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PROGRAM DOCUMENTATION COOPER-BESSEMER LSV-16, DIESEL

B. M. Allen, et al

Arthur D. Little, Incorporated

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NOVEMBER 1971

DIRECTORATE OF MILITARY CONSTRUCTION
OFFICE OF THE CHIEF OF ENGINEERS
DEPARTMENT OF THE ARMY
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PART I - ENGINEERING DESCRIPTION

1. PROGRAM NUMBER

2. REVISION LOG

Date	Changes	Comments

3. TITLE

LSV-16

4. PURPOSE OF PROGRAM

The computer program provides the OCE with a mathematical model of the Cooper-Bessemer LSV-16 diesel engine with associated electrical generating equipment and synchronous fuel control. This model may be exercised to predict the performance of the diesel engine power system to electrical load changes and air shock waves due to changes in the environment.

5. STEP SOLUTION

5.1 OVERALL DESCRIPTION

This program is capable of simulating in detail the dynamic performance of the Cooper-Bessemer, Model LSV-16, diesel engine-generator set resulting from sudden changes in load and/or ambient pressure and temperature. These disturbances are described analytically within the program. The program is set up to generate analytically the following disturbances: (1) a step load change, (2) a free-field overpressure with accompanying overtemperature, or (3) an overpressure and overtemperature of arbitrary profile. This model of diesel engine performance is sufficiently detailed to evaluate the thermodynamic state within each cylinder, in the inlet and exhaust manifolds, and at the entrance and exit of turbocharger components at each instant of time. The pressure forces acting on each piston are translated through appropriate kinematic and dynamic relations to shaft output torque.

The computer program was adapted from a general purpose program which was developed by ADL for the OCE for the analysis of other diesel engine power systems. The general purpose program considers two and four-stroke-per-cycle diesels, with various scavenging and super-charging accessories. The general purpose program can also be arranged to include more than one diesel generating set to determine the performance under load-sharing conditions when the sets are connected to a common bus.

The general purpose program is set up to solve a series of algebraic and differential equations which relate the time history of the physical processes which are involved in the operation of a typical diesel.

For the LSV-16 engine, these processes can be divided into related subsystems.

Subsystem 1. The shaft connecting the diesel and the alternator.
Subsystem 2. The alternator and voltage control.
Subsystem 3. The diesel cylinder and valving processes.
Subsystem 4. The turbo-supercharger.
Subsystem 5. The fuel control.

As mentioned, these subsystems involve the solution of a series of differential equations which are time dependent. Each subsystem has a characteristic time constant which must be considered in the numerical integration process. Thus, to minimize computer solution time, a master (or clock) routine asks for the state of each subsystem at intervals which are timed to optimize computer processing time.

To minimize programming effort, each subsystem uses identical input, output and numerical integration routines which operate on individual data files (stored in common data storage). Only the equations which relate to specific equipment, i.e., the fuel control, the valve area, must be recoded. The variables in these data files are divided into several categories: a) constant coefficient, b) non-constant coefficients, c) dependent variables, d) independent variables, e) derivatives of dependent variables, and f) counters and control switches. Some confusion may result to the casual observer as the same variable (Y(3) for instance) may represent one quantity in the turbocharger subsystem and another in the diesel. It is emphasized that this coding process was undertaken to speed coding of new diesel alternator combinations at minimum cost to the OCE. A full description of the program organization is given in FILE DOCUMENTATION, paragraph 5.2.

5.2 THE LSV-16 PROGRAM

5.2.1 Clock Program

At periodic time intervals, the clock or MAIN program controls the flow of information within the mathematical model. The logic consists of initializing, indexing, and timing the various subsystems so that together, they simulate a complete interacting system.

5.2.2 Ambient and Load Conditions

This subsystem is responsible for coordinating the engine's performance with its environment and load. In describing the environment, there are three options. The first is that of having constant inlet pressure, temperature, and exhaust pressure. The second option is using a standard air shock. The third option is to input pressure, temperature and exhaust pressure profiles. Under all of these options the generator load is set by the alternator subsystem and may be varied independently of the environmental pressures and temperatures.

5.2.3 Shaft Motion, Subsystem 1

The Equation of Motion, Subsystem 1, has three tasks. It calculates angular shaft speed of the engine-generator set, determines the time from this information and keeps an energy balance for the engine.

5.2.4 Alternator, Subsystem 2

Alternator, Subsystem 2, has been represented simply as a load requiring constant power. As such, this subsystem has no analysis which requires integration. Therefore, the generator shaft torque has been characterized as a simple function.

5.2.5 Diesel Engine, Subsystem 3

In the detailed analysis of diesel performance, the state of the working fluid in all cylinders is defined as a function of time. In order to do this, the behavior of the supercharger elements and the state of the working fluid in the manifolds as a function of time must also be identified. Such an analysis is necessary to: (1) reveal conditions of temperature and pressure which may compromise the mechanical operation of the machine; (2) allow a full understanding of the effects which dictate the torque-speed relationship of the drive shaft; and (3) make possible an examination of devices and methods to alleviate the effects of overpressure.

Figure 1 (page 5) identifies the parameters which characterize the processes occurring in the engine in sufficient detail to meet these three objectives. For simplicity, only one cylinder is shown in this diagram.

A detailed dynamic analysis of the diesel engine reduces to the prediction of the pressures in all cylinders at every instant of time. Knowing these pressures and the crank configuration, one calculates the torque, τ_g, one subtracts the

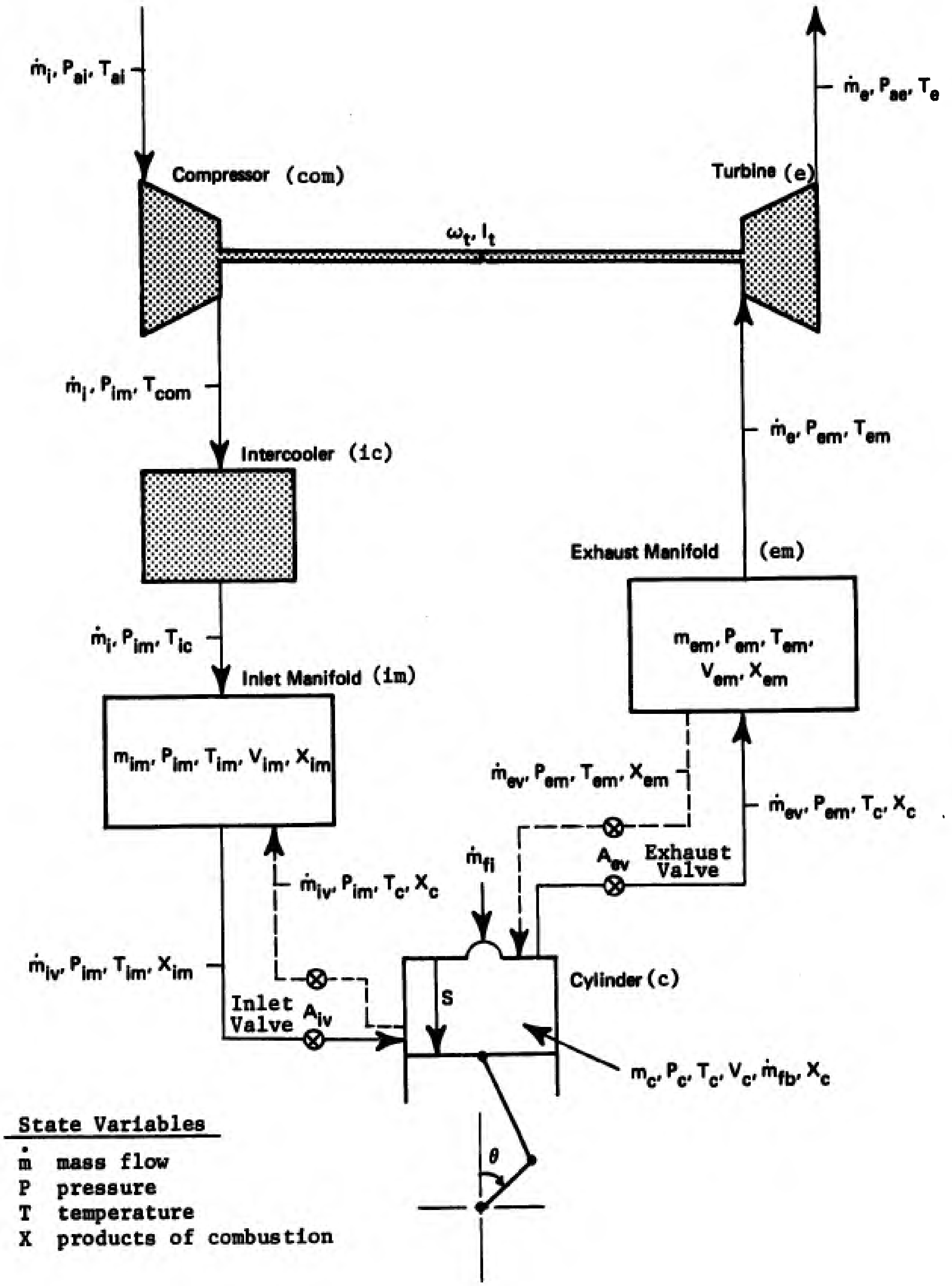


FIGURE 1 SCHEMATIC DIAGRAM FOR A TURBOCHARGED ONE-CYLINDER DIESEL ENGINE

crank and piston assembly inertia, $\tau_{d\omega/dt}$, and the friction torque, τ_f, to get the torque, τ_d, exerted at the engine output shaft coupling. In principle, this is expressed as:

$$\tau_g - \tau_f - I\frac{d\omega}{dt} = \tau_d$$

The friction torque depends mainly on speed and to a much lesser extent on load, and is usually evaluated from results of motoring tests, although these tests do not account for the influence of cylinder pressure. In our analysis, we assume that the friction torque is a function of speed only. The friction torque at rated load and speed is typically about 15 percent of the gas torque so that a precise evaluation of its magnitude is not critical to dynamic performance evaluation, particularly under conditions of sudden electric load change.

The pressure within a cylinder depends on the mass of gas in it, the gas composition, gas temperature and cylinder volume. In order to compute the time varying cylinder pressure, one solves an appropriate energy equation, continuity equation, and equation of state of the gas within the cylinder at discrete, closely spaced intervals of time throughout the engine cycle. In order to perform this computation, one must also compute the instantaneous states of the gases within the manifolds throughout the engine cycle. This calculation is made by application of the energy, continuity and state equations to the manifolds. In practice, crank angle is substituted for time as a matter of convenience, because valve operation and fuel injection are single functions of this variable.

5.2.6 Turbocharger, Subsystem 4

The turbocharger is modeled in a quasi-steady-state manner. In effect, the ambient conditions and the thermodynamic conditions in the manifolds are related through the known performance characteristics of the turbo elements. It is assumed that the gas dynamic and thermodynamic performance of both the compressor and turbine at every instant of time is characterized by steady-state performance maps. These performance maps relate the properties of the working fluid at the entrance and exit of the compressor (or turbine) as dependent on the shaft speed and torque. There is an equation of motion, similar to that for the engine crankshaft, to relate the compressor and turbine torques to the turbocharger shaft speed.

The performance map for the compressor is based on constant speed data supplied by Cooper-Bessemer, the turbocharger manufacturer. As noted previously, the compressor data was not complete and must be extrapolated to meet the anticipated performance envelope. This extrapolation process is complete and is represented by the compressor map which is plotted as Figure 2 (page 8). Each curve on that figure represents a constant speed condition which relates corrected mass flow to stage pressure ratio. The data collected in the Cooper-Bessemer test program terminated at 12,000 rpm. We have extended the map to 18,100 rpm using the data from the "bootstrap" tests. We have also fitted intermediate constant speed lines by a least squares error technique. Values of corrected mass flow for conditions of pressure ratio and speed are determined by a linear interpolation method. The expanded map was necessary to interpolate accurately.

Data which represents the compressor efficiency at various speeds and pressure ratios has also been generated from the limited test data. This data is represented by constant speed lines which relate pressure ratio to efficiency by a second order polynomial. Intermediate values are again interpolated by a linear technique. These data are shown as Figure 3 (page 9).

No such data was available for the turbine, so it was necessary to formulate the performance of the turbine in equation form. The equations are based on first principles of fluid mechanics and thermodynamics, and the small amount of information available concerning the turbine. Performance information generated by this method introduces imprecision into the dynamic performance evaluation of the engine. However, the power and torque delivered by the diesel is mainly determined by fuel rate and only secondarily by the behavior of the turbocharger. This fact significantly lessens the overall effect of imprecision in the definition of the behavior of the turbocharger turbine.

5.2.7 Fuel Control, Subsystem 5

The basis for the mathematical model of the fuel control system is a type 2301/LSG control system manufactured by the Woodward Governor Company, shown in Figure 4 (page 10). In this application, the fuel control system is used as an isochronous control of electric frequency. The governor system consists essentially of four separate assemblies shown on Figure 4 (page 10): a frequency sensor, a 2301 control amplifier, a load sensor and amplifier, and a hydraulic actuator. The input signal to the frequency sensor is the generator

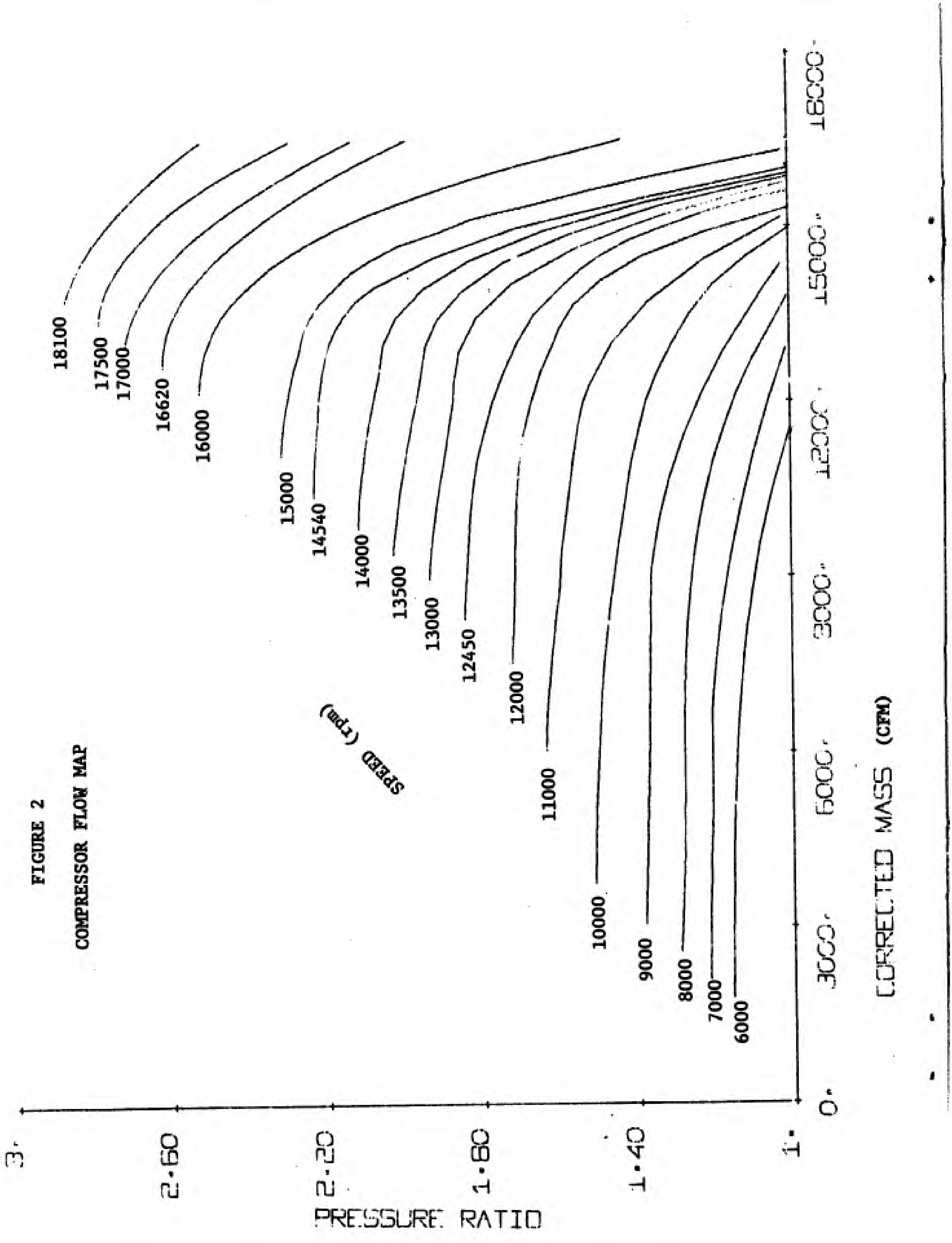
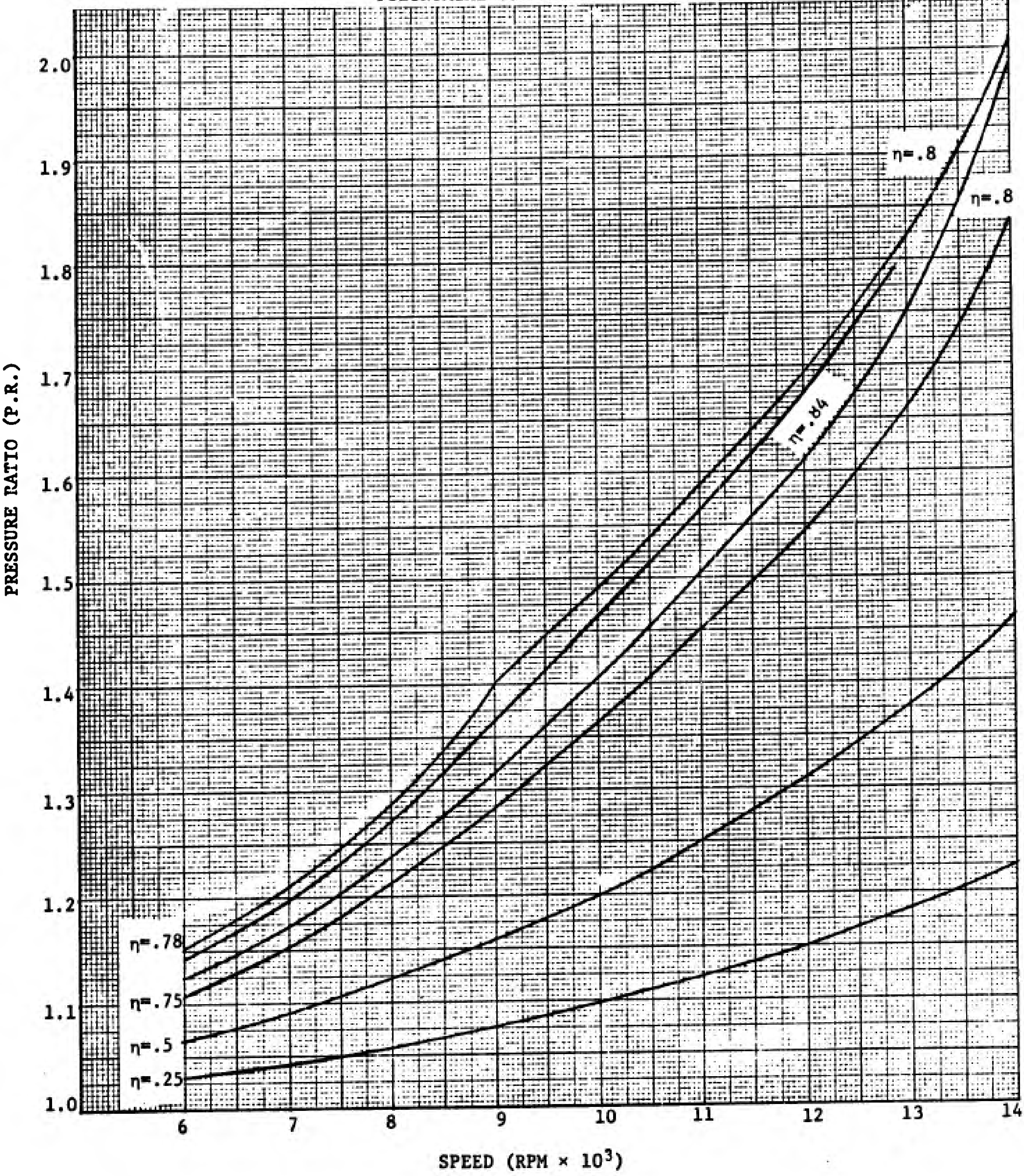


