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A Computer Program (VEHSIM) for Vehicle Fuel Economy and Performance Simulation (Automobiles and Light Trucks)

Volume I: Description and Analysis

DEPARTMENT OF
TRANSPORTATION

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Russell W. Zub

Transportation Systems Center
Cambridge MA 02142

October 1981
Final Report

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16. Abstract

This report presents an updated description of a vehicle simulation program, VEHSIM, which can determine the fuel economy and performance of a specified vehicle over a defined route as it executes a given driving schedule. Vehicle input accommodated by VEHSIM include accessories, engine, rear axle, converter, transmission, tires, aerodynamic drag coefficient, and shift logic. The report is comprised of four volumes. Volume I presents a description of the numerical approach and equations, Volume II is a user's manual, Volume III contains the program listings, and Volume IV describes a simulation of the Integrated Overdrive Transmission with a split-torque converter.

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PREFACE

The present description of the VEHSIM program consists of a series of volumes which reflect the updated status of the program as of November 1980. The following sources were incorporated into this report:

- o Report No. KHL-TSC-76-1381. "A Computer Program (VEHSIM) for Highway Vehicle Fuel Economy, Performance and Other Parameters," by S. Moffat and D. Cruz (Kentron Hawaii, Ltd.), March 12, 1976.
- o Report No. DOT-TSC-HS027-PM-79, "A Computer Program (VEHSIM) for Vehicle Fuel Economy and Performance Simulation (Automobiles and Light Trucks," by E. Withjack (TSC), November 1976.

The vehicle performance simulation computer model, VEHSIM, was developed at the Transportation Systems Center of the U.S. Department of Transportation as an engineering tool for studies required in support of the Automotive Energy Efficiency Program (AEEP), the Automotive Fuel Economy Regulatory Program (AFER), and the Transportation Energy Efficiency Project (TEEP). The development of VEHSIM was initiated under AEEP for automotive applications in studies requiring parametric investigation of automotive fuel economy, performance, and emissions. In the Spring of 1976, the SAE Vehicle Correlation and Simulation Subcommittee was formed to direct the necessary revisions to make VEHSIM applicable to truck and bus simulation. Revisions included improved computational methods, detailed component data specifications, and essentially enhanced operational convenience through adaptation of remote terminal capability.

Because of the need to simulate heavy duty vehicles, primarily for SAE/DOT truck and bus fuel program, VEHSIM was divided into two separate programs and data bases: VEHSIM for simulation of light duty trucks and automobiles, and HEVSIM for heavy duty vehicles.

Although the basic simulation of the mechanics of the vehicles for both programs is similar, differences in the two programs include distinctly different data bases, shift logic simulations, and some computational routines. A description of HEVSIM can be obtained from the following reference:

> Buck, R., "A Computer Program (HEVSIM) for Heavy Duty Vehicle Fuel Economy and Performance Simulation, Volume I: Description and Analysis," Transportation Systems Center, Cambridge MA.

The applicability of VEHSIM can be examined by comparing vehicle test results to simulation results. This was reported in a previous paper.* Also, VEHSIM was used to determine and quantify the effect of design variables on performance and fuel economy.**

The purpose of this document is to present an updated description of VEHSIM. This was possible through the cooperative effort of many people. In particular, the following people are to be thanked for their contributions: Mr. Richard Buck, TSC, for his helpful suggestions in the implementation of the split torque converter; Mr. Richard Meisner, TSC, for his contributions to the transmission shift logic chapter; Mr. Joseph Burshstein, SDC-ISI, for his thorough analysis of the enhancements and general overall contributions to all the volumes of this report; Mr. Jack Dolan, SDC-ISI, for the source code implementation of the enhancements, contributions to Volume II, and help in presenting suggestions for a document useful to the novice programmer; Mr. Michael Bessendorf, SDC-ISI for his development of the graphical output programs and suggestions for restructuring the program; and Mr. Tim Collins, Kentron International Inc., for creating the Scan program.

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*Malliaris, A.C., et al., "Simulated Sensitivities of Auto Fuel Economy, Performance and Emissions," SAE Paper 760157, February 1976.

**Zub, R.W. and Colello, R.G., "Effect of Vehicle Design Variables on Top Speed Performance and Fuel Economy," SAE Paper 800215, February 1980.

In addition, Mr. Emery Swanson, Ms. Kathy Morely, Mr. Robert Martin and support staff of Raytheon are to be complimented on their professional job of assembling this document.

METRIC CONVERSION FACTORS

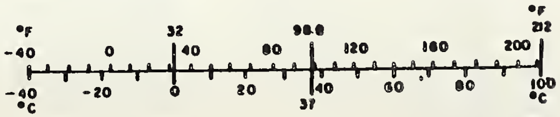
Approximate Conversions to Metric Measures

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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

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



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LIST OF SYMBOLS

a	Acceleration, ft/sec^2
AR	Axle Ratio
b	Grade, %
C_d	Aerodynamic drag coefficient
e_f	Gear efficiency for ith gear, %
e_r	Differential efficiency, %
e_t	Tire efficiency, %
F_{ACCEL}	Inertia force due to acceleration, lbs
F_{AERO}	Aerodynamic drag force, lbs
F_{GRADE}	Force due to route grade, lbs
F_{roll}	Force due to tire rolling resistance, lb
F_w	Force acting at wheel hub, lbs
g_i	Gear ratio for ith gear
HP	Horsepower
I_1	Moment of inertia of torque converter pump, $ft\text{-}lbs\text{-}sec^2$
I_2	Moment of inertia of torque converter, $ft\text{-}lbs\text{-}sec^2$
I_A	Moment of inertia of accessories, $ft\text{-}lb\text{-}sec^2$
I_E	Moment of inertia of engine flywheel, $ft\text{-}lb\text{-}sec^2$
I_p	Moment of inertia of propshaft, $ft\text{-}lbs\text{-}sec^2$
I_w	Moment of inertia of a wheel and tire assembly, $ft\text{-}lb\text{-}sec^2$
$IGIN_2$	Moment of inertia for ith gear (input mode), $ft\text{-}lb\text{-}sec^2$
$IGOUT_2$	Moment of inertia for ith gear (output mode), $ft\text{-}lb\text{-}sec^2$
K_o	Transmission output capacity factor

LIST OF SYMBOLS (CONTINUED)

N_1	Torque converter input speed, RPM
N_E	Engine speed (= N_1), RPM
N_p	Propshaft speed, RPM
N_w	Wheel speed, RPM
R	Wheel radius, ft
r_f	Fuel rate, lbs/hr
SR	Torque converter speed ratio
T_1	Torque converter input torque, lb-ft
T_2	Torque converter output torque, lb-ft
T_A	Accessory torque, lb-ft
T_E	Engine torque, lb-ft
T_F	Front end rotating inertia torque, lb-ft
T_{GS_i}	Gear i spin loss, lb-ft
TR	Rotating inertia torque of rear end, lb-ft
TRS	Rear axle spin loss, lb-ft
T_w	Torque at wheel hub, lb-ft
TR	Torque converter torque ratio
t	time, sec
W	Weight, lbs
Z_i	Rolling resistance force linear term, lbs/1000 lbs W
Z_2	Rolling resistance force velocity dependent term, lbs/1000 lbs per MPH
Z_3	Constant in aerodynamic force equation
Z_4	Yaw angle senstivity coefficient
ϕ	Angle of wind relative to vehicle

1. INTRODUCTION

The Vehicle Performance Simulation Computer Model (VEHSIM) is a program which simulates the performance and fuel economy characteristics of a motor vehicle as it executes a given driving schedule. Particular considerations are given to determining where and when, during the schedule, energy is consumed.

VEHSIM also provides the user with a convenient way to evaluate the individual vehicle components (i.e. engine, torque converter, drag coefficient, weight, etc.) and to determine their effects on the fuel consumption of the vehicle. Also, detailed analyses and monitoring, both qualitative and quantitative, of the variously proposed driving schedules may be made.

VEHSIM is programmed in FORTRAN IV compiler language. A simulation exercise may be conducted from a remote terminal interactively or in batch. Alternatively, the program may be submitted in batch via a card deck.

The report describes VEHSIM in a series of four volumes. Volume I presents the description of the numerical approach and equations, and Volume II is a user's manual. Volume III contains the program listing. Volume IV incorporates enhancements that include simulation of the integrated overdrive transmission with a split-torque converter.

2. SIMULATION TECHNIQUE

2.1 CONTINUOUS SIMULATION METHOD

The basic equations are given in Section 2.7.2. At any given time step, Δt, the acceleration and velocity of the vehicle are specified. From these, the horsepower in terms of torque and rpm, needed at the wheels, is computed and followed back to the engine by way of the differential, gear box, and torque converter. After losses to accessories, rotating inertias, tire slip, etc., are computed, the output state in terms of torque and rpm of the engine is known. At this point, an interpolation of the engine map is performed and fuel flow, manifold vacuum, and throttle setting are determined.

If it is found that more torque is being required of the engine than it can produce at that speed, the wheel acceleration is modified and the process repeated. This would correspond to a 100 percent wide-open throttle (WOT) condition. Should less power than the minimum engine output be required, as in a coast-down condition, the brakes would be applied and the engine would assume a minimum throttle setting.

Most of the computations in "going back" from the wheels are simple and direct. However, in the case of the accessories, a linear interpolation of a torque vs. rpm map is performed for each accessory. An interpolation is also needed for the torque converter, but in this case tables of speed ratio and torque ratio vs. output capacity factor are used. (It should be noted that in the coast condition, of course, only speed ratio is computed since the torque ratio is always unity.)

Upon determining the engine output speed and torque, a double linear interpolation of the engine map is performed. The speed point is determined by interpolating between the two closest given speeds. If this speed is off the map, the highest (or lowest) two speed points are projected linearly to determine the slope for other engine parameters. If the speed is below engine minimum (idle speed), it is set to that minimum. Another interpolation is performed to find the torque setting at each of the two speed points. From these two values, the true engine state is computed by using the speed slope already determined.

The engine map routine performs one of the most critical calculations in VEHSIM; it interpolates the input engine data to find the instantaneous fuel flow rate. It also determines whether or not the "demand" from the wheels may be satisfied by the engine without further consideration by the control logic.

As may be seen in Figure 1, the engine-routine views the map as a set of nine regions. Region 1 is the actual input engine map data. Regions 2 through 9 are "off-the-map" regions, and the control logic may have to take some corrective action. Region 2 contains points with valid load demands but which are below minimum engine speed. In this case the torque and fuel flow rates from the lowest two engine speeds are projected down to the desired speed. (Note that if the result is less than the idle speed of the engine, the control logic will pin the engine at idle speed and converter spin loss (or clutch slip) will account for the energy difference.) Region 3 contains points with valid load demands but which are above the maximum engine speed that was fed into the model. In this case, the torque and fuel flow rates from the highest two speeds are projected up to the desired speed.

Regions 5, 8 and 9 are areas in which the engine is overtaxed and is beyond 100 percent WOT. These are definitely areas in which the control logic must adjust the demand at the wheels by reducing the required acceleration. Regions 4, 6 and 7 are areas in which the engine's energy absorbtion capability (motoring torque) is insufficient to absorb all the energy coming back from the wheels (as in a coast-down condition). In these areas the control logic must apply the brakes.

2.2 DESIGN CONSIDERATIONS

Any digital simulation of a real-time process must make certain assumptions and evaluate various trade-offs in an attempt to

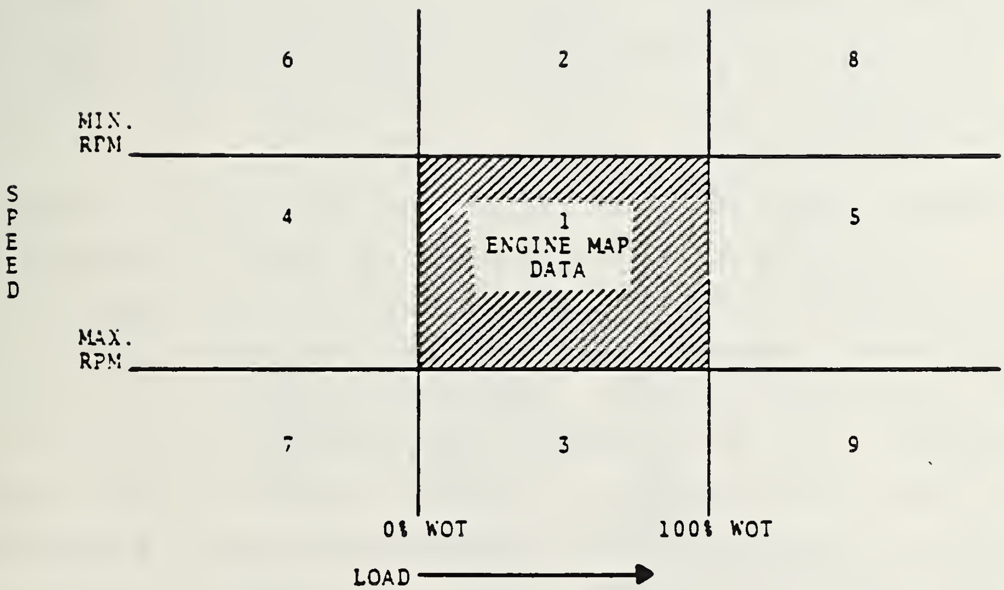


FIGURE 1. ENGINE MAP REGIONS AS SEEN BY THE VEHSIM ENGINE ROUTINE

obtain the most accurate results for the most reasonable cost. The decision to compute back from the wheels to the engine at every time step rather than generate extensive engine state tables was made to maintain accuracy. At the same time, the program was designed to perform constant velocity driving schedule segments in a minimum number of time-steps, a few steps to allow rotational inertias to damp out and the vehicle to reach steady state at the required velocity, and one long step to complete the segment. This minimum step method was used to conserve computer time. Linear interpolations are used for all table look-ups also to conserve computer time.

The default time step is .05 seconds but may be increased by the user if he feels that a savings in computer run costs outweighs accuracy considerations. To date, runs using up to .25 seconds have given acceptable accuracy with a substantial reduction in cost. Of course, the particular drive cycle will influence the decision to change the time step. For example, a drive cycle comprised of many transient calculations would require a smaller time step than one having many constant velocity segments.

2.3 MODES OF OPERATION

The desired performance criterion, as specified by the driving schedule, is the factor which determines the mode of operation of the vehicle. VEHSIM has three primary modes of operation: constant acceleration, constant velocity, and constant throttle setting. These modes are actually segment types which make up the driving schedule. The basic idea is that the control logic tries to maintain one of the operational modes specified in each segment of the schedule by adjusting the demand on the engine accordingly. In a very real sense, the control logic is "driving" the vehicle. The interaction between these modes of operation and the adjustment of the demand on the engine is shown in Figure 2. In each segment of the driving schedule, checks are made to determine which type of operational mode is currently being followed. The control logic then adjusts either the acceleration or throttle until the specified condition is satisfied.

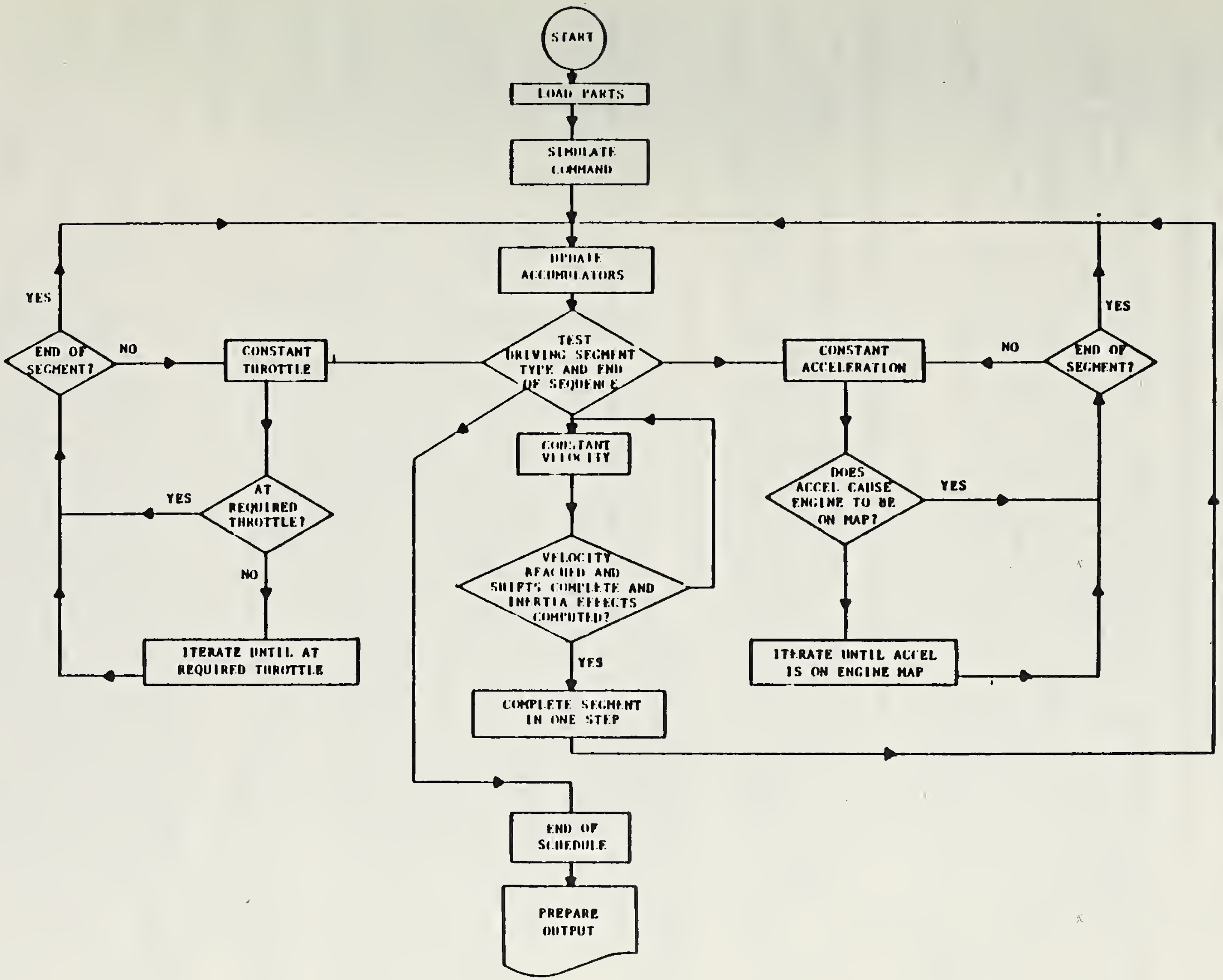


FIGURE 2. FLOW CHART ON CONTROL LOGIC

2.3.1 Constant Acceleration Mode

In this mode, VEHSIM attempts to reach and maintain a constant rate of acceleration (or deceleration). Should this condition require the engine to produce a torque greater than its maximum allowable value, a lesser acceleration would be attempted, and the 100 percent WOT (wide-open throttle) point would be used. For negative accelerations (coast-down conditions), the 0 percent WOT torque is the minimum torque allowed. This torque is negative since it reflects motoring of the engine. Should the computed torque value at the engine be less than 0 percent WOT, the brakes would absorb the difference.

Note that a vehicle may or may not be able to achieve a given positive acceleration rate, due to the maximum horsepower curve of the engine. However, any negative acceleration rate is possible since it simply requires additional braking to be negotiated.

2.3.2 Constant Velocity Mode

This mode is similar to the constant acceleration mode in that it attempts to maintain an acceleration rate of zero. However, there are some differences in the control logic. Since it is not certain that the velocity at the beginning of the segment is equal to the desired velocity, a few time-steps are computed to urge the vehicle to reach this velocity and to allow certain transient phenomena, such as shifting into a new gear or computing rotating inertia effects, to die out. When this steady-state is reached, the remainder of the segment is computed in one large time-step to conserve computer time.

2.3.3 Constant Throttle Mode

The throttle position is defined as the percent of "throw" (maximum torque minus minimum torque) at a particular engine RPM. As such, the actual torque at 0 percent WOT is usually a negative number, which indicates motoring, rather than making a "quantum jump" from one to the other, thus preserving the continous nature of the simulation. Again, as with the other modes of operation, the acceleration at the wheels is the parameter varied in order to maintain a constant percent throttle for any engine RPM.

2.4 COMPUTATION OF ENERGY LOSSES

A number of accumulators are present in the program which keep track of where (accessories, drag, etc.) and when (cruise, idle, acceleration or deceleration) the energy losses occur during the entire simulation. The totals are printed at the end of the driving cycle as percent of engine horsepower-hours to assist the user in determining the relative effects of these parameters on fuel economy and performance.

There are four types of "devices" for which losses are computed. The first of these is the "in-line" device. This is a vehicle component which is actually part of the path of energy flow (drivetrain) from the engine to the wheels. The tires, differential, gear box and torque converter (or clutch mechanism) fall into this category. The loss for an in-line device simply consists of energy-out minus energy-in over the time-step being used.

The second type of loss is that of the "state" device. This is a device which has a loss associated with it as a function of RPM, but which is not part of the drivetrain such as the engine accessories' load. The losses are computed by taking the difference between the power required before and after the time-step and applying it for that duration.

The third type of loss is associated with certain "reversible" processes. The word "device" here ceases to be meaningful since the loss being referred to only exists if the states of the vehicle before and after the complete simulation are different. For example, should the vehicle start from 0 MPH and complete the simulation traveling at 55 MPH, a loss to kinetic energy would be obvious. If, however, the final speed was also 0 MPH, the net loss to kinetic energy would be zero. Other losses of this type include the rotating inertia losses and potential energy (grade). Note that it is possible to end up with a negative loss here (e.g.

starting at the top of a hill and ending at the bottom). Such a situation would be treated by the program as an energy "gain" and handled separately so that it would not be confused with energy output from the engine.

The final type of loss concerns those devices which have "inherent" losses. Engine motoring and the brakes are two such situations in which any associated power acting across a time-step is inherently considered to be irrevocably lost energy.

2.5 TRANSMISSION SHIFT LOGIC

When simulating a vehicle with a manual transmission, VEHSIM expects to see a maximum engine or vehicle speed in the shift logic data. If, for example during a simulation, the engine attempts to exceed this maximum engine speed, the control logic will authorize an upshift to the next higher gear. During an upshift the vehicle is allowed to coast, acted upon only by aerodynamic drag, rolling resistance, and gravity (grade). The engine, meanwhile, is disengaged from the drivetrain and is allowed to spin down by using the motoring torques to absorb the rotating energy of the engine, flywheel, and accessories. When the two speeds on either side of the clutch plates match, the engine is engaged to the drivetrain.

The user specifies the downshift engine speed or vehicle speed for all gears so that when the downshift is performed the engine speed will be below the engine upshift speed. This requires tailoring of each engine and transmission shift logic individually. For a manual transmission, the shift logic over the EPA drive cycles is based on mph as specified by the EPA. The shift logic for the automatic transmission is furnished by the manufacturer. Whenever VEHSIM detects the engine speed dropping below the downshift point for the gear engaged at that time, the control logic will authorize a downshift to the next lower gear. During a downshift the same forces act on the overall vehicle as it is allowed to coast. However, the engine is throttled up to provide the energy necessary to increase the flywheel RPM to the new speed in the new gear. Again, when the speeds across the clutch plates match, the engine is re-engaged.

If a vehicle is in top gear when the maximum engine speed is reached, the program relies on the engine map to limit the available horsepower (governor droop should be built into the map for heavy duty trucks with diesel engines). If the vehicle is in gear 1 when a downshift is requested, no action is taken.

The major problem with any shift logic, whether manual or automatic, is to prevent "stutter," i.e. switching back and forth from one gear to another. In order to counteract this possibility, VEHSIM will prevent a shift from occuring if the projected speed following an upshift is below the downshift speed for the new gear, or if the projected speed following a downshift is above the upshift speed for the new gear. Should this condition occur, the program would assume that a shift at that point would not be advisable and would set the throttle to a value that would simply maintain the engine at the shift speed. This would continue until another new condition was requested (e.g. a change in grade).

The VEHSIM output record provides shift frequency data which may be used as an aid in determining the validity of the shift logic. Additionally, this shift "stutter" problem may be suspected should the output record indicate total engine horsepower-hours significantly greater or less than a few percent of one hundred. When this condition occurs, the user should check the number of shifts being performed, and modify the shift logic if this number seems high by separating the shift lines more, particularly on the wide-open throttle end.

2.5.1 Linear Load Profile

Shift logic simulation is probably one of the least understood algorithms in a vehicle simulation program. Shift logic is usually characterized by a load vs. vehicle or engine speed. Common load designations are vacuum, in inches of Hg, throttle angle, and percent WOT. Ideally, a shift logic should be tailored to a particular vehicle/engine combination for desired performance requirements. However, this is difficult to simulate since shift logics rarely accompany engine maps.

To circumvent this problem, shift logic may be input to the simulation program with load designated in either manifold vacuum or percent WOT. Manifold vacuum is useful when a shift logic and engine map are received as a unit, but percent WOT is far more versatile. The percent WOT approximates the throttle angle input to shift logics by calculating the percent of torque range as follows:

$$\% \text{ WOT} = \frac{Tq - Tq_{min}}{Tq_{max} - Tq_{min}} \times 100$$

where: Tq = Engine torque

Tq_{min} = Minimum torque

Tq_{max} = Maximum torque.

Figure 3 illustrates the difference between the calculated percent throttle and its actual value.

This method allows the same shift logic to be used with a variety of engine-vehicle combinations with similar hp to inertia weight ratios. It has long been used with the assumption that the resulting errors are small.

To determine the significance of these errors, a vehicle was simulated with a linear percent WOT engine profile and with the correct profile. The engine used was a 1979 GM 5.7-liter spark ignition engine in a 4500 lb. vehicle with a 4-speed automatic transmission. Two different shift logics were used to eliminate any peculiarities of a particular shift logic. The shift logics are shown in Figure 4.

