,TBDN,T9OC,T9ON                                   COMMON14
      COMMON T9I1,T9I1GR,VVOS,VVOA,VVOD,AVIO,AVIS,TVIMJ,VVDF,VVDMI,PAOFRCOMMON15
      COMMON FUELE,ITICYC,ICLOK1,ISHIFT,WHLSLP,WHLOLD                   COMMON16
      COMMON ICYEND,NLINE,ICYCLE,NGI,NGIOLD,VEPA,VANALG,PAOFPO,VVOAO    COMMON17
      COMMON VVOSO,DELTA,DELT,ISEQ,IGO,ESDOTO,IGEAR                     COMMON18
      EQUIVALENCE (DIST,VVOD),(BS,VVIBBR)                               COMMON19
      DIMENSION FTIME(60),ESPEED(60),ATORQS(60),VAR(10),X(225),NVOLT(15)COMMON20
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      DIMENSION TIMLEN(5),TIMAVG(5)                                     COMMON22
      COMMON VAR,X,NVOLT,VAL,NLT,NGT,IPDX,ISPEED,TIMMAX,TIMLEN,TIMAVG   COMMON23
      EQUIVALENCE (FTIME(1),X(46)),(ESPEED(1),X(106)),(ATORQS(1),X(166))COMMON24
      COMMON IOLD1,IOLD2,IOLD3,ISW1,ISW2,ISW3,IENGNO,IENGIN             COMMON25
      COMMON EINTRQ,FINTRQ,RIF,RFINR,DFDOT,GNU,FGNU,TRQIDL,T9ICD,R,DF   COMMON26
      DIMENSION COMM(26),ENGTRQ(20),ENGFUL(20),ENGVAC(20),ENGSTT(20)    COMMON27
      DIMENSION ENGSTP(20),EFFTAB(9,9,9),RAEFTB(11,11)                  COMMON28
      COMMON COMM,ENGTRQ,ENGFUL,ENGVAC,ENGSTT,ENGSTP,EFFTAB             COMMON29
      DIMENSION A(10),C(10)
      COMMON A,C,FUIDL,VACIDL,NSPEED,NVEL,NTIMES,SPDINC,VELINC,TIMINC   COMMON31
      COMMON TFTORQ,RIEPIF,CVTTRQ,ISIM,TSNEW,BSNEW,T9ICDN,T9ICDO        COMMON32
*
 1000 FORMAT(H1,6/,49HFUEL EXPENDED TO REV UP FROM EPS TO ENGSTP AT T=0,
     1 9H  FUELE =, F7.5,X,2HLB)
*
      DT2    = DT/2.0
      PAOFRO = FUIDL
      IENGIN = 2
      RFINR  = 1.0/RIEPIF
*
      REPEAT 10, WHILE DF < ENGSTP(1)
      FINTRQ = FSPEED(ENGTRQ,NSPEED,SPDINC,PAON-800.0)
      OBHP   = FINTRQ*PAON/5252.0
      PAOFR  = FSPEED(ENGFUL,NSPEED,SPDINC,PAON-800.0)*OBHP
      FUELE  = FUELE + (PAOFRO + PAOFR)*DT2*HRPSEC
      PAOFRO = PAOFR
      CALL ENGWHL
   10 CONTINUE
*
      PRINT 1000,FUELE
      RETURN
      END
```

APPENDIX F
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U. S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE, CAMBRIDGE, MA. 02142