FIGURE 2

COMPRESSOR FLOW MAP

PRESSURE RATIO vs. SPEEDS

AT CONSTANT SPEEDS, (η,P.R.) POINTS USED TO CONSTRUCT POLYNOMIAL CURVE FIT



SCHEMATIC DIAGRAM:

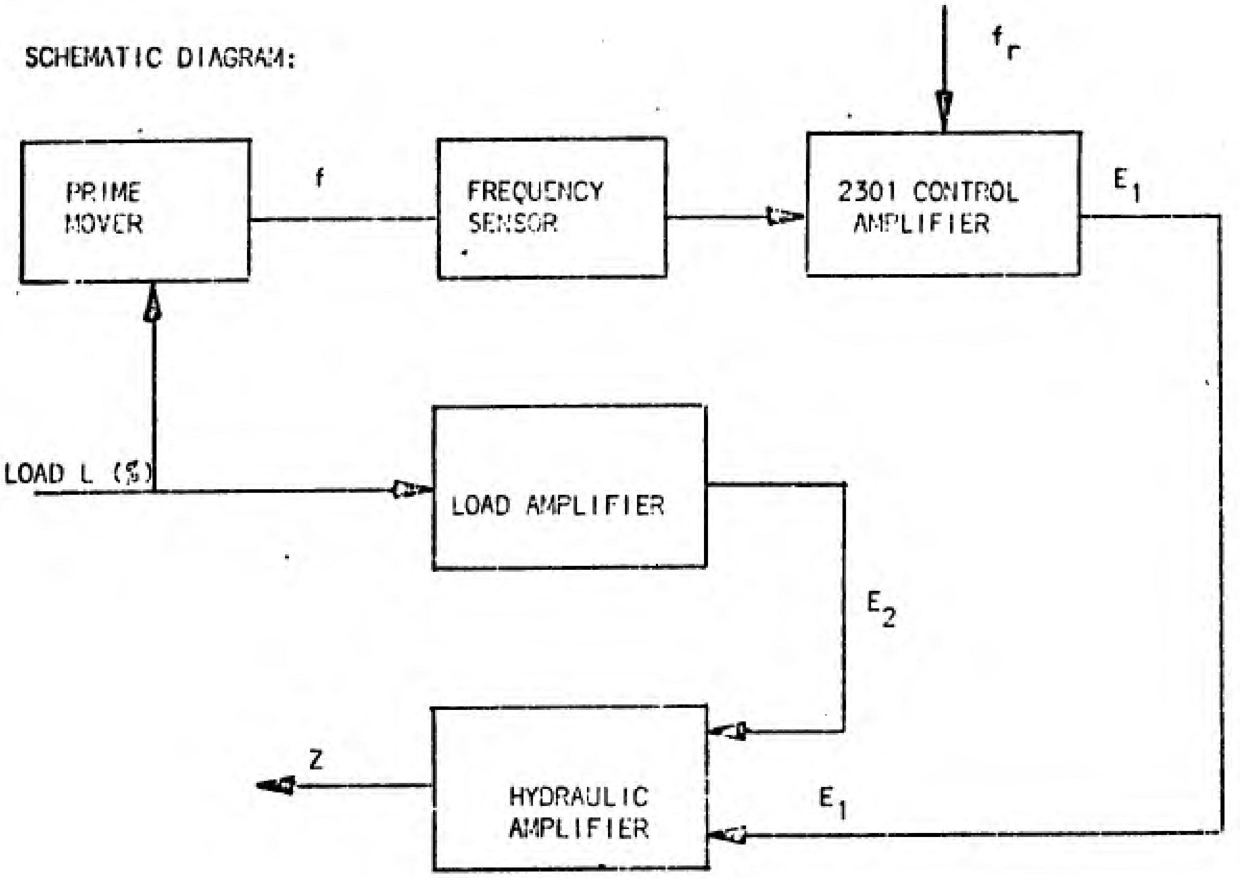


FIGURE 4

ANALYTICAL DESCRIPTION OF 2301/LSG CONTROL SYSTEM (COOPER-BESSEMER) frequency. This frequency is converted to a d-c voltage signal which is compared to a potentiometer voltage in order to obtain an error signal. This error signal, after being suitably amplified, serves as the input to the electro-hydraulic actuator, where it regulates a solenoid coil and piston assembly which controls the flow of hydraulic fluid in the actuator. The actuator, in turn, controls the injector lift position and fuel pressure and thus the fuel injection rate. The load sensor produces an output d-c voltage related to the electrical load and feeds this voltage to the same hydraulic actuator. Thus, the fuel is quickly changed in response to a load change.

Previous work on engine simulation, particularly that related to the testing of the Allison gas turbine (Reference 12), had shown that a precise characterization of the fuel control system was required to provide accurate performance simulations of the prime mover-electric generator system. In particular, this prior work made evident that the use of the mathematical representation provided by the manufacturer together with nominal values for its field-adjustable input variables was not adequate for accurate simulations. Therefore, in the program for testing the Enterprise diesel, the behavior of the fuel control system was determined by application of a more or less standard test. In these tests, the characteristics of the two integral parts of the fuel-governing system--the electronic sensing and control element and the electro-hydraulic actuator--were measured by application of a Model 1410 servo-response analyzer unit manufactured by EMR, Division of Weston Instruments, Inc. This servo-response analyzer applied sine waves at selected frequency as an input stimulus to the system, and measured the sine wave (amplitude and phase) response at the output points of interest in the system. The application of the servo-response analyzer was made separately to the 2301 control amplifier and to the hydraulic actuator units of the Woodward fuel control. The measured response data were then processed by computer to obtain the transfer function characterization in an analytical form (Reference 13).

5.2.8 Manufacturer's Data

Table 1 (page 12) lists the minimum information required to apply this simulation program to the Cooper-Bessemer diesel engine-generator set, or any other specific engine-generator set. This table also describes how and where this information is utilized by the computer program; viz., as input data, as coded FORTRAN statements, or as test data to correlate with values computed by the program. This information was furnished by the engine manufacturer. Since the generator was not modeled in detail, only a minimum of information concerning it

TABLE 1

INFORMATION NEEDED FOR DIESEL ENGINE SIMULATION

1. Bore - INPUT DATA: appears in piston cross-sectional area, A(12), and piston perimeter A(25) in Subsystem 3

2. Stroke and Engine Compression Ratio - INPUT DATA: appear in cylinder clearance volume, A(16); and total displacement volume A(5) in Subsystem 1, and A(17), in Subsystem 3

3. Crankshaft Kinematics - SUBROUTINE TABLE: in Subsystem 3

4. Alternator Frequency and Rated Speed - INPUT DATA: appears in alternator frequency over rated speed, A(2), in Subsystem 2; and rated speed, A(40), in Subsystem 3

   - SUBROUTINE ENVIR: alternator frequency setpoint, G(5)

5. Rated Shaft and Electrical Power - INPUT DATA: rated shaft power, A(3), in Sub 2; rated electrical power, A(7), in Sub 2; rated electrical power, A(19), in Sub 5;

6. BMEP and IMEP - CORRELATION DATA: BMEP, G(48); IMEP, G(49)

7. Brake Specific Fuel Consumption - CORRELATION DATA: BSFC, G(51)

8. Number of Cylinders, Firing Order and Strokes per Cycle - INPUT DATA: number of cylinders, L(1), and four times no. cylinders, L(2), and number of strokes per cycle, L(3), in Subsystem 3; Firing order appears in simultaneous crankshaft angles for cylinders, X(1) to X(20), in Sub 3

9. Total Rotary Inertia for Engine and Generator and Effective Reciprocating Piston Mass - INPUT DATA: total rotary inertia, A(8), in Sub 3; effective reciprocating mass of each piston, A(32) and A(33), in Sub 3

10. Valve Timing Diagrams - INPUT DATA: crank angles for exhaust and inlet valve opening and closing, A(1), A(2), A(4), A(5), in Sub 3

11. Open Area of Inlet and Exhaust Valves Versus Crank Angle on Single Cylinder - FUNCTION AIV, FUNCTION AEV: in Sub 3

12. Inlet and Exhaust Manifold Volumes and Arrangement - INPUT DATA: inlet and exhaust manifold volumes, A(91) to A(100), in Sub 3; cylinders #1 - #20 connected to inlet and exhaust manifold numbers L(31) to L(99), in Sub 3

TABLE 1 (Cont'd.)

13. A Description of the supercharging and/or scavenging system to include a description of the components, their arrangement, and a complete set of performance data for each component (compressor, turbine, or blower) - SUBROUTINE CMAP, FUNCTION DPIC, SUBROUTINE PCLYE, FUNCTION TIC, SUBROUTINE TMAP: in Subsystem 4

    - INPUT DATA: as required in model formulated by above subroutines

14. Cylinder Pressure versus crank angle (or pressure-volume) and temperature versus crank angle diagrams at 100 percent rated power - CORRELATION DATA: peak cylinder pressure, G(15), peak cylinder temperature, G(16); and cylinder pressure and temperature, Y(j) and U(1,j) for j cylinder in Sub 3

15. Description of the fuel injection system including fuel injection rate at the delivery valve of each cylinder versus crank angle for 100 percent power - SUBROUTINE RACK: in Sub 3;

    - INPUT DATA: fuel injection begins (used only at initial time step), A(3), in Sub 3

16. Fuel injection rate as a function of fuel rack position - SUBROUTINE XLIFT: in Subsystem 5

17. A mathematical description of the controller giving the transfer functions describing its response to speed and electrical load, and any other sensed parameter - SUBROUTINE SUB5, SUBROUTINE YPR5: in Subsystem 5

18. Ambient conditions for which performance data pertains (as applicable) - INPUT DATA: nominal ambient pressure, A(63), in Sub 3;

    - SUBROUTINE ENVIR: ambient pressure at inlet, G(10), ambient pressure at exhaust, G(11), and ambient temperature at inlet, G(12)

19. The fraction of the energy in the fuel that appears as mechanical friction, heat transfer from the working cylinder volumes, exhaust heat, - CORRELATION DATA: G(38) to G(43)

was required. Where elements of information are missing from manufacturer's sources, they must be provided by other knowledgeable in the technology of diesel engine design and performance. In addition to the information listed, it is desirable, if not necessary, for accurate simulation to have the performance data of Items 4, 5, 6, 15, 16, and 20 supplied for several off-design operating points, including points above and below rated power. In this specific case of modeling the Cooper-Bessemer diesel, the information supplied by the manufacturer was refined and added to during the test program at the Cooper-Bessemer Plant in Grove City, Pennsylvania.

5.2.9 Tuning of the Simulation Program

After all the known algorithms and operating data have been programmed either as FORTRAN coding or input data, the simulation computer program should be tuned by a series of initial runs. The extent of tuning depends on the amount of manufacturer's data available for comparison with the computed values.

The minimum amount of test data required for tuning the diesel-generator simulation is Brake Mean Effective Pressure (Item 6, Table 1), Indicated Mean Effective Pressure (Item 6), and Brake Specific Fuel Consumption (Item 7). These values are correlated with output appearing in the G array while simulating a constant electrical load, i.e., "steady-state." It is desirable to also compare the computed energy balance with measured values. The energy balance based on percentage fuel energy is printed in positions G(38) to G(43) of the G array. This is illustrated in Table 13 (page 73) with a detailed description of the G array on pages 84 to 88.

If transient data is provided, additional tuning of the simulation can be performed for load change operation. Adjusting the coefficients for the fuel control transfer functions, spring constant and frictional force in fuel linkage, and burning rate can significantly alter the transient response, i.e., frequency error, of the simulation. It is preferable to determine the burning rate from steady-state tuning.

Table 2 on page 15 summarizes the tuning variables for steady-state and transient simulation operation.

Once the simulation program is operating properly at one steady-state electrical load, it is easier to achieve steady state at a new load by a load change rather than estimating a new set of input values. Input data for load change runs are set in the A array of SUB2 (See page 98). If the simulation has not

TABLE 2

COOPER-BESSEMER LSV-16 DIESEL ENGINE SIMULATION TUNING

Simulation Component	Tuning Variable	Input Variable	*Subsystem	Primary Correlation Parameters Affected	Output	Influence of Increase In Tuning Variable
Diesel (steady-state)	cylinder wall heat transfer coefficient	A(9)	3	heat balance	G(38-43)	to dissipate larger percentage of fuel energy to cylinder walls
	burning rate	A(10)	3	heat balance, Brake Specific Fuel Consumption (B.S.F.C.)	G(38-43), G(51)	to decrease exhaust temperature, increase efficiency of engine which results in smaller B.S.F.C.
	fricition coefficient	A(36)	3	heat balance, brake work	G(38-43), G(46)	increase energy loss to friction
	exhaust manifold heat transfer coefficient	A(52)	3	heat balance	G(38-43)	to dissipate more heat in exhaust manifold
	exhaust and inlet value coefficients	A(58),A(59)	3	B.S.F.C.	G(51)	to decrease B.S.F.C. by increasing brake work
Turbocharger (steady-state)	turbine and compressor efficiency adjustment factors	A(3),A(4)	4	B.S.F.C.	G(51)	to decrease B.S.F.C.
Fuel Control (transient)	governor constants	A(7-12), A(16-18), A(20-22)	5	frequency error	G(4)	(requires detailed analysis of transfer function terms)
	fuel linkage spring constant	A(3)	5	frequency error	G(4)	to decrease frequency error during load change
	fuel linkage friction constant	A(4)	5	frequency error	G(4)	to increase deadtime in linkage

*Refer to Input Data Description (page 54) achieved a good steady-state at the end of this load change run, the user can use the punched cards for the Y array in SUB3, and the computer printout to resubmit a new steady-state run. The punch option is controlled by L(14) in the MAIN as shown on page 92.

A checklist of input data required to describe simulation of a new electrical load is presented in Table 3, page 17. This checklist assumes the user is satisfied with the previous steady-state tuning variables and they are held constant. The tuning variables (Table 2, page 15) are assumed to be dependent on the hardware and not change for new electrical loads.

When tuning the program for steady-state operation prior to standard air-shock simulations, L(7) in the MAIN input deck should be set to 2. The program shall then use ambient conditions input by cards rather than set in subroutine ENVIR. The current version of ENVIR contains ambient conditions for the factory tests at Cooper-Bessemer, Grove City, Pennsylvania, for June 21, 1972. Other options with the variable L(7) are presented on page 92. Table 4 on page 18 contains a checklist for transient simulation runs.

5.3 MATHEMATICAL EQUATIONS

The equations that follow are those which have been coded in the computer program simulating the Cooper-Bessemer model LSV-16 diesel engine. These relationships provide the basis for the mathematical model and have been displayed here in the building block format consistent with the program structure. A schematic of the system is shown on Figure 5 (page 20).