The results of the vehicle simulations showed slightly lower fuel economies for the linearly interpolated cases (see Table 1). The small differences are primarily a result of the fact that 35

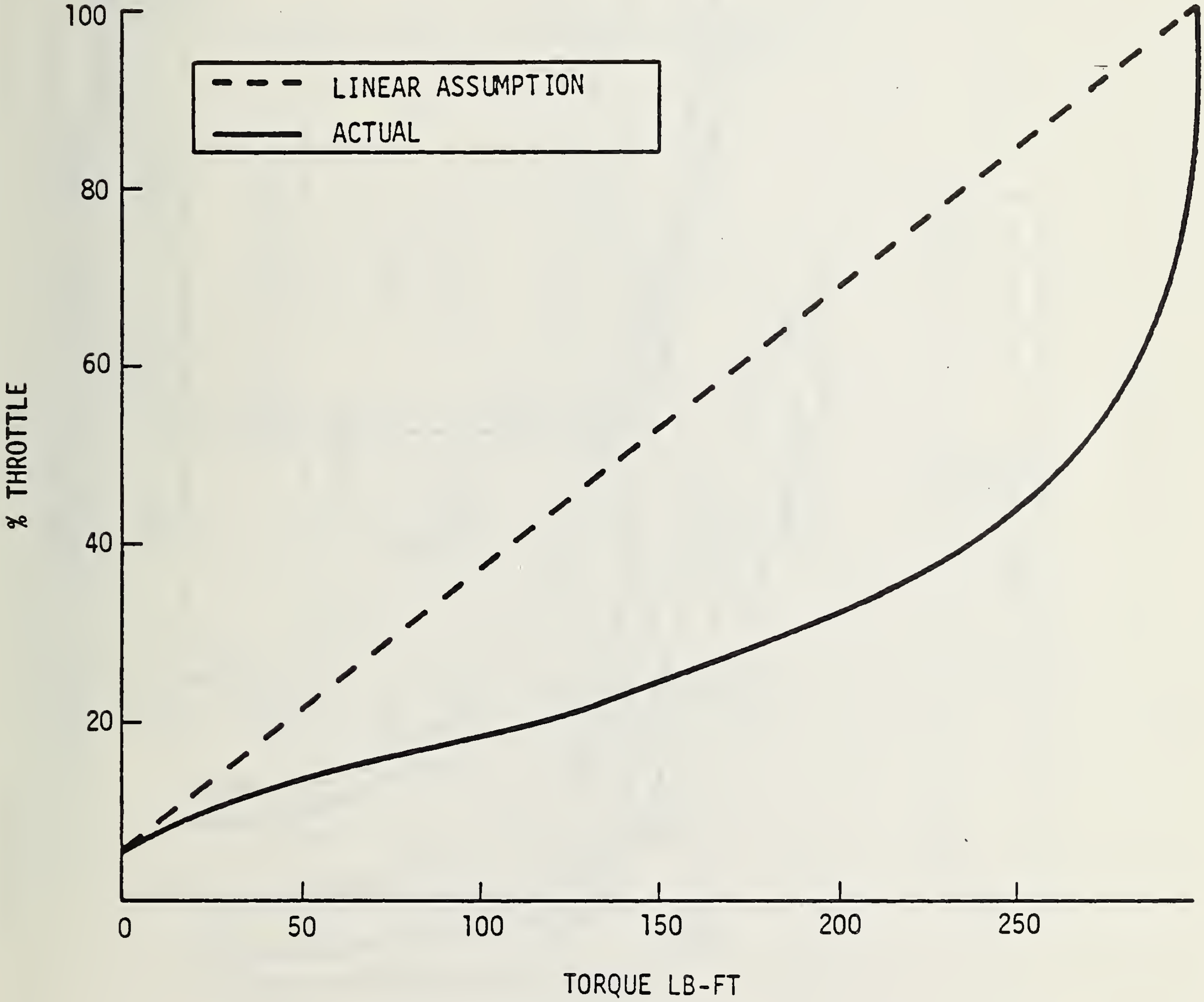


FIGURE 3. THROTTLE CURVE FOR 1979 CHEVROLET 350 CID AT 1000 RPM

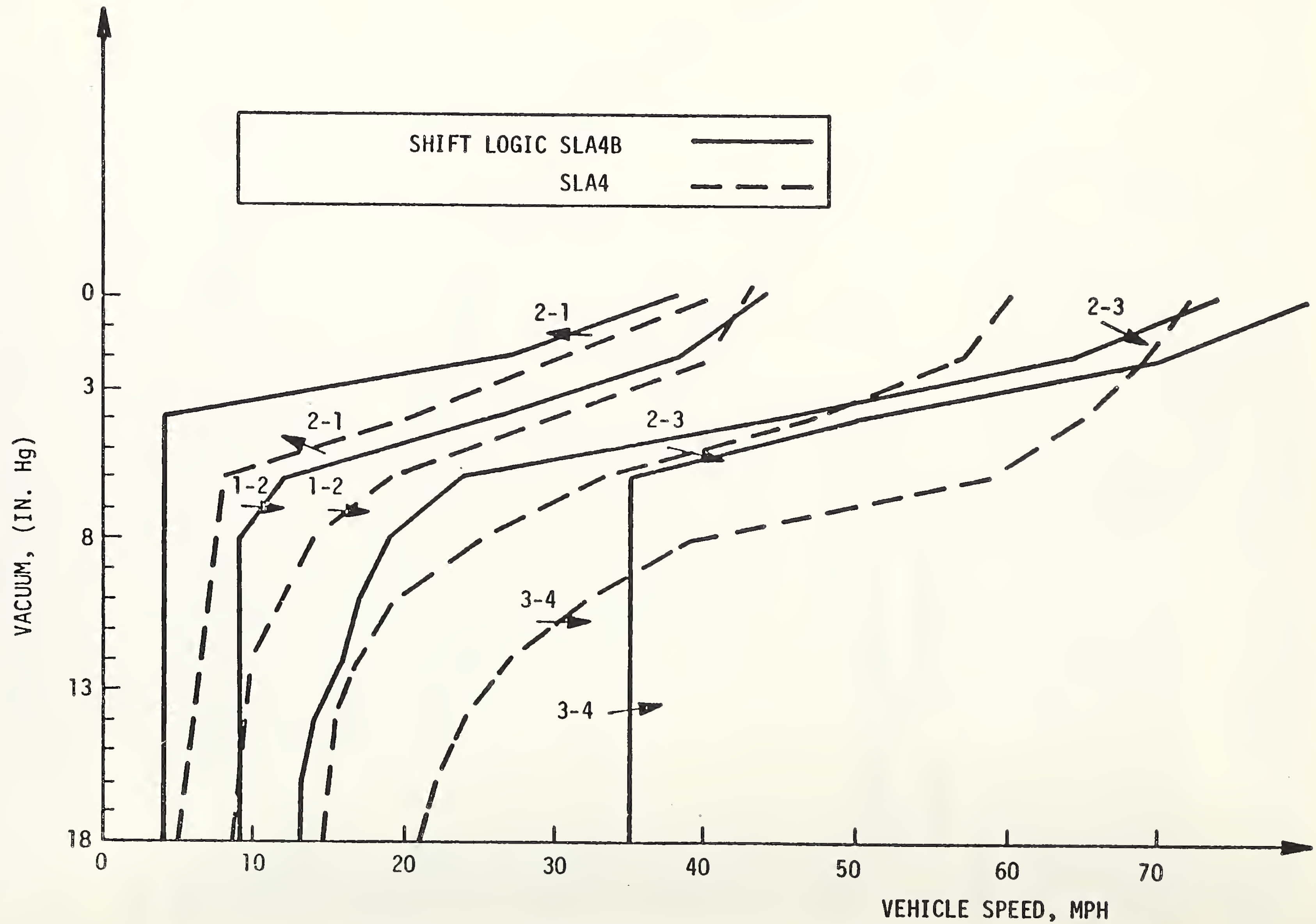


FIGURE 4. COMPARISON OF SHIFT LOGICS

TABLE 1. FUEL ECONOMY FOR DIFFERENT SHIFT PROFILES

SHIFT LOGIC SLA4	ACTUAL	LINEARLY INTERPOLATED	% DIFF
URBAN	14.66	14.36	2.0
HWY	18.84	18.78	0.3
COMBINED	16.29	16.06	1.4
SHIFT LOGIC SLA4B	**ACTUAL**	**LINEARLY INTERPOLATED**	**% DIFF**
URBAN	14.26	14.02	1.7
HWY	17.99	17.98	0.1
COMBINED	15.73	15.56	1.0

percent of the urban cycle time is spent at idle and 75 percent of the highway cycle time is spent in high gear. These times are nearly independent of shift logic percent WOT errors. Therefore, fuel economy is only slightly affected. As shown in Figure 5, the linear profile shifts at lower speeds for a given throttle opening and, thus, operates at a slightly higher engine efficiency. This effect of higher engine efficiencies is outweighed by the lower torque converter efficiency resulting from the lower speeds; therefore, linear profiles produce slightly lower fuel economies. Lockup gears would negate or reverse this trend, increasing the effectiveness of lockup gears.

Additionally, shift problems associated with manifold vacuum may arise due to irregularities in engine map data. This problem may be circumvented by assuming that the manifold vacuum varies with engine load by*

$$VAC = 20.5 - 20.3 \frac{T_A}{T_{A,\ max}}$$

where: VAC = Manifold Vacuum (in. Hg)

T_A = Torque (lb-ft).

At wide open throttle, the vacuum level is 0.2 in. Hg due to the air cleaner and other restrictions to the air flow in the intake manifold. A comparison of the accuracy of this assumption and the actual engine data has not been made to date.

2.6 DRIVING SCHEDULE AND ROUTE

The driving schedule specifies vehicle motion according to one of the following segment types: constant vehicle acceleration, constant speed, or constant percent of full throttle. The calculation procedure for each of these segment types has been

*Blumberg, Paul, N., "Powertrain Simulation: A Tool for the Design and Evaluation of Engine Control Strategies in Vehicles," SAE Paper 760158, February 1976.

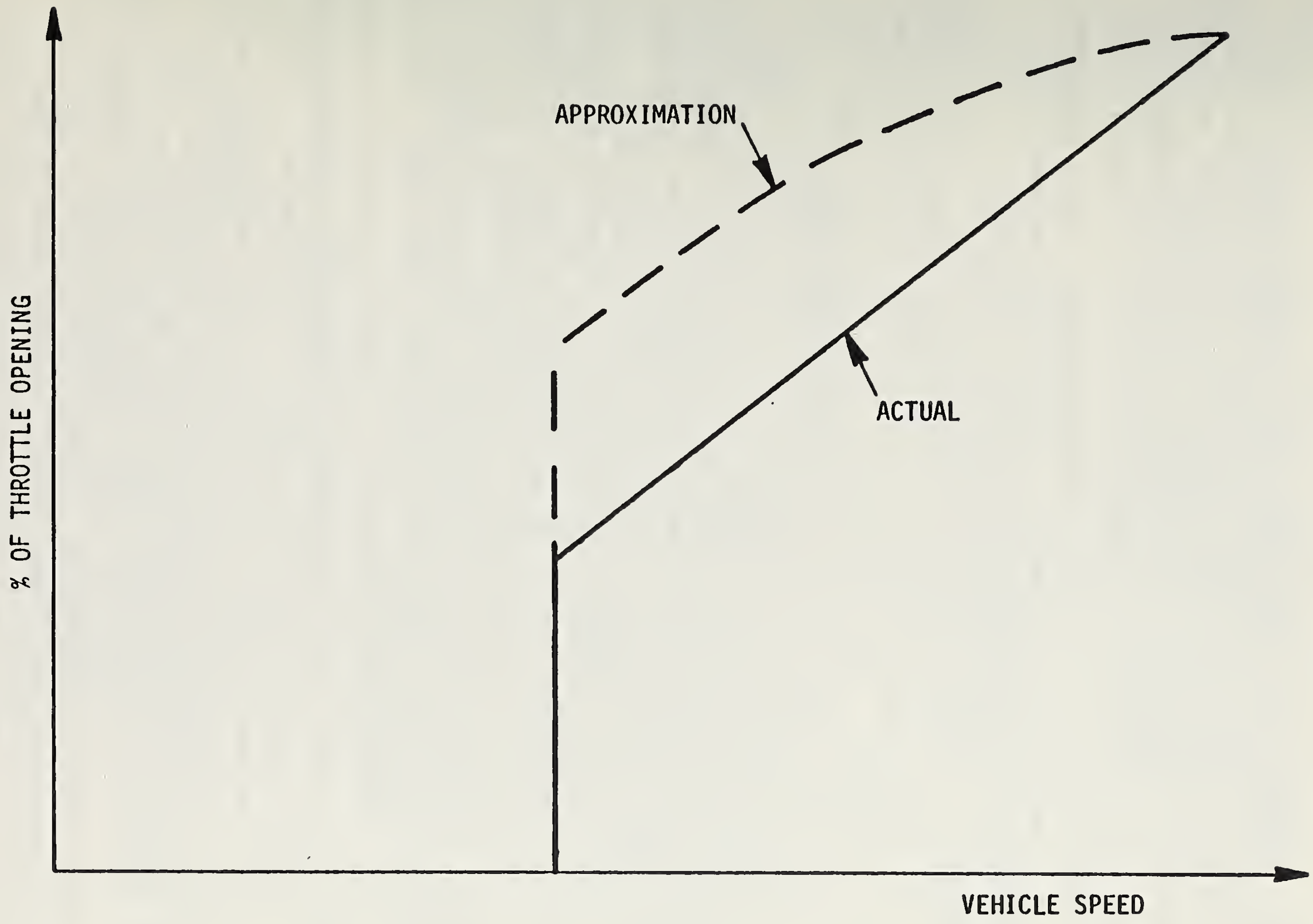


FIGURE 5. EFFECT OF LINEAR APPROXIMATION ON A SIMPLIFIED SHIFT LINE

previously described, and will not be repeated here. There are other important considerations, however, which should be noted concerning the driving schedule and route.

Sudden changes in acceleration must be avoided when specifying driving schedule data, especially for a large vehicle such as a truck or bus. Such changes can result in unrealistic and artificially high torque demands. This problem can be circumvented by inserting a zero acceleration segment between two radically different accelerations and/or that change in sign. In this manner the peaks and valleys of sequential acceleration segments in a driving schedule are smoothed to negotiable profiles.

Specification of an unrealistic constant acceleration is permissible, but the program would only allow maximum engine horsepower to be delivered. The calculation procedure would then be similar to the case where 100 percent WOT is specified.

The end conditions for a segment may be specified by the attainment of any one of five criteria. One should be cautious of the possible consequences if only one end condition is specified. An example would be specification of an unattainable terminal speed for an underpowered vehicle. A simulation may be terminated by completion of either the driving schedule or route, whichever endpoint is reached first. A typical example is a general purpose route of 500 miles of level road, which may be used in conjunction with a driving schedule of any length 500 miles or less absolute distance.

A detailed route description may be prescribed, although the driving schedule may be relatively simple. For example, a route which incorporates many grades and changing wind velocities may be used with a driving schedule made up of 55 MPH initial conditions and 55 for an absolute distance equal to or greater than the total distance of the route. The simulation would attempt to follow the route by adjusting the accelerations as necessary to try to maintain the specified speed, in this case 55 MPH. Throughout such a simulation, there may not be sufficient engine power to maintain constant speed on uphill sections of the route; the brakes would be applied to augment engine braking, if necessary, on a downhill milepost interval to prevent exceeding the speed limit.

The driving schedule and route input formats were designed to provide simulation of essentially any road course. More often than not, a problem lies in providing the required data to make it possible for a vehicle to perform as desired.

2.7 COMPUTATIONAL PROCEDURE

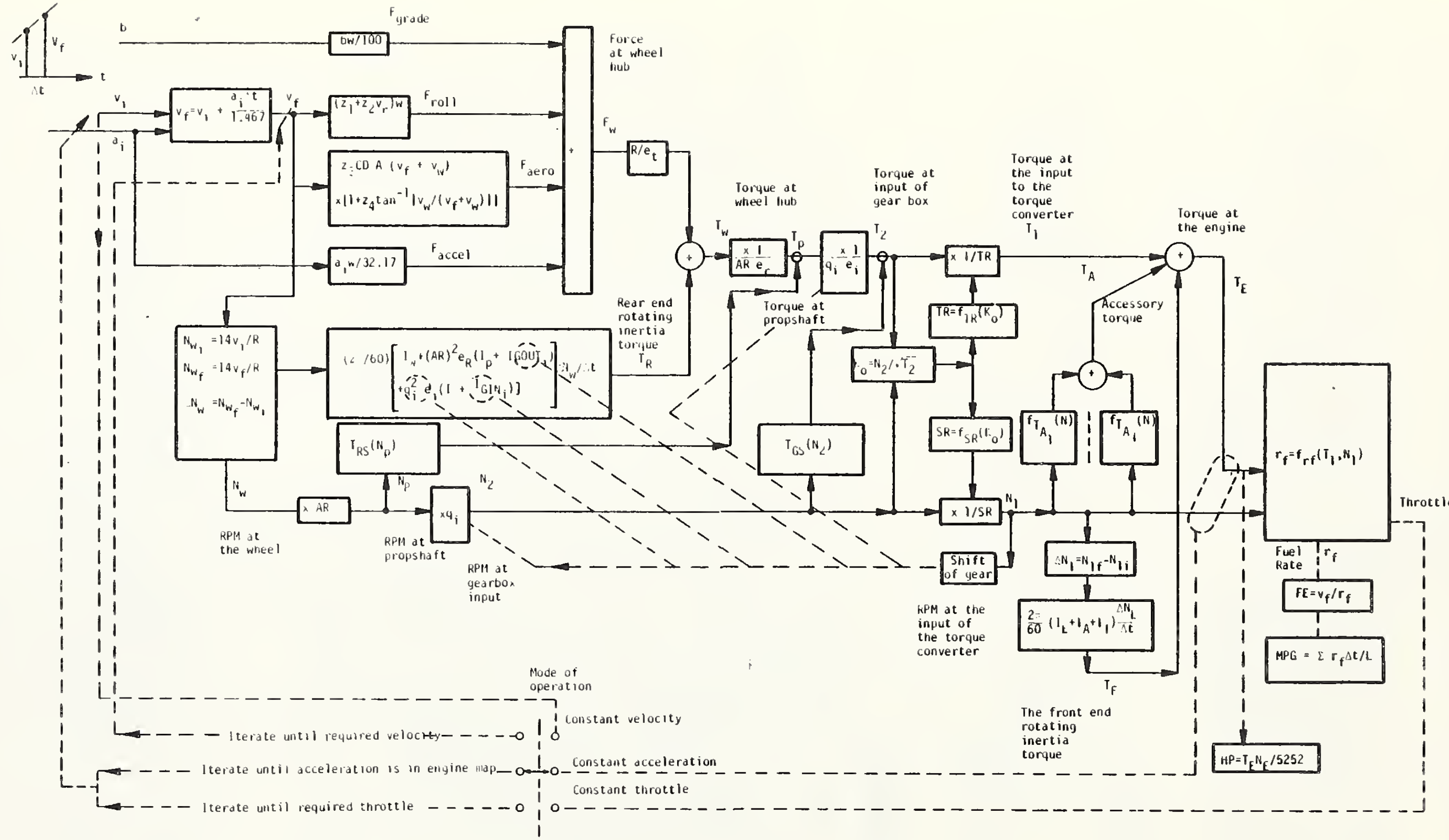
This section will present a description of the mathematical formulation of vehicle performance within VEHSIM. A program listing is included in Volume III.

2.7.1 Overview of Equations

Since VEHSIM uses the "deterministic" method of computing vehicle performance (i.e. the engine state is determined by demand at the wheels), the primary considerations are velocity and acceleration of the overall vehicle. The force acting on the vehicle at any given time is equal to the D'Alembert (inertial) force plus the sum of all the external forces. These external forces are aerodynamic drag, rolling resistance, and gravity (grade). After converting this force at the road level to a torque at the wheel hub, VEHSIM transmits this back to the engine by way of the differential, gear box, and torque converter (or clutch mechanism). Along the way the accessory torques and the torques due to rotating inertia changes are added in as well.

2.7.2 Analysis

The following equations are used to compute back from the wheels. The interaction of these equations is presented in the form of the analog computer scheme in Figure 6.



a_i = initial acceleration
A - frontal area
b - grade ( )
CD - drag coefficient
e_t - tire efficiency
e_R - efficiency of differential
e_i - efficiency of the i-th gear
F_{accel} - inertial force
F_{aero} - aerodynamic drag force
FE - instantaneous fuel economy
F_{grade} - force due to route grade
F_{roll} - rolling resistance
F_w - force at the wheel hub
HP - horsepower

I_w, I_p, I_2 - moments of inertia for the wheel, propshaft, and torque converter, resp.
I_E, I_A, I_i - moments of inertia for engine flywheel, accessories, and torque converter pump, resp.
$IGOUT_i$ - output moment of inertia for the i-th gear
$IGIN_i$ - input moment of inertia for the i-th gear
K_o - output capacity factor of the torque converter
L - distance covered by a vehicle
N_2 - RPM at the gear box
N_p - RPM at the propshaft
N_w - RPM at the wheel
N_1 - RPM at the input to the torque converter $N_1 = N_E = N_A$ (torque converter, engine, accessory RPM)
q_i - gear ratio for the i-th gear
AR - axle ratio

R - rolling radius of the wheel
T_W - Torque at the wheel hub
T_R - rear end rotating inertia torque
T_p - torque at propshaft
T_E - torque at the engine
T_1 - torque at the input to the torque converter
T_2 - torque at the rear box
T_{A_k} - torque at the k-th accessory
T_A - total accessory torque
T_F - front end rotation inertia torque
v_i - initial velocity
v_f - final velocity
w - car weight

z_1, z_2 - input constants (F_{roll} equation)
z_3, z_4 - input constants (F_{aero} equation)
Δt - time step
ΔN_w - increment of RPM at the wheel

FIGURE 6. DYNAMICS MODEL OF VEHSIM

At the wheels:

$$v_f = v_i + \frac{a_i \Delta t}{1.467} \tag{1}$$

where: v_i = initial velocity (MPH)

a_i = initial acceleration (ft./sec^2)

v_f = final velocity (MPH)

Δt = time step (sec).

The rolling resistance force F_{ROLL} is given by:

$$F_{ROLL} = (Z_1 + Z_2\ v_f)W/1000 \tag{2}$$

where: Z_1 = Rolling resistance coefficient (lb/1000 lb)

Z_2 = Rolling resistance coefficient (lb/1000 lb-MPH)

W = Vehicle weight (lbm).

Although this equation does not account for tire inflation pressure, this variable can be included indirectly by means of a carpet plot as shown in Figure 7. The equilibrium rolling resistance varies linearly with the reciprocal of the inflation pressure.

The aerodynamic drag force F_{AERO} is:

$$F_{AERO} = Z_3\ C_D\ A\ (V_v + V_p)^2\ \{1. - Z_4 \tan^{-1}[v_n/V_v + V_p)]\} \tag{3}$$

where: $Z_3 = \rho(1.467)^2/2g$ is an input constant

C_D = drag coefficient

Z_4 = C_D sensitivity coefficient (to yaw angle)

A = frontal area (ft^2)

V_p = wind velocity component parallel to the direction of the vehicle

v_n = wind velocity component normal to the direction of the vehicle

V_v = vehicle velocity.

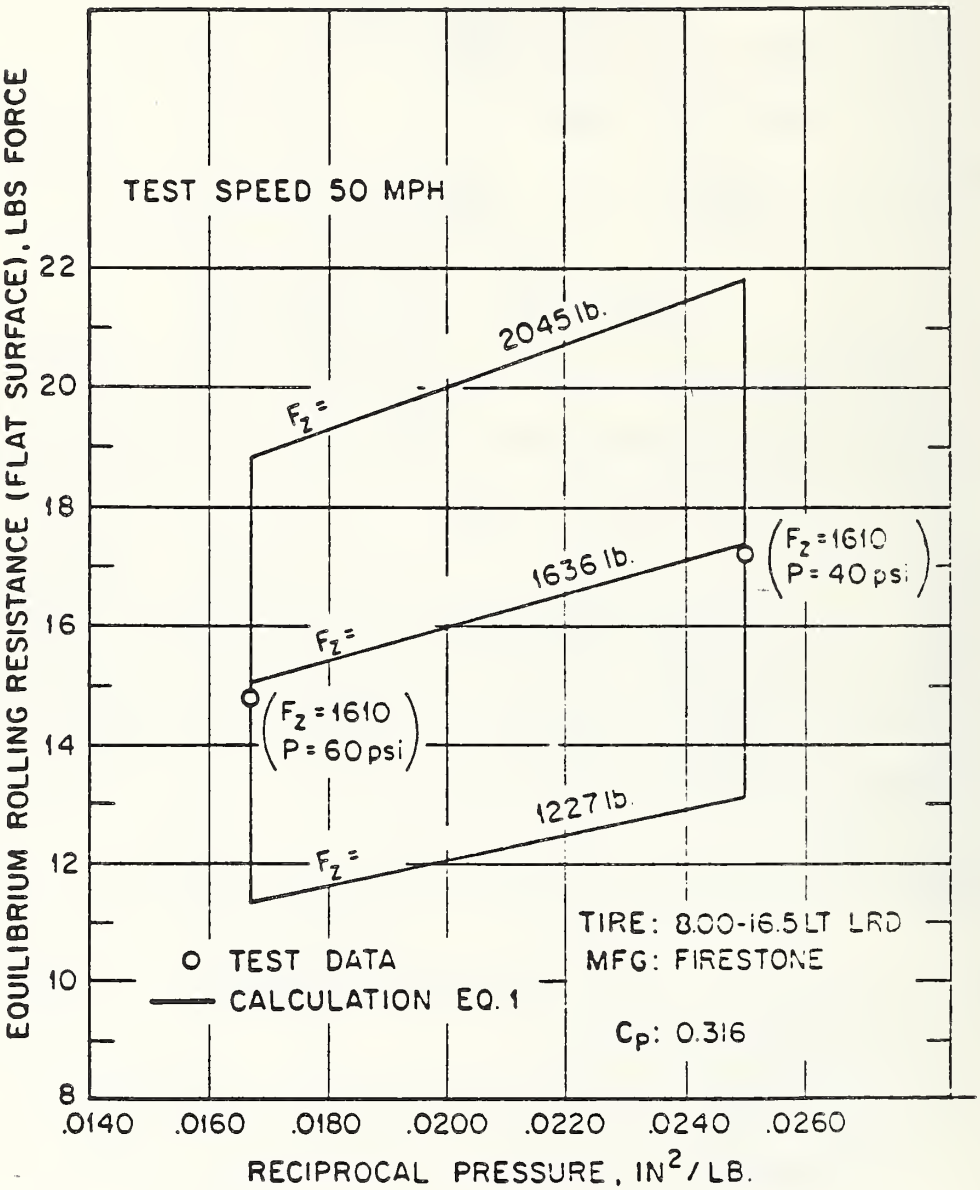
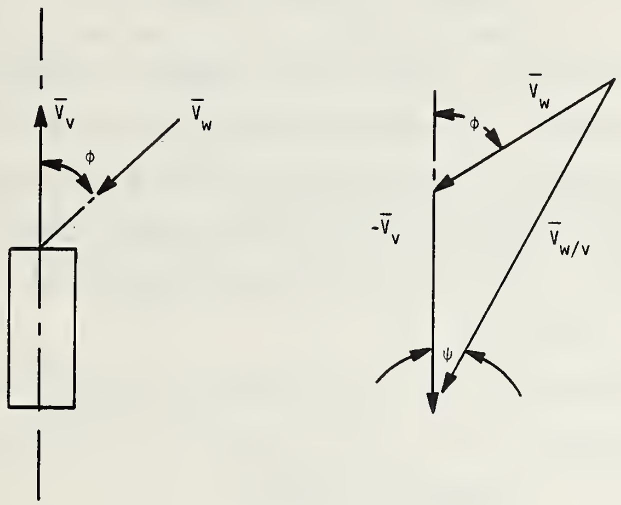


FIGURE 7. EQUILIBRIUM ROLLING RESISTANCE (FLAT SURFACE) VERSUS LOAD AND INFLATION PRESSURE: FIRESTONE 8.00-16.5 LT LRD

The interaction of the velocity vectors can be seen in Figure 8.



$$\mathrm{TAN}\psi = \frac{\dfrac{V_w V_n}{V_w}}{\dfrac{V_v + V_n V_p}{V_n}}$$

$$\mathrm{TAN}\psi = \frac{V_n}{V_v + V_p}$$

$$\psi = \mathrm{TAN}^{-1} \frac{V_n}{V_v + V_p}$$

FIGURE 8. VELOCITY VECTORS

The inverse tangent function computes the yaw angle, which is the angle of the air motion (including wind) as seen by the vehicle. The coefficient Z_4 is a measure of how sensitive the drag coefficient is to the yaw angle. For yaw angles of up to 30 degrees, considering bluff bodies such as trucks and buses, this sensitivity factor appears to have a value of about 0.02 per degree of yaw up to about 30 degrees yaw.*,** VEHSIM accepts this coefficient on the vehicle input information data card as the C_d sensitivity coefficient.

*"The Aerodynamics of Basic Shapes for Road Vehicles," The Motor Industry Research Association, Report No. 1969/2, 1969.
**"Truck Aerodynamics," H. Flynn and P. Kyropoulos, SAE Transactions 1962, Vol. 70, C. 1962m p. 297-308.

The angle of wind direction PHI referenced to the vehicle direction ($\phi = 0$, for headwinds; $\phi = 180$ for tailwinds) and wind velocity VWIND are inputed using MODIFY PHI and MODIFY WIND cards, respectively. Default values are wind velocity VWIND and direction PHI both equal to zero. The user is cautioned that this wind modification feature is an approximation and may not be reasonable in all cases due to different vehicle designs. This modification should not be used for vehicles which cannot be approximated as bluff bodies, and it should be restricted to yaw angles only up to about 30 degrees.

The inertial force due to acceleration F_{ACCEL} is:

$$F_{ACCEL} = \frac{a_i \, W}{32.17} \tag{4}$$

where: a_i = acceleration (ft/sec^2)

W = weight (lbm),

and the force due to route grade F_{GRADE} is:

$$F_{GRADE} = bW/100 \tag{5}$$

where b is percent grade being traveled.

The force acting at the wheel hub (F_w) is then given by:

$$F_w = (F_{ROLL} + F_{AERO} + F_{ACCEL} + F_{GRADE})/e_t \tag{6}$$

where e_t is the tire efficiency. This should not be confused with the rolling resistance coefficients introduced earlier.