5.3.1 Nomenclature

A	area, in^2
A, A', B, B'	fuel controller constants, rad-sec^{-1} and (rad-sec^{-1})^2
AF	air-fuel ratio, dimensionless
a, b	polynomial coefficients
C_p	specific heat of gas at constant pressure, in-lbf-lbm^{-1}-°R^{-1}
C_v	specific heat of gas at constant volume, in-lbf-lbm^{-1}-°R^{-1}

TABLE 3

CHECKLIST OF INPUT DATA CHANGES TO SIMULATE STEADY-STATE AT A NEW ELECTRICAL LOAD

Subsystem		Input Data
MAIN	-	coefficients for equation of motion, G(24)-G(27)
	-	inlet and exhaust manifold pressures, G(61)-G(84)
	-	total compressor mass flow, G(58)
SUB1	-	no changes required
SUB2	-	shaft power required and electrical load, A(5) and A(8)
SUB3	-	crankshaft angles, X(1)-X(16); advise starting all runs with X(1) = 0° crank
	-	all values describing states of gases in the cylinders and exhaust manifolds, Y(1-90); advise using punched output from previous run at or near same percent load. Be sure that these data were punched when cylinders positioned as above, i.e., X(1) = 0°
SUB4	-	turbocharger shaft speed for initial load condition, Y(1)
SUB5	-	initial fuel control settings to give desired actuator position, Y(1)-Y(9), Y(11)

TABLE 4

CHECKLIST OF INPUT DATA TO SIMULATE LOAD CHANGE AND/OR OVERPRESSURE CONDITIONS

Subsystem		Input Data
1. FACTORY TEST LOAD CHANGE		
MAIN	-	flag for ambient conditions, L(7) = 0
	-	length of run, A(2)
SUB1	-	no changes required
SUB2	-	time when load changes, A(4)
	-	fraction of rated shaft power before and after load change, A(5) and A(6)
	-	fraction of rated electrical power before and after load change, A(8) and A(9)
SUB3	-	no changes required
SUB4	-	no changes required
SUB5	-	no changes required
2. STANDARD CONDITIONS AIRSHOCK AND/OR LOAD CHANGE		
MAIN	-	flag for ambinet conditions, L(7) = 2
	-	length of run, A(2)
	-	ambient temperature about inlet before shock, A(39)
	-	time at beginning of inlet shock, A(39)
	-	time inlet shock reaches peak value, A(40)
	-	time at beginning of inlet shock decay, A(41)
	-	time at end of inlet positive phase, A(42)
	-	ambient pressure about inlet before shock, A(43)
	-	peak pressure of inlet shock, A(44)
	-	time at beginning of exhaust shock, A(45)
	-	time exhaust shock reaches peak value, A(46)
	-	time at beginning of exhaust shock decay, A(47)

TABLE 4 (cont'd.)

Subsystem		Input Data
MAIN		time at end of exhaust positive phase, A(48)
	-	ambient pressure about exhaust before shock, A(49)
	-	peak pressure of exhaust shock, A(50)
SUB1	-	no changes required
SUB2	-	time when load changes, A(4)
	-	fraction of rated shaft power before and after load change, A(5) and A(6)
	-	fraction of rated electrical power before and after load change, A(8) and A(9)
SUB3	-	no changes required
SUB4	-	no changes required
SUB5	-	no changes required

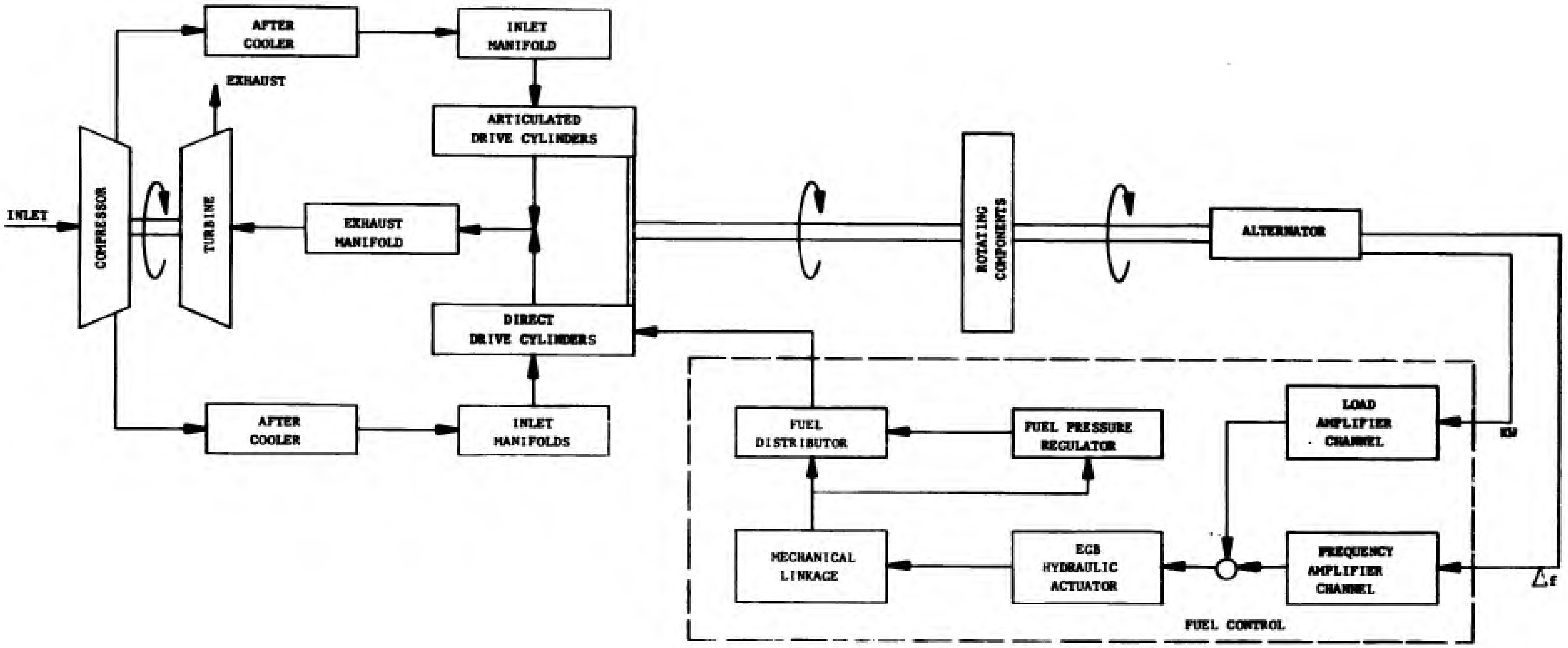


FIGURE 5

SCHEMATIC OF LSV-16 ENGINE

C_1, C_2	constants used in fuel control analysis, dimensionless
D	differential operator, d/dt, sec^{-1}
d	piston diameter, in
E	energy, in-lbf
E_1	voltage input to fuel control electronic unit, volt
E_2	variable used in fuel control analysis, volt-rad-sec^{-1}
E_{2a}	variable used in fuel control analysis, volt-rad^2-sec^{-2}
E_{31}, E_{32}	variables used in fuel control analysis, volt
ER	energy released from fuel, in-lbf-lbm^{-1}
e	eccentric distance between slave rod connection and master rod connection to crankshaft, in.
F	Coulomb (frictional) force
FR	fuel rate, lbm-hr
f	generator frequency, Hz, or friction coefficient, lbf-sec-in^{-1}
G	gain for fuel control electronic unit, (volts-Hz^{-1})$(rad\text{-}sec^{-1})^4$
G'	gain for fuel control hydraulic unit, (deg-$volt^{-1}$)$(rad\text{-}sec^{-1})^2$
g_o	gravity constant, lbm-in-lbf^{-1}-sec^{-2}
h	heat transfer coefficient, lbf-sec^{-1}-in^{-1}-$°R^{-1}$, or specific enthalpy, in-lbf-lbm^{-1}
I	polar moment of inertia, in-lbf-sec-rad^{-1}
i	electric current, amp
J	dimensional constant, in-lbf-Btu^{-1}

K_A	constant, rad^4-sec^{-4}
KW	generated electrical power, kw
K_o	dimensional constant, in-lbf-$sec^{-1}HP^{-1}$
K_3	fuel burning constant, sec^{-1}
k	ratio of specific heats, dimensionless
L	master rod length, in.
LHV	lower heating value of fuel, in-lbf-lbm^{-1}
ℓ	articulated rod length, in
M_p	mass of piston, lbm
m	mass, lbm
$\dot{m}$	rate of change of mass and mass rate of flow, lbm-sec^{-1}
N	angular velocity of crankshaft, rpm
N_c	number of cylinders
N_s	number of strokes per cycle
N_t	turbocharger speed, rpm
N_t^*	turbocharger corrected speed, rpm
P	pressure, lbf-in^{-2}
Q	energy, Btu or in-lbf
R	gas constant, in-lbf-lbm^{-1}-°R^{-1}
R	crank radius of master connecting rod, in
R_ℓ	electric load resistance, ohm
S	length of piston travel, in, where S = 0 at Top Dead Center
T	temperature, °R
t	time, sec

U	internal energy, Btu or in-lbf, or variable used in fuel control analysis, volt-rad^3-sec^{-3}
u	specific internal energy, in-lbf-lbm^{-1}, or mean blade velocity for turbine, in-sec^{-1}
V	volume, in^3
V_5	fluid velocity from turbine stator, in-sec^{-1}
v	electric voltage, volt
W_c^*	compressor corrected mass flow, lbm-sec^{-1}
x	products of combustion expressed as fraction of gas charge, dimensionless
Z	injector lift, in
α	polynomial coefficient
γ_1	constant, volt-Hz^{-1}
η	efficiency, dimensionless
θ	crankshaft angle, degrees
θ_1	potentiometer output for hydraulic actuator, volts
θ_2	potentiometer output for fuel door, volts
τ	torque, in-lbf
τ	time constant in frequency display channel, seconds
ϕ	hydraulic actuator output, deg., or u/V_5, dimensionless
ω	angular velocity of crankshaft, rad-sec^{-1}
ω_t	angular velocity of turbocharger shaft, rad-sec^{-1}

Subscripts

a	articulated (slave) connecting rod assembly
ae	ambient about turbocharger exhaust
ai	ambient about turbocharger intake

ak	crankcase
aux	auxiliaries
b	base
c	cylinder, or compressor
com	compressor exit
D	displacement
d	developed, or delay
e	exhaust
em	exhaust manifold
ev	exhaust valve
ex	exhaust
f	friction, or fuel
fb	burning fuel
fi	injected fuel
g	gas
HT	heat transfer
i	in, or inertia
ic	intercooler
im	inlet manifold
iv	inlet valve
j	cylinder number
m	master connecting rod assembly
n	normal conditions
o	rated conditions, or out
p	products, or piston
pk	peak

r	reactants
s	load, or isentropic
t	turbocharger, or turbocharger turbine
w	wall
+	positive phase
5	station at turbine stator exit

Superscripts

'	differential operator, d/dθ
.	differential operator, d/dt
*	corrected or normalized quantity

5.3.2 Ambient and Load Conditions, Environment

As described in Section 5.2.2, there exists, at this time three ways to establish engine inlet pressure and temperature and exhaust pressure. One of these options is to generate a standard airshock.

The overpressure decay is described by the equation:

$$P(t) = P_{pk} (1 - t/t_{+}) e^{-t/t_{+}}$$

where $P(t)$ is the overpressure (at either inlet or exhaust) at any time t after the arrival of the shock front, P_{pk} is the peak overpressure, and t_{+} is the duration of the positive phase. The inlet temperature is calculated according to the expression:

$$\frac{T(t)}{T_{aio}} = \frac{\frac{P(t)}{P_{aio}} \left[1 + \frac{k-1}{k+1} \frac{P(t)}{P_{aio}} \right]}{\frac{P(t)}{P_{aio}} + \frac{k-1}{k+1}}$$

where $T(t)$ is the inlet temperature at time t. The values of the ramp rate, the duration of the peak overpressure, the duration of the positive phase, and the relative timing of the inlet and exhaust overpressure are input via data cards.

5.3.3 Shaft Motion, Subsystem 1

The equation of motion required to relate the cylinder pressures to changes in crankshaft speed can be expressed as:

$$\frac{d\omega}{d\theta} = \frac{\sum_j \left[(P_{cj} - P_{ak}) A_p S_j' - f\omega (S_j')^2 - \frac{M_p}{g_o} \omega^2 S_j' S_j'' \right] - \tau_s - \tau_{aux}}{\frac{I}{g_o} \omega + \Sigma \frac{M_p}{g_o} \omega (S_j')^2}$$

where S is linear piston motion, and the summation is carried out with respect to each cylinder j. This equation of motion takes into account the rotary inertia of the crankshaft, the inertia of the pistons, and the friction torque, which is expressed as

$$\tau_f = \sum_j f\omega (S_j')^2$$

The formulation of friction torque is based on the assumption that the friction losses take place between the piston and cylinder, and that the friction drag is proportional to piston speed.

The equation of motion shown above appears in the computer program as:

$$\frac{d\omega}{d\theta} = \frac{a - b*\omega - c*\omega^2 - \tau_s - \tau_{aux}}{d*\omega}$$

where

$$a = \sum_j (P_{cj} - P_{ak}) ApS'j$$

$$b = \sum_j f\omega (S'j)^2$$

$$c = \sum_j \frac{M_p}{g_o} S' S''$$

$$d = \frac{I}{g_o} + \sum_j \frac{M_p}{g_o} (S_j')^2$$

The following equations are used to compute the energy balance. The equations are set up in terms of energy rates, or power, and integrated over a cycle as follows:

$$Q = \int_{0}^{4\pi} \frac{\dot{E}}{\omega} \, d\theta$$

so as to yield the energy which goes into a specific function during each cycle. These energy equations are:

$$\dot{Q}_w = \sum_j h_c A_{HTj} (T_{cj} - T_w)$$

$$\dot{Q}_f = \sum_j f (\omega S_j')^2$$

$$\dot{Q}_{ex} = C_p \dot{m}_e (T_e - T_{ai})$$

$$\dot{Q}_{ic} = C_p \dot{m}_e (T_{com} - T_{ic})$$

$$\dot{Q}_{em} = A_{em} h_{em1} (T_{em1} - T_{wem}) + A_{em} h_{em2} (T_{em2} - T_{wem})$$

$$\dot{Q}_{in} = \dot{m}_{fi} (LHV)$$

$$\dot{Q}_s = \tau_d \omega$$

where:

$$\tau_d = \tau_g - \tau_f - \tau_i$$

$$\tau_g = \sum_j (P_{cj} - P_{ak}) A_p S_j'$$

$$\tau_f = \sum_j f (S_j')^2$$

$$\tau_i = \sum_j M_p \left[(S_j')^2 \dot{\omega} + S_j' S_j'' \omega^2 \right]$$

and the summation is carried out over all cylinders j. The following performance indices are calculated using the integrated energies outlined above:

$$\text{B.h.p.} = Q_s\ \omega J/\pi\ K_o\ N_c$$

$$\text{I.h.p.} = (Q_s + Q_f)\ \omega J/\pi\ K_o\ N_c$$

$$\text{B.m.e.p.} = Q_s\ J/V_D$$

$$\text{I.m.e.p.} = (Q_s + Q_f)\ J/V_D$$

$$FR = 3600\ Q_{in}\ \omega J/\pi\ N_c\ (LHV)$$

5.3.4 Alternator, Subsystem 2

The alternator has been modeled simply as a load requiring constant power. As such, there is little computation and no integration performed in this subsystem. Alternator torque and frequency are calculated as follows:

If time is before that at which the load change occurs

$$\tau_s = \frac{Eo}{\omega}$$

If time is equal to or after that at which the load change occurs

$$\tau_s = \frac{Eofo}{\omega}$$

where fo is the frequency setpoint, and in this case frequency is calculated as:

$$f = fo\ \frac{\omega}{\omega_o}$$

The current program computes a delayed frequency in an attempt to simulate the slow frequency sensor used for data display during the factory tests at Cooper-Bessemer, Grove City, Pennsylvania, on June 21, 1971. This displayed frequency was not sensed by the fuel control electronics but was recorded as test data. The frequency display channel is represented by the simple transfer function:

$$\Delta f_d = \Delta f/(D\tau + 1)$$

5.3.5 Diesel Engine, Subsystem 3

As previously discussed, the application of the energy equation, a continuity equation, and an equation of state to each cylinder and manifold is necessary to define the condition of the working fluid in each of these systems at all instants of time. To compute the torque-speed characteristic of the engine, we must, in addition, apply the kinematic-dynamic relations for crank action taking account of friction torque. Relations governing the flow into and out of cylinders and manifolds are also required. The development of all the governing equations can be found in standard texts on thermodynamics, gas dynamics, heat transfer, and mechanics (References 4-7). Special forms useful to engine design and analysis appear in any number of papers and texts on internal combustion engine (References 3, 8-10). Accordingly, the forms we use will be briefly summarized.

The energy equation applied to open system:

$$\frac{dQ}{dt} - \frac{PdV}{dt} = \frac{dU}{dt} + \Sigma\, \dot{m}_o H_o - \Sigma\, \dot{m}_i h_i$$

With combustion:

$$\frac{dE}{dt} = \frac{dU_p}{dt} - \frac{dU_r}{dt}$$

Without combustion:

$$\frac{dU}{dt} = \frac{d}{dt}(mu)$$

Heat transfer:

$$\frac{dQ}{dt} = h\, A_{HT}\, (T_c - T_w)$$

The continuity equation applied to open system:

$$\frac{dm}{dt} = \dot{m}_i - \dot{m}_o$$

Perfect gas relations:

$$PV = mRT$$

$$C_p - C_v = R$$

$$\frac{C_p}{C_v} = k$$

$$h = C_p T$$

$$u = C_v T$$

Isentropic compressible flow through an orifice:

$$\dot{m} = \frac{AP_1}{\sqrt{T_1}} \sqrt{\frac{2g_o k}{R(k-1)}} \left(\frac{P_2}{P_1}\right)^{1/k} \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right]^{1/2} \quad \text{for } \frac{P_2}{P_1} \geq 0.53$$

$$\dot{m} = \sqrt{\frac{kg_o}{R}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \frac{AP_1}{\sqrt{T_1}} \quad \text{for } \frac{P_2}{P_1} < 0.53$$

Gas composition within volume under conditions of perfect mixing:

$$\frac{dx}{dt} = \frac{\Sigma x_i \dot{m}_i - \Sigma x_o \dot{m}_o - x \frac{dm}{dt}}{m}$$

By combination and manipulation of the above-listed basic thermodynamic and fluid dynamic equations, we arrive at a set of equations suitable for describing the processes occurring in the cylinders and manifolds of a multi-cylinder, turbocharged diesel engine. These equations are written for the most general case, and thus will describe processes occurring during the intake, compression, fuel injection, combustion, expansion, exhaust, and scavenge parts of the cycle. It should be pointed out that some terms are zero during parts of the cycle.* All operations common to both two-and four-cycle engines are present. Crank angle is taken as the independent variable relating all events in the cylinders and manifolds. The following equations, where the superscript ' indicates d/dθ, describe processes occurring in a cylinder:

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*The fact that some terms are zero during parts of the cycle is illustrated clearly in Figures IV-1 to IV-3 of Reference 11. Contrary to the note in Figure IV-1, the flows, $\dot{m}$, as used in the current analysis, are always signed quantities. It should be noted also that some of the equations in these figures do not apply to a turbocharged engine.

$$P_c' = \frac{k - 1}{\omega V_c} \left[- h_c A_{HT} (T_c - T_w) + (ER)(m_{fb}') \right] - \frac{k}{V_c} P_c V_c'$$

$$+ \frac{RkT_1}{V_c} m_{iv}' - \frac{RkT_2}{V_c} m_{ev}'$$

where:

$$\begin{aligned} T_1 &= T_{im} & P_c &\leq P_{im} \\ &= T_c & P_c &> P_{im} \\ T_2 &= T_c & P_c &\geq P_{em} \\ &= T_{em} & P_c &< P_{em} \end{aligned}$$

$$m_c' = m_{fb}' + m_{iv}' - m_{ev}'$$

$$x_c' = \frac{m_{fb}'}{m_c} \left[1 + AF - x_c \right] + \frac{m_{iv}'}{m_c} \left[x_{im} - x_c \right] - \frac{m_{ev}'}{m_c} \left[x_{em} - x_c \right]$$

$$m_f' = m_{fi}' - m_{fb}'$$

$$T_c = \frac{P_c V_c}{m_c R}$$

The flow through the valves is described as follows:

$$m_{iv}' = 2.05 \frac{A_{iv} P_{im}}{\omega \sqrt{T_{im}}} \left[\frac{P_c}{P_{im}} \right]^{1/k} \left[1 - \left(\frac{P_c}{P_{im}} \right)^{\frac{k-1}{k}} \right]^{1/2} \qquad 0.53 P_{im} \leq P_c \leq P_{im}$$

$$= 0.532 \frac{A_{iv} P_{im}}{\omega \sqrt{T_{im}}} \qquad P_c < 0.53 P_{im}$$

$$= -2.05 \frac{A_{iv} P_c}{\omega \sqrt{T_c}} \left[\frac{P_{im}}{P_c}\right]^{1/K} \left[1 - \left(\frac{P_{im}}{P_c}\right)^{\frac{k-1}{k}}\right]^{1/2} \qquad 0.53\, P_c \leq P_{im} < P_c$$

$$= -0.532 \frac{A_{iv} P_c}{\omega \sqrt{T_c}} \qquad P_{im} < 0.53\, P_c$$

$$m'_{ev} = 2.05 \frac{A_{ev} P_c}{\omega \sqrt{T_c}} \left[\frac{P_{em}}{P_c}\right]^{1/k} \left[1 - \left(\frac{P_{em}}{P_c}\right)^{\frac{k-1}{k}}\right]^{1/2} \qquad 0.53\, P_c \leq P_{em} \leq P_c$$

$$= 0.532 \frac{A_{ev} P_c}{\omega \sqrt{T_c}} \qquad P_{em} < 0.53\, P_c$$

$$= -2.05 \frac{A_{ev} P_{em}}{\omega \sqrt{T_{em}}} \left[\frac{P_c}{P_{em}}\right]^{1/k} \left[1 - \left(\frac{P_c}{P_{em}}\right)^{\frac{k-1}{k}}\right]^{1/2} \qquad 0.53\, P_{em} \leq P_c < P_{em}$$

$$= -0.532 \frac{A_{ev} P_{em}}{\omega \sqrt{T_{em}}} \qquad P_c < 0.53\, P_{em}$$

The numerical coefficients given are applicable only to the inch, pound force, pound mass, second, degree Rankine system of physical units which has been used in this analysis. The valve areas A_{ev} and A_{iv} are computed from crankshaft angle by means of least square fits of the valve area curves provided by the engine manufacturer.

The processes in the inlet manifold are described by:

$$P'_{im} = \frac{kR}{\omega V_{im}} \left[T_3\, m'_i - \Sigma\, T_4\, m'_{iv}\right]$$

where:

$$T_3 = T_{ic} \qquad \dot{m}_i \geq 0$$

$$= T_{im} \qquad \dot{m}_i < 0$$

$$T_4 = T_{im} \qquad P_{im} \geq P_c$$

$$= T_c \qquad P_{im} < P_c$$

and the summation is over all of the inlet valves.

$$m'_{im} = m'_i - \Sigma\, m'_{iv}$$

$$x'_{im} = \frac{m'_i}{m_{im}} x_{im} - \Sigma \frac{m'_{iv}}{m_{im}} (x_c - x_{im})$$

$$T_{im} = \frac{P_{im} V_{im}}{m_{im} R}$$

The processes in each of the exhaust manifolds are similarly described by:

$$P'_{em} = \frac{kR}{\omega V_{em}} \left[- T_5\, m'_e + \Sigma\, T_6\, m'_{ev} \right] + \frac{k-1}{\omega V_{em}} (- h_{em} A_{em})(T_{em} - T_{wem})$$

where:

$$T_5 = T_{em} \qquad m'_i \geq 0$$

$$= T_{ae} \qquad m'_i < 0$$

$$T_6 = T_c \qquad P_c \geq P_{em}$$

$$= T_{em} \qquad P_c < P_{em}$$

and the summation is over all of the exhaust valves connected to a particular manifold. The last term in the pressure equation takes into account the change in pressure due to heat transferred from the exhaust manifold gases to the water jacket surrounding the exhaust manifold.

$$m'_{em} = - m'_e + \Sigma\, m'_{ev}$$

$$x'_{em} = \frac{m'_e}{m_{em}} x_{em} + \Sigma \frac{m'_{ev}}{m_{em}} (x_c - x_{em})$$

$$T_{em} = \frac{P_{em} V_{em}}{m_{em} R}$$

The following equations are used to automatically adjust, as desired, the coefficients determining the friction loss and the heat transferred to the cylinder walls in order to match computed steady-state performance with energy balance data supplied by the manufacturer. The friction coefficient is determined by:

$$f_o = \frac{\dot{Q}_{fo}}{\dot{Q}_{fx}} f_x$$

where $\dot{Q}_{fx}$ is the energy loss corresponding to an arbitrarily chosen (or the last computed coefficient) coefficient f_x, and f_o corresponds to the desired energy loss, $\dot{Q}_{fo}$. The analogous equation for cylinder heat transfer coefficient is:

$$h_{co} = \frac{\dot{Q}_w}{\dot{Q}_{wx}} h_{cox}$$

In both of these equations, the energy loss rates are expressed in terms of a percentage of the power equivalent of the incoming fuel.

The equation for adjusting the heat transfer coefficient during transient conditions has been expressed as:

$$\frac{h_c}{h_{co}} = \left(\frac{m_c \ \omega}{m_{co} \ \omega_o}\right)^{0.8}$$

The heat transfer coefficient characterizing the flow of heat from the exhaust manifold gas to the water jacket surrounding the exhaust manifold has been handled in a similar manner:

$$\frac{h_{em}}{h_{emo}} = \left(\frac{\dot{m}_e}{\dot{m}_{eo}}\right)^{0.8}$$

The general form of the fuel injection schedule for a cylinder is shown in Figure 6 (page 35). Fuel injection begins somewhat before top dead center, the injection rate rises linearly to a maximum, remains constant for a period, and then decays linearly.

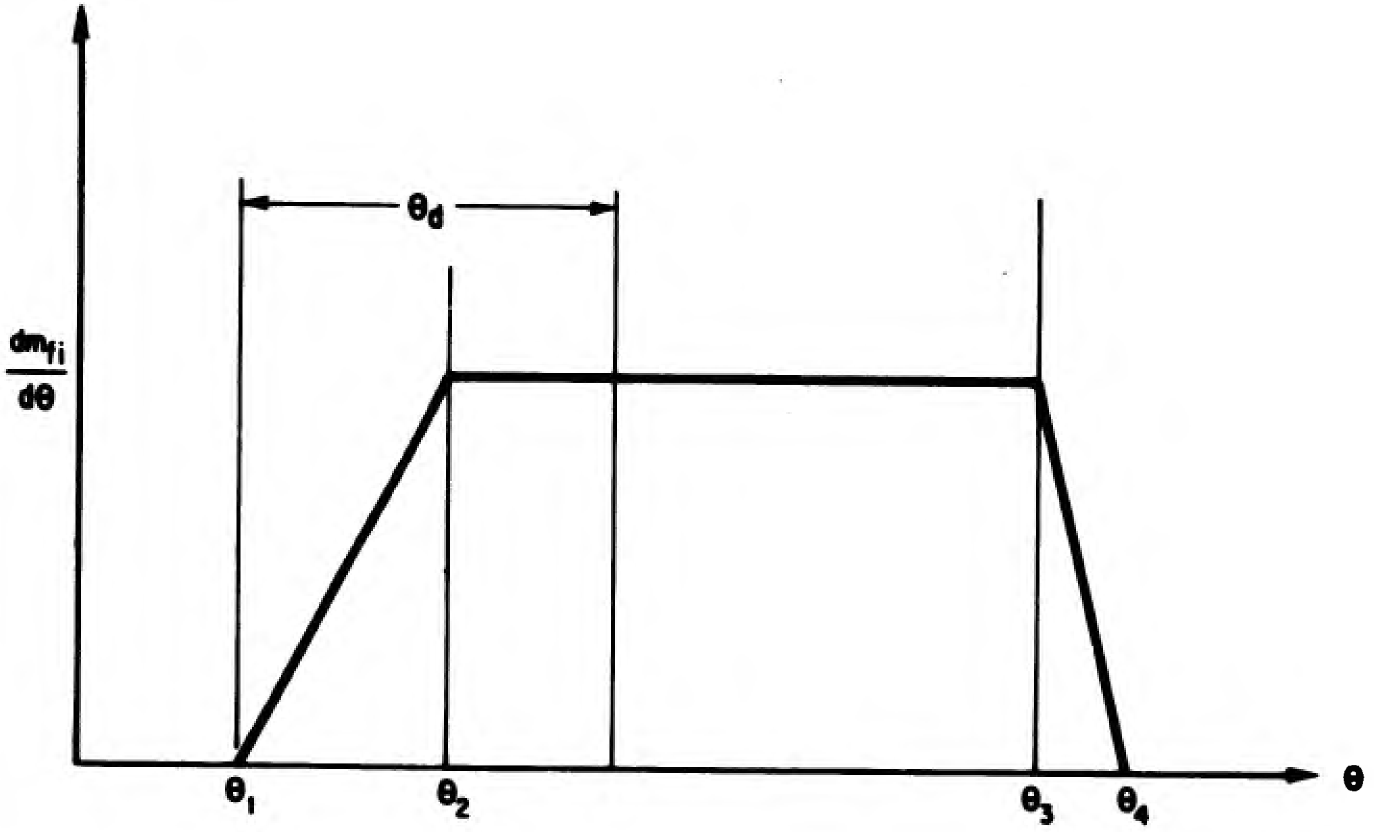


FIGURE 6 FUEL INJECTION SCHEDULE

After the fixed delay, the burning rate thereafter is proportional to the product of the unburned fuel in the cylinder and a function of the air-fuel ratio. That is:

$$\dot{m}_{fb} = K_3 \, m_f \left[1 - e^{\frac{-(1 - x_c) \, m_a}{45 \, m_f}} \right]$$

The delay time under conditions of environmental transients is adjusted in accordance with the relation:

$$\theta_d = \theta_{dn} \frac{P_{imn}}{P_{im}}$$

expressed in terms of crankshaft angle. This latter equation results from the assumption that the delay time of a given diesel-fueled engine is determined by mass and heat transfer to-and-from the fuel droplets and a subsequent simplification of the relationship which governs these transport phenomena.

The constant, K_3, the normal delay time and the cylinder heat transfer coefficient are adjusted to get a best match between experimental and computed indicator cards for a rated power condition.

In the Cooper-Bessemer LSV-16 diesel, the angles θ_2 and θ_3 are computed as functions of the injector position. These functions were obtained from polynomial curve fits by the least squares method using injection timing data supplied by the engine manufacturer. These data were from fuel injector bench tests conducted by Cooper-Bessemer. The injection rate ramp, $\theta_2 - \theta_1$, is set as constant; $\theta_4 - \theta_3$ is computed from a linear least squares curve fit to test data recorded on June 21, 1971 at Cooper-Bessemer.

The total fuel delivered during a single injection is the integrated area under the fuel injection schedule.

$$m_{fi} = \int_{\theta_1}^{\theta_4} \frac{dm_{fi}}{d\theta} \, d\theta$$

This simply reduces to:

$$m_{fi} = \frac{1}{2} (\theta_2 - \theta_1) \left(\frac{dm_{fi}}{d\theta} \right)_{max} + (\theta_3 - \theta_2) \left(\frac{dm_{fi}}{d\theta} \right)_{max} + \frac{1}{2} (\theta_4 - \theta_3) \left(\frac{dm_{fi}}{d\theta} \right)_{max}$$

The value $\left(\frac{dm_{fi}}{d\theta}\right)_{max}$ is the top of ramp fuel rate for a single cylinder.

The mass fuel rate for the LSV-16, $\dot{m}_{fi}$, was determined by actual weight measurements of fuel consumed during the tests at Cooper-Bessemer (June 1971). Since the fuel injector pump pressure for the bench tests was different than the on-site engine, these test data were used in lieu of the manufacturer's specified fuel rate curves. However, it should be noted that the injection timing data are singularly a function of the hardware, viz., kinematics of fuel cam, and were applicable. The top of ramp fuel rate is determined from the total fuel consumption and injection timing by:

$$\left(\frac{dm_{fi}}{d\theta}\right)_{max} = \frac{N_s \dot{m}_{fi}}{2N_c \left(\frac{\omega}{2\pi}\right)\left(\theta_3 - \theta_2 + \frac{1}{2}(\theta_2 - \theta_1 + \theta_4 - \theta_3)\right) \frac{2\pi}{360}}$$

It should be noted that to adapt the above equation to a new engine only, the algorithms for fuel consumption, $\dot{m}_{fi}$, and injection timing, θ_1, θ_2, θ_3, θ_4, require revision.

In Figure 6 (page 35), θ_d represents the ignition delay angle.

The algorithm for fuel rate is programmed as:

$$\dot{m}_{fi} = -.02027 + 4.55788Z + 123.07835Z^2$$

The last relationship involved in the injection and combustion processes is a correction to the lower heating value of the fuel which takes into account the differences between the combustion process in the cylinder and the laboratory methods used to measure the lower heating value. This expression for the effective energy released by the fuel during combustion is:

$$ER = LHV + a_1 (T_c - T_b) - a_2 (T_c - T_b)^2$$

The form of this equation results from the fitting of a second order curve in $T_c - T_b$ to the results of a thermodynamic analysis of the combustion process.

To evaluate the equation of motion, it is necessary to describe the piston kinematics as a function of crank position. The kinematics for the Cooper-Bessemer LSV-16 Diesel involve master and articulated (slave) power rods. This connecting rod assembly is illustrated by Figures 7 (page 39) and 8 (page 40) which were forwarded to ADL. The mathematic equations describing this geometry are shown below.