We find the rear-end rotating inertia torque T_R using the following equation:

$$T_R = \frac{2\pi}{60} \{(TI)I_w + (AR)^2 \, e_r \, [(I_p - IGOUT_i) + g_i^2 ei \, (I_2 + IGIN_i)]\} \tag{7}$$

where: TI = number of wheels;

e_r and e_i are the efficiencies of the differential and the i^{th} gear, respectively

$IGOUT_i$ = output moment of inertia for the i^{th} gear

$IGIN_i$ = input moment of inertia for the i^{th} gear

I_w, I_p and I_2 are the moments of inertia for a wheel, the propshaft and the torque converter turbine, respectively

gi = gear ratio for the i^{th} gear

AR is the axle ratio and ΔN_w is the change in RPM's at the wheels, i.e.

$$\Delta N_w = (N_w)_f - (N_w)_i \quad (8)$$

where

$$(N_w)_t = \frac{60}{2\pi} X \frac{V_t}{R} X\ 1.467 \quad (9)$$

for any time t,

R = rolling radius of the wheel (ft),

V_t = vehicle speed (MPH).

We may now compute the total torque at the wheel hub (T_w) as follows from equations (6) and (7):

$$T_w = R\ F_w + T_R \quad (10)$$

Proceeding back through the differential we obtain the propshaft state as:

$$N_p = (AR)\ N_w \quad (11)$$

and

$$T_p = \frac{T_w}{(AR)\ e_r} + T_{RS} \quad (12)$$

where T_{RS} = axle spin loss interpolated from axle tabular input.

The input to the gear box then follows from:

$$N_2 = g_i \, N_p \tag{13}$$

and

$$T_2 = \frac{T_p}{gi \; e_i} + T_{GS_i} \tag{14}$$

where T_{GS_i} = gear spin loss for gear i interpolated from tabular input.

The output capacity factor (Ko) of the torque converter, where

$$Ko = \frac{N_2}{\sqrt{T_2}} \quad , \tag{15}$$

provides us with a means of interpolating the torque converter tables to obtain the speed ratio (SR) and torque ratio (TR). The input to the torque converter is then given by:

$$N_1 = N_2/(SR) \tag{16}$$

and

$$T_1 = T_2/(TR) \tag{17}$$

By definition, the input speed of the torque converter, the engine speed, and the accessory speeds are all equal, i.e.

$$N_1 = N_E = N_A \tag{18}$$

A speed ratio is used to relate the accessory RPM and engine RPM, because these two speeds are usually different.

The accessory speed (N_A) gives us a parameter with which to interpolate the accessory tables to get the accessory torque (T_A) where:

$$T_A = \sum_{N=1}^{NACC} (T_A)_n \tag{19}$$

and NACC is the total number of accessories.

The front end rotating inertia torque (T_F) is given by the equation:

$$T_F = \frac{2\pi}{60} (I_E + I_A + I_1) \frac{\Delta N_E}{\Delta t} \tag{20}$$

where:

I_E, I_A and I_1 are the moments of inertia for the engine flywheel, sum of the accessories and the torque converter pump respectively; and ΔN_E is the change in RPM's at the engine, i.e.

$$\Delta N_E = (N_E)_f - (N_E)i. \tag{21}$$

We can now find the torque at the engine (T_E) from:

$$T_E = T_1 + T_A + T_F. \tag{22}$$

Given T_E and N_E we can interpolate the engine map to obtain fuel rate, manifold vacuum and throttle position.

Horsepower at any point Z, of course, is given simply by:

$$HP_Z = T_Z \times N_Z/5252 \tag{23}$$

where the torque is in lb.-ft. and the speed is in RPM. The engine speed and torque determine a specific fuel rate on the engine map. A typical engine map is shown in Figure 9.

The instantaneous fuel economy in MPG is then computed from:

$$(FE)_f = 0.68\left[V_f/rf\right] * \rho_f \tag{24}$$

where V_f = vehicle velocity (ft/sec)

ρ_f = fuel density (lb/gal)

rf = fuel rate (lb/hr).

The cumulative fuel economy is given by total miles driven divided by total gallons consumed.

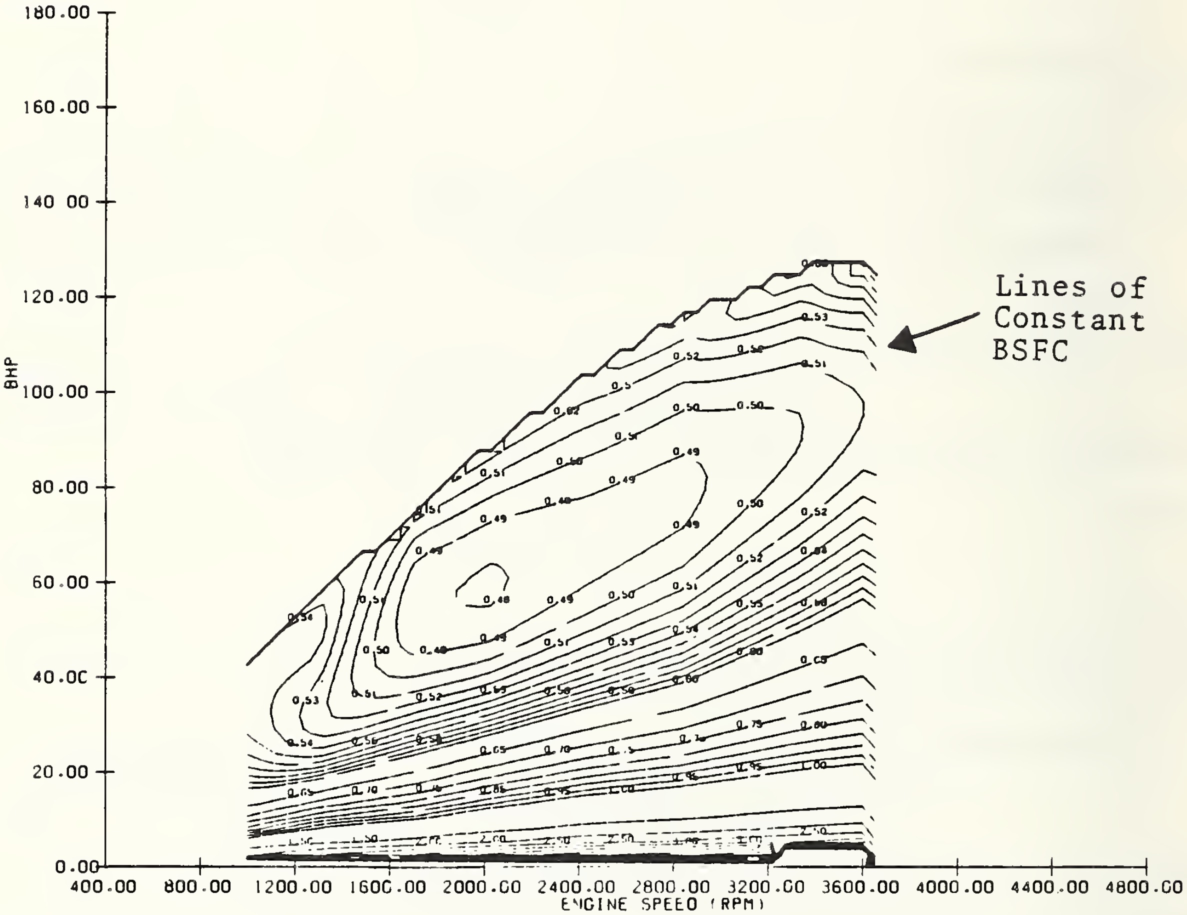


FIGURE 9. ENGINE MAP OF 1978 PONTIAC 301.0 CID-2BBL

3. EFFICIENCY CONSIDERATIONS

The program is most efficient when a large scenario is being executed in such a way as to optimize data retrieval from the disk. For example, a series of *USE commands could be used to "construct" the vehicle to be used initially. Then a sequence of alternating *MODIFY and *SIMULATE commands would allow the user to try ten different vehicle weights with five different rear axle ratios and so forth. This would require no further disk accesses and would accomplish some fifty trials. At that point a different driving schedule could be retrieved from the disk and the process repeated for another fifty trials. If, on the other hand, the user alternated driving schedules for each *MODIFY command, the program would use a great deal more time to retrieve data from disk, and therefore cost more to run.

The default time step of .05 seconds may be overridden with a *MODIFY command to perform the same run with a longer time step to cut cost. (Note: Due to certain tolerances built into the program, a step of less than .05 is not recommended.)

4. ADDITIONAL COMMENTS

In general, whenever VEHSIM needs an interpolated data point which is beyond the actual table or map provided, the program uses the last two points to project the rest of the curve as a straight line approximation. The user, therefore, should ensure that the last two (or first two) values in a table "point" in the right direction. There are exceptions to the rule, e.g., the speed ratio of the drive converter is never allowed to exceed unity or be less than zero. If, however, the user wishes to ensure that this number never goes beyond .98, for example, he should add an extra data point onto the high RPM end of the table which would project this constant value beyond the range he has already specified.

In particular, the engine map data projections to higher or lower speed points are potentially crucial to achieving reliable results. Since the engine map is the single most important piece of data for the model, great care should be taken by the user to ensure that these data are complete, especially at the "low end" if urban stop-and-go driving schedules are to be used. Note that a "motoring" torque at each speed should be provided if available. However, if idle speed is less than the minimum speed curve given by the map, the extrapolation down to idle may give undesired results. For example, if an engine motors at -10. lb.-ft. at 1600 RPM and -2. lb.-ft at 1200 RPM, and the idle is set to 800 RPM, the motoring torque at idle would project to +6. lb.-ft. which may be too large and could result in an exorbitant figure for the HP-HR produced by the engine. In this case, the *MODIFY command (see Volume II) could be used to reset the idle, or more data could be input between 1200 and 800 RPM.

One further note should be made concerning engine data. The engine map should contain throttle angle settings; however, since calibration settings differ between test facilities and since percent WOT is such a critical figure for much of the control logic for the model, the actual throttle angles are not used to compute percent WOT. Instead, the maximum and minimum torques at each speed setting are defined to be 100 percent and 0 percent WOT respectively. Therefore, if the 2200 RPM setting motors at -30.lb.-ft. and has a maximum of 170. lb.-ft., VEHSIM would compute 50 percent WOT for this speed to be 70. lb.-ft. (i.e. halfway between -30. and 170.) Since many driving schedules specify segments according to percent WOT, and since shift logic may depend on percent WOT as well, the user should ensure that the motoring torques are included in the engine map, even though for a particular driving schedule the engine may not actually be "operating" in the low torque range.

When specifying driving schedule data, care must be exercised to prevent too sudden of an acceleration change. This can be accomplished by adding a zero acceleration segment between two radically different accelerations that change sign. This has the effect of rounding off the peaks and valleys of sequential acceleration segments in a driving schedule that would be too demanding and unrealistic.

The shift logic input data is similar in format to that typically used by manufacturers to specify transmission shift points. Engine load (vacuum or percent throttle) and speed (vehicle MPH or engine RPM) points are specified in such a manner that a shift line is established to signal either an upshift or downshift for each gear.

Typically, during simulations the gear upshifts are executed under conditions of increasing vehicle speed and little change in percent throttle (or vacuum). Downshifts into lower gears are normally performed under increased load conditions (decreased vacuum) at a nearly constant vehicle speed upon demand for acceleration. The large decrease in vacuum results in a downshift. Should the shift logic be biased to downshift unnecessarily by an extreme sensitivity to vacuum decrease, the downshift may be followed by an upshift in the next iteration cycle. This pattern of shifting may continue throughout a drive cycle segment and result in an unusually large number of shifts.

In developing a shift logic, in view of the above possibility, it is recommended that downshift lines be specified at vehicle speeds (holding vacuum or throttle constant) no greater than 80 percent of the upshift speed for the gear change considered.

The VEHSIM output record provides shift frequency data which may be used as an aid in determining the validity of the shift logic. Additionally, this shift "stutter" problem may be suspected should the output record indicate total engine horsepower-hours significantly greater or less than a few percent of one hundred. When this condition occurs, the user should check the number of shifts being performed, and modify the shift logic if this number seems high by separating the shift lines more, particularly on the wide-open throttle end (low vacuum).

5. PROGRAM ORGANIZATION

The general overview of data flow within VEHSIM is displayed in Figure 10.* In this illustration, "VEHSIM Processing" is organized as a system of subroutines. The subroutines involved immediately and distantly in the simulation process are presented in Figure 11. The functions performed by these subroutines are presented in Table 2.*

The main simulation subroutine is SIMCTR. It incorporates operations necessary to follow the given drive schedule and shift logic. Accordingly, in a process of simulation, the named subroutine periodically refers to GOBACK subroutine, which incorporates dynamics equations, and to SHIFTS subroutine. The GOBACK subroutine calls to ENGINE subroutine. Other subroutines in Figure 11 serve the ones named above.

Additional subroutines developed to extend capabilities of VEHISM are described in Volume IV, and will be included in Volume V to be published at a later date.

Appendix A contains Logic Flow charts for important simulation and utility subroutines. The cross reference list of the VEHSIM subroutines is included in Appendix B. Subroutine names in alphabetical order are incorporated into column "Symbol."

The subroutines which call to the given subroutine (named in column "Symbol") are identified in column "Referenced in."

*Agarwal, B., "Documentation of VEHSIM," Automated Sciences Group, Inc., Silver Springs MD, March 4, 1980.

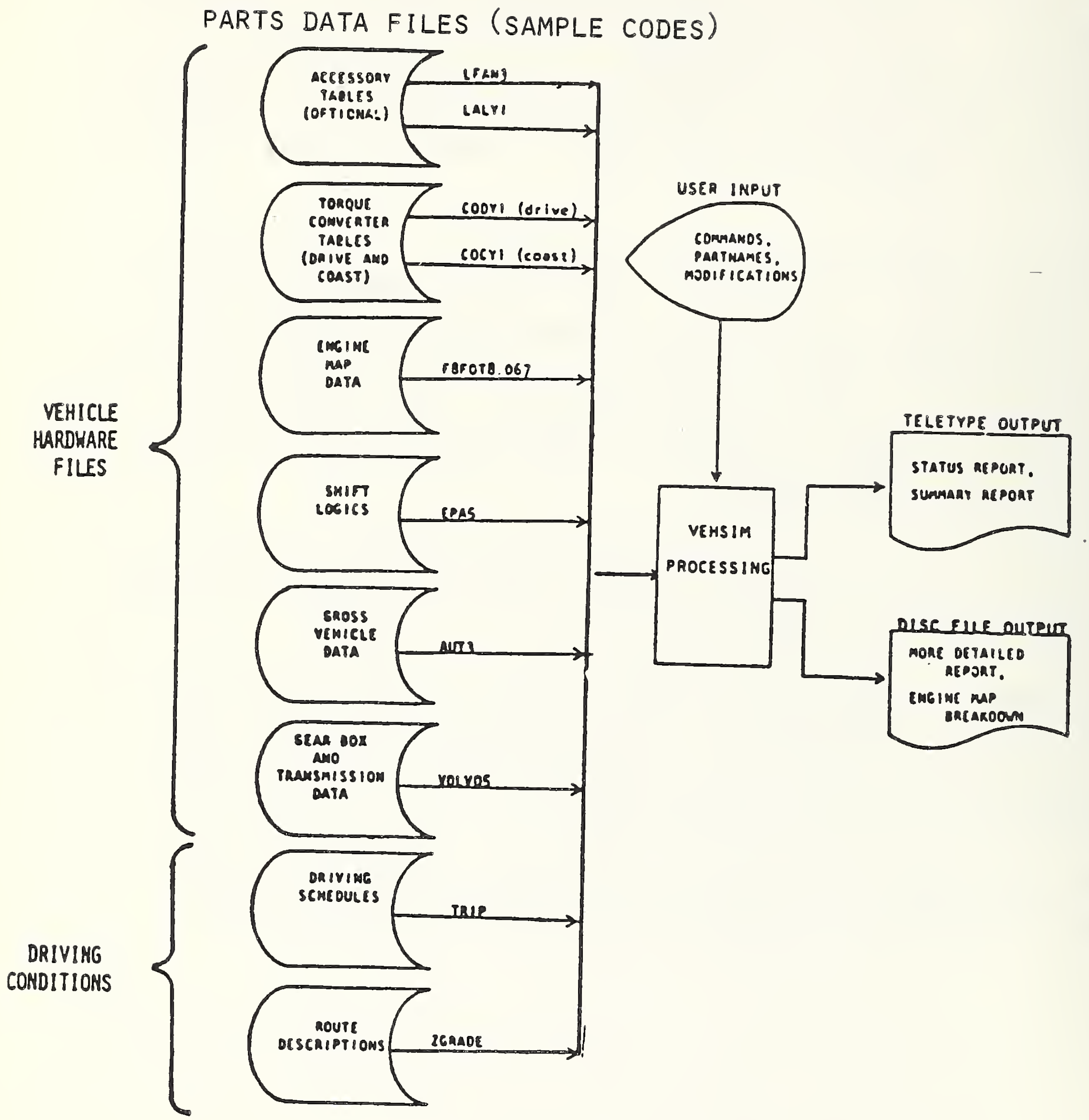


FIGURE 10. VEHSIM DATA FLOW

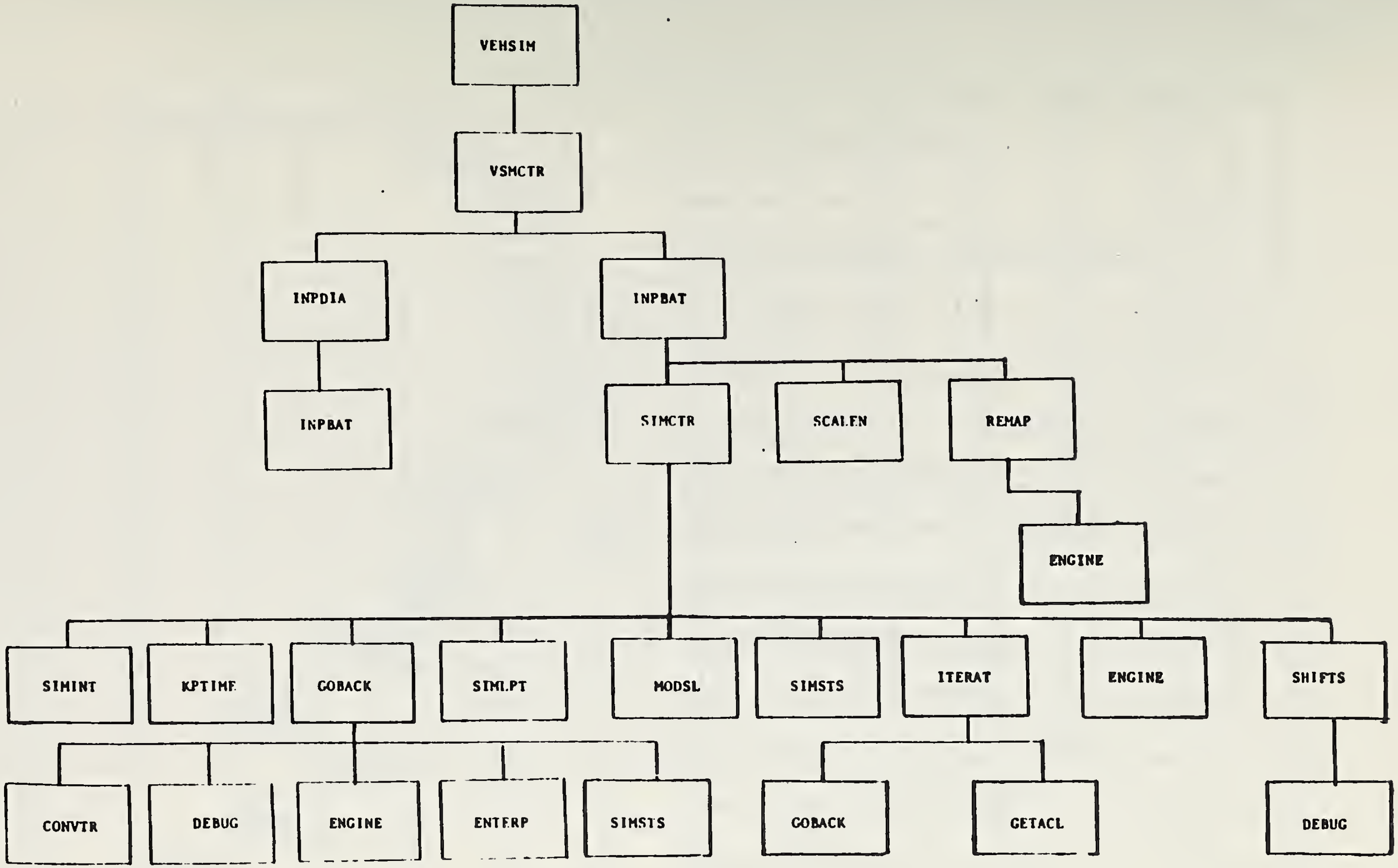


FIGURE 11. SUBROUTINES OF VEHSIM

TABLE 2. FUNCTIONS PERFORMED BY VEHSIM SIMULATION SUBROUTINES

1	2	3	4	5	6	7	8	9	10	11	12	13
VEHSIM (90)							Vehicle Simulation Main Program in MACRO					
	VSMCTR (277)						Vehicle Simulation Control Program					
		INPDIA (712)					Input Dialogue Processing Routine					
			INPBAT				Command Processing Section of "INBAT"					
		INPBAT (1952)					Batch and Command Processing					
			SIMCTR (1181)				Simulation Processing					
				SIMINT (286)			Simulation Initialization					
				KPTME (25)			Keep Count of Time Spent in Simulation					
				GOBACK (221)			Main Engineering Routine					
					CONVTR (94)		Converter Routine					
					DEBUG (96)		Debug Routine					
					ENGINE (196)		Engine Mapping Routine					
					ENTERP		Interpolation Routine					
					SIMSTS (117)		Simulation Status Processing					
				SIMLPT (565)			Simulation Printout Routine					

TABLE 2. FUNCTIONS PERFORMED BY VEHSIM SIMULATION SUBROUTINES (CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13
				MODSL (82)				Modify Shift Logic				
				SIMSTS 2								
				ITERAT (116)				Iterate to Desired Velocity				
					GOBACK 2							
					GETALL (86)			Get Acceleration				
				ENGINE 2								
				SHIFTS (126)				Shift Processing				
					DEBUG 2							
			SCALEN (93)					Scale Engine Map				
			REMAP (139)					Unit Conversion				
				ENGINE 3								

6. SIMULATION COMPARISON

In addition to TSC's VEHSIM, there are various vehicle simulation programs* which most likely use identical techniques in modeling vehicle fuel economy. A comparison of the results of the programs is difficult to make since access to these programs is very limited. However, through the courtesy of Mr. Doug Lewis of General Motors Engineering Staff a comparison was performed between VEHSIM and GM's General Purpose Automotive Vehicle Performance and Economy Simulation (GPSIM).

In order to compare the two simulation programs, VEHSIM and GPSIM, simulations with identical input data were performed. A Chevrolet Citation with a GM-mapped 2.8 liter engine, four speed manual, and simulated accessory loading was run over the EPA urban and highway schedules and performance schedules.

The GPSIM program was run at Mitre Corporation on an IBM 370 computer, while the VEHSIM program was run on a DEC System-10 computer at TSC.

The results of the simulations are shown in Table 3. The difference in the composite fuel economy is 1 percent and the difference in 0-60 mph is 3.8 percent. Other evaluation criteria and percent differences are also presented in Table 3. Because the input data is identical for each program, the discrepancy between the results is attributed to numerical methods associated with the fuel economy and performance calculations. Without access to the GPSIM source code, a comparison of the programming modeling techniques cannot be made; however, the results indicate the programs correlate well.

*Waters, William C., "General Purpose Automotive Vehicle Performance and Economy Simulation," SAE Paper 720043, February 1972.
*Hwang, David N., "Fundamental Parameters of Vehicle Fuel Economy and Acceleration," SAE Paper 690541, October 1968.

The largest difference between the results of the two programs occurs in the acceleration profiles. This can be explained by examining when the gear shift occurs and its duration. The shift from 2-3 occurs at 58 mph which affects the 0-60 mph time. Before this shift, the two acceleration profiles were relatively close as indicated by the 0-50 mph times. The shift time is a greater precent of the 0-60 mph time than the 0-50 mph time, thereby affecting the 0-60 mph time to a greater extent. This is substantiated by the 1/4 mile time. The 1/4 mile times are relatively close because the vehicle remains in 3rd gear at the 1/4 mile time in this case. In conclusion, the acceleration profiles are a function of many variables including the shift mechanism and time. If the shift mechanism of both programs were identical, then the shift times would most likely be closer to each other subsequently making the acceleration times more accurate.