Master (left bank) connecting rods:

$$S = S_m, \; S' = S'_m, \; S'' = S''_m$$

where:

$$S_m = R + L - R \cos \theta - (L^2 - R^2 \sin^2 \theta)^{1/2}$$

$$S'_m = R \sin\theta + 1/2(L^2 - R^2 \sin^2 \theta)^{-1/2} R^2 \sin 2\theta$$

$$S''_m = R \cos\theta + R^2 \cos 2\theta (L^2 - R^2 \sin^2 \theta)^{-1/2} + R^4 \sin^2 \theta \cos^2 \theta (L^2 - R^2 \sin^2 \theta)^{-3/2}$$

Articulated (right bank) connecting rods:

$$S = S_a, \; S' = S'_a, \; S'' = S''_a$$

where:

$$S_a = R + e + \ell - (R \cos (\theta + \beta) + e \cos (\beta - \phi - \infty) + \ell \cos \Psi)$$

$$S'_a = R \sin(\theta + \beta) + \frac{R^2}{2L^2} e \cos(\beta - \alpha) \left(1 - \frac{R^2}{L^2} \sin^2\theta\right)^{-1/2} \sin 2\theta$$

$$- \frac{R}{L} e \sin(\beta - \alpha) \cos\theta + \ell (1 + \eta^2)^{-3/2} \frac{\partial\eta}{\eta_{\partial\theta}}$$

$$S''_a = R \cos(\theta + \beta) + \frac{R^2}{2L^2} e \cos(\beta - \alpha) \left[\frac{R^2}{2L^2} \left(1 - \frac{R^2}{L^2} \sin^2 \theta\right)^{-3/2} \sin^2 2\theta \right.$$

$$\left. + 2\cos 2\theta \left(1 - \frac{R^2}{L^2} \sin^2\theta\right)^{-1/2} \right] + e \frac{R}{L} \sin(\beta - \alpha) \sin\theta$$

$$+ \ell \left[- 3(1 + \eta^2)^{-5/2} \left(\eta \frac{\partial\eta}{\partial\theta}\right)^2 + \left(\eta \frac{\partial^2\eta}{\partial\theta^2} + \left(\frac{\partial\eta}{\partial\theta}\right)^2\right)(1 + \eta^2)^{-3/2} \right]$$

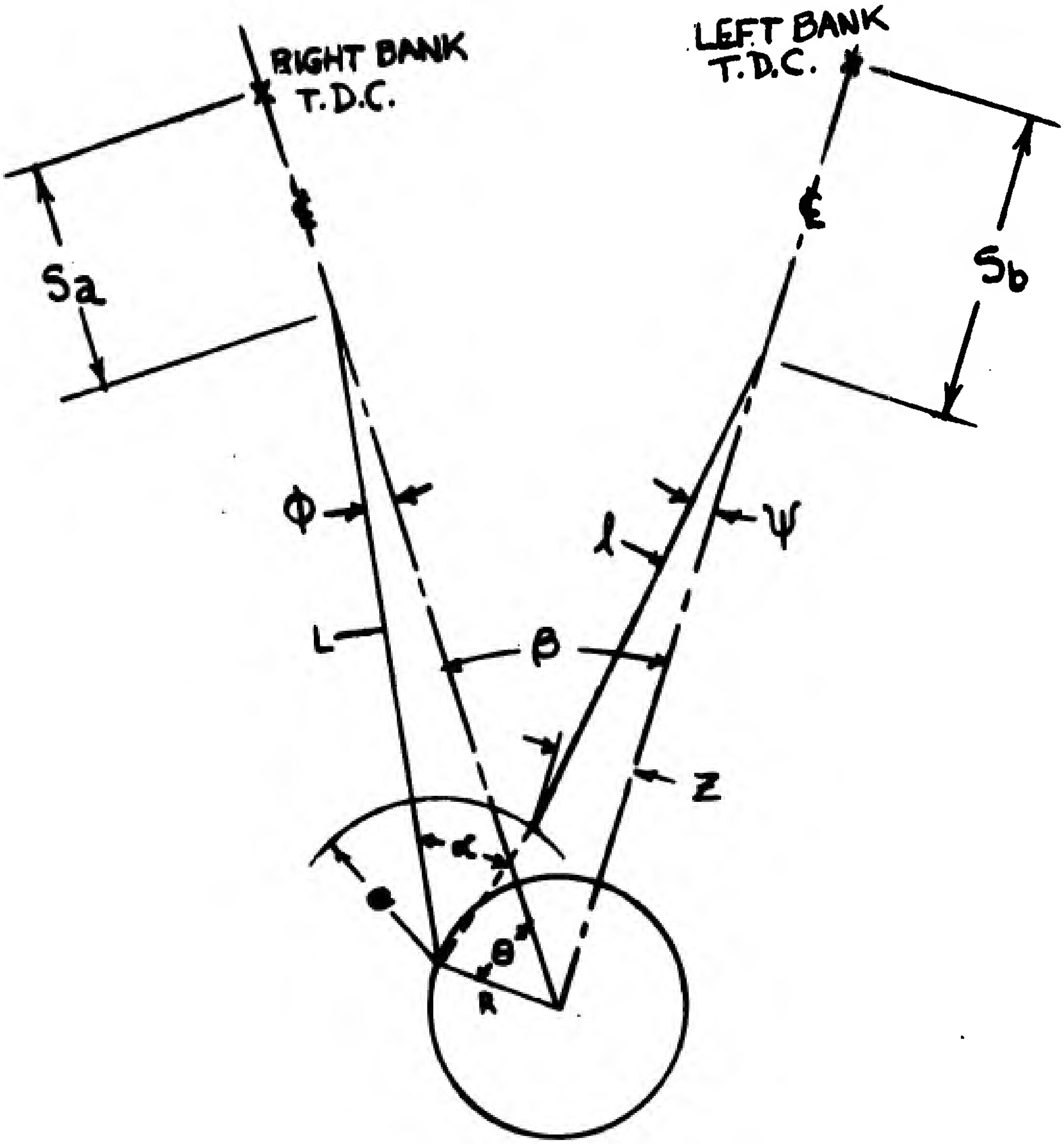
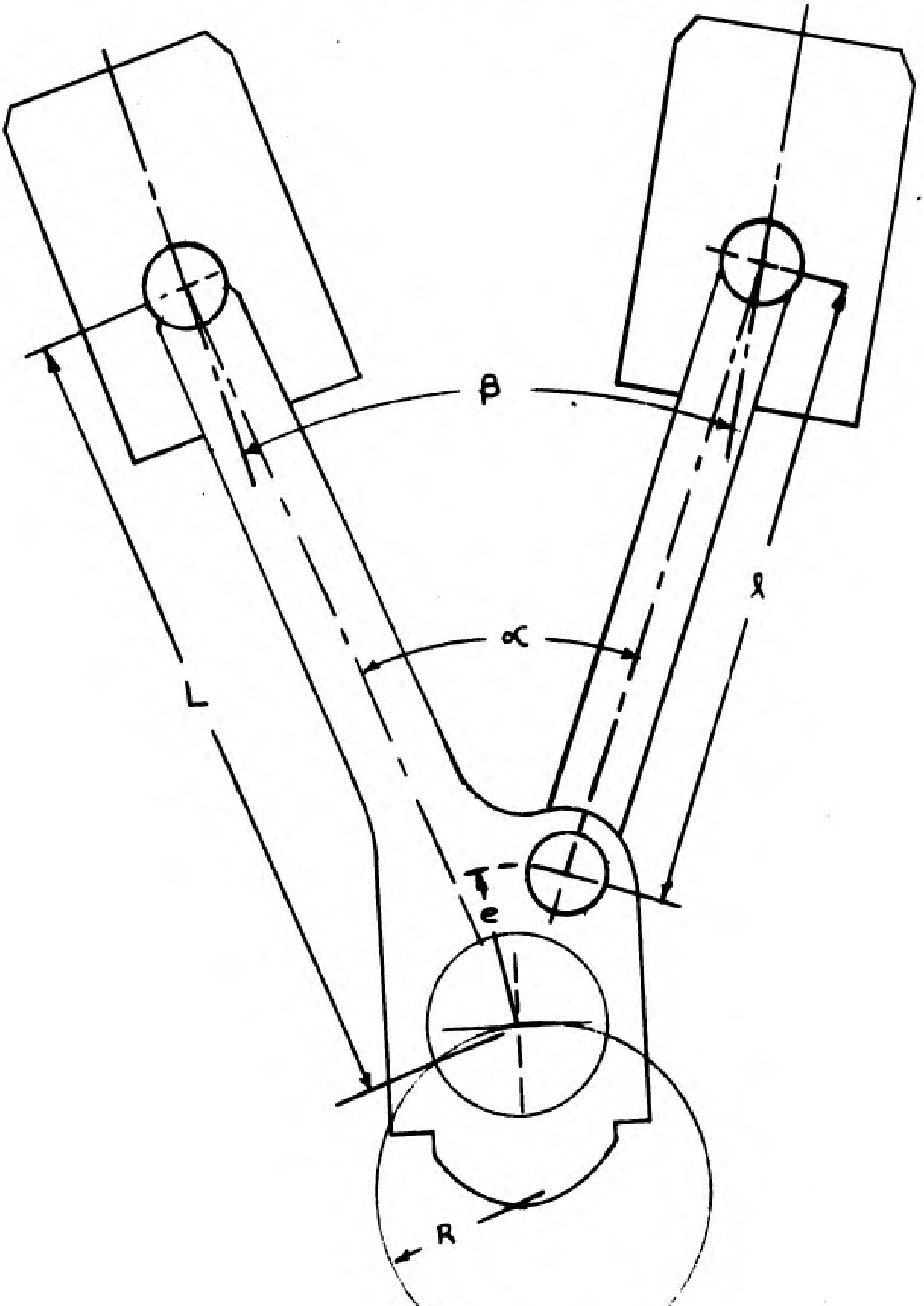


FIGURE 7

CONNECTING ROD GEOMETRY

CONNECTING ROD GEOMETRY

LSV SERIES - ARTICULATED ROD ON MASTER POWER ROD



where:

$$\eta = Z/\sqrt{\ell^2 - Z^2}$$

$$\frac{\partial \eta}{\partial \theta} = \frac{\partial Z}{\partial \theta}\left[Z^2(\ell^2 - Z^2)^{-3/2} + (\ell^2 - Z^2)^{-1/2}\right]$$

$$\frac{\partial^2 \eta}{\partial \theta^2} = (\ell^2 - Z^2)^{-1/2}\left[Z\left(Z\frac{\partial^2 Z}{\partial \theta^2} + 2\left(\frac{\partial Z}{\partial \theta}\right)^2\right)(\ell^2 - Z^2)^{-1}\right.$$

$$\left. + 3Z^3(\ell^2 - Z^2)^2\left(\frac{\partial Z}{\partial \theta}\right)^2 + \frac{\partial^2 Z}{\partial \theta^2} + \left(\frac{\partial Z}{\partial \theta}\right)^2(\ell^2 - Z^2)^{-1} Z\right]$$

$$Z = R\sin(\theta + \beta) + e\sin(\beta - \phi - \alpha)$$

$$\frac{\partial Z}{\partial \theta} = R\cos\beta\cos\theta - R\sin\beta\sin\theta - \frac{R^2}{2L^2} e\sin(\beta - \alpha)\sin 2\theta$$

$$\left(1 - \frac{R^2}{L^2}\sin^2\theta\right)^{-1/2} - \frac{R}{L} e\cos(\beta - \alpha)\cos\theta$$

$$\frac{\partial^2 Z}{\partial \theta^2} = -R\cos\beta\sin\theta - R\sin\beta\cos\theta - \frac{R^2}{2L^2} e\sin(\beta - \alpha)$$

$$\left[\frac{R^2}{2L^2}\left(1 - \frac{R^2}{L^2}\sin^2\theta\right)^{-3/2}(\sin^2 2\theta) + 2\cos 2\theta\left(1 - \frac{R^2}{L^2}\sin^2\theta\right)^{1/2}\right]$$

5.3.6 Turbocharger, Subsystem 4

The turbocharger model is built around its equation of motion:

$$\dot{\omega}_t = (\tau_t - \tau_c)/I_t$$

The compressor performance is represented by the map of performance data shown in Figure 2 (page 8). Given the values for

$$N_t^* = N_t\sqrt{\frac{540}{T_{ai}}}$$

and the pressure ratio, P_c/P_{ai}, the map returns a value for the corrected mass flow $Q\sqrt{540/T_{ai}}$ and the compressor efficiency η_c for each of two manifolds. The following equations are used to calculate the mass flow through the compressor, the compressor exit temperature, and compressor torque:

$$W_c^* = \frac{Q}{842.8}\sqrt{\frac{540}{T_{ai}}}$$

$$\dot{m}_i = \frac{P_{ai}}{14.243}\sqrt{\frac{540}{T_{ai}}}\,W^*$$

$$T_{com} = T_{ai}\left\{1 + \frac{1}{\eta_c}\left[\left(\frac{P_c}{P_{ai}}\right)^{\frac{k-1}{k}} - 1\right]\right\}$$

$$\tau_c = \frac{C_p\,\dot{m}_i\,T_{ai}}{\eta_c\,\omega_t}\left[\left(\frac{P_c}{P_{ai}}\right)^{\frac{k-1}{k}} - 1\right]$$

The intercooler, during the time spans of interest for simulation (less than 10 seconds), has an almost constant exit temperature for the entrance temperature excursions which result from an air shock of magnitude of P_o established as a criterion for design of NIKE-X/SAFEGUARD Power Systems. However, the intercooler temperature varies significantly for different steady-state operating points. Therefore, the intercooler temperature has been treated as a function of mass air flow through the intercooler. This function was obtained by a least squares curve fit to empirical data obtained at several steady-state operating points during the tests at Cooper-Bessemer in June 1971.

Since there are six manifolds exhausting to the turbocharger turbine, this unit has been treated as if it were distinct units, one for each exhaust manifold, with the exhaust streams mixing after the turbines. Thus, the following set of equations is used for each part of the turbocharger.

$$u = 0.627\,\omega_t$$

$$\phi = \frac{u}{V_5}$$

$$\eta_t = 1.229\phi \left[0.9304 - \phi + 0.8526 \sqrt{1.4706 - 1.8608\phi + \phi^2}\right]$$

$$+ 0.1813\phi^2 - 0.1800\phi$$

$$\frac{P_5}{P_{em}} = \left\{ 0.7158\ \eta_t \left[\left(\frac{P_{ae}}{P_{em}}\right)^{0.2658} - 1\right] + 1\right\}^{3.762}$$

$$\left.\begin{aligned} V_5 &= 44.49 \sqrt{T_{em}} \\ \frac{\dot{m}_e \sqrt{T_{em}}}{P_{em}} &= 5.04 \end{aligned}\right\} \frac{P_5}{P_{em}} < 0.534$$

$$\left.\begin{aligned} V_5^2 &= V_1^2 + 12270\ T_1 \left[1 - \left(\frac{P_5}{P_{em}}\right)^{0.2658}\right] \\ &\text{where } V_1 = 4.20\ \frac{\dot{m}_e\ T_{em}}{P_{em}} \end{aligned}\right\} 1 \geq \frac{P_5}{P_{em}} \geq 0.534$$

$$\frac{\dot{m}_e \sqrt{T_{em}}}{P_{em}} = 20.39 \sqrt{\left(\frac{P_5}{P_{em}}\right)^{1.467} \left[1 - \left(\frac{P_5}{P_{em}}\right)^{0.2658}\right]}$$

$$\tau_t = 200.7\ \frac{\dot{m}_e\ T_{em}\ \eta_t}{\omega_t} \left[1 - \left(\frac{P_{ae}}{P_{em}}\right)^{0.2658}\right]$$

$$T_e = T_{em} \left\{1 + \eta_t \left[\left(\frac{P_{ae}}{P_{em}}\right)^{0.2658} - 1\right]\right\}$$

After these calculations are completed for each exhaust manifold driving the turbine, the total torque, total mass flow, and exhaust temperature are calculated as follows:

$$\dot{m}_e = \sum_{i=e}^{6} \dot{m}_{ei}$$

$$\tau_t = \sum_{i=e}^{6} \tau_{ti}$$

$$T_e = \frac{\sum_{i=e}^{6} T_{ei} \dot{m}_{ei}}{\dot{m}_e}$$

5.3.7 Fuel Control, Subsystem 5

The fuel control system for the Cooper-Bessemer LSV-16 Diesel engine-generator set contains four distinct components:

- a frequency sensor
- a 2301 amplifier
- a Woodward Load Sensor
- an hydraulic actuator

The following three transfer functions were used to mathematically describe these components.

The transfer function best describing the 2301 amplifier and frequency sensor:

$$E_1 = \gamma_1(\Delta f)$$

$$\frac{E_3}{E_1} = \frac{A_1(D + A_2)(D + A_3)(D + A_4)}{D\left(D^2 + A_5 + A_6\right)}$$

where:

E_1 = 2301 amplifier's input voltage (volts)

γ_1 = frequency error conversion factor = - .77 (Hz/volt)

Δf = frequency error (Hz)

E_3 = 2301 amplifier's output voltage (volts)

A_1 = 0.671028

A_2 = 0.454837
A_3 = 3.41375
A_4 = 1006.72
A_5 = 20.9821
A_6 = 616.105

The Cooper-Bessemer LSV-16 Diesel engine-generator set also includes a load sensing device with the fuel control system. The transfer function given by the manufacturer (Woodward Governor Company) is:

$$\frac{E_2}{L\%} = K \frac{T_1 D + 1}{T_2 D + 1}$$

where:

E_2 = load sensor output voltage, drive voltage at the coil of the hydraulic actuator (volts)
$L\%$ = electrical load (percent)
K = .0282 (volts/percent)
T_1 = .8 (sec)
T_2 = .4 (sec)

Measurements made during the week of June 21, 1971 by ADL at Cooper-Bessemer show a value:

K = .0580 (volts/percent) for 60% to 110% load range

Different values of the constants T_1, T_2 were measured for up and down changes between 60% and 110% loads.

60% to 110% T_1 = .738
T_2 = .495
110% to 60% T_1 = .585
T_2 = .475

The values currently input to the simulation of the LSV-16 for the load sensor were developed from tuning the complete fuel control system which includes a model of the 2301 amplifier, load sensor, hydraulic actuator, and fuel linkage. Inconsistencies in any of these components on the real engine makes it necessary to change the value of known parameters of other components to better match the fuel delivery measured for load changes. (See Section 5.2.9 for a discussion on tuning.) The short term constants, T_1 and T_2, for the load sensor were adjusted to improve the simulation of measured load changes.

The value of the long term constant, K, was adjusted within the accuracy of the measured data to meet the requirement of the bias voltage into the hydraulic actuator at 60% and 110% steady-state operation. At steady-state operation at these two loads, the actuator required a unique voltage input to it from the 2301 amplifier and load sensor to match the data measured via a potentiometer. The 2301 amplifier outputs a bias voltage (at zero frequency error) of 2.614 volts. By changing the constant K to .0559 (volts/percent), the same 2301 bias voltage combined with the load sensor output satisfies the actuator position at both a 60% and 110% load.