TABLE 3. TSC VEHSIM AND GM GPSIM SIMULATION COMPARISON USING IDENTICAL VEHICLE DATA

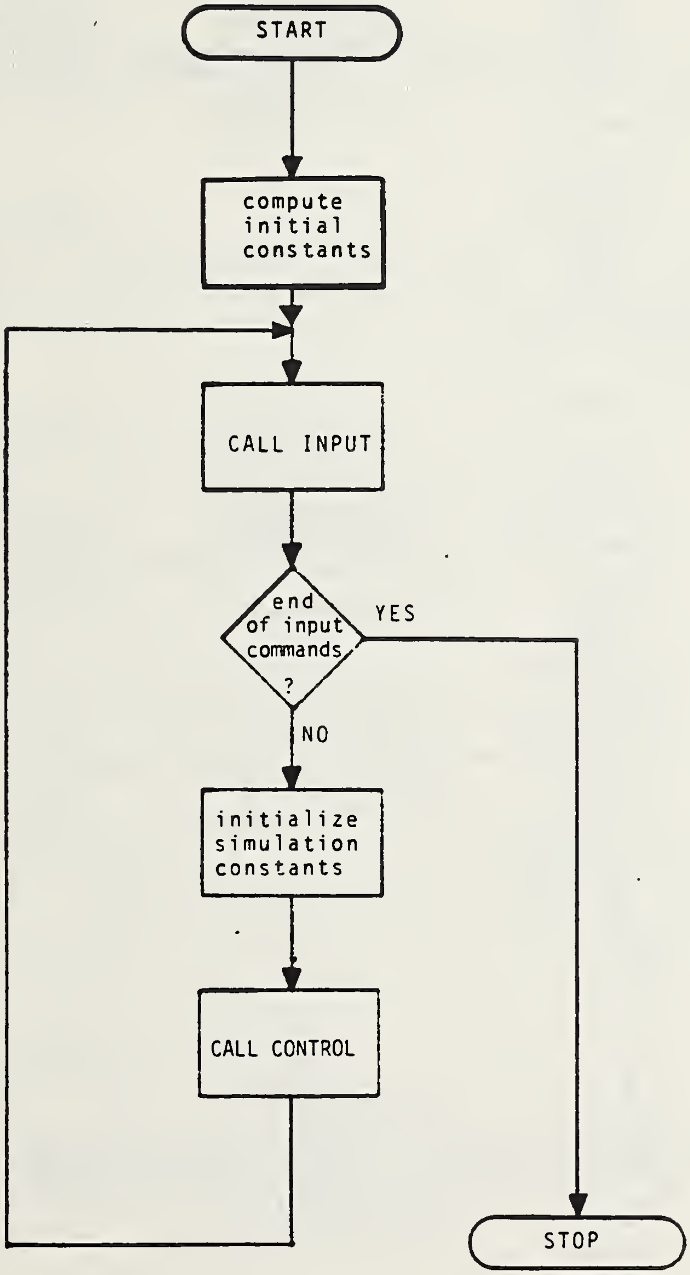
CRITERIA	VEHSIM	GPSIM	%Δ
Fuel Economy			
Highway (MPG)	34.60	34.41	0.55
Urban (MPG)	23.43	23.13	1.28
Composite (MPG)	27.41	27.14	0.98
Top Speed			
@ 4500 RPM (MPH)	117.6	117.6	0.0
55 mph (WOT)			
Acceleration (g)	.160	.159	0.63
Engine Power (hp)	89.04	88.82	0.25
Torque (lb-ft)	145.0	144.8	0.14
Acceleration			
0-50 mph (sec)	7.24	7.40	2.21
0-60 mph (sec)	10.40	10.80	3.84
1/4 mile (sec)	17.60	17.80	1.13
Gradeability			
5 mph (%G)	51.5	52.6	2.06
25 mph (%G)	57.8	56.6	2.08
55 mph (%G)	16.6	16.6	0.0

APPENDIX A

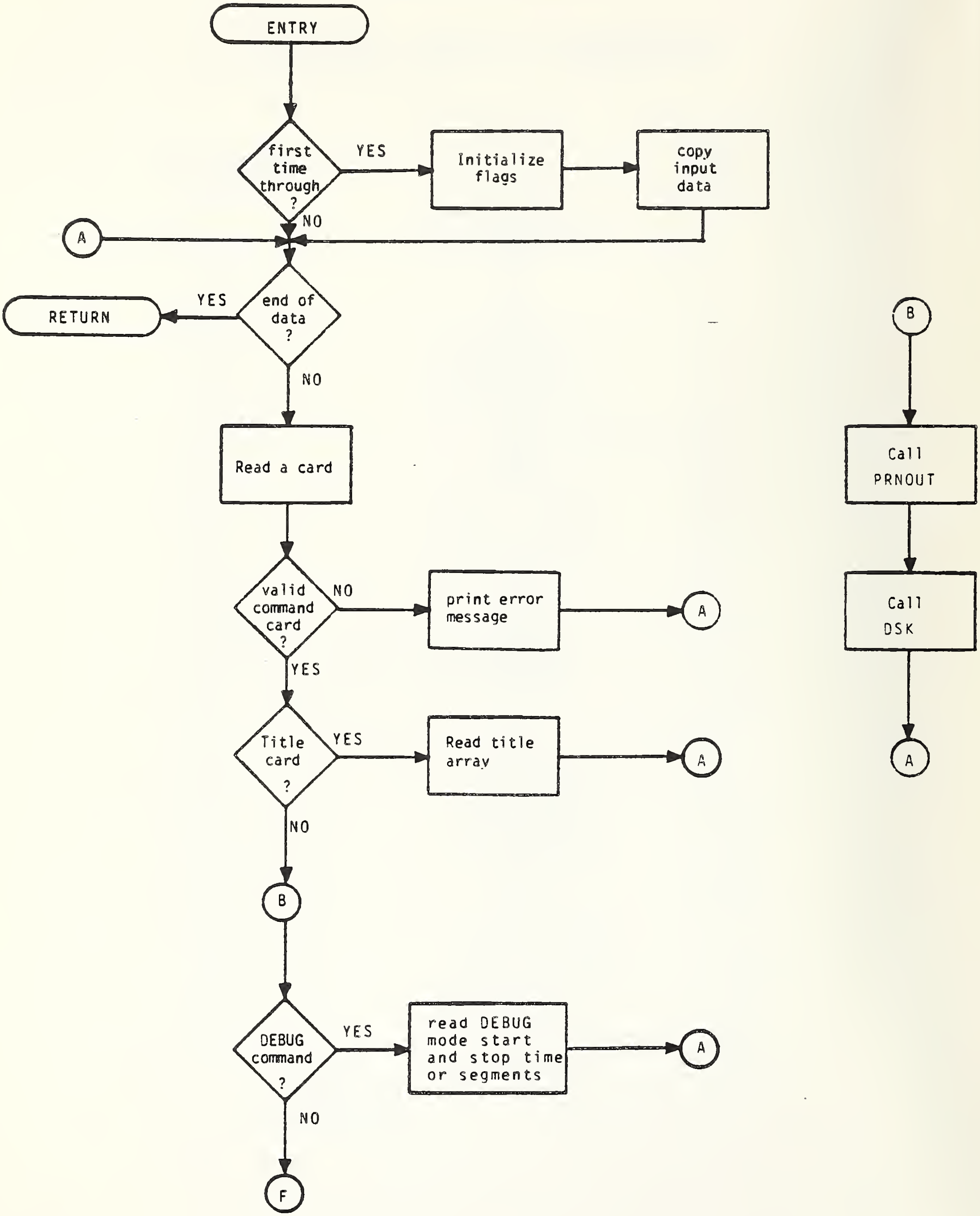
FLOW LOGIC

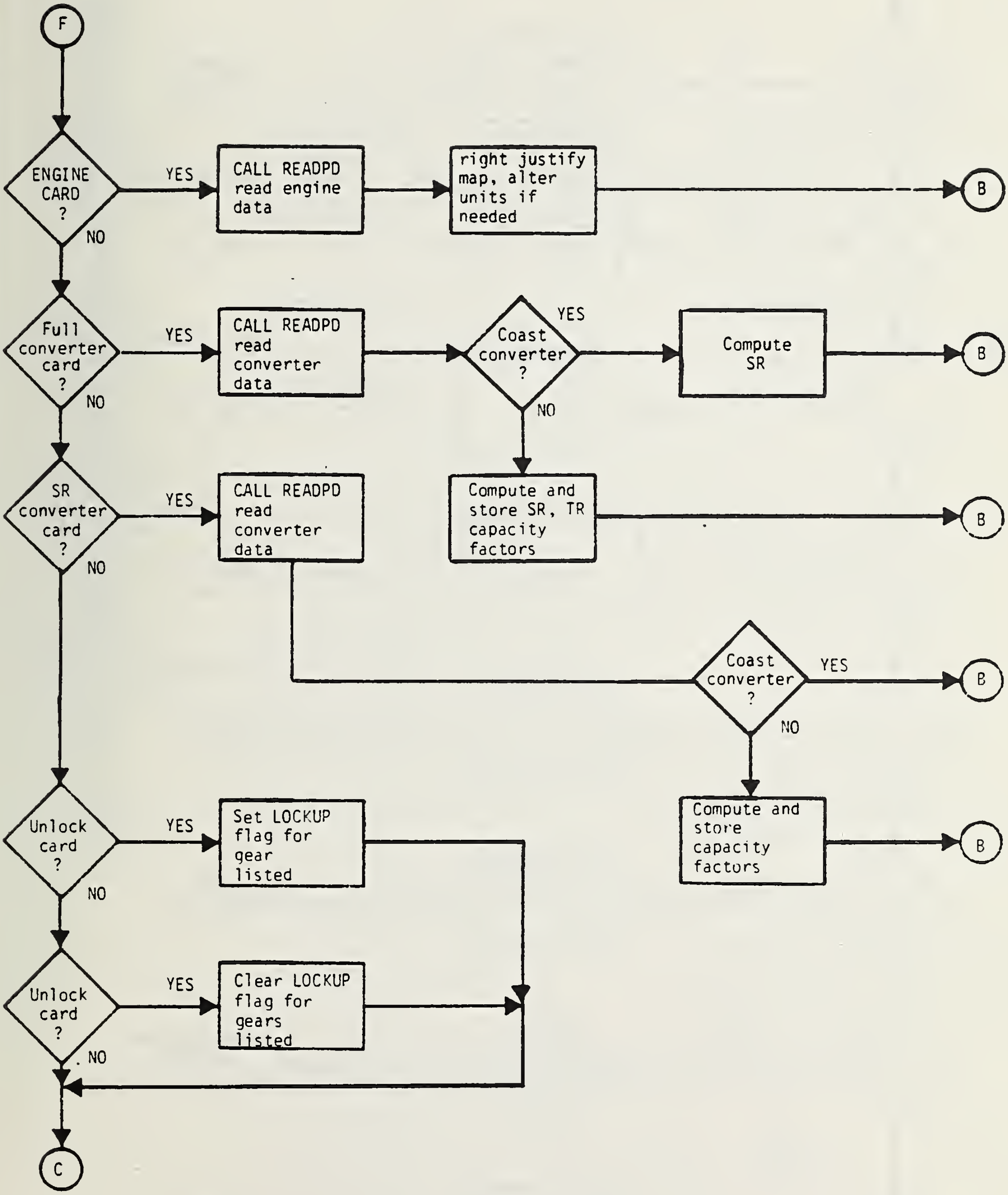
CROSSREFERENCE LISTING OF SUBROUTINES

SUBROUTINE SIMINT

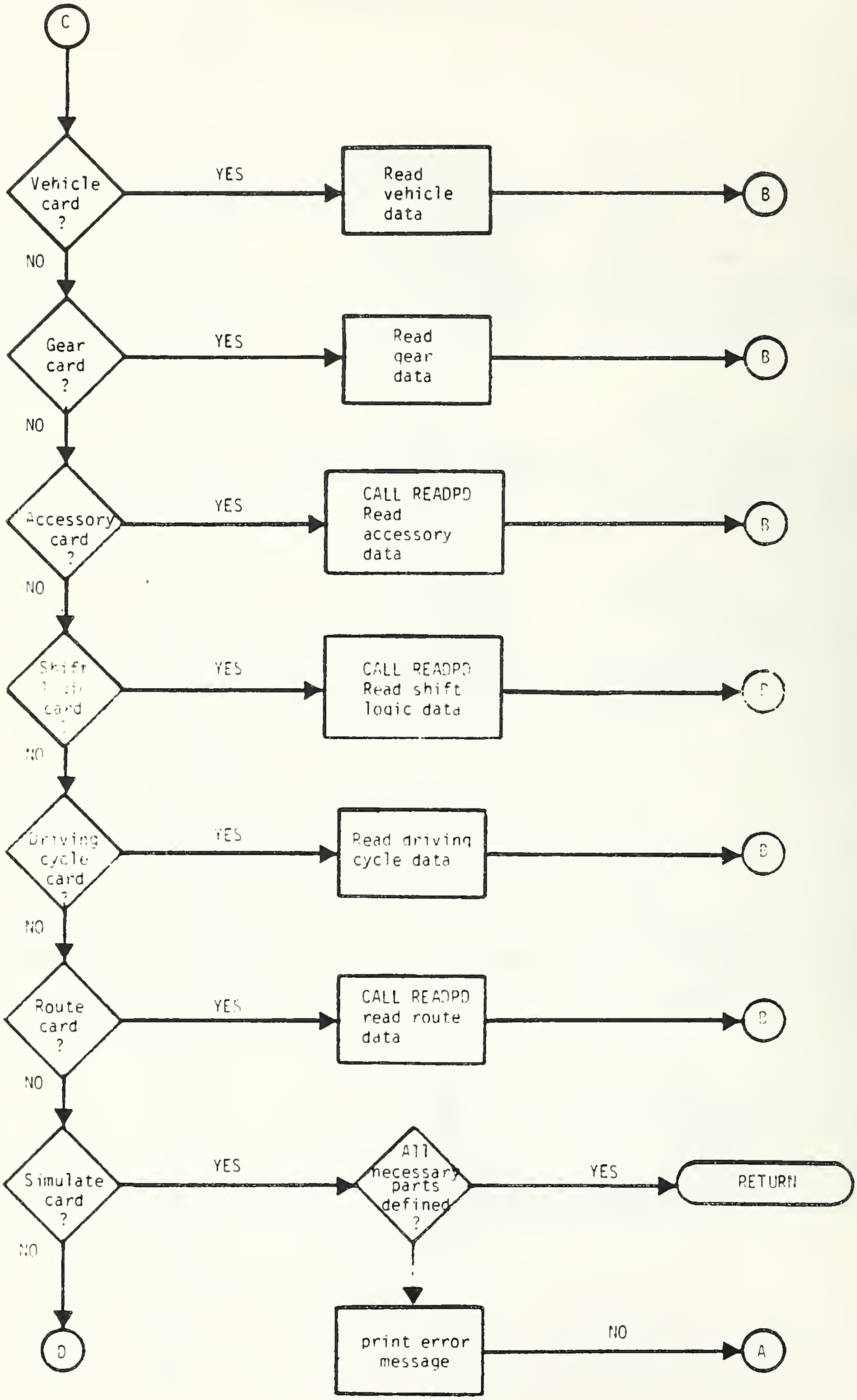


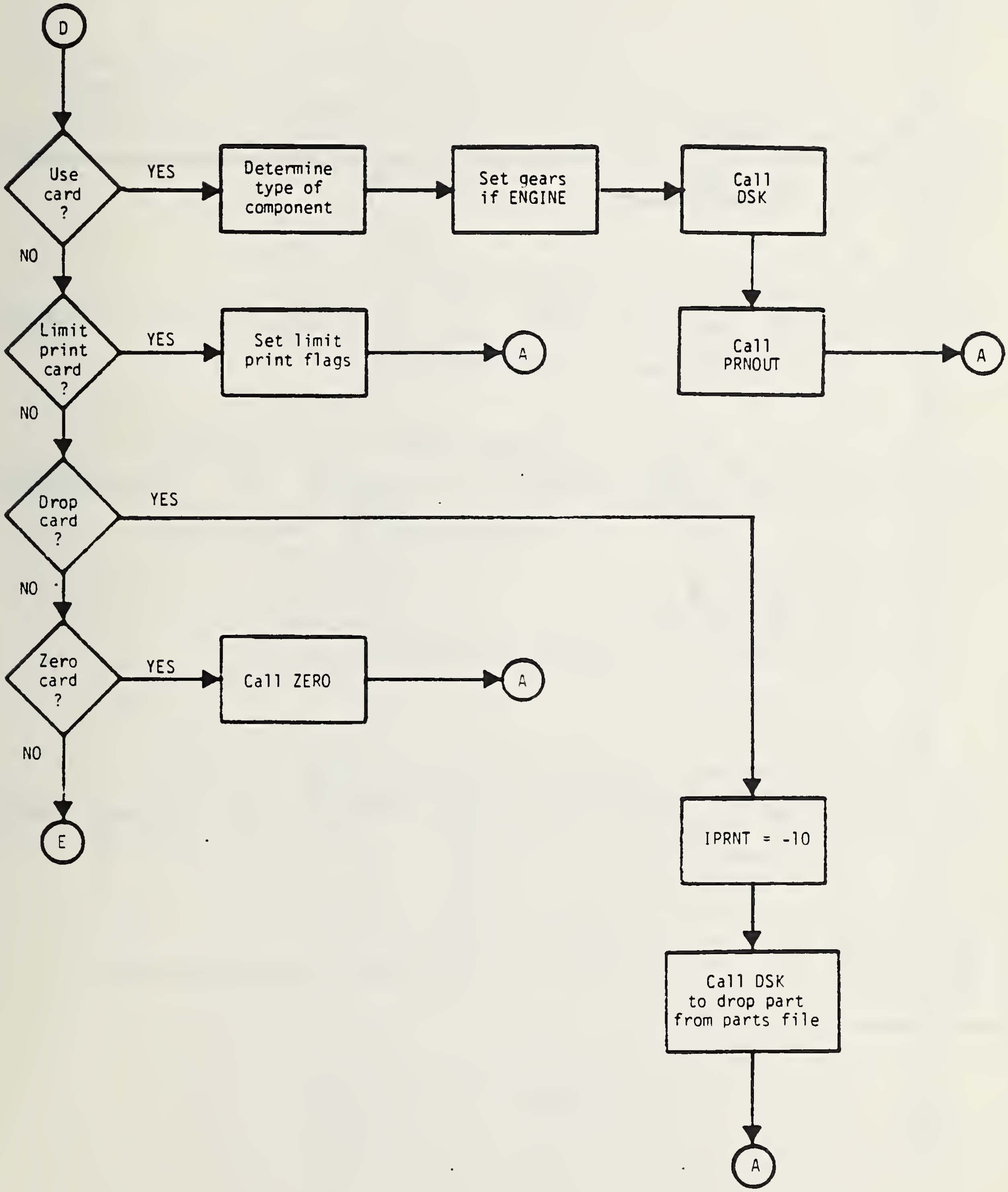
SUBROUTINE INPBAT

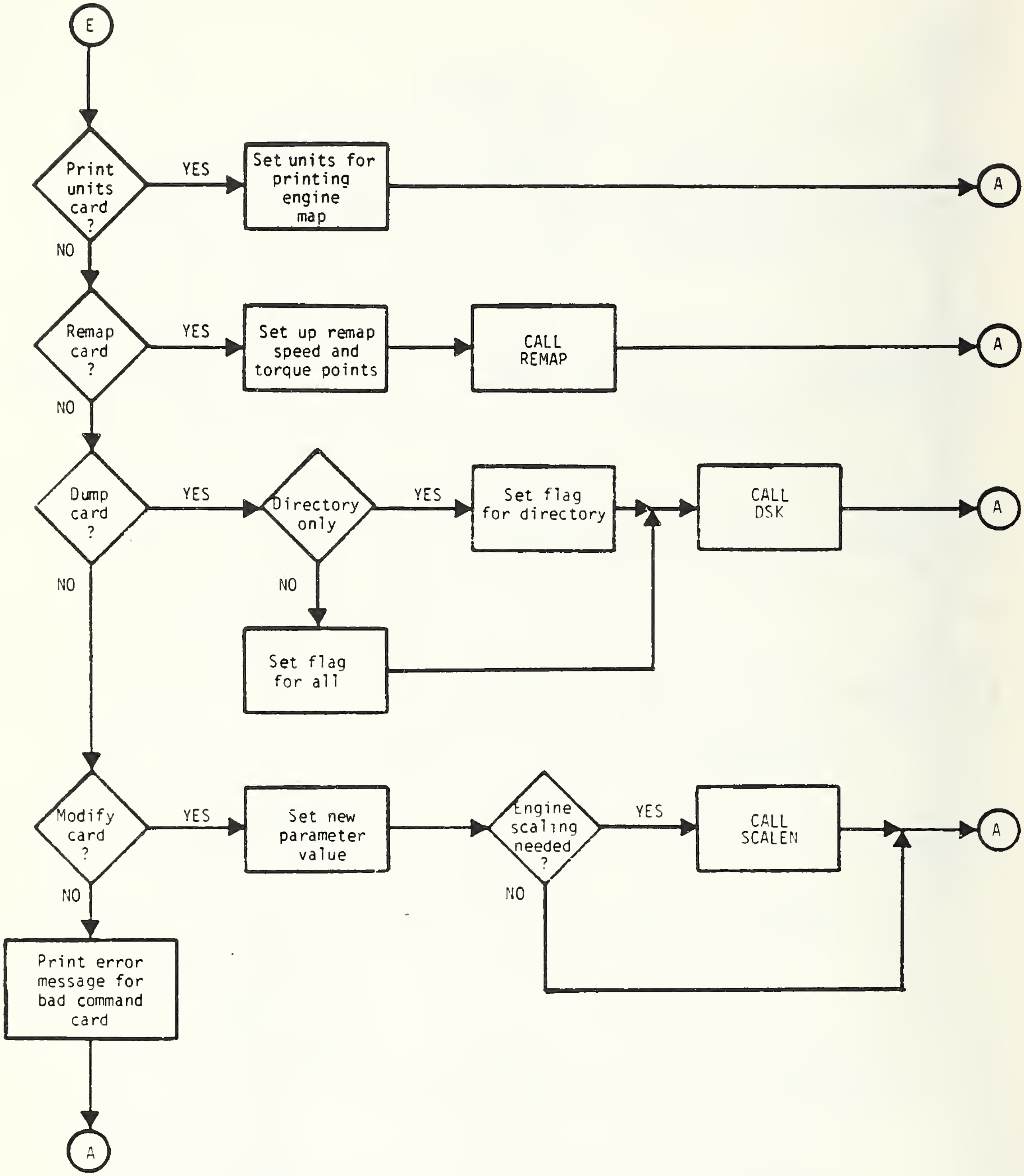



F
ENGINE CARD ?
YES
NO
CALL READPD read engine data
right justify map, alter units if needed
B
Full converter card ?
YES
NO
CALL READPD read converter data
Coast converter ?
YES
NO
Compute SR
B
SR converter card ?
YES
NO
CALL READPD read converter data
Compute and store SR, TR capacity factors
B
Coast converter ?
YES
NO
B
Compute and store capacity factors
B
Unlock card ?
YES
NO
Set LOCKUP flag for gear listed
Unlock card ?
YES
NO
Clear LOCKUP flag for gears listed
C

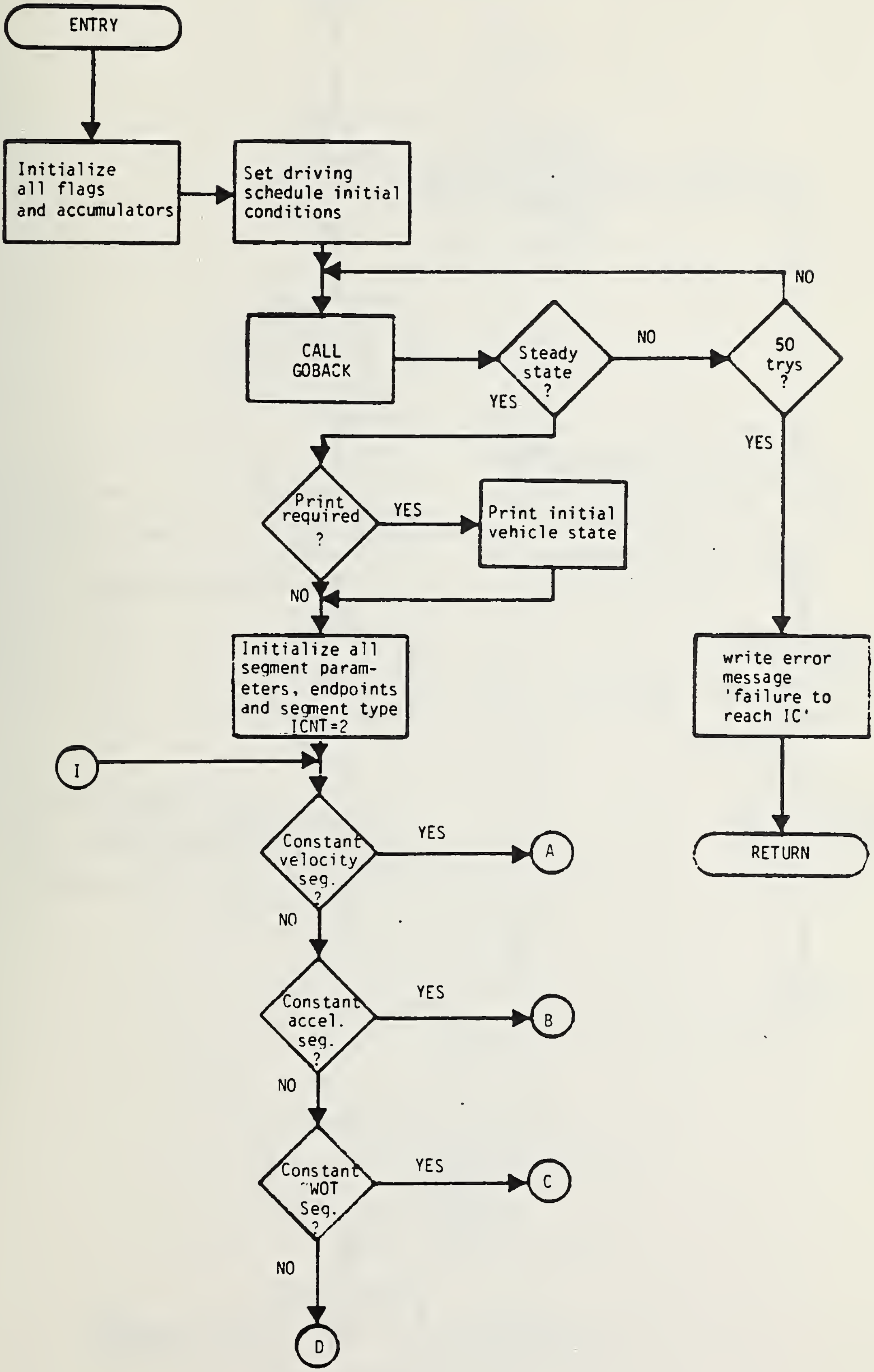
INPBAT (CONTINUED)



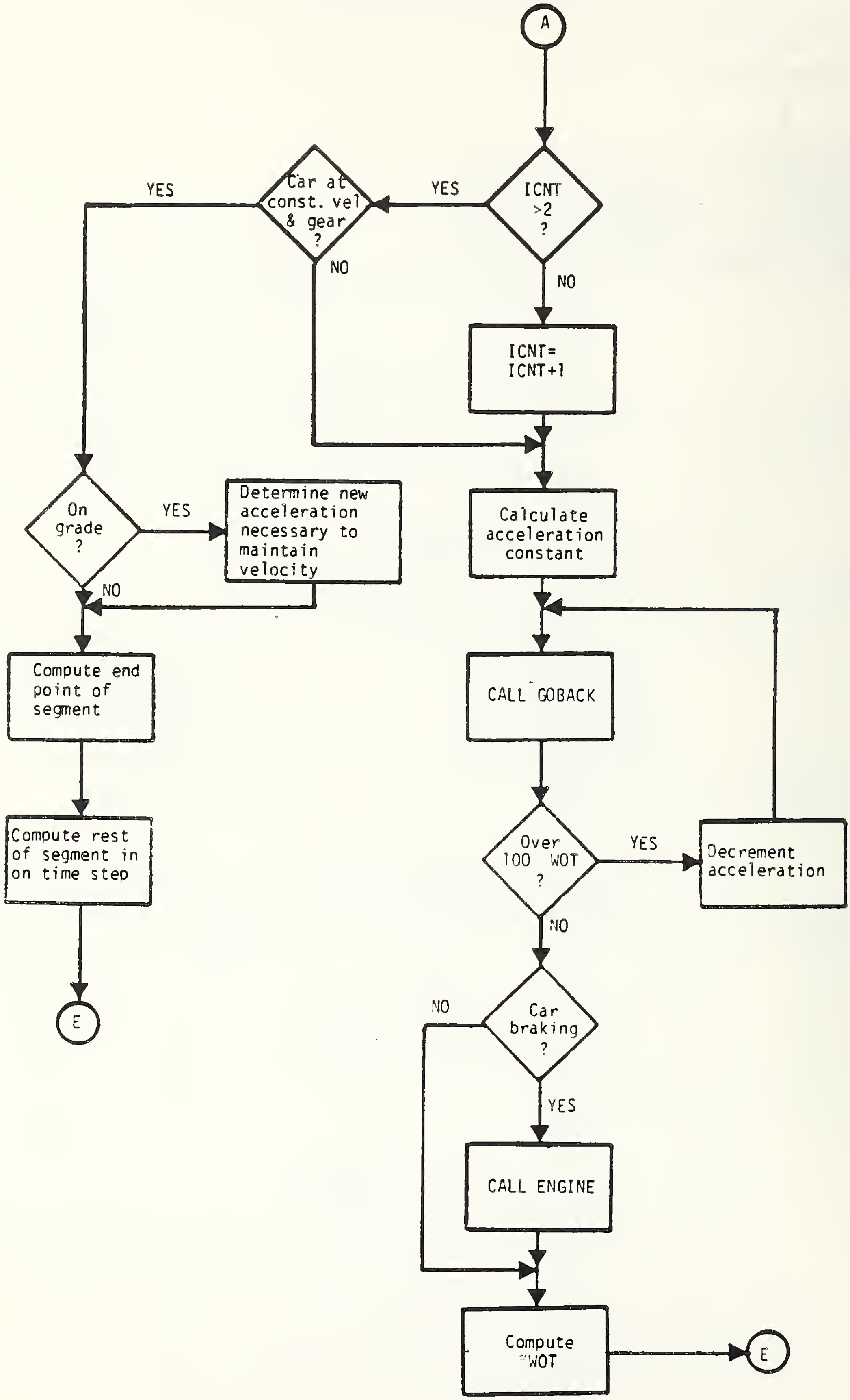

D
Use card ?
YES
NO
Determine type of component
Set gears if ENGINE
Call DSK
Call PRNOUT
A
Limit print card ?
YES
NO
Set limit print flags
A
Drop card ?
YES
NO
IPRNT = -10
Call DSK to drop part from parts file
A
Zero card ?
YES
NO
Call ZERO
A
E


E
Print units card ?
YES
NO
Set units for printing engine map
A
Remap card ?
YES
NO
Set up remap speed and torque points
CALL REMAP
A
Dump card ?
YES
NO
Directory only
YES
NO
Set flag for directory
CALL DSK
A
Set flag for all
Modify card ?
YES
NO
Set new parameter value
Engine scaling needed ?
YES
NO
CALL SCALEN
A
Print error message for bad command card
A

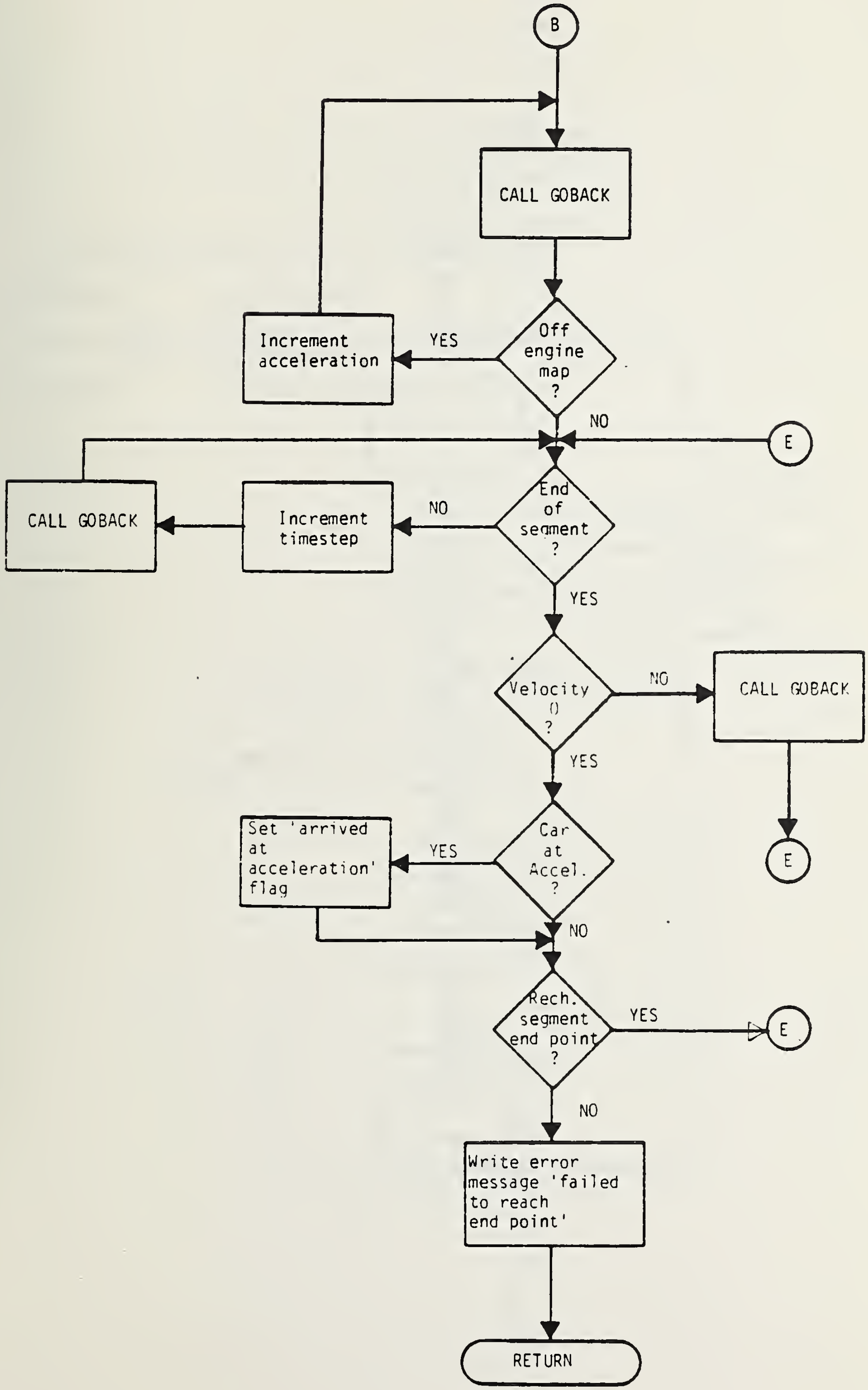
SUBROUTINE SIMCTR



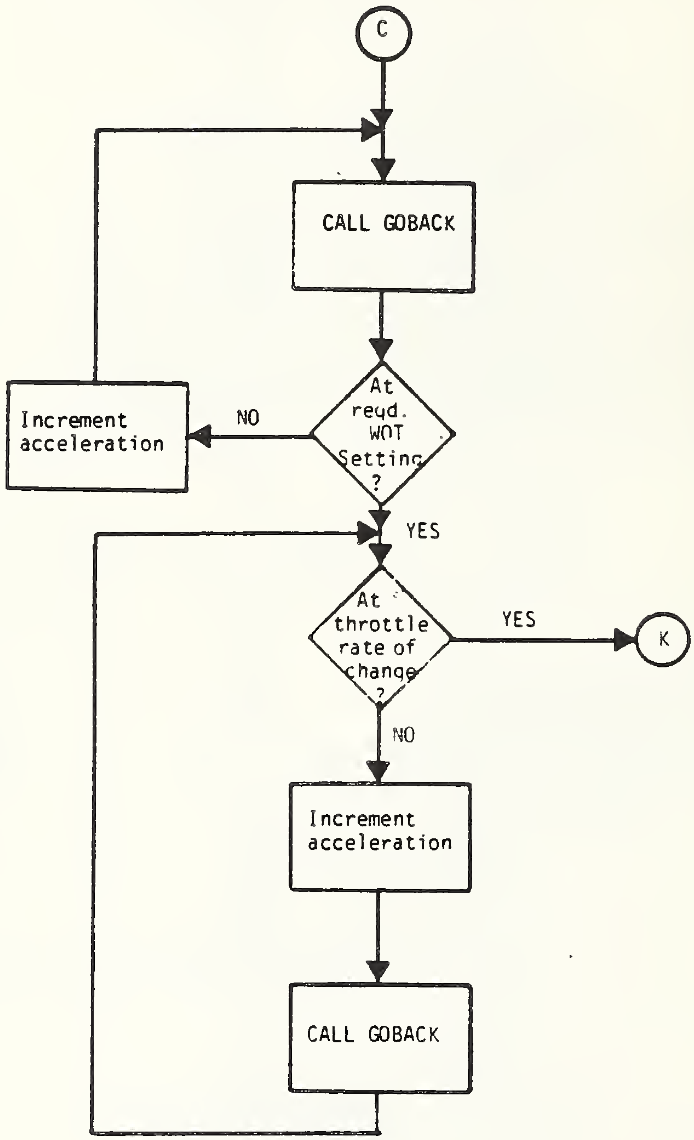
SIMCTR (CONTINUED)



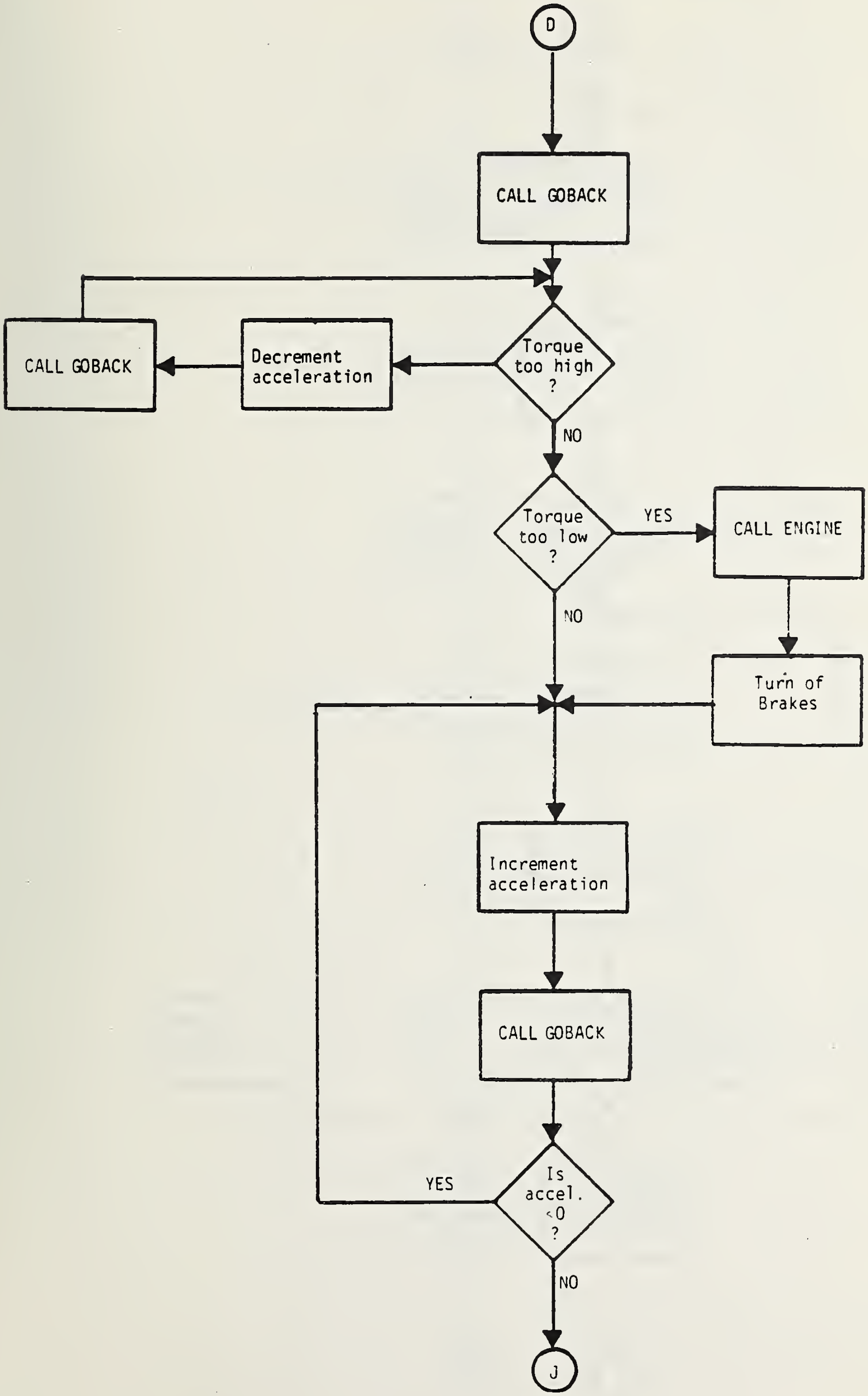
SIMCTR (CONTINUED)



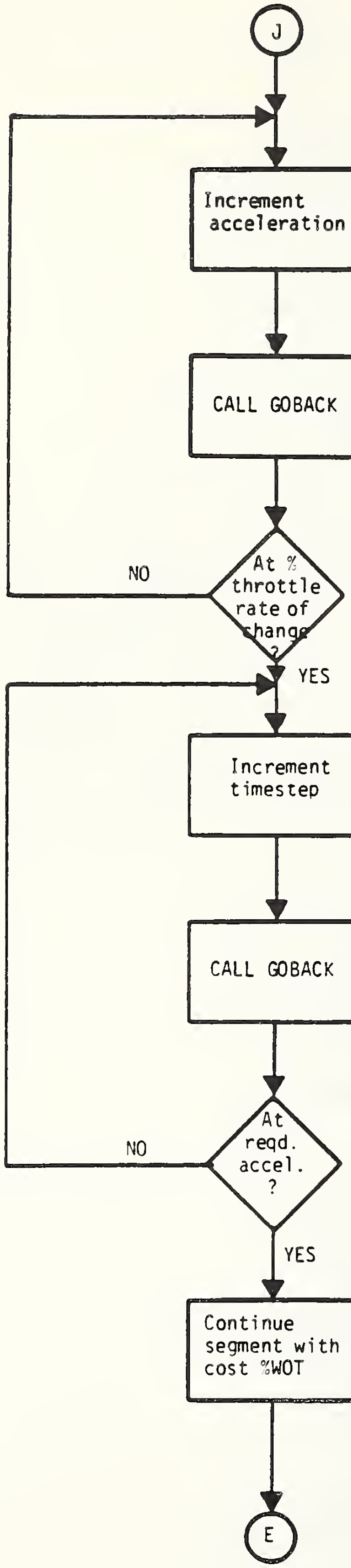
SIMCTR (CONTINUED)

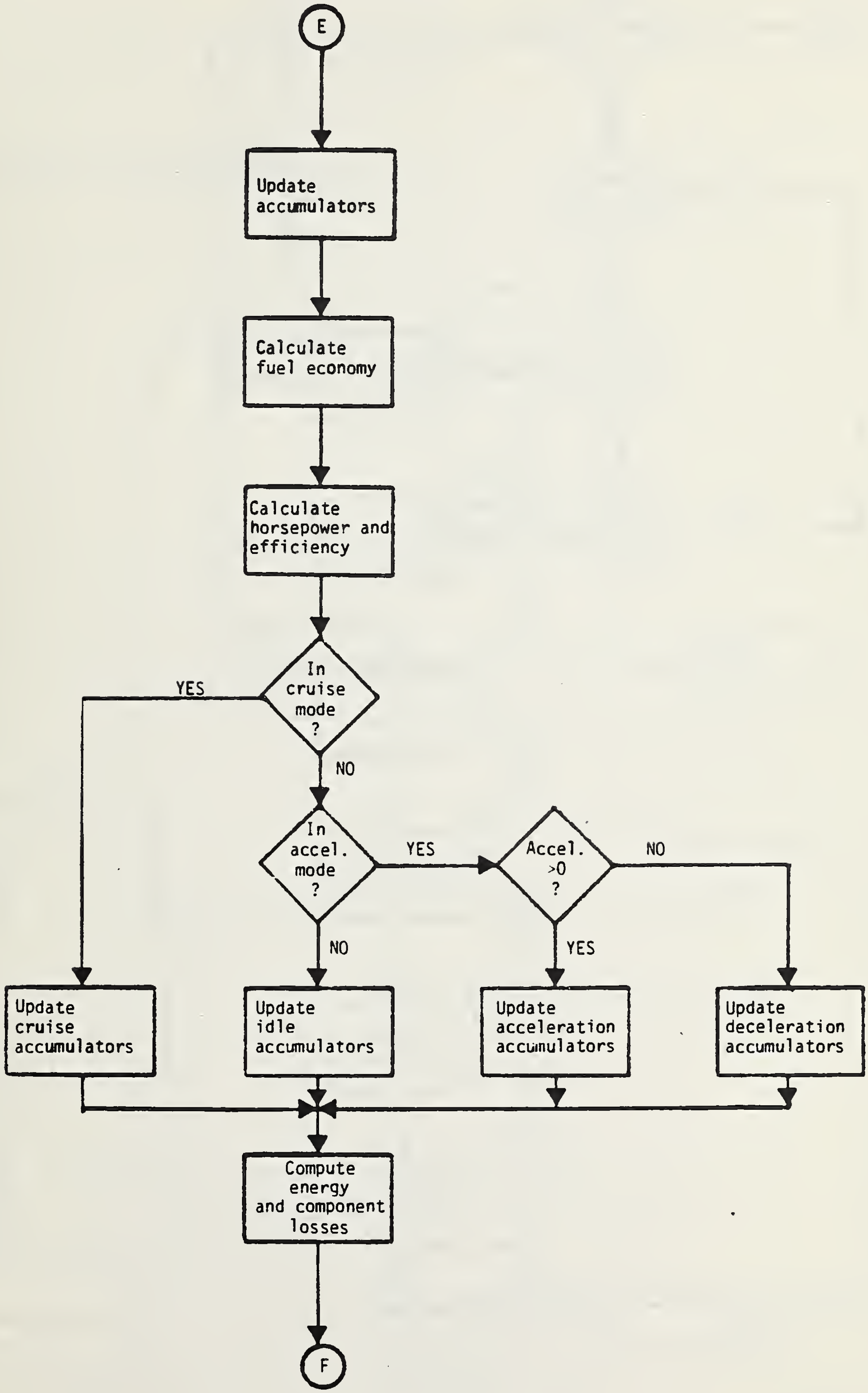


SIMCTR (CONTINUED)

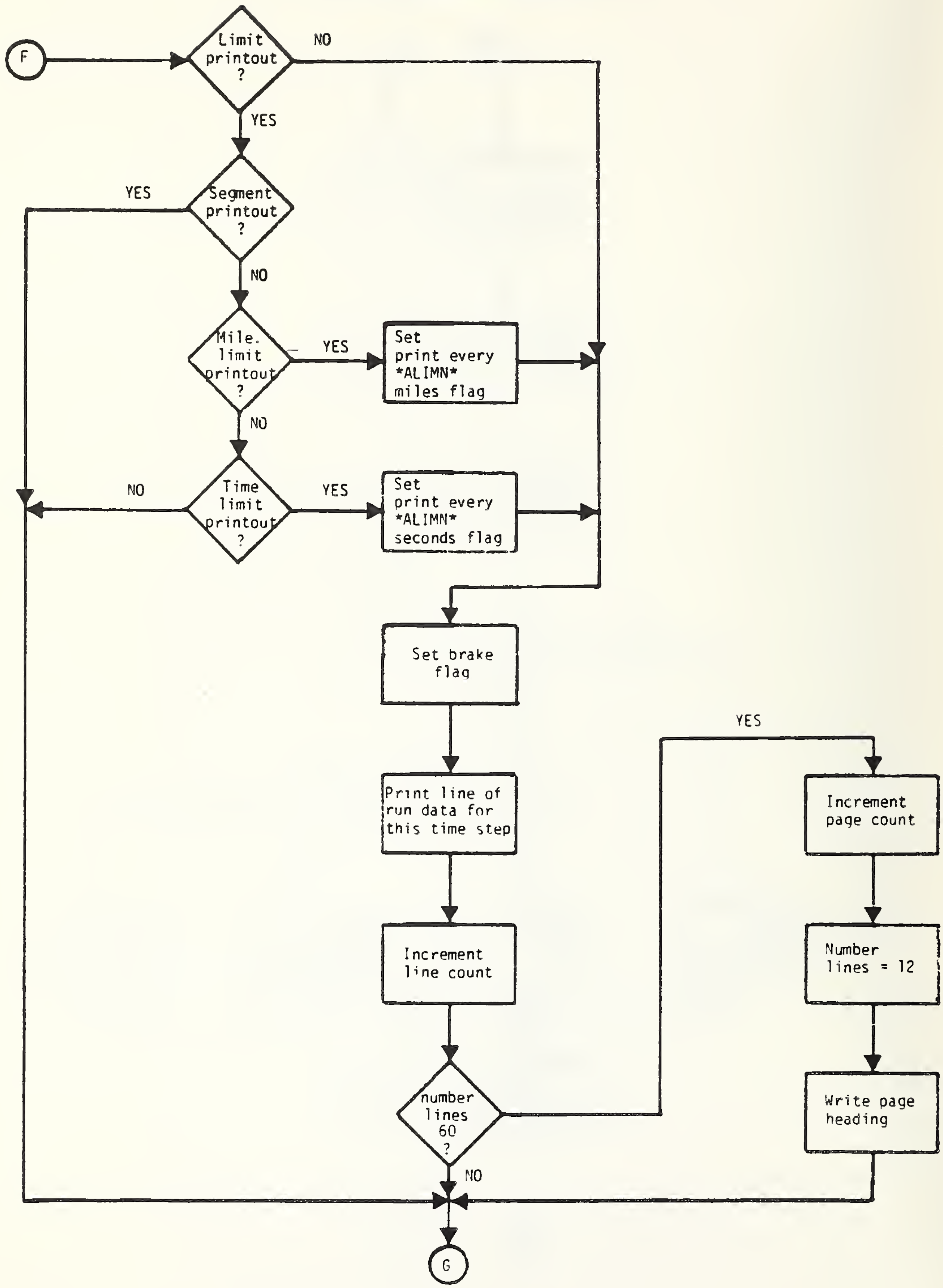


SIMCTR (CONTINUED)

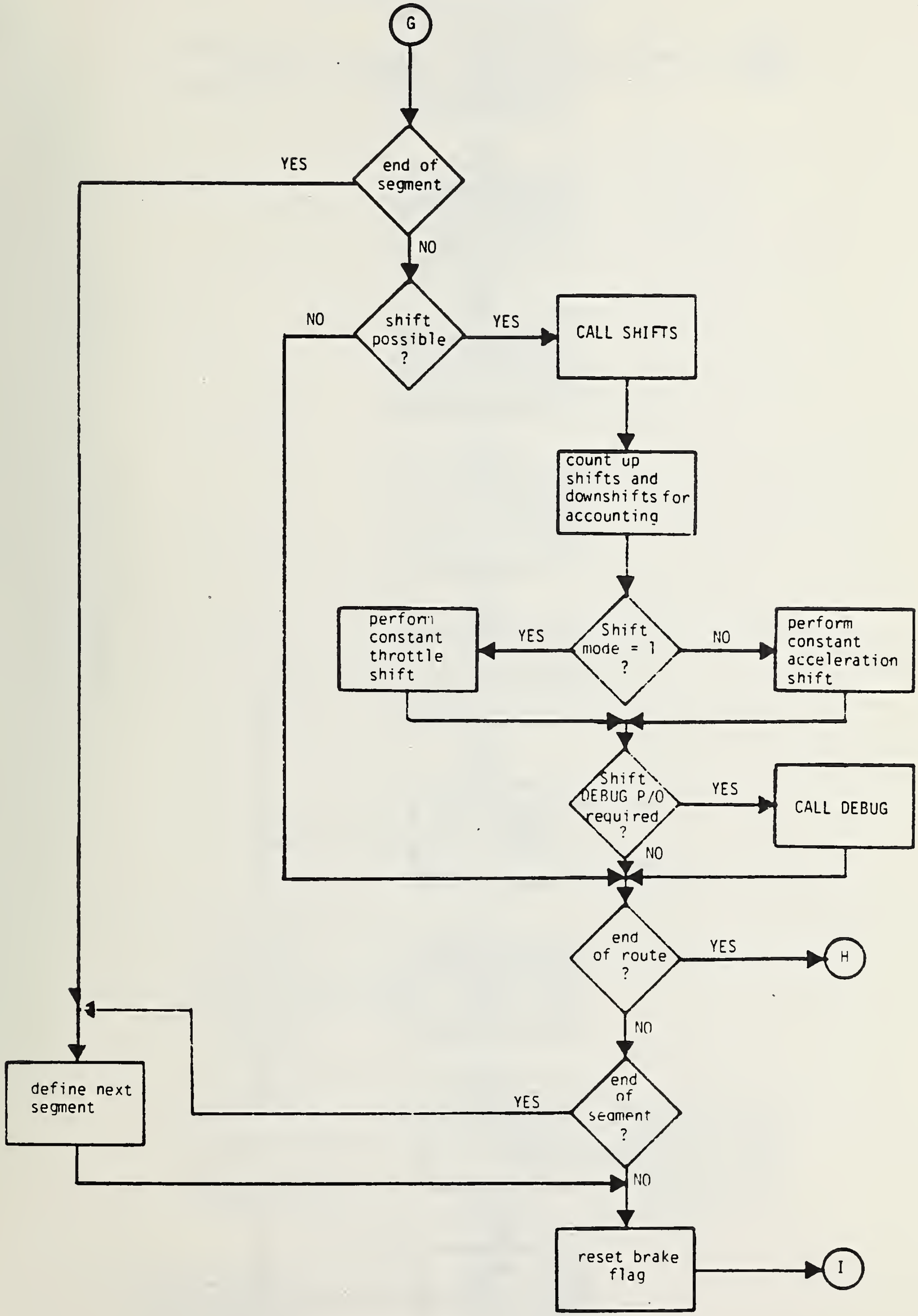


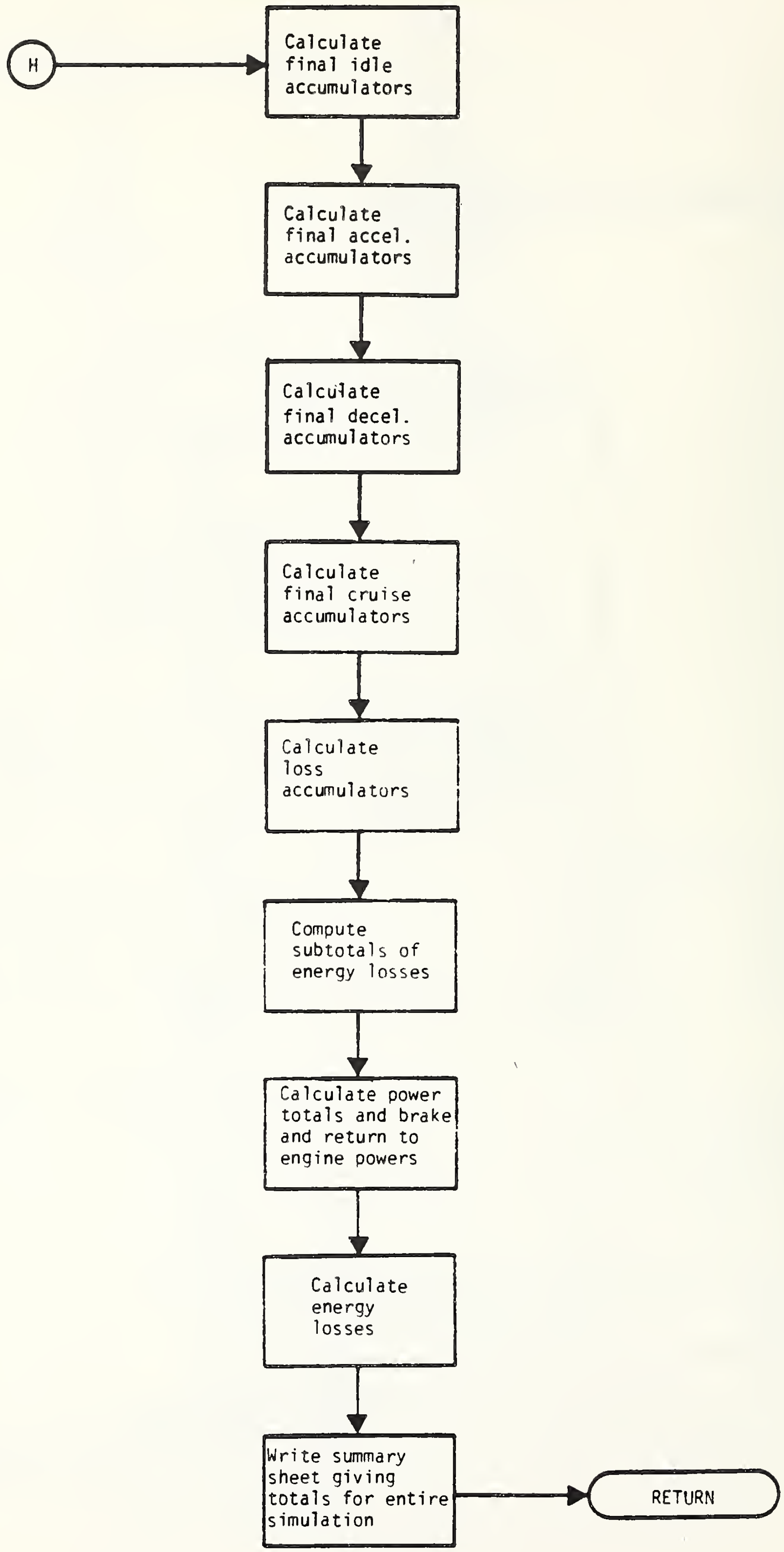

E
Update accumulators
Calculate fuel economy
Calculate horsepower and efficiency
In cruise mode ?
YES
NO
In accel. mode ?
YES
NO
Accel. >0 ?
NO
YES
Update cruise accumulators
Update idle accumulators
Update acceleration accumulators
Update deceleration accumulators
Compute energy and component losses
F

SIMCTR (CONTINUED)