The values currently input for the load sensor are:

$K = 0.0559$ (volts/percent)

$T_1 = 1.2$

$T_2 = 0.3$

The transfer function for the hydraulic actuator:

$$\frac{\theta_1}{(E_2 + E_3)} = \frac{U_1}{(D + U_2)(D + U_3)}$$

where:

θ_1 = hydraulic actuator output position via voltage on potentiometer (volts)

$E_2 + E_3$ = hydraulic actuator input voltage which is sum of voltages out of 2301 amplifier and load sensor (volts)

$U_1 = 807.167$

$U_2 = 97.9718$

$U_3 = 11.4239$

Inconsistencies occurred in the transfer functions resulting from the data obtained from measurements on the hydraulic actuator inasmuch as the phase data were poorly fitted by the transfer functions obtained by the least squares fitting process when applied to all data, phase data only, and amplitude data only. Our judgment, based on the advertised behavior of the hydraulic actuator, is that the transfer function obtained by fitting the amplitude data only is the most trustworthy obtainable. This is the transfer function presented above.

Recorded strip-chart data from load changes on the Cooper-Bessemer LSV-16 Diesel indicated an actuator transport deadtime of 20 to 30 milliseconds. After close examination, this deadtime was also found in the servo test data made on the same engine. The simulation accounts for this transport deadtime by an input variable, currently 25 milliseconds. At any simulated time, t, the fuel linkage spring mass system equation is supplied the actuator position which was computed with the actuator transfer function 25 milliseconds earlier in time. Thus if θ_1 is presented as a function of time:

$$\theta_1^* (t) = \theta_1 (t - .025)$$

where:

$\theta_1^* (t)$ = position being demanded by hydraulic actuator, volts, at time t, seconds, including transport deadtime

$\theta_1 (t - .025)$ = position computed by hydraulic actuator, volts, at time t - .025, seconds, resulting from transfer function

The response of the fuel control system is communicated to the fuel delivery system by a mechanical linkage commonly referred to as a common rail system. This linkage was modeled by a spring mass system with Coulomb (friction) damping. This is numerically described by the following equation of motion in differential form:

$$\ddot{\theta}_{1d} + \frac{k}{m} (\theta_{1d} - \theta_1^*) + \frac{F}{m} = 0$$

where:

m = mass of system (lbm)

θ_{1d} = dynamic (actual) position of fuel linkage at hydraulic actuator end via potentiometer, volts

θ_1^* = position being demanded by hydraulic actuator via potentiometer, volts, including transport deadtime correction

k = spring constant of system (lbf/volt)

F = Coulomb (frictional) force in system, lbf

The position of the fuel door is then determined from the static relationship developed from tests at Cooper-Bessemer, Grove City, Pennsylvania by:

$$\theta_2 = 1.63 + 1.411\ \theta_{1d}$$

where:

θ_2 = position of fuel door control shaft via potentiometer, volts

The fuel injector lift is determined by another empirical equation:

$$Z = .007 + .0041845\ (\theta_2 - 2.13)$$

where:

Z = injector lift, inches

The fuel rate and injection timing are computed as functions of injector lift. (See page 37.)

6. ACCURACY LIMITATIONS

A discussion follows of the major assumptions inherent to this analysis. We assume the state of the fluid in the cylinder and manifolds at any instant of time is uniform throughout the volume; that is, in each case at a particular instant, it is characterized by a single value of pressure, temperature, and composition.

The assumption of a homogeneous mixture having a single instantaneous state within the cylinder is a common simplification of engine performance analysis. As applied to the manifold, it has the effect of smoothing out pressure waves within the manifolds. To have real validity, the characteristic wavelengths associated with a pressure disturbance felt by the manifold must be long in comparison with the length of the manifold. Inherent in this assumption is the stipulation of complete mixing within the manifolds.

The assumption is made that the gas constant and the specific heats of the cylinder charge are constant and independent of pressure, temperature, and composition. The gas constant is little affected by gas composition for equilibrium products of combustion. The assumption of constant specific heats will not materially influence the dynamic load-speed relations for the engine having once made adjustments in the cylinder heat transfer and combustion models to match actual engine steady-state performance at rated power points.

A constant heat transfer coefficient and cylinder wall temperature is assumed. Heat transfer to and from the working cylinder is computed on the basis that heat transfer takes place across the cylinder wall whose inside surface is exposed to the working fluid; this area is variable with stroke; and the value of the heat transfer coefficient and cylinder wall temperature are selected so that heat rejection to the cooling water corresponds to operational experience or test data, if available. Because the torque and power developed by a diesel engine are relatively insensitive to the heat rejected to the cooling water (as more is rejected to the cooling jackets, less is rejected in the exhaust), this simple analytical model is considered adequate to account for heat transfer effects.

The breathing characteristics of the cylinder are defined in terms of appropriate compressible flow relations. The valves are treated as variable area orifices. The flow through them is treated as quasi-steady state. The flow areas for the valves are set by analytical expressions that approximate their open area as a function of crank angle derived from valve lift diagrams. The actual open area is reduced by a constant orifice flow coefficient to get the effective flow area. This analytical model of the breathing characteristics of an engine represents a reasonable practical limit of technical sophistication and appears to be sufficient for the purpose.

The rate at which heat is released within the cylinder during combustion is most difficult to express analytically with any precision. The physical processes involved are so complex that to attempt an exact theoretical treatment is not practical at this time. The best that has been done is to use a combination of theory and empiricism to specify a burning rate. (For example, see Reference 3.)

7. REMARKS

The development of a mathematical model of a diesel is not straightforward; however, the following suggestions are made for the programs developed.

Obtain good steady-state data sheets for steady-state operation of the diesel at various load conditions. This data must include a cylinder and exhaust manifold pressure time history and fuel consumption.

Calculate friction torque from the cylinder pressure time history. Adjust friction factor to get BMEP.

Adjust cylinder combustion burning rate to get experimental IMEP and BSFC.

Adjust cylinder and exhaust manifold heat transfer coefficients to obtain experimental heat rejection.

Adjust compressor and turbine efficiency to obtain steady-state turbocharger rated speeds.

Obtain frequency error during load change tests.

Tune fuel control gain and time constant to simulate actual frequency errors.

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PART II - COMPUTER FUNCTIONAL DESCRIPTION

1. REVISION LOG

Date	Changes	Comments

2. FUNCTIONAL FLOW CHART

The Clock or MAIN program controls the solution of the equations which describe the performance of the LSV-16 engine. As previously described, these equations are separated into 5 subsystems, which are integrated numerically to determine the state of each system as a function of time. The flow of information to describe this interaction is shown on the Functional Flow Chart, Figure 9 (page 55).

3. EQUIPMENT AND OPERATING SYSTEM

The program has been developed primarily on CDC 6000 digital computer equipment where it requires 68K words of storage. Essential configuration consists of a card reader, a central processing unit, a tape or disk drive, and a printer.

4. INPUT REQUIREMENTS

The main program and each subsystem requires a separate input deck. Thus, for the LSV-16 program, six input decks each having a fixed format as per Table 5 (page 56), are required. A sample of one input deck is shown on Figure 10 (page 57). The complete input deck setup is shown on Figure 11 (page 58) which illustrates the job stream.

5. SECONDARY STORAGE INPUT FORMAT

There are no secondary storage input devices required.

6. INPUT DATA DESCRIPTION

6.1 DATA DECK

A data deck consists of six independent sets of input cards, each applying to a specific subsystem. The order of these input sets must agree with the order in which the input subroutines are called by the MAIN: MAIN, Subsystem 1 (equation of motion), Subsystem 2 (alternator), Subsystem 3 (diesel engine), Subsystem 4 (turbocharger), and Subsystem 5 (fuel control).

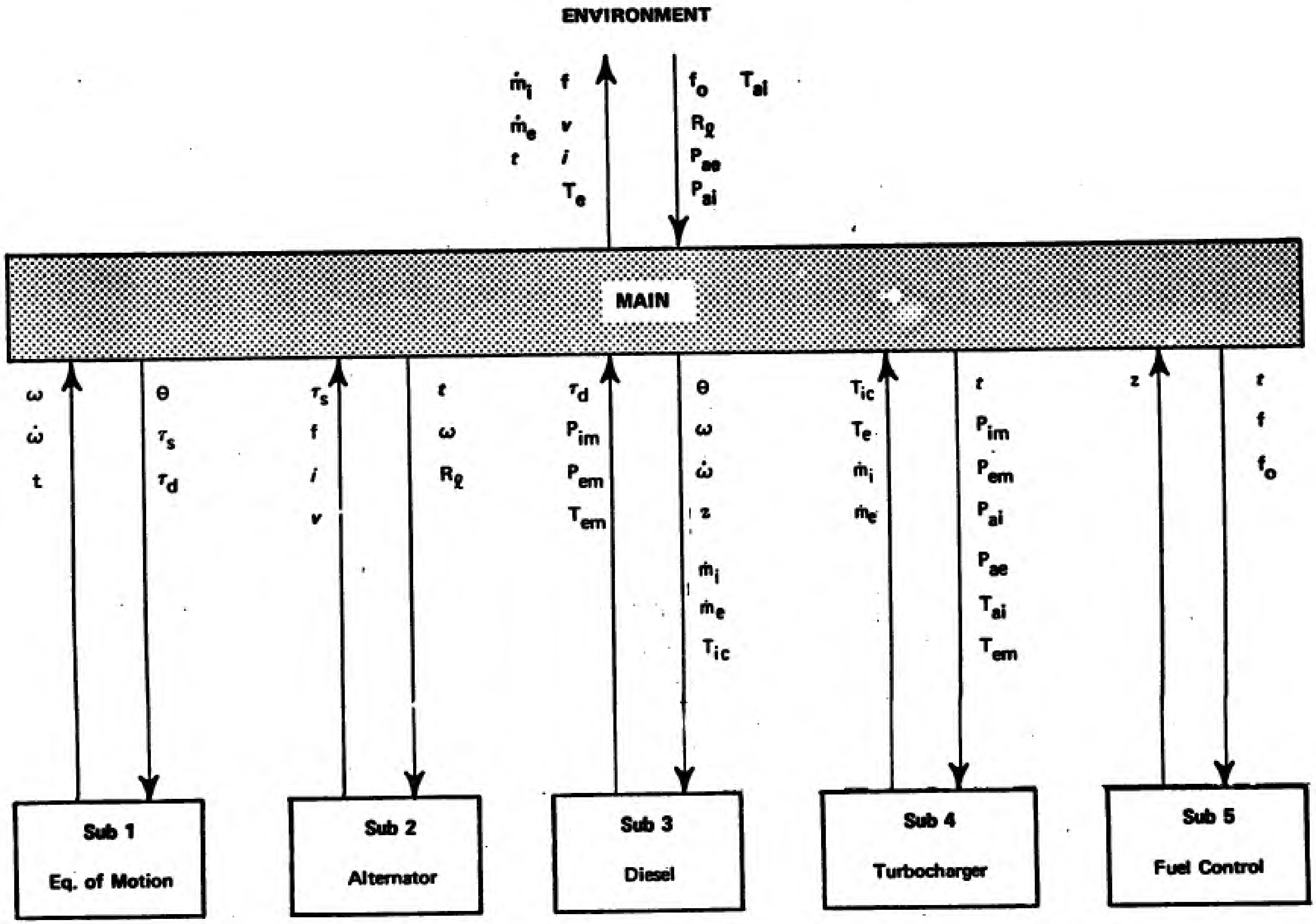


FIGURE 9

FUNCTIONAL FLOW CHART - LSV-16 PROGRAM

TABLE 5

DATA CARD FORMAT

C1, C2, I1, I2, Z in FORMAT (A1, 1X, A1, 2I3, 1X, 6F10.5)

C1 (column #1) alphabetic character = I for input data on card
= P for print instructions on card
= R for return, terminates

C2 (column #3) alphabetic cha4acter (variable name) which can be A, B, F, G, L, X, Y

I1 (columns #4-6) value of subscript for first parameter appearing on card, or to be printed

I2 (columns #7-9) value of subscript for last parameter appearing on card (6 items or less per card), or last parameter to be printed

Z (columns #11-70) numerical values of vector

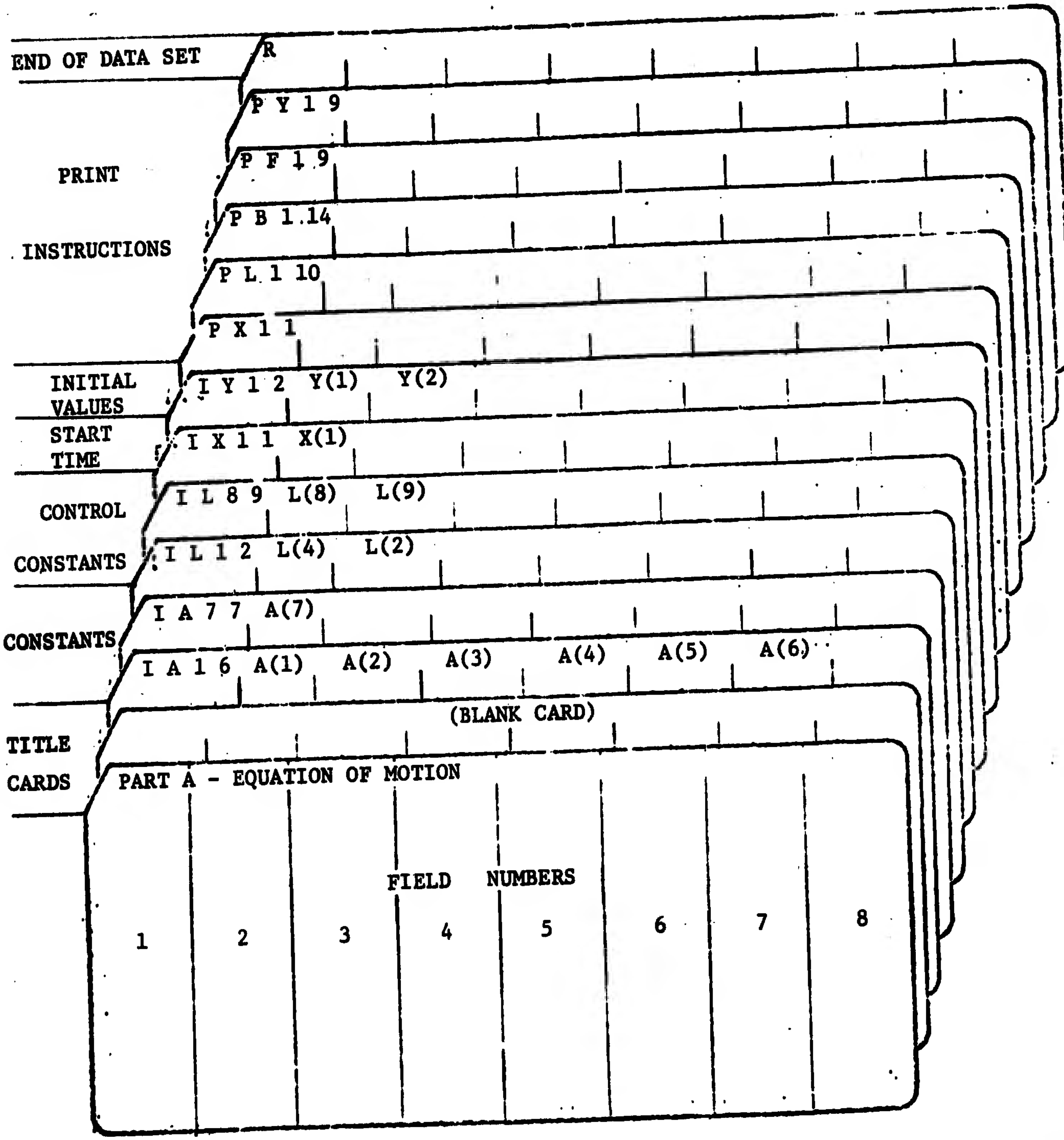
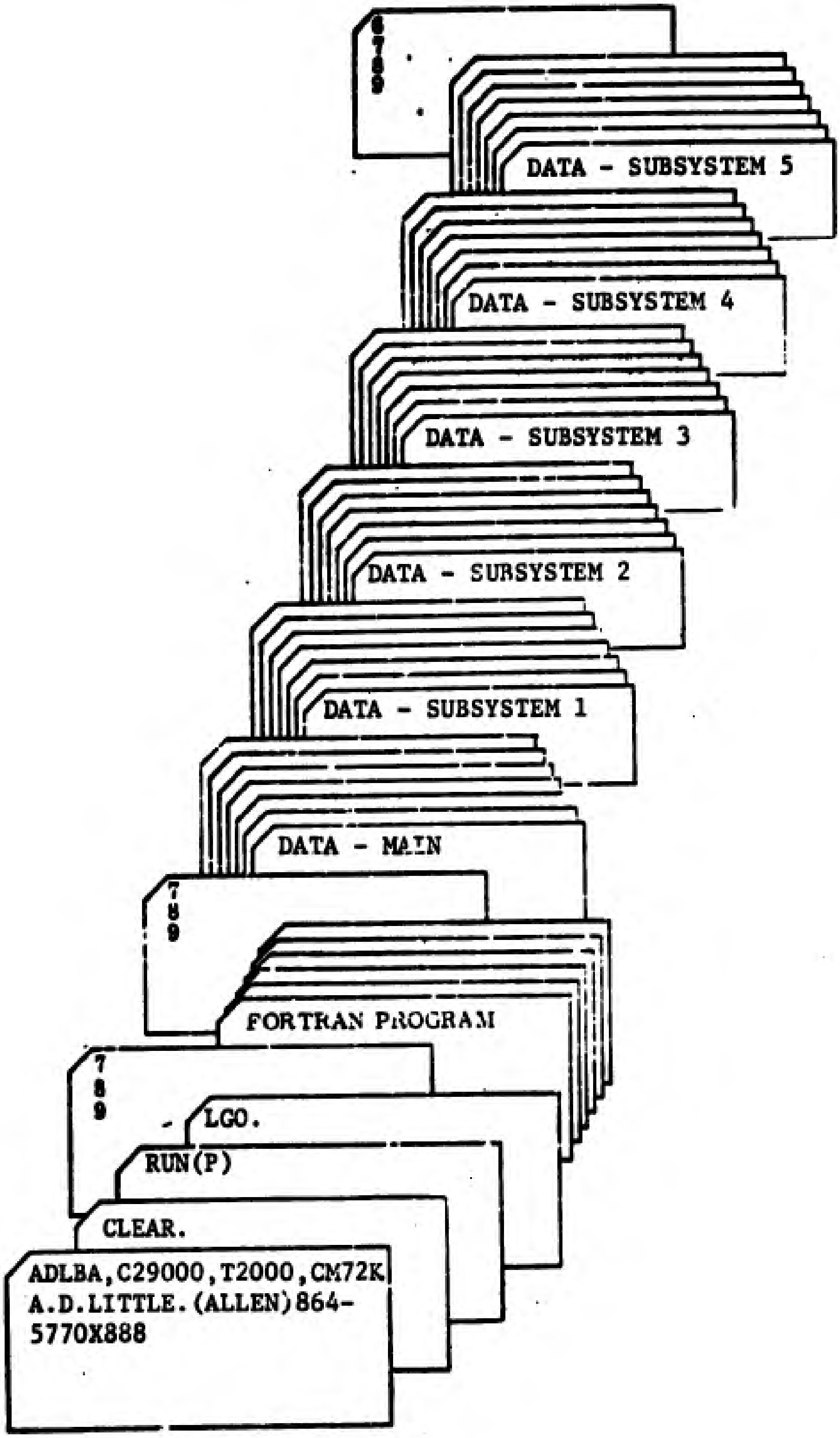


FIGURE 10 - MAIN OR SUBSYSTEM INPUT DECK
(SAMPLE)



```
ADLBA,C29000,T2000,CM72K
A.D.LITTLE.(ALLEN)864-
5770X888
CLEAR.
RUN(P)
LGO.
```

FIGURE 11

JOB STREAM

Each input set starts with two title cards and ends with a return card, R. The sequence of data cards within each input set is unimportant. This is due to the alpha-character testing performed by the input routines. Each input subroutine accepts the variables: X, A(I), B(I), F(I), L(I), Y(I), and, in addition, G(I) in the MAIN for the data format.