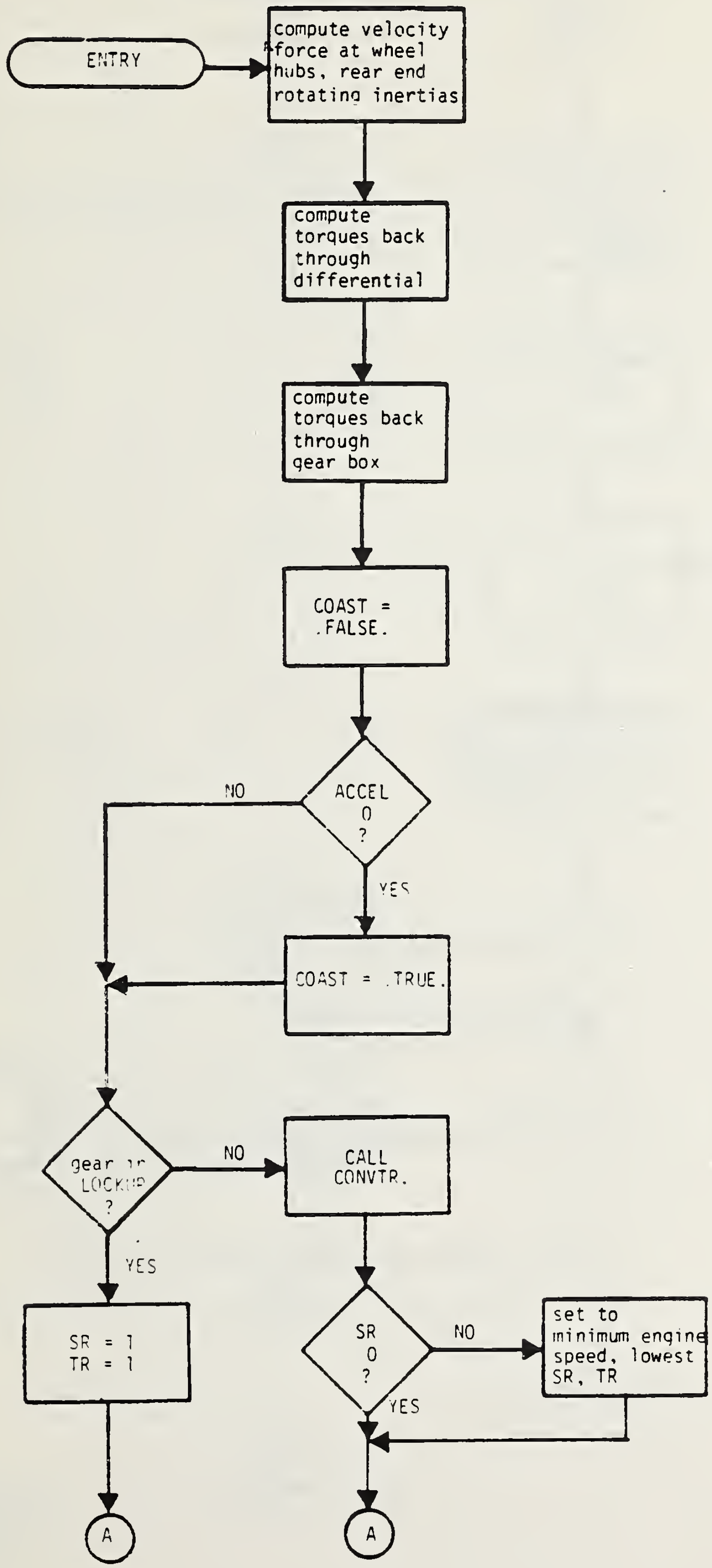


SIMCTR (CONTINUED)

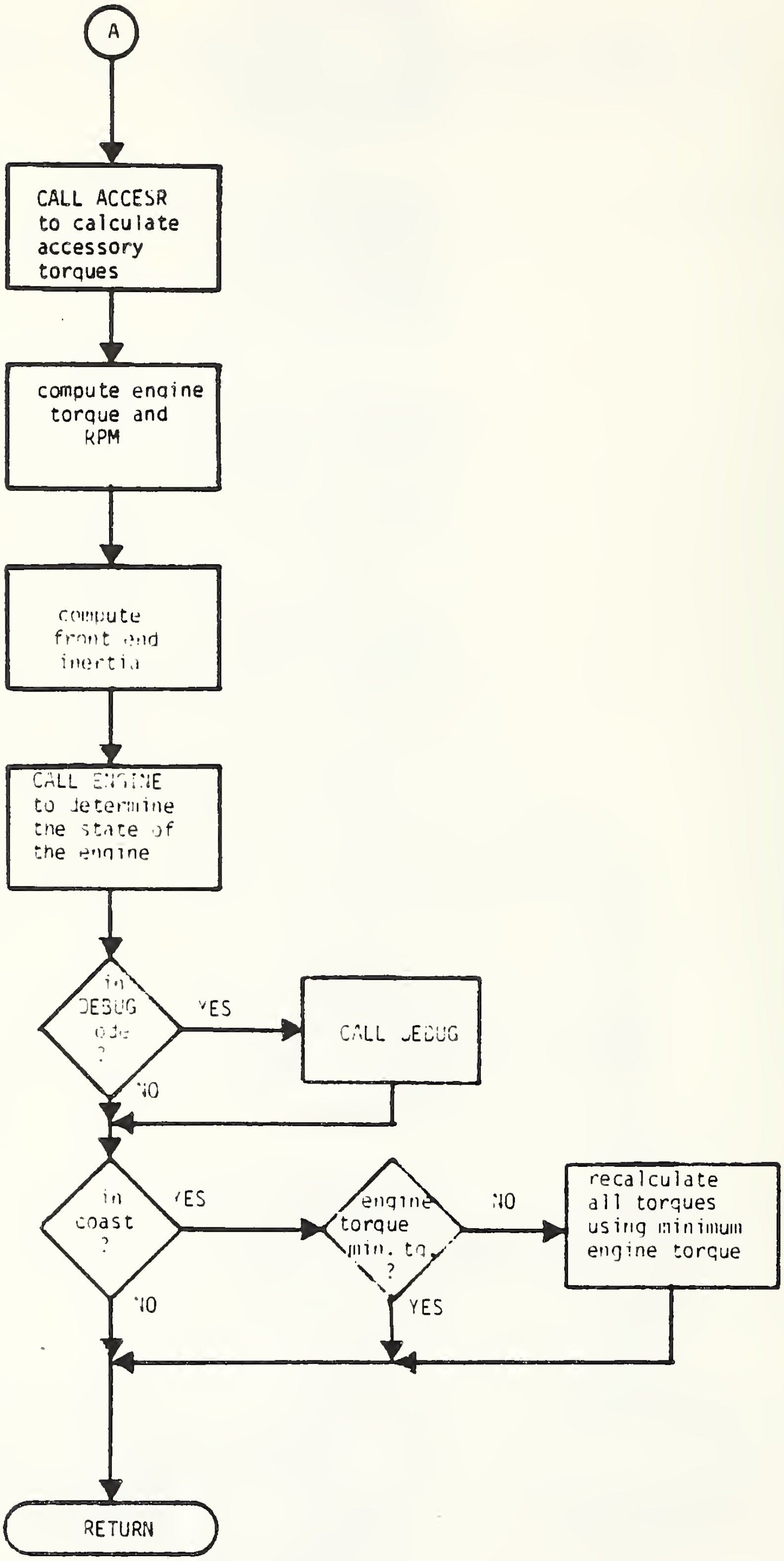



H
Calculate final idle accumulators
Calculate final accel. accumulators
Calculate final decel. accumulators
Calculate final cruise accumulators
Calculate loss accumulators
Compute subtotals of energy losses
Calculate power totals and brake and return to engine powers
Calculate energy losses
Write summary sheet giving totals for entire simulation
RETURN

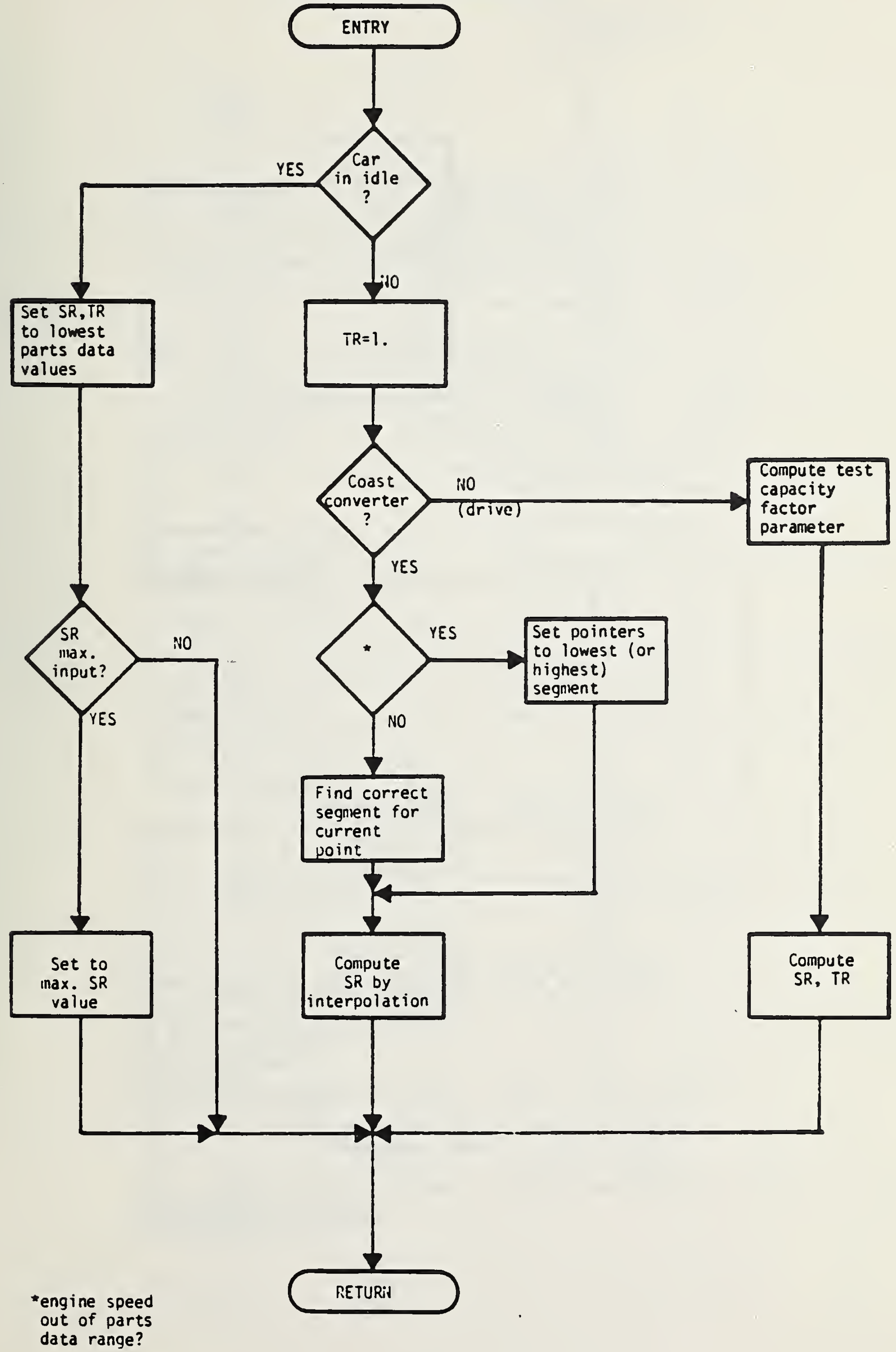
SUBROUTINE GOBACK



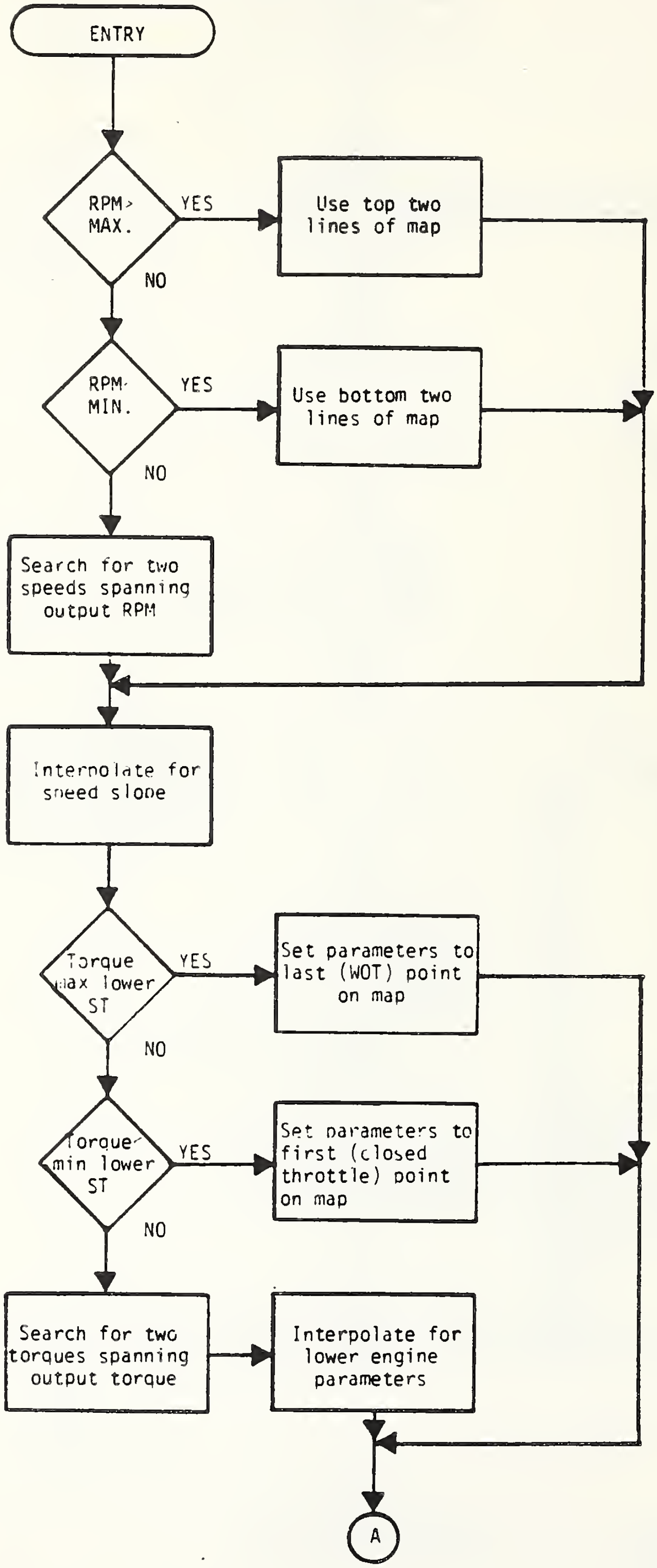
GOBACK (CONTINUED)



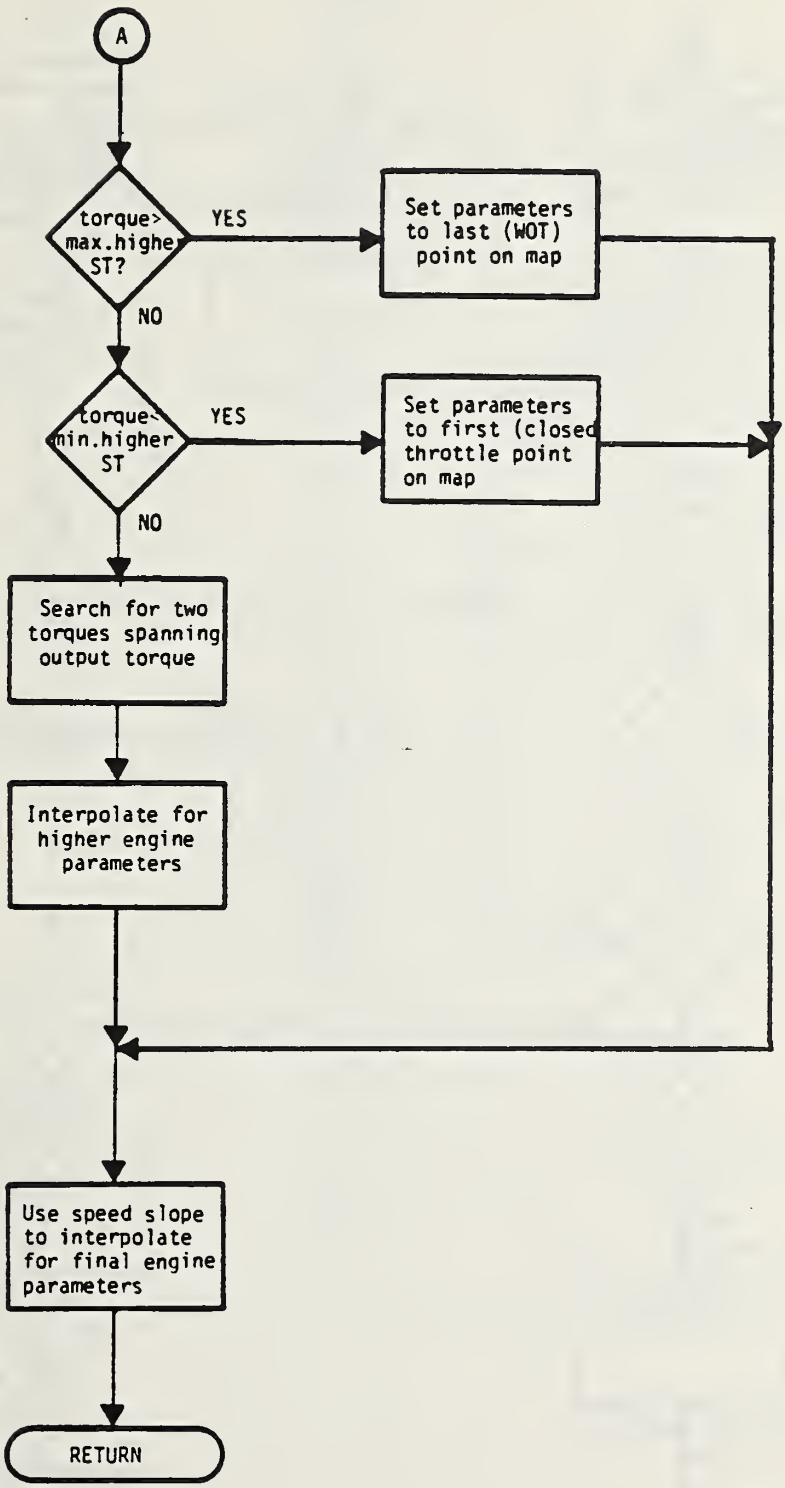
SUBROUTINE CONVTR



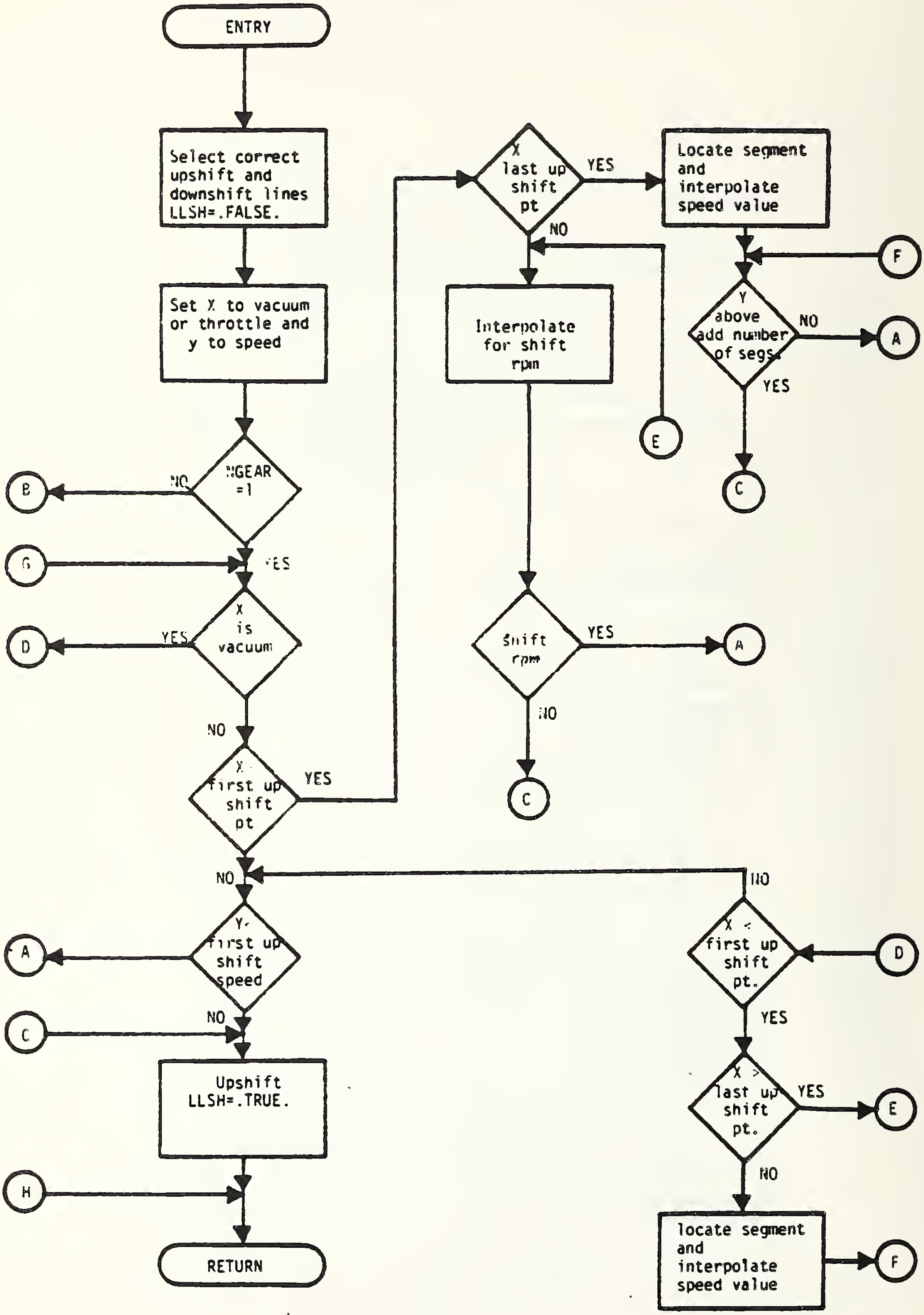
SUBROUTINE ENGINE



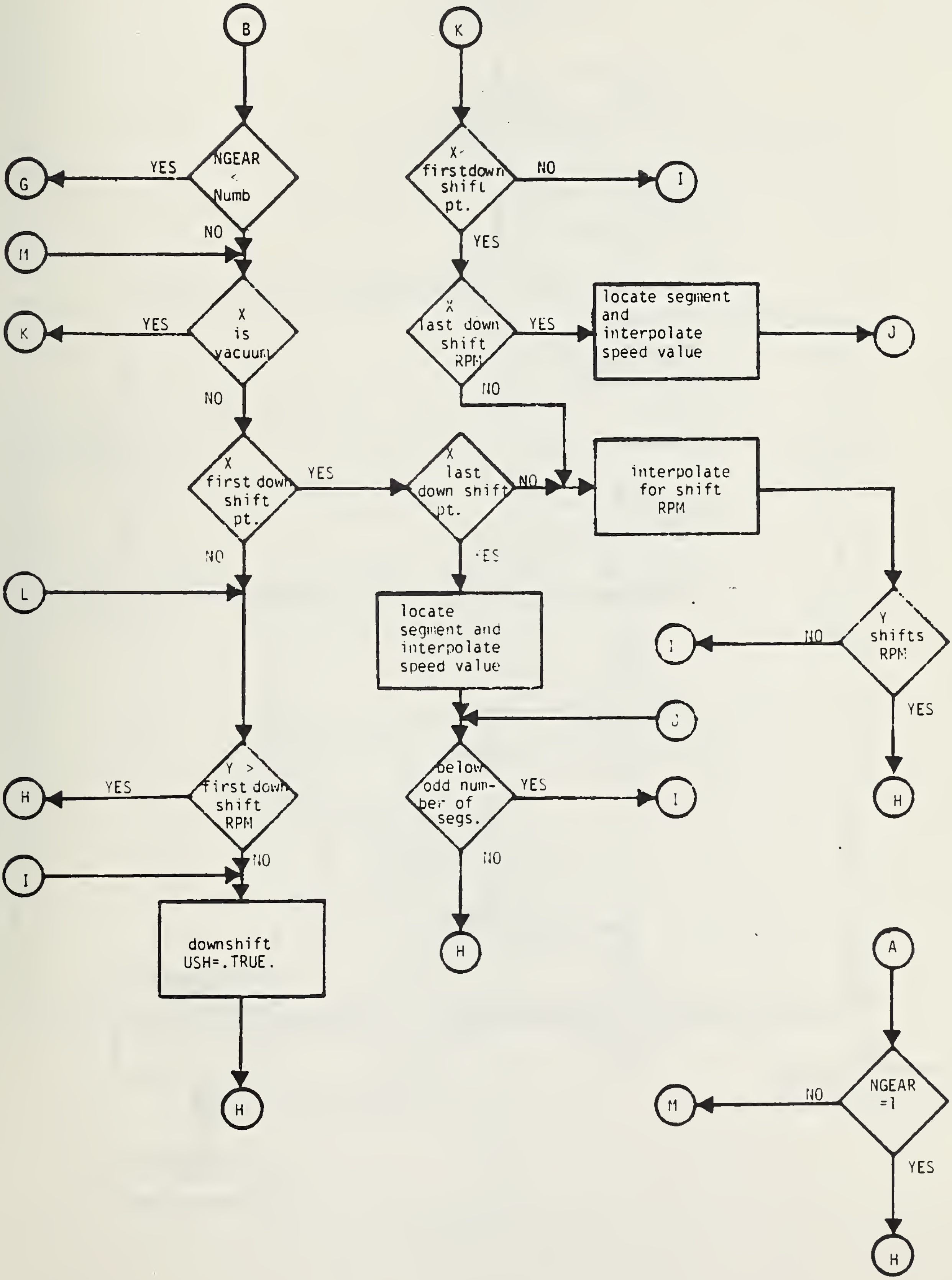
ENGINE (CONTINUED)



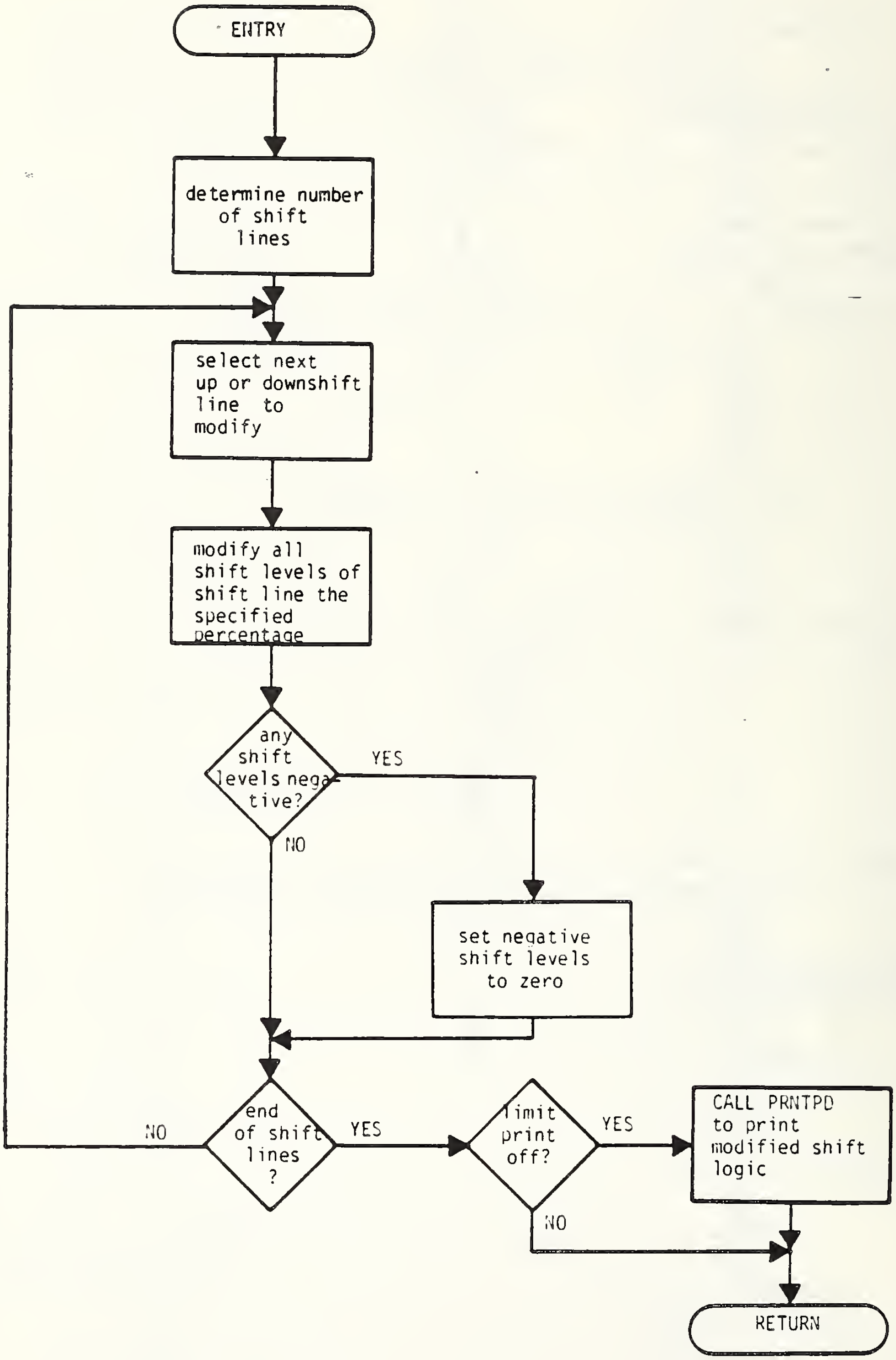
SUBROUTINE SHIFTS



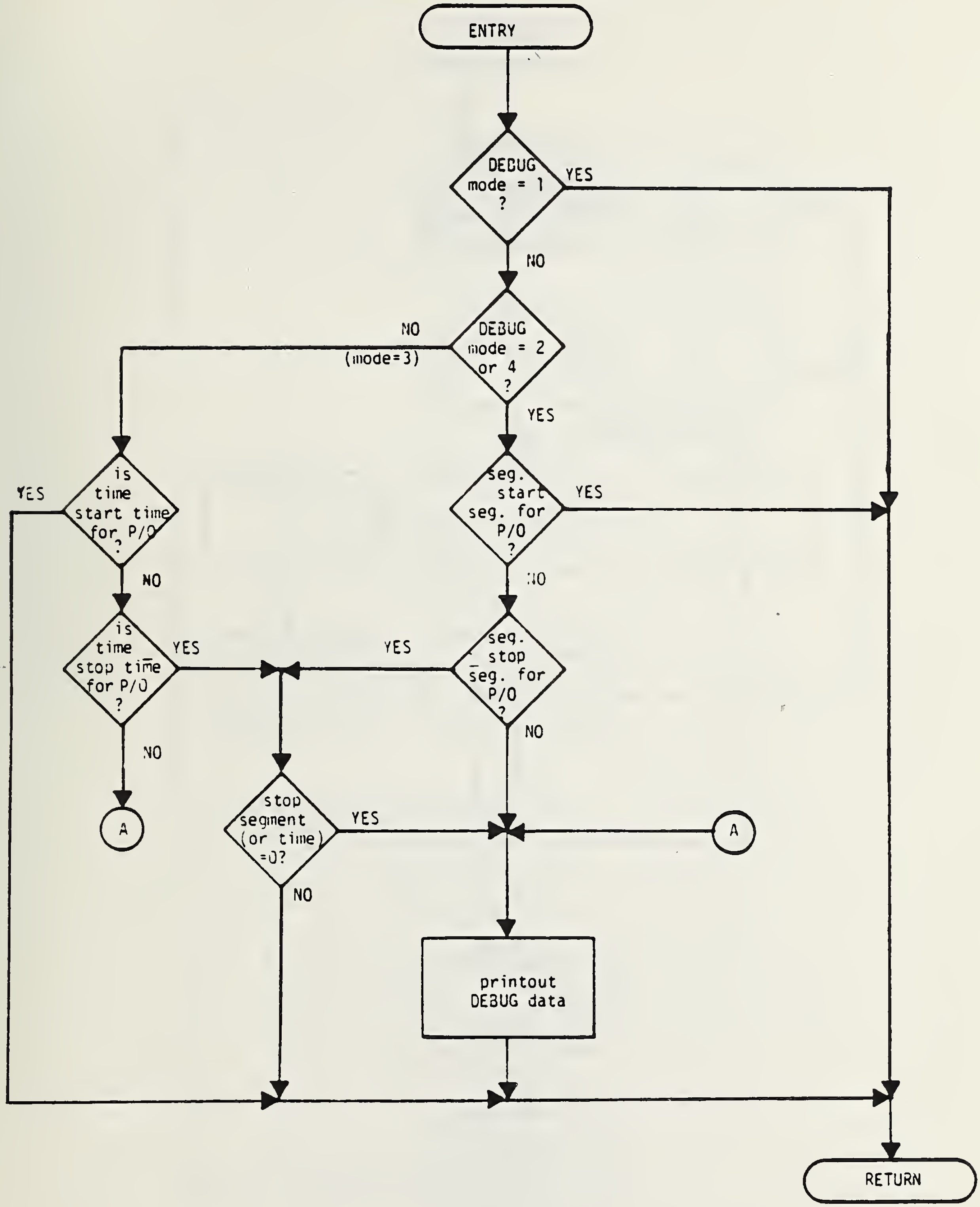
SHIFTS (CONTINUED)



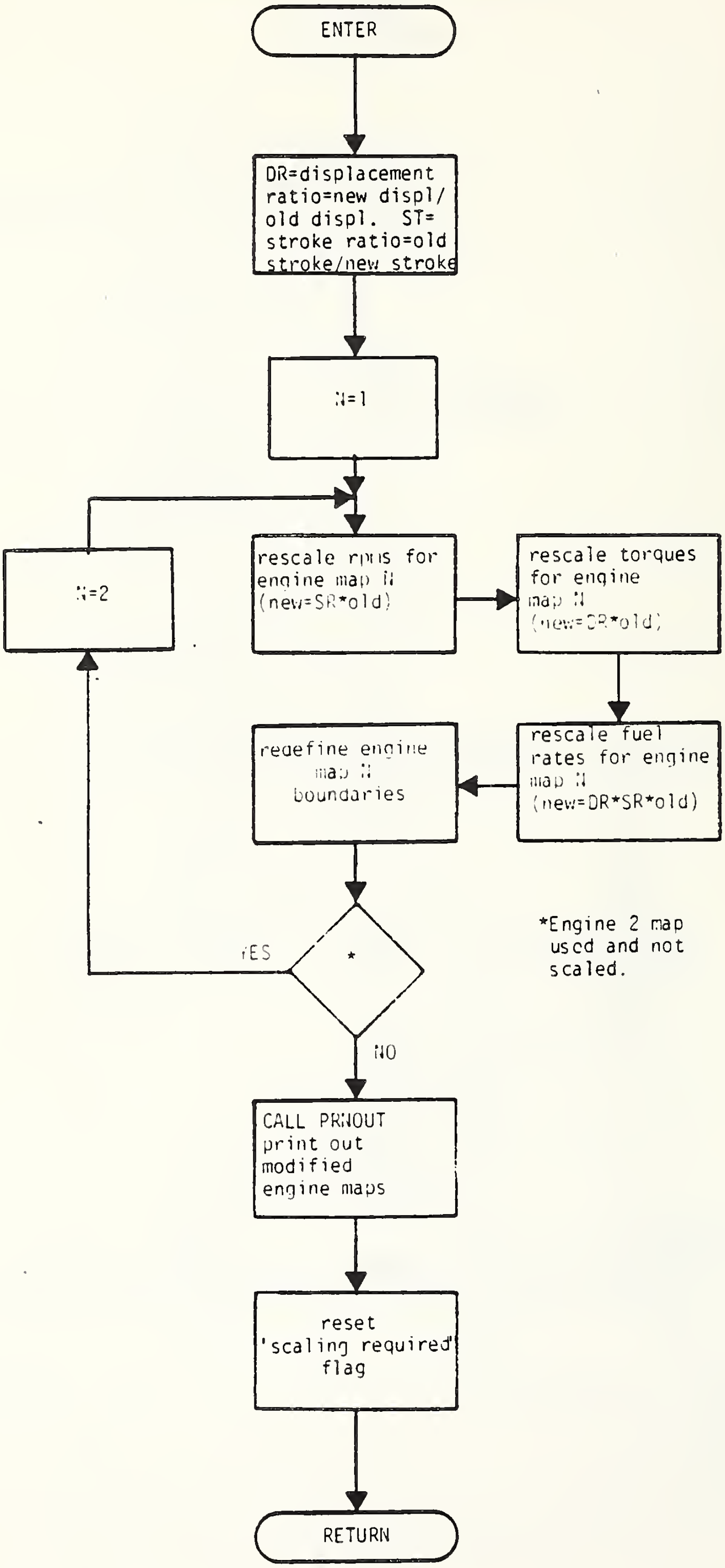
SUBROUTINE MODSL



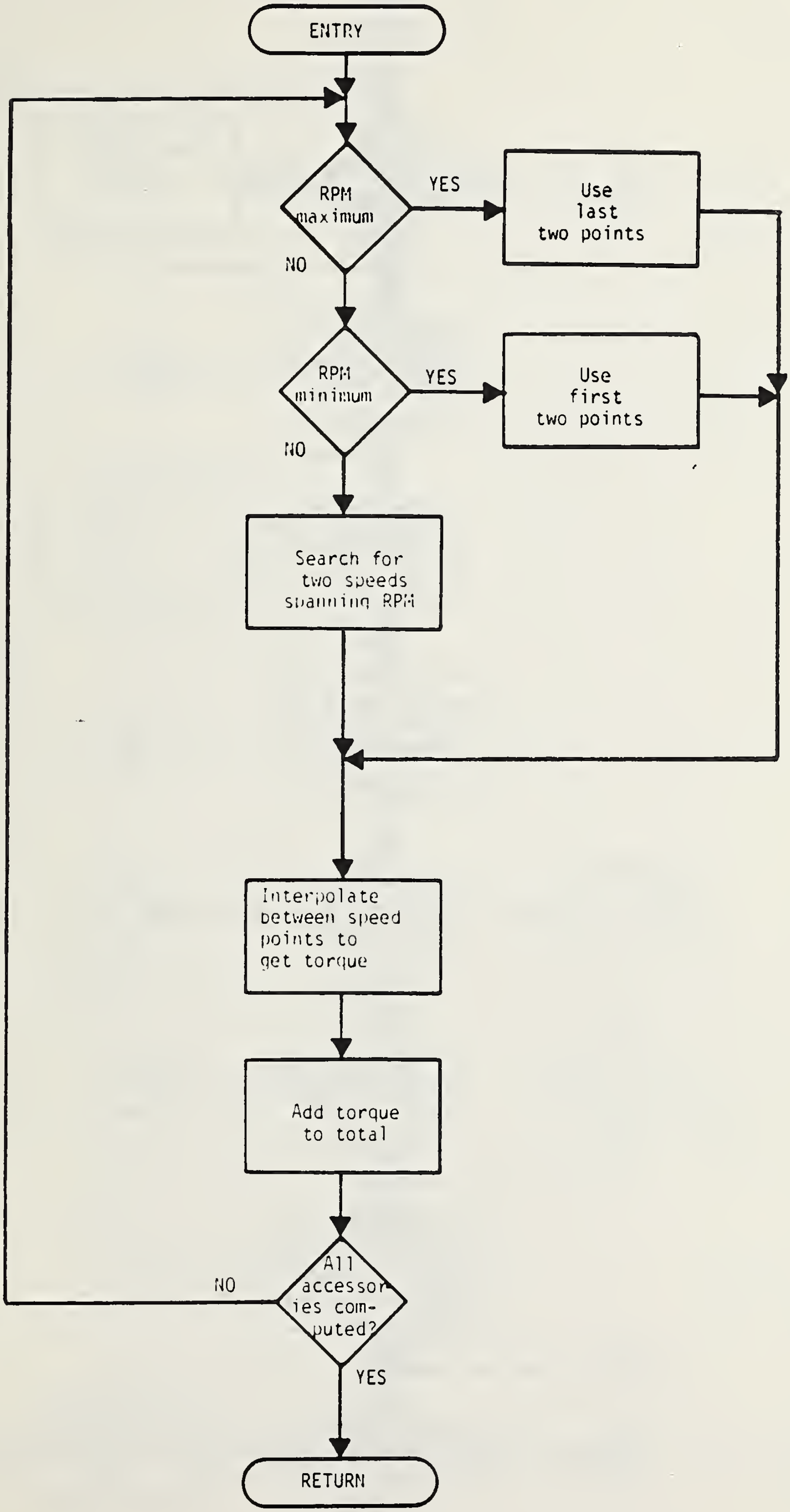
SUBROUTINE DEBUG



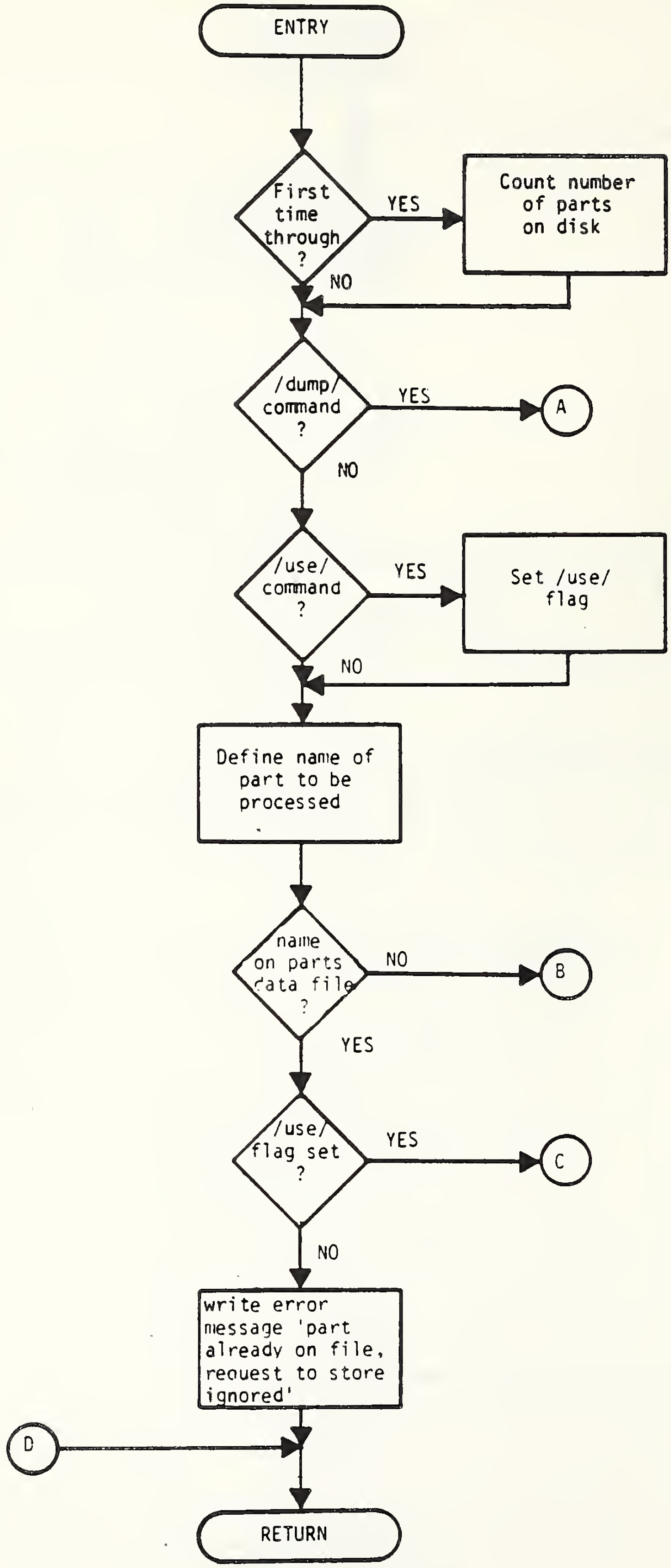
SUBROUTINE SCALEN



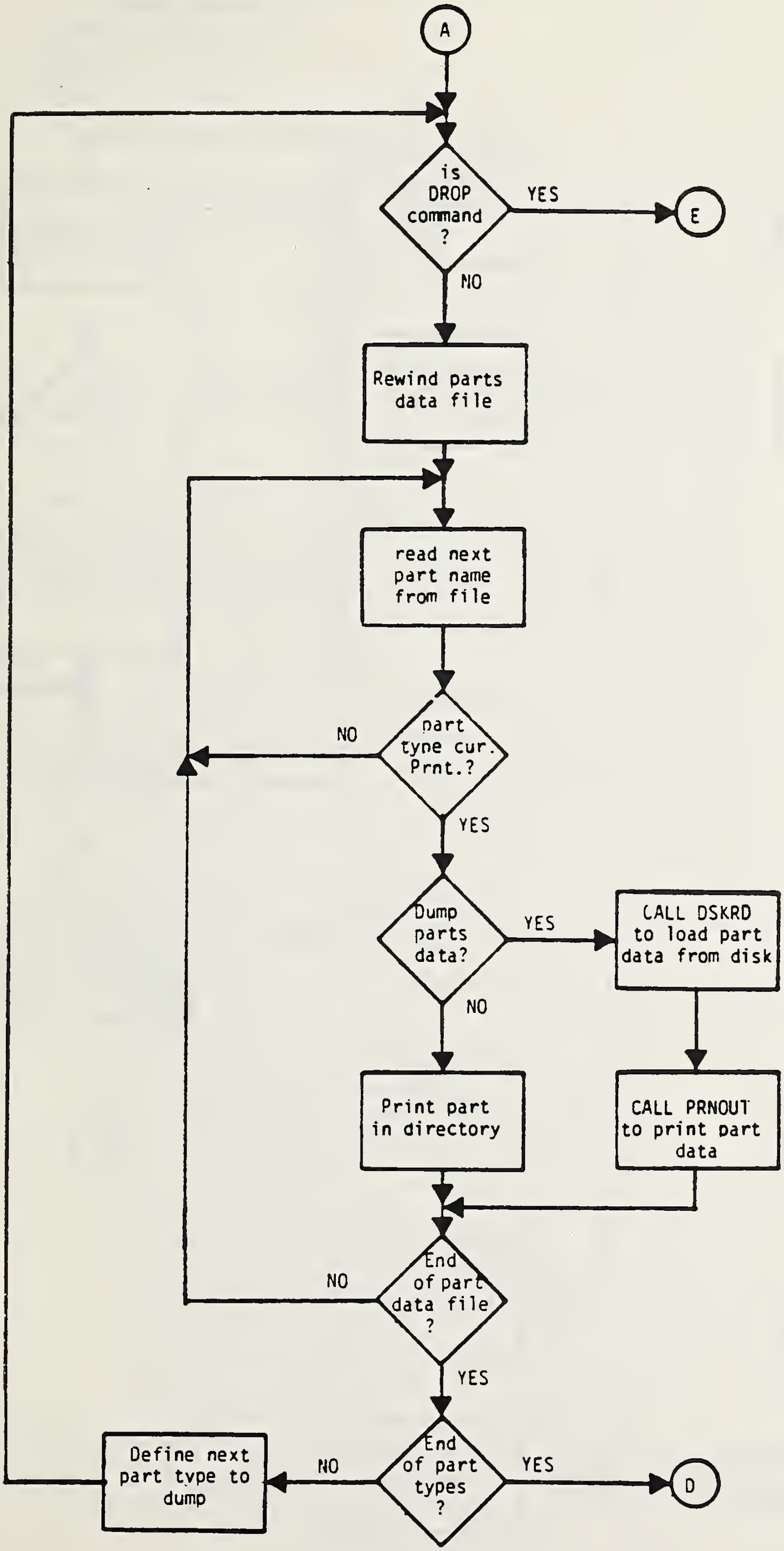
SUBROUTINE ACCESR

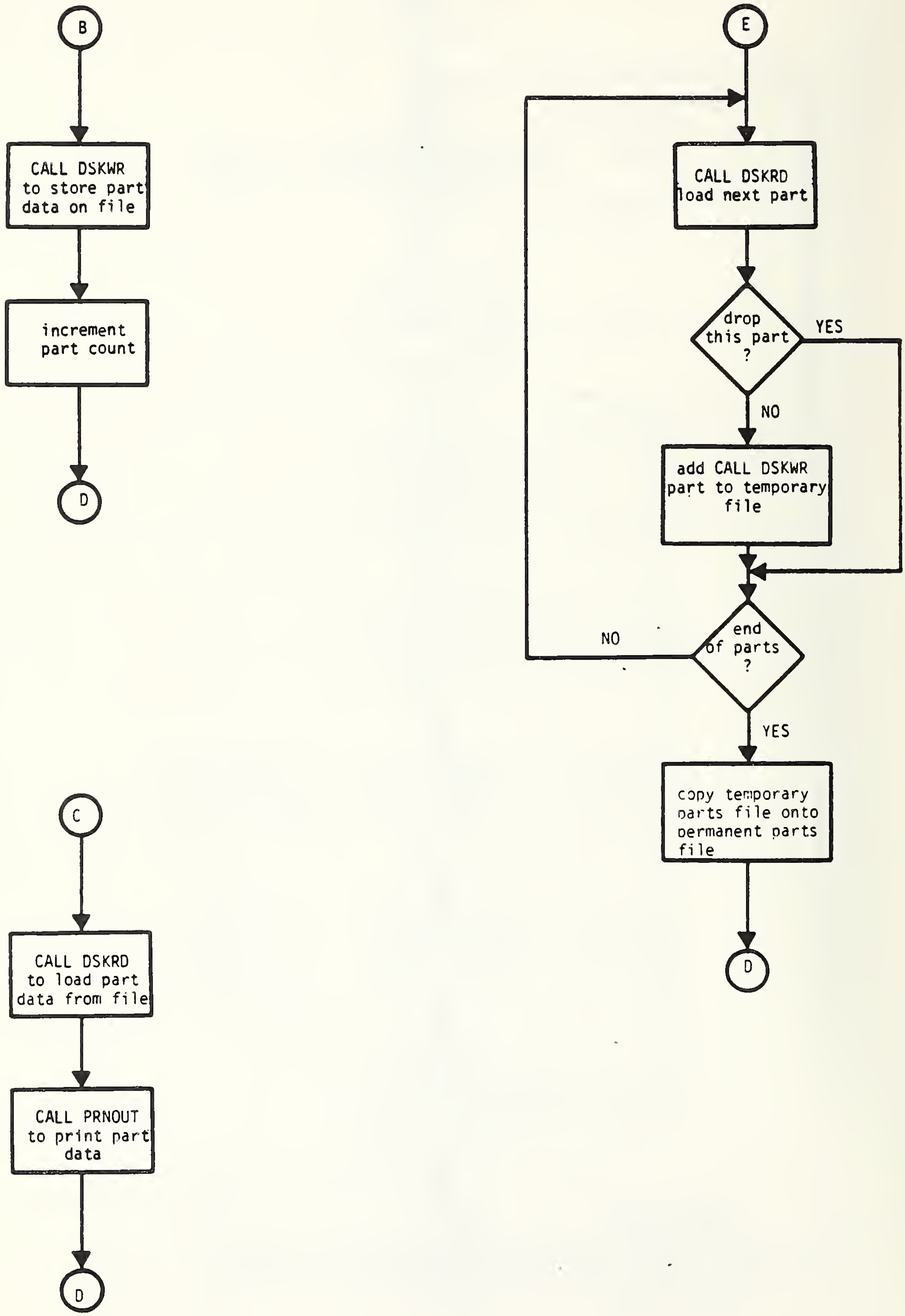


SUBROUTINE DSK

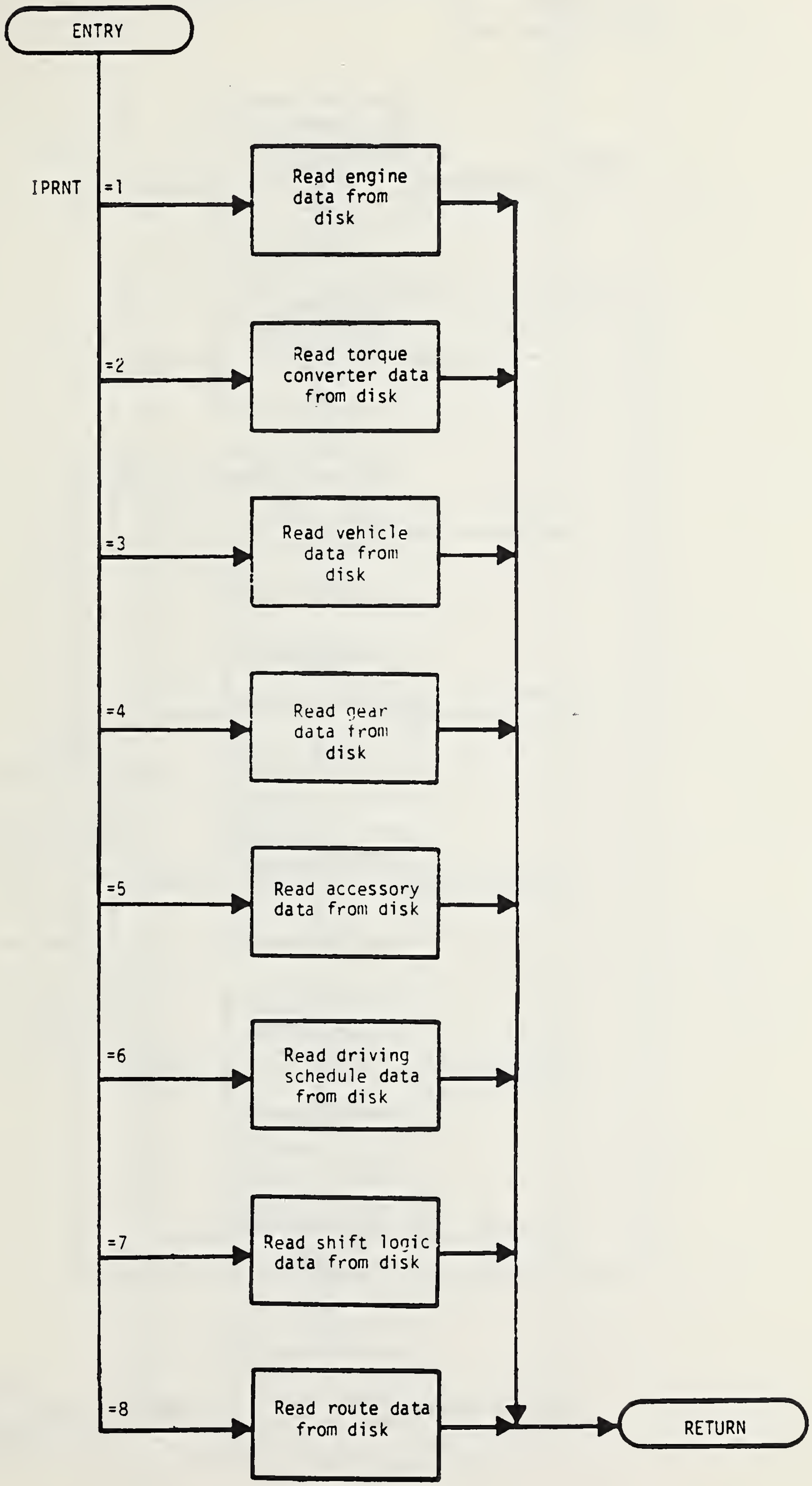


DSK (CONTINUED)