Data preparation for the LSV-16 is an extensive task. As an aid, input data keys have been prepared on Tables 6-11 (pages 60 to 67). The variables which appear on the input cards are shown on this key. The variables are defined in paragraph 11 which also gives the source of the particular input variable.

For simulation of the LSV-16 at various electrical load levels only a portion of the data must be changed. These variables are listed on Table 3 (page 17). An example of a typical data deck is shown on Table 12 (page 69).

6.2 MAIN INPUT DESCRIPTION

Each variable shown on the input coding key, Table 6 (page 60), must be present in the MAIN input data deck. This data deck controls the air shock transients which are applied to the diesel power system. Specifically, the standard air shock may be applied to the system by the adjustment of the variables A(30) to A(50). A typical data list is shown on the example case.

Note that within each subsystem's input data deck are variables which are repeated, i.e., overlayed input. This illustrates that new values can be assigned to variables already input without removing or altering the original data card. The simulation program uses the last value assigned for all computations.

6.3 SHAFT MOTION, SUBSYSTEM 1, INPUT

Each variable is shown on Table 7 (page 61). No variables should be changed for any transient load or shock conditions.

6.4 ALTERNATOR, SUBSYSTEM 2, INPUT

Each variable is shown on Table 8 (page 62). Variable A(3) is the initial shaft power. This may be calculated from the alternator load and the alternator efficiency. A(4) is the time of the load change and A(5) is the fraction of the shaft power which is retained after time A(5). Variables A(7) and A(8) are the load power in KW before and after load change.

INPUT DATA FOR MAIN -
COOPER-BESSEMER LSV-16 DIESEL,110 PERCENT I.D.

I A 2 3	θ_{max}(deg)	$\Delta\theta$(deg)				
I A 2 2	θ_{max}(deg)					
I A 38 38	T_{a1}(°R)					
I L 2 7	(title print freq.)		(tape 8 output freq.)	(print freq.)	(flag)	(environment flag)
I L 4 4	(tape 8 output freq.)					
I L 5 5	(print freq.)					
I L 14 16	(punch flag)	(flag)				
I G 22 27	θ(deg)	T_e(°F)	a(in-lbf)	b(in-lbf-sec/rad)	c(in-lbf-sec^2/rad^2)	d(in-lbf-sec^2/rad)
I G 57 57	T_c(°R)					
I G 60 60	T_{ic}(°R)					
I G 61 66	P_{im1}(lbf/in^2)	$\dot{m}_{11}$(lbm/sec)	T_{im1}(°R)	P_{im1}(lbf/in^2)	$\dot{m}_{12}$(lbm/sec)	T_{im2}(°R)
I G 67 72	P_{em1}(lbf/in^2)	$\dot{m}_{e1}$(lbm/sec)	T_{em1}(°R)	P_{em2}(lbf/in^2)	$\dot{m}_{e2}$(lbm/sec)	T_{em2}(°R)
I G 73 78	P_{em3}(lbf/in^2)	$\dot{m}_{e3}$(lbm/sec)	T_{em3}(°R)	P_{em4}(lbf/in^2)	$\dot{m}_{e4}$(lbm/sec)	T_{em4}(°R)
I G 79 84	P_{em5}(lbf/in^2)	$\dot{m}_{e5}$(lbm/sec)	T_{em5}(°R)	P_{em6}(lbf/in^2)	$\dot{m}_{e6}$(lbm/sec)	T_{em6}(°R)
P G 1 90						
R -0 -0						

TABLE 6

INPUT CODING KEY - MAIN

INPUT DATA FOR SUB1 -
PART 1. - EQUATION OF MOTION

I A 1 6 $\Delta\theta$(rad) π/180(rad/deg) LHV(in-lbf/lbm) J(in-lbf/BTU) $V_D(in^3)$

I A 7 7 K(in-lbf/sec-HP)

I L 1 2 (no. of equations) (title print freq.)

I L 8 9 (no. of strokes/cycle) (end of cycle counter)

I X 1 1 θ_o(rad)

I Y 1 2 ω(rad/sec) t(sec)

P X 1 1

P L 1 10

P D 1 14

P F 1 9

P Y 1 9

R -0 -0

TABLE 7

INPUT CODING KEY - SUB 1

INPUT DATA FOR SUB2 -
PART 2 - ALTERNATOR

I	A	1	6	Δt(sec)	fe/w(Hz-sec/rad)	E_o(in-lbf/sec)	t_o(sec)	E/E_o	E/E_o
I	A	7	9	KWo(kw)	KW/KWo(kw)	KW/KWo(kw)			
I	L	1	2	(flag to set torque)	(title print freq.)				
I	X	1	1	t_o(sec)					
P	X	1	1						
P	L	1	10						
R		-0	-0						

TABLE 8

INPUT CODING KEY - SUB 2

INPUT DATA FOR SUB3 -
PART 3 - DIESEL ENGINE, SIXTEEN CYLINDERS

I A 1 6	(deg)	(deg)	(deg)	(deg)	(deg)	
I A 7 12	AF	I(in-lbf-sec^2)	h_c(lbf/in-sec-°R)	K_3(1/sec)	LHV(in-lbf/lbm)	A_p(in^2)
I A 10 10	K_3(1/sec)					
I A 13 18		R(in-lbf/lbm-°R)	T_w(°R)	V_o(in^3)	V_D(in^3)	πD/90(rad)
I A 16 17	V_o(in^3)	V_D(in^3)				
I A 19 24	π/180(rad/deg)	k	kR(lb-lbf/lbm-°R)			
I A 25 30	πd(in)				π	π29 (deg)
I A 25 25	πd(in)					
I A 31 36		M_p(lbf-sec^2/in)	M_p(lbf-sec^2/in)	J(in-lbf/BTU)	C_p(in-lbf/lbm-°R)	f_o(lbf-sec/in)
I A 32 33	M_p(lbf-sec^2/in)	M_p(lbf-sec^2/in)				
I A 37 42	$\dot{Q}_{fo}$(%)	$\dot{Q}_{wo}$(%)	m_{co}(lbm)	ω_o(rad/sec)	$\Delta\theta_c$(deg)	$\dot{Q}_{aux}$(BTU/sec)
I A 36 38	f_o(lbf-sec/in)	$\dot{Q}_{fo}$(%)	$\dot{Q}_{wo}$(%)			
I A 43 48	(deg)	P_{imm}(lbf/in^2)	θ_d(deg)	(deg)	(deg)	(lbf/in^2)
I A 49 54	(lbf/in^2)	(lbm)	(lbm)	h_{em}(lbf/in-sec-°R)	A_{em}(in^2)	T_{wem}(°R)
I A 52 53	h_{em}(lbf/in-sec-°R)	A_{em}(in^2)				
I A 52 52	h_{em}(lbf/in-sec-°R)					
I A 55 60	T_b(°R)	a(in-lbf/lbm-°R)	a(in-lbf/lbm-°R^2)	c_{ev}	c_{iv}	f_{ev}
I A 55 55	T_b(°R)					

TABLE 9

INPUT CODING KEY - SUB 3

TABLE 9 (Cont'd.)

I A 58 59	c_{ev}	c_{iv}				
I A 61 64	f_{iv}	k_{ev}	P_{amb}(lbf/in)	$\dot{m}_{eo}$(lbm/sec)		
I A 63 64	P_{amb}(lbf/in)	$\dot{m}_{eo}$(lbm/sec)				
I A 65 65	$\dot{Q}_{aux}$(BTU/sec)					
I A 91 92	VI_1(in^3)	VI_2(in^3)				
I A 93 98	VI_3(in^3)	VI_4(in^3)	VI_5(in^3)	VI_6(in^3)	VI_7(in^3)	VI_8(in^3)
I B 1 1	θ(deg)					
I B 37 39	f_c(lbf-sec/in)	h_{co}(lbf/in-sec-°R)	h_c(lnf/in-sec-°R)			
I B 36 38	f_o(lbf-sec/in)	f_c(lbf-sec/in)	h_{co}(lbf/in-sec-°R)			
I L 1 5	(no. of cylinders)	(4 times the no. of cyl.)	(strokes/cycle)	(no. of equa. to be integrated)	(no. of intake manifolds)	
I L 11 16	(mode)	(mode)	(mode)	(mode)	(mode)	(flag)
I L 16 16	(flag)					
I L 18 18	(counter)					
I L 21 24		(no. of exhaust manifolds)	(flag)	(title print frequency)	(total no. of manifolds)	
I L 31 36	inlet manifold connections					
I L 37 42	inlet manifold connections					
I L 43 46	inlet manifold connections					
I L 51 56	exhaust manifold connections					
I L 57 62	exhaust manifold connections					
I L 63 66	exhaust manifold connections					
I X 1 6	(deg)	(deg)	(deg)	(deg)	(deg)	(deg)
I X 7 12	(deg)	(deg)	(deg)	(deg)	(deg)	(deg)
I X 13 16	(deg)	(deg)	(deg)	(deg)	(deg)	(deg)

TABLE 9 (Cont'd.)

I Y 1 6		ω(rad/sec)	m_{f1}(lbm)	P_{c1}(lbf/in^2)	m_{c1}(lbm)	x_{c1}
I Y 3 8	m_{f1}(lbm)	P_{c1}(lbf/in^2)	m_{c1}(lbm)	x_c	m_{f2}(lbm)	P_{c2}(lbf/in^2)
I Y 9 14	m_{c2}(lbm)	x_{c2}	m_{f3}(lbm	P_{c3}(lbf/in^2)	m_{c3}(lbm)	x_{c3}
I Y 15 20	m_{f4}(lbm)	P_{c4}(lbf/in^2)	m_{c4}(lbm)	x_{c4}	m_{f5}(lbm)	P_{c5}(lbf/in^2)
I Y 21 26	m_{c5}(lbm)	x_{c5}	m_{f6}(lbm)	P_{c6}(lbf/in^2)	m_{c6}(lbm)	x_{c6}
I Y 27 32	m_{f7}(lbm)	P_{c7}(lbf/in^2)	m_{c7}(lbm)	x_{c7}	m_{f8}(lbm)	P_{c8}(lbf/in^2)
I Y 33 38	m_{c8}(lbm)	x_{c8}	m_{f9}(lbm)	P_{c9}(lbf/in^2)	m_{c9}(lbm)	x_{c9}
I Y 39 44	m_{f10}(lbm)	P_{c10}(lbf/in^2)	m_{c10}(lbm)	x_{c10}	m_{f11}(lbm)	P_{c11}(lbf/in^2)
I Y 45 50	m_{c11}(lbm)	x_{c11}	m_{f12}(lbm)	P_{c12}(lbf/in^2)	m_{c12}(lbm)	x_{c12}
I Y 51 56	m_{f13}(lbm)	P_{c13}(lbf/in^2)	m_{c13}(lbm)	x_{c13}	m_{f14}(lbm)	P_{c14}(lbf/in^2)
I Y 57 62	m_{c14}(lbm)	x_{c14}	m_{f15}(lbm)	P_{c14}(lbf/in^2)	m_{c14}(lbm)	x_{c14}
I Y 63 68	m_{f16}(lbm)	P_{c16}(lbf/in^2)	m_{c16}(lbm)	x_{c16}	P_{m1}(lbf/in^2)	m_{m1}(lbm)
I Y 69 74	x_{m1}	P_{m2}(lbf/in^2)	m_{m2}(lbm)	x_{m2}	P_{m3}(lbf/in^2)	m_{m3}(lbm)
I Y 75 80	x_{m3}	P_{m4}(lbf/in^2)	m_{m4}(lbm)	x_{m4}	P_{m5}(lbf/in^2)	m_{m5}(lbm)
I Y 81 86	x_{m5}	P_{m6}(lbf/in^2)	m_{m6}(lbm)	x_{m6}	P_{m7}(lbf/in^2)	m_{m7}(lbm)
I Y 87 92	x_{m7}	P_{m8}(lbf/in^2)	m_{m8}(lbm)	x_{m8}		
P X 1 6						
P B 1 40						
P F 1 90						
P Y 1 93						
P L 1 20						
R -0 -0						

INPUT DATA FOR SUB4 ---
PART 4 - TURBOCHARGER

I	A	1	2	Δt(sec)	I_t(ft-lbf-sec^2)
I	A	3	3	FF	FACT
I	L	1	1	(no. of differential equations)	
I	X	1	1	t_o(sec)	
I	Y	1	1	ω_t(rad/sec)	
P	X	1	1		
P	F	1	1		
P	Y	1	1		
P	B	1	10		
P	B	11	20		
P	B	21	30		
P	B	31	40		
P	B	41	48		
R		-0	-0		

TABLE 10

INPUT CODING KEY - SUB 4

INPUT DATA FOR SUBS - PART 5 - FUEL CONTROLLER

I A 1 1	$\Delta\tau$(sec)					
I A 6 6	γ_1(Hz/volt)					
I A 7 12	A_1	A_2	A_3	A_4	A_5	A_6
I A 16 19	K	T_1	T_2	KW_o(kilowatts)		
I A 20 22	U_1	U_2	U_3			
I A 23 25	(volts)	(volts)	(volts)			
I L 1 2	(no. of differential equations)	(title print frequency)				
I Y 1 6	e_1(volts)	$\dot{e}_2$(volts/sec)	e_2(volts)	$\ddot{e}_3$(volts/sec^2)	$\dot{e}_3$(volts/sec)	e_3(volts)
I Y 7 9	f_2(volts)	g_1(volts)	g_2(volts)			
P X 1 1						
P B 1 6						
P F 1 9						
P Y 1 9						
R -0 -0						

TABLE 11

INPUT CODING KEY - SUB 5

6.5 DIESEL, SUBSYSTEM 3, INPUT

All constant coefficients (A variables) and counters (L variables) should not be changed during a transient. Only the dependent variables (Y variables) should be changed if the diesel is at a different steady-state load condition. Each input variable is shown on Table 9 (page 63).

6.6 TURBOCOMPRESSOR, SUBSYSTEM 4, INPUT

Only Y(1), the turbine shaft speed, should be changed for various load conditions. Each input variable is shown on Table 10 (page 66).

6.7 FUEL CONTROL, SUBSYSTEM 5, INPUT

No changes are required for the fuel control for air shock or load change simulations starting at the same load. Only the Y values need be changed for new initial loads. (See Table 3, page 17). Each input variable is shown on Table 11 (page 67).

7. SUMMARY OF REQUIRED CARDS

The entire job deck including the CDC control cards for compilation of the FORTRAN version of the LSV-16 program and execution of the attached data deck is shown on Figure 11 (page 58).

8. PROGRAM OUTPUT

8.1 INPUT CARD LIST

At the start of each computer run, the input data cards are read in, and then listed in order. This listing is merely precautionary, and need be referred to only in case some trouble, perhaps due to an error in the data cards themselves, is to be analyzed. It should be noted that each data set is printed on a separate page and is labeled with a statement such as "INPUT DATA FOR SUB1," as well as the information on the TITLE card of that set. The printout is illustrated in example case, paragraph 12. Classified overpressure data is not listed as described in Section 8.4.