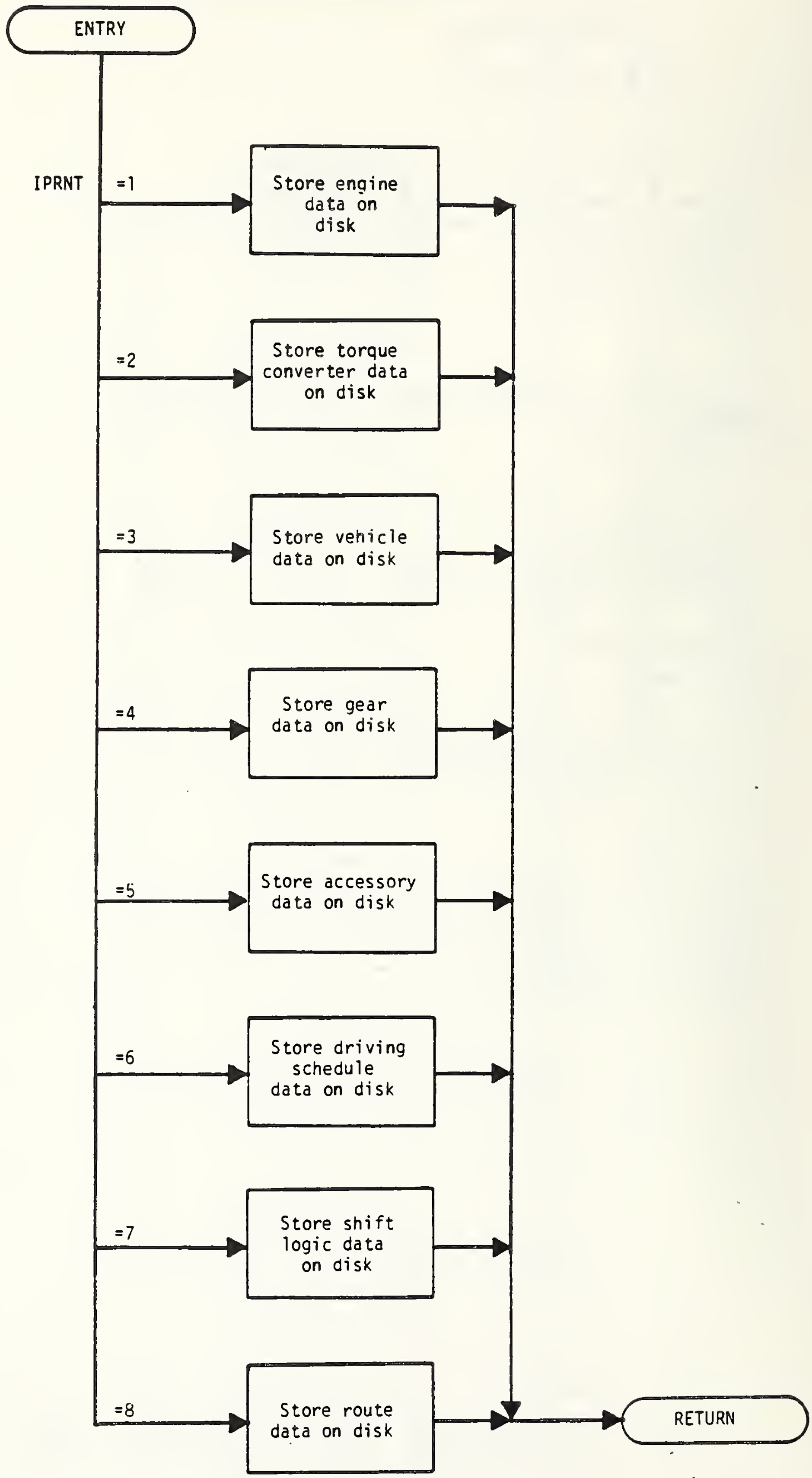



B
CALL DSKWR to store part data on file
increment part count
D
C
CALL DSKRD to load part data from file
CALL PRNOUT to print part data
D
E
CALL DSKRD load next part
drop this part ?
YES
NO
add CALL DSKWR part to temporary file
end of parts ?
NO
YES
copy temporary parts file onto permanent parts file
D

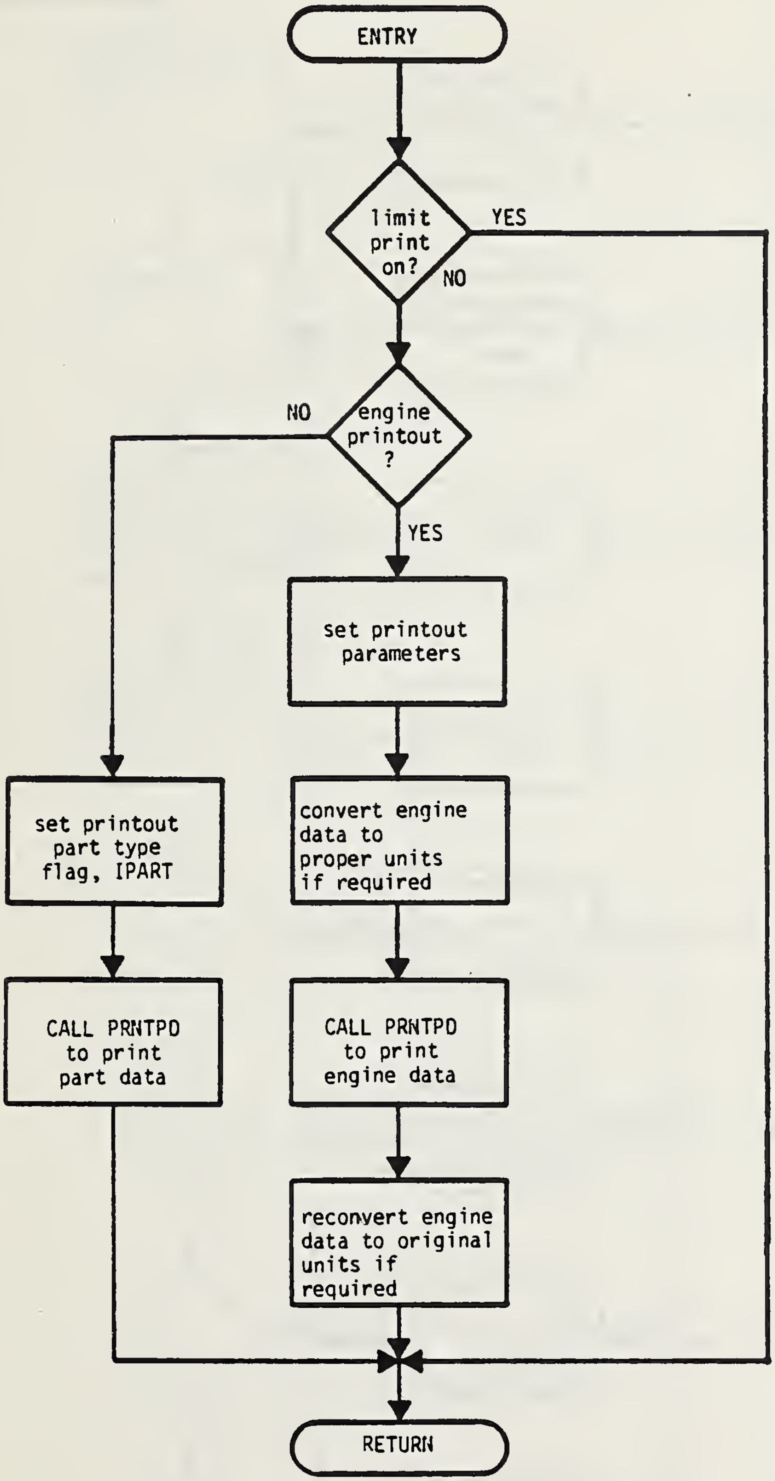
SUBROUTINE DSKRD



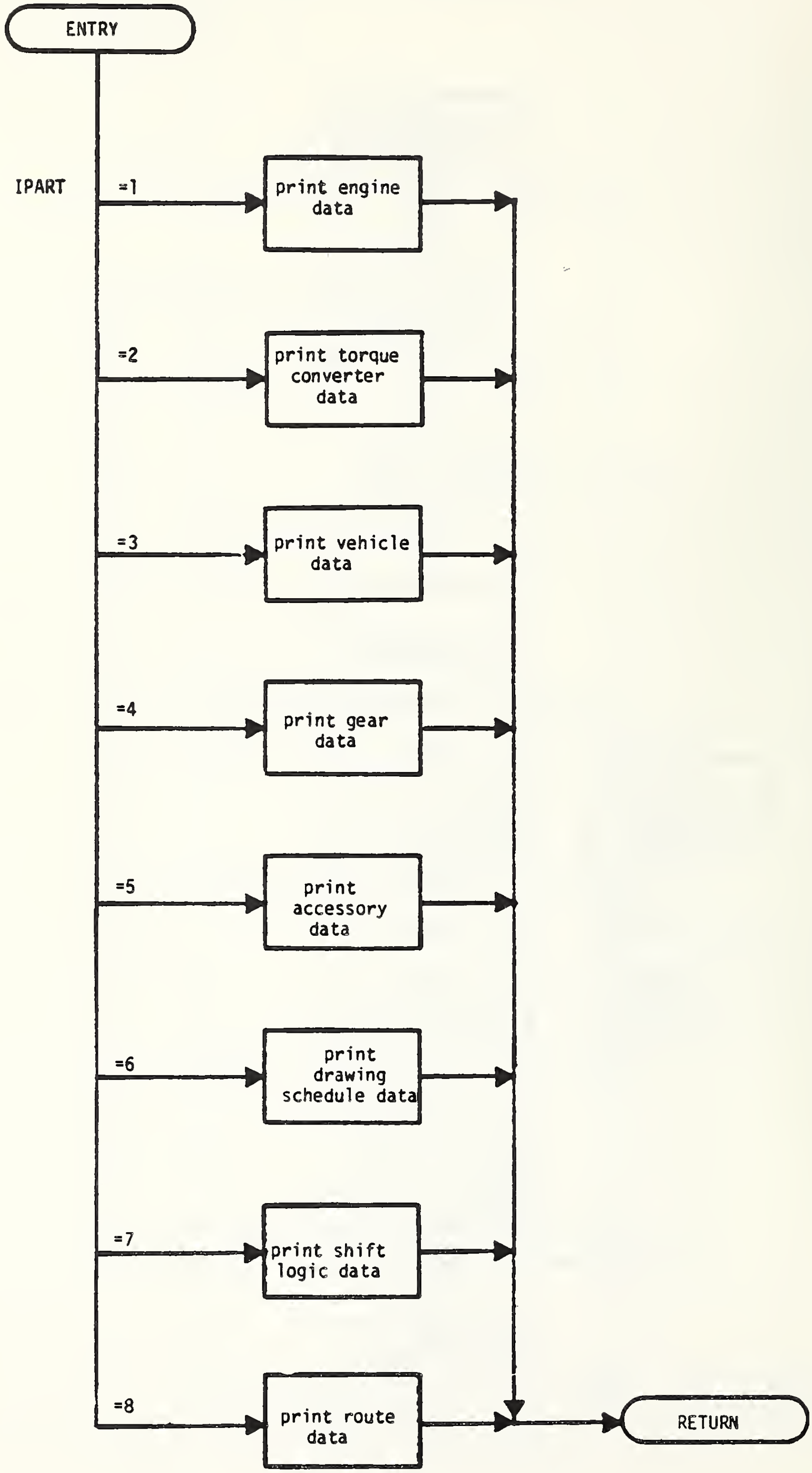
SUBROUTINE DSKWR



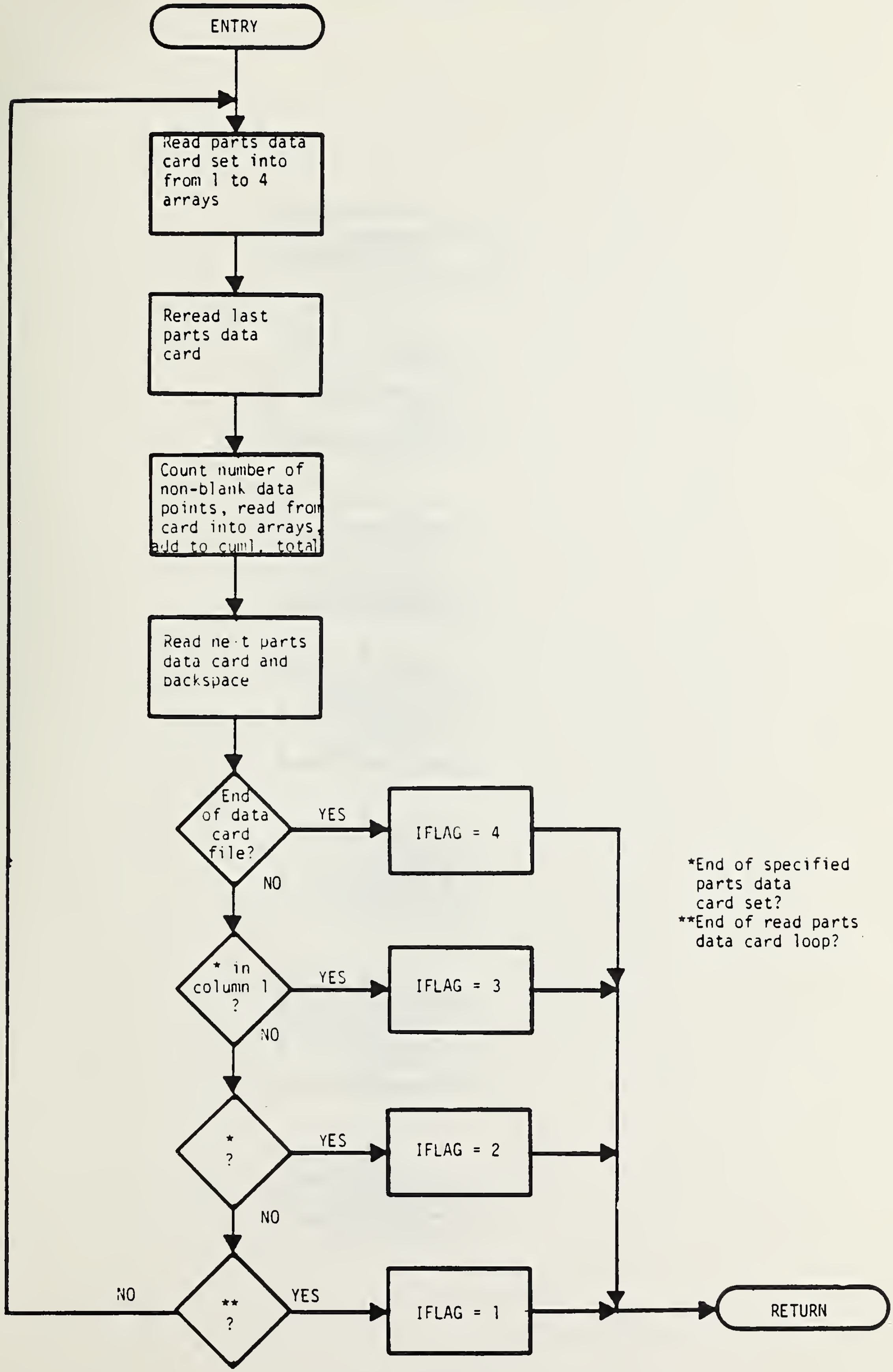
SUBROUTINE PRNOUT



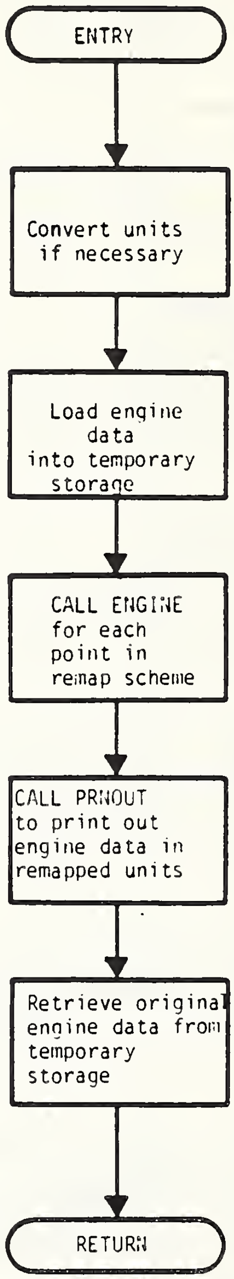
SUBROUTINE PRNTPD



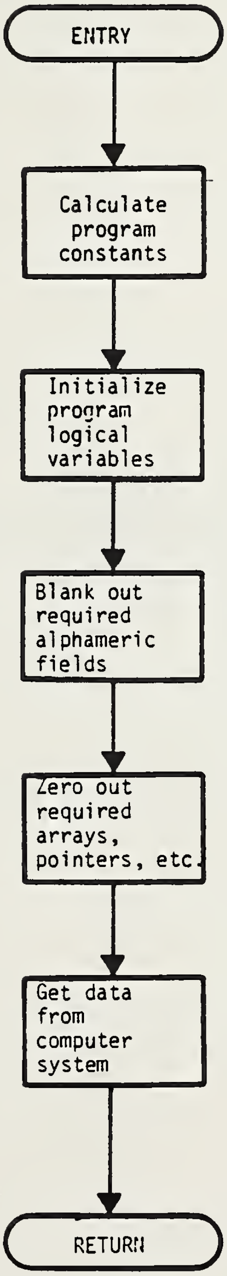
SUBROUTINE READPD



SUBROUTINE REMAP



SUBROUTINE ZERO



APPENDIX B
SUBROUTINE CROSS REFERENCES

Flags	Symbol	Octal Value	Defined in	Referenced in (all symbols)
U	ACCESS			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,ZERO, MAIN.
U	ACCTYP			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,MAIN.
U	ADJ1.			ASCIZ,ENTERP,LOOKUP,RCRCNT,NUMCHR,ICRCNT
	ASCIZ	400001'	ASCIZ	HLPCMD,LOOKUP
U	ASIN.			SIMIPT
U	ATAN.			GOBACK
U	CDEBUG			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,ITERAT,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMIPT,SIMSTS, VSMBIK,ZERO,MAIN.
U	CHKPIL			DSK,DSKDIR,HLPCMD,VSMCTR
M	CLOSE	400025'	VSMCTR	
U	CLOSE.			DSKCTR,HLPCMD,VSMCTR
	CLSIPT	400442'	VSMCTR	INPBAT
U	CLPTCH			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,MAIN.
U	CNTRL			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,ITERAT,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMIPT,SIMSTS, VSMBIK,ZERO,MAIN.
U	CONSUF			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,MAIN.
U	CONST			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,MODEL,PRNOUT,PRNTPD,SCALEN,SHIFTS,SIMCTR,SIMINT,SIMIPT, SIMSTS,VSMBIK,ZERO,MAIN.
	CONVTR	400001'	CONVTR	GOBACK
U	COS.			SIMCTR,SIMINT,SIMIPT
U	CRLF			HLPCMD
	CTBLD	400046'	DEBUG	GOBACK,SIMCTR,SIMIPT,SIMSTS
U	CURVES			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,ZERO,MAIN.
U	DBED			DSKDIR
U	DATE			ZERO
	DBPCMD	400350'	INPBAT	INPDIA
	DEBUG	400001'	DEBUG	GOBACK,SHIFTS,SIMCTR
U	DEC.			RCRCNT
U	DISK			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,ZERO,MAIN.
	DMPCMD	401623'	INPBAT	INPDIA
	DRPCMD	401436'	INPBAT	INPDIA
U	DSCHED			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,ITERAT,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,ZERO, MAIN.
U	DSHIFT			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMIPT,SIMSTS,VSMBIK,MAIN.
	DSK	400001'	DSK	INPBAT,PRNTPD,SIMCTR
	DSKCTR	400001'	DSKCTR	DSK,DSKDEL,DSKDIR,INPBAT,SIMCTR,VSMCTR
	DSKDEL	400001'	DSKDEL	INPBAT

Flags	Symbol	Octal Value	Defined in	Referenced in (all symbols)
	DSKDIR	#000001'	DSKDIR	INPDAT
	DSKRD	#000001'	DSKRD	DSK,DSKDEL,DSKDIR
	DSKWR	#000001'	DSKWR	DSK,DSKDEL
"	DSORT.			GETACI
"	DYNAM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VSMBLK,ZERO,MAIN.
"	ENC.			PRNTPD,VSMCTR
"	ENDOF			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,READPD,REMAP,SCALEN,SIMCTR,SIMINT,SIMIPT,SIMSTS, VSMBLK,ZERO,MAIN.
	ENGINE	#000001'	ENGINE	GOBACK,REMAP,SIMCTR
"	ENGMAP			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,ENGINE,GOBACK, HLPCMD,INPDAT,INPDIA,ITERAT,PRNOUT,PRNTPD,REMAP,SCALEN,SHIFTS,SIMCTR,SIMINT, SIMLPT,SIMSTS,VSMBLK,ZERO,MAIN.
	ENTERP	#000001'	ENTERP	GOBACK,SIMCTR
"	ERRSND			VSMCTR
"	ERRSMS			VSMCTR
"	EXIT			GOBACK,INPDAT,INPDIA,SIMCTR,SIMSTS,VSMCTR
"	EXIT.			MAIN.
"	EXP?.			GOBACK,SIMCTR
"	EXP.			SIMCTR
"	FBRAKE			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
"	FILES			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VSMBLK,VSMCTR,MAIN.
"	FILSPC			INPDAT,VSMCTR
"	FIX.			DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,ENGINE,HLPCMD,INPDAT,INPDIA, ITERAT,LOOKUP,PRNTPD,READPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VALID2,VSMCTR
"	GET			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,ENGINE,GOBACK, HLPCMD,INPDAT,INPDIA,PRNOUT,PRNTPD,REMAP,SCALEN,SHIFTS,SIMCTR,SIMINT,SIMLPT, SIMSTS,VSMBLK,VSMCTR,ZERO,MAIN.
	GETACI	#000001'	GETACI	ITERAT
"	GETDDP			INPDIA,SIMSTS
"	GETPAM			VSMCTR
	GOBACK	#000001'	GOBACK	ITERAT,SIMCTR,SIMINT
"	GPTIME			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
"	HCONS			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
"	HISTO3			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
	HLPCMD	#000001'	HLPCMD	INPDIA
	ICRCNT	#000001'	ICRCNT	DSKDIR,HLPCMD,INPDAT,INPDIA,LOOKUP,VALID2
"	IGE1			DSKDIR,VALID2
	INPDAT	#000001'	INPDAT	VSMCTR
"	INPCOM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIN,SIMINT,SIMLPT,SIMSTS,VSMBLK,VSMCTR,ZERO, MAIN.
	INPDIA	#000001'	INPDIA	VSMCTR

Flags	Symbol	Octal Value	Defined in	Referenced in (all symbols)
	INPPSE	'000023'	INPDIA	SIMSTS
U	IN.			DSKDIR,HLPCMD,INPBAT,INPDIA,READPD,SIMSTS,VALID2,VSMCTR
U	IO			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,PRNOUT,PRNTPD,REMAP,SCALEN,SIMCTR,SIMINT,SIMLPT,SIMSTS, VSMBIK,ZERO,MAIN.
U	IOLST.			DEBUG,DSK,DSKDEL,DSKDIR,DSKRD,DSKWR,ENGINE,GETACI,GOBACK,HLPCMD,INPBAT, INPDIA,ITERAT,LOOKUP,MODSL,NOPART,PRNTPD,RCRCNT,READPD,SCALEN,SIMCTR,SIMINT, SIMLPT,SIMSTS,SLOOKP,VALID2,VSMCTR
	ITERAT	'000001'	ITERAT	SIMCTR
U	JOPPPE			VSMCTR
	KPTIME	'000001'	KPTIME	SIMCTR,SIMINT,SIMSTS
U	LDIMEN			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,REMAP,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,ZERO, MAIN.
	LINCMD	'001713'	INPBAT	INPDIA
	LOOKUP	'000001'	LOOKUP	DSKDIR,HLPCMD,INPBAT,INPDIA
U	MAIN.	'000000'	MAIN.	
U	MASKS			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,LOOKUP,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,MAIN.
U	MISC			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,ZERO, MAIN.
U	MOCOM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,MAIN.
	MODCMD	'002006'	INPBAT	INPDIA
U	MODE			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VALID2,VSMBIK,VSMCTR, MAIN.
	MODSL	'000001'	MODSL	INPBAT
U	MTCP.			DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,SKPREC,INPBAT,READPD
	NOPART	'000001'	NOPART	INPBAT,INPDIA
	NWRCNT	'000001'	NWRCNT	DSKDIR,INPBAT,RCRCNT,READPD
	NXTCRD	'000051'	READPD	INPBAT
U	OLDIO			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,SCALEN,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,ZERO, MAIN.
U	OLDMAP			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPBAT,INPDIA,PRNOUT,PRNTPD,REMAP,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBLK,ZERO, MAIN.
U	OPEN.			DSKCTR,HLPCMD,VSMCTR
	OPTLPT	'000235'	VSMCTR	INPBAT
	OUTCMD	'000425'	INPBAT	INPDIA
U	OUTP			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPBAT,INPDIA,ITERAT,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBLK, MAIN.
U	OUTSTR			ASCIZ
U	OUT.			DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,ENGINE,GETACI,GOBACK,HLPCMD,INPBAT,INPDIA, ITERAT,LOOKUP,MODSL,NOPART,PRNTPD,SCALEN,SIMCTR,SIMINT,SIMLPT,SIMSTS,SLOOKP, VALID2,VSMCTR

Flags	Symbol	Octal Value	Defined in	Referenced in (all symbols)
U	PRNTIM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,MODSL,PRNOUT,PRNTPD,SCALEN,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK, ZERO,MAIN.
	PRNOUT	000001'	PRNOUT	DSK,DSKDIR,INPDAT,REMAP,SCALEN
	PRNTPD	000001'	PRNTPD	MODSL,PRNOUT
U	PROT			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
U	PUT			DSKDIR,VALID?
	RCRCNT	000001'	RCRCNT	ASCIZ,INPDAT,ICRCNT
	READPD	000001'	READPD	INPDAT
U	RELEAS			DSKCTR,VSMCTR
	REMAP	000001'	REMAP	INPDAT
U	RENTER	000117'	VSMCTR	
U	RESET			INPDIA
U	RESETM			GOBACK,LOOKUP,SIMCTR,SIMINT,SIMLPT,VSMCTR
U	RESET.			MAIN.
U	RMPCMD	050333'	INPDAT	
U	RTB.			DSK,DSKDEL,DSKDIR,DSKRD
U	RTE			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBLK,ZERO,MAIN.
U	RUNID			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,VSMCTR,ZERO, MAIN.
	SCALEN	000001'	SCALEN	INPDAT
U	SECNDS			KPTIME
U	SEGMO			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,MAIN.
U	SETC			VSMCTR
U	SHFTL			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,MODSL,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK, ZERO,MAIN.
	SHIFTS	000001'	SHIFTS	SIMCTR,SIMINT
U	SIMCM2			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,MAIN.
	SIMCMD	000536'	INPDAT	INPDIA
U	SIMCOM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
	SIMCTR	000001'	SIMCTR	INPDAT
	SIMINT	000001'	SIMINT	SIMCTR
	SIMLPT	000001'	SIMLPT	SIMCTR,SIMINT
	SIMSTS	000001'	SIMSTS	GOBACK,SIMCTR
U	SIN.			SIMCTR,SIMINT,SIMLPT
	SKPREC	000001'	SKPREC	HLPCMD
	SLOOKP	000001'	SLOOKP	INPDAT
U	SNG.2			VSMCTR
U	SNG.8			GETACL
U	SNG.6			GETACL
U	SQRT.			CONVTR,INPDAT
U	SSTIME			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,KPTIME,PRNOUT,PRNTPD,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBIK,MAIN.

Flags	Symbol	Octal Value	Defined in	Referenced in (all symbols)
"	STOP.			INPDIA
	STSCMD	"006620'	INPDAT	INPDIA
"	TIME			DSK,VSMCTR
"	TMAP			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,ENGINE,GOBACK, HLPCMD,INPDAT,INPDIA,ITERAT,PRNOUT,PRNTPD,REMAP,SHIFTS,SIMCTR,SIMINT,SIMLPT, SIMSTS,VSMBLK,MAIN.
"	TOICOM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GETACI,GOBACK, HLPCMD,INPDAT,INPDIA,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBLK, ZERO,MAIN.
"	TRACE			DSK,INPDIA,PRNTPD
"	TRACEL			LOOKUP
	TRACMD	"002050'	INPDAT	INPDIA
"	TRANCM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIR,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
"	TRORPM			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SHIFTS,SIMCIR,SIMINT,SIMLPT,SIMSTS,VSMBLK,MAIN.
	TTICMD	"000704'	INPDAT	INPDIA
"	TTYCLE			INPDIA,SIMINT,SIMSTS
"	TTYINP			GOBACK
"	TTYOUT			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIR,SIMINT,SIMLPT,SIMSTS,VSMBLK,VSMCTR,ZERO, MAIN.
"	TTYSET			SIMLPT,SIMSTS
"	TTYSTS			VSMCTR
	UAICMD	"027212'	INPDAT	INPDIA
"	UNICMD	"013511'	INPDAT	
	USECMD	"073010'	INPDAT	INPDIA
"	VARISC			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,MODSL,PRNOUT,PRNTPD,SHIFTS,SIMCTR,SIMINT,SIMLPT,SIMSTS,VSMBLK, VSMCTR,ZERO,MAIN.
	VALID2	"000001'	VALID2	INPDAT
"	VEHICL			ASCIZ,CONVTR,DEBUG,DSK,DSKCTR,DSKDEL,DSKDIR,DSKRD,DSKWR,GOBACK,HLPCMD, INPDAT,INPDIA,PRNOUT,PRNTPD,SIMCIR,SIMINT,SIMLPT,SIMSTS,VSMBLK,ZERO,MAIN.
"	VSECTR	"000001'	VSMCTR	
"	WTP.			DSKWR
	ZSECMD	"011571'	INPDAT	INPDIA,VSMCTR
	ZERO	"000001'	ZERO	INPDAT
"	ZEROP			SIMINT

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