8.2 DIAGNOSTIC PRINTOUT

The diagnostic printout is controlled by the input data cards with a P in column 1 (see Table 12, page 69). This allows the programmer to select variables to be printed out without recoding FORTRAN Statements. Each subsystem has its own individual set of diagnostic output.

TABLE 12

SAMPLE DATA LIST

```
CCOPER-BESSEMER LSV-16 DIESEL,110 PERCENT LD.

I A  2  2    2160.
I A  2  3   720.       5.0
I A  2  2   1440.
I A  2  2   90.
I A 38 38  541.
I L  2  7   1.         0.        6.        1.        9.          0.
I L  4  4    1.
I L  5  5    9.
I L 14 16   +1.0         0.        0.
I G 22 27    0.        850.     986400.     262.3     19.36     346300.
I G 57 57   1310.
I G 60 60   572.5
I G 61 66   22.65    7.015     572.        22.65     7.015     572.
I G 67 72  19.3               1391.        19.3                1378.
I G 73 78   19.3               1293.       19.3                 1345.
I G 79 84    19.3               1365.      19.3                 1328.
P G  1 90
R
PART 1 - EQUATION OF MOTION

I A  1  6 0.08726646.0174532931.68327E+8 9338.0   67041.41  3.14159265
I A  7  7 6600.0
I L  1  2  10.          1.
I L  8  9 4.0        -2.0
I X  1  1 0.0
I Y  1  2 37.699112 0.0
P X  1  1
P L  1 10
P B  1 15
P F  1 10
P Y  1 10
R
PART 2 - ALTERNATOR

I A  4  4     .045
I A  1  4 0.0025     1.591549  2.6995E+07   20.
I A  5  6    1.076     .6029
I A  7  7  2950.
I A  8  9    1.078    .5966
I L  1  2 0.          1.
I X  1  1 0.0
P X  1  1
P L  1 10
R
PART 3 - DIESEL ENGINE, SIXTEEN CYLINDERS

I A  1  5    35.        200.        338.        475.       640.
I A  7 12    15.00      344455.      .42        90.     .1682148E9  188.6917
I A  9 10      .50        105.
I A 14 17    640.       900.       415.122    67041.41
I A 19 21 .017453293  1.4       896.0
I A 25 25      48.6946
I A 29 30 3.14159265  720.
I A 32 36  1.77795    1.92805    9338.0     2250.       3.0
I A 37 42    6.0        4.1      .18866     37.6991     2.5          2.5
I A 37 42    6.0        4.1      .18866     37.6991     1.0          2.5
I A 43 48 5.00        22.65      10.0      0.001      0.001      0.001
```

TABLE 12 (Cont.)

```
I A 49 54 0.001     0.00000500.00000501.45      2435.0    700.0
I A 48 49    .005      .005
I A 52 53    .6       4112.
I A 52 52    .46
I A 55 60 520.0     197.6     0.6381    0.70      0.70      0.50
I A 55 55   540.
I A 58 59   1.8     1.8
I A 61 64 0.50      1.15      14.7      3.455
I A 63 64   14.10     2.412
I A 65 65    73.61
I A 91 92  44490.    44490.
I A 93 98   5894.     3561.     6670.    5037.     5980.     5835.
I B  1  1 0.0
I B 37 37    3.0
I B 39 39    .50
I L  1  5    16.       64.        4.       35.        2.
I L 11 16 1.0       2.0       3.0       4.0       5.0       0.0
I L 16 16   1.0
I L 18 18 22.0
I L 21 24    0.        6.        2.       1.
I L 31 36  1.          1.        1.        1.        1.        1.
I L 37 42    1.        1.        2.        2.        2.        2.
I L 43 46    2.        2.        2.        2.
I L 51 56    2.        5.        5.        4.        4.        6.
I L 57 62    1.        3.        1.        2.        2.        1.
I L 63 66    5.        3.        3.        6.
I X  1  6 0.        540.      90.        270.     630.      450.
I X  7 12  180.     360.      396.09    216.09    486.09    666.09
I X 13 16 306.09    126.09    576.09    36.09
I Y  1  6 0.        3.7739E+010.        2.3121E+011.9718E-021.1192E-01
I Y  7 12 0.        4.3659E+011.7051E-015.3061E-010.        2.2718E+01
I Y 13 18 1.5941E-011.2052E-020.        4.7733E+012.6642E-016.7940E-03
I Y 19 24 0.        2.3642E+016.7529E-025.3100E-010.        1.8197E+02
I Y 25 30 2.7392E-015.2844E-010.        2.2390E+012.6613E-017.4077E-03
I Y 31 36 3.4275E-037.6036E+022.6583E-014.7484E-023.5155E-035.6248E+02
I Y 37 42 2.7202E-013.2952E-010.        2.4976E+012.6724E-011.2242E-02
I Y 43 48 0.        1.0866E+022.7705E-015.2353E-010.        2.2549E+01
I Y 49 54 3.5353E-025.2188E-010.        1.2034E+022.6781E-011.1716E-02
I Y 55 60 0.        2.2808E+012.3121E-019.0832E-030.        2.8946E+01
I Y 61 66 1.2197E-015.3393E-010.        2.3192E+014.9902E-023.7940E-02
I Y 67 72 2.3586E+012.8509E+002.2723E-052.3739E+012.8680E+003.9813E-04
I Y 73 78 2.1710E+011.5321E-015.1688E-011.7652E+019.0482E-024.5036E-01
I Y 79 84 2.8193E+011.9057E-015.1092E-012.2661E+011.3140E-015.1631E-01
I Y 85 90 3.3293E+011.8372E-015.0134E-011.5046E+011.2953E-014.6174E-01
P B  1 60
P F  1 90
P Y  1 90
P L  1 20
R
PART 4 - TURBOCHARGER

I A  1  2  .001      .643
I A  3  4   .65     .87
I L  1  1   1.0
I X  1  1    0.
I Y  1  1   1319.47
P X  1  1
P F  1  1
P Y  1  1
```

TABLE 12 (Cont.)

```
P B  1 10
P B 11 20
P B 21 30
P B 31 40
P B 41 48
R
PART 5 - FUEL CONTROLLER

I A  1  5  .01       60.       1000.       12.6        .2
I A  6  6  -0.770
I A  7 12 .671028    .454837   3.41375    1006.72   20.9821    616.105
I A 16 19   .0641      .8         .4     2960.
I A 17 17     1.2
I A 20 22   807.167   97.9718  11.4229
I A 23 25  2.614       7.5        -0.2
I L  1  2   12.        1.
I X  1  1    0.
I Y  1  6 0.0        0.0       0.0        0.0        0.0        0.0
I Y  7  9  -6.8843    -.904       7.75
I Y  7  9  -6.92     -.889       7.62
I Y  7  7  -13.8486
I Y 11 11   6.85
P X  1  1
P B  1  7
P Y  1 12
P F  1 12
Z
```

The subsystem diagnostic printouts, as well as the MAIN printout, are controlled by the input data cards described earlier, both as to the order of the arrays printed, and the number of items within that array printed. With the exceptions of MAIN and SUB3, the print routines can print the variables:

X, A(I), B(I), F(I), G(I), L(I), Y(I)

The print routine for Subsystem 3 has the added capability for printing an array X(I) instead of a single value X, and for printing an array U(I,J). The major mode and sub-modes for each cylinder, M(I), M1(I), M2(I), M3(I), and M4(I), as well as its crankshaft angle, X(I), are printed, with appropriate column headings, after the U array. The print routine for MAIN has only the capability to print:

A(I), B(I), G(I), L(I)

The first items in the MAIN printout are the time (in seconds) and the crankshaft angle (in degrees). These are clearly labeled as such. A key is attached for the interpretation of the diagnostic printout. See Table 13 (page 73).

8.3 FINAL OUTPUT

After the initialization printout, the MAIN and five subsystem print routines are called at regular intervals controlled by L(5) in MAIN. At the completion of a run, certain variables are printed in column form at an interval (normally closer spaced) which can be different than that between the normal printouts. This interval is controlled by L(4) in MAIN. From left to right, the following variables from logical unit 8 are printed:

Time, seconds
Crankshaft angle, degrees
Frequency error, percent
Peak cylinder pressure, psia
Peak cylinder temperature, °F
Inlet manifold pressure, psia
Exhaust manifold pressure, psia
Exhaust temperature, °F
Turbocharger shaft speed, rpm
Compressor pressure ratio
Compressor corrected mass flow, lbm/sec
Fuel rate, lbm/hr
Turbine mass flow, lbm/sec

These various columns are labeled at the top with an abbreviated name and their units. After this so-called TAPE B1 PRINTOUT, which is performed by subroutine PRT8, the six basic PRINT routines (PRTM, PRT1, PRT2, PRT3, PRT4, PRT5) are called for a final time.

COOPER-BESSEMER LSV-16 DIESEL.110 PERCENT LD.

TIME = sec
ANGLE = degrees

G(1-10)	t(sec)	ω(rad/sec)	$\dot{\omega}$(rad/sec^2)	f(Hz)	f_o(Hz)	τ_d(in-lbf)	τ_s(in-lbf)	KW(Kw)	Z(inches)	P_{ai}(lbf/i
G(11-20)	P_{ae}(lbf/in^2)	T_{ai}(°R)	θ(rad)	Δf(%)	P_{cmax}(lbf/in^2)	T_{cmax}(°F)	P_{im}/P_{ai}	W_c*(lbm/sec)	$\dot{m}_f$(lbm/hr)	N_t(RPM)
G(21-30)	τ_d(ft-lbf)	θ(deg)	T_e(°F)	a(in-lbf)	b(in-lbf-sec/rad)	c(in-lbf-sec^2/rad^2)	d(in-lbf-sec^2/rad)	P_{cl}(lbf/in^2)	T_{cl}(°R)	$\Delta\theta$(deg)
G(31-40)	$\dot{Q}_w$(BTU/sec)	$\dot{Q}_f$(BTU/sec)	$\dot{Q}_{in}$(BTU/sec)	$\dot{Q}_{ex}$(BTU/sec)	$\dot{Q}_{ic}$(BTU/sec)	$\dot{Q}_s$(BTU/sec)	$\dot{Q}_{em}$(BTU/sec)	Q_w/Q_{in}(%)	Q_f/Q_{in}(%)	Q_{ex}/Q_{in}(
G(41-50)	Q_{ic}/Q_{in}(%)	Q_s/Q_{in}(%)	Q_{em}/Q_{in}(%)	Q_{in}(BTU)	ΣQ_{out}(BTU)	BHP(HP)	IHP(HP)	BMEP(lbf/in^2)	IMEP(lbf/in^2)	FR(lbm/h
G(51-60)	BSFC(lbm/HP/hr)	$\dot{Q}_{aux}$(BTU/sec)	τ_{aux}(in/lbf)	$\frac{Q_{aux}}{Q_{in}}$ (%)	$\dot{m}_e$(lbm/sec)	T_{com}(°R)	T_e(°R)	$\dot{m}_i$(lbm/sec)	ω_t(rad/sec)	T_{ic}(°R)
G(61-70)	P_{im1}(lbf/in^2)	$\dot{m}_{i1}$(lbm/sec)	T_{im1}(°R)	P_{im1}(lbf/in^2)	$\dot{m}_{i2}$(lbm/sec)	T_{im2}(°R)	P_{em1}(lbf/in^2)	$\dot{m}_{e1}$(lbm/sec)	T_{em1}(°R)	P_{em2}(lbf/in^2
G(71-80)	$\dot{m}_{e2}$(lbm/sec)	T_{em2}(°R)	P_{em3}(lbf/in^2)	$\dot{m}_{e3}$(lbm/sec)	T_{em3}(°R)	P_{em4}(lbf/in^2)	$\dot{m}_{e4}$(lbm/sec)	T_{em4}(°R)	P_{em5}(lbf/in^2)	$\dot{m}_{e5}$(lbm/s
G(81-90)	T_{em5}(°R)	P_{em6}(lbf/in^2)	$\dot{m}_{e6}$(lbm/sec)	T_{em6}(°R)						
X	θ_o(rad)									
L(1-10)	(no. of equs.)	(title print freq.)						(no. of strokes/cycle)	(end of cycle counter)	Title counter (print counter)
B(1-10)	Q_w(BTU)	Q_f(BTU)	Q_{in}(BTU)	Q_{ex}(BTU)	Q_{ic}(BTU)	Q_s(BTU)	Q_{em}(BTU)	Q_w/Q_{in}(%)	Q_f/Q_{in}(%)	Q_{in}/Q_{in}(%
B(11-14)	Q_{ex}/Q_{in}(%)	Q_{ic}/Q_{in}(%)	Q_s/Q_{in}(%)	Q_{em}/Q_{in}(%)						
F(1- 9)			Derivatives of Y(1-9)							
Y(1- 9)	ω(rad/sec)	t(sec)	Q_w(BTU)	Q_f(BTU)	Q_{in}(BTU)	Q_{ex}(BTU)	Q_{ic}(BTU)	Q_s(BTU)	Q_{em}(BTU)	

TABLE 13

DIAGNOSTIC OUTPUT KEY

PART 2 - ALTERNATOR

X	to (sec)	secs.								
L(1-10)	(flag)	(title print freq.)								(print counter)
X(1- 4)	(deg)	(deg)	(deg)	(deg)	(deg)	(deg)				
B(1-10)	G(deg)	T_f(in-lbf)	T_i(in-lbf)	T_d(in-lbf)	c(in-lbf-sec^2/rad^2)	d(in-lbf-sec^2/rad)	$\bar{m}_c$(lbm)			
B(11-20)	$\dot{Q}_w$(BTU/sec)	$\dot{Q}_f$(BTU/sec)	$\dot{Q}_{in}$(BTU/sec)	$\dot{Q}_{ex}$(BTU/sec)	$\dot{Q}_{lc}$(BTU/sec)	$\dot{Q}_s$(BTU/sec)	$\dot{Q}_{em}$(BTU/sec)	$\dot{Q}_{aux}$(BTU/sec)		
B(21-30)				T_g(a)(in-lbf)	$\dot{m}_{f1}$(lbm/hr)	θ_1(deg)	Z(mm)			θ_d(deg)
B(31-40)	θ_2(deg)	θ_3(deg)	θ_4(deg)	$\Delta\theta_2$(deg)		f_o(lbf-sec/in)	f_c(lbf-sec/in)	h_{co}(lbf/in-sec-°R)	h_c(lbf/in-sec-°R)	$\Delta\theta_1$(deg)
B(41-50)	$\Delta\theta_3$(deg)	h_{em1}(lbf/in-sec-°R)	h_{em2}(lbf/in-sec-°R)	h_{em3}(lbf/in-sec-°R)	h_{em4}(lbf/in-sec-°R)	h_{em5}(lbf/in-sec-°	h_{em6}(lbf/in-[illegible]			
B(51-60)	(lbm/rad)	(lbm/rad)	(lbm/rad)	(lbm/rad)	(lbm/rad)	(l[illegible])				
F(1-10)										
F(11-20)										
F(21-30)										
F(31-40)				Derivatives of Y(1-9)						
F(41-50)										
F(51-60)										
F(61-70)										
F(71-80)										
F(81-90)										
Y(1-10)		ω(rad/sec)	m_{f1}(lbm)	P_{c1}(lbf/in^2)	m_{c1}(lbm)	x_{c1}	m_{f2}(lbm)	P_{c2}(lbf/in^2)	m_{c2}(--	x_{c2}
Y(11-20)	m_{f3}(lbm)	P_{c3}(lbf/in^2)	m_{c3}(lbm)	x_{c3}	m_{f4}(lbm)	P_{c4}(lbf/in^2)	m_{c4}(lbm)	x_{c4}	m_{f5}(lbm)	P_{c5}(lbf/in^2)
Y(21-30)	m_{c5}(lbm)	x_{c5}	m_{f6}(lbm)	P_{c6}(lbf/in^2)	m_{c6}(lbm)	x_{c6}	m_{f7}(lbm)	P_{c7}(lbf/in^2)	m_{c7}(lbm)	x_{c7}
Y(31-40)	m_{f8}(lbm)	P_{c8}(lbf/in^2)	m_{c8}(lbm)	x_{c8}	m_{f9}(lbm)	P_{c9}(lbf/in^2)	m_{c9}(lbm)	x_{c9}	m_{f10}(lbm)	P_{c10}(lbf/in^2)
Y(41-50)	m_{c10}(lbm)	x_{c10}	m_{f11}(lbm)	P_{c13}(lbf/in^2)	m_{c11}(lbm)	x_{c11}	m_{f12}(lbm)	P_{c12}(lbf/in^2)	m_{c12}(lbm)	x_{c12}
Y(51-60)	m_{f13}(lbm)	P_{c13}(lbf/in^2)	m_{c13}(lbm)	x_{c13}	m_{f14}(lbm)	P_{c14}(lbf/in^2)	m_{c14}(lbm)	x_{c14}	m_{f15}(lbm)	P_{c15}(lbf/in^2)
Y(61-70)	m_{c15}(lbm)	x_{c15}	m_{f16}(lmb)	P_{c16}(lbf/in^2)	m_{c16}(lbm)	x_{c16}	P_{m1}(lbf/in^2)	m_{m1}(lbm)	x_{m1}	P_{m2}(lbf/in^2)
Y(71-80)	m_{m2}(lbm)	x_{m2}	P_{m3}(lbf/in^2)	m_{m3}(lbm)	x_{m3}	P_{m4}(lbf/in^2)	m_{m4}(lbm)	x_{m4}	P_{m5}(lbf/in^2)	m_{m5}(lbm)
Y(81-90)	x_{m5}	P_{m6}(lbf/in^2)	m_{m6}(lbm)	x_{m6}	P_{m7}(lbf/in^2)	m_{m7}(lbm)	x_{m7}	P_{m8}(lbf/in^2)	m_{m8}(lbm)	x_{m8}
Y(91-93)										
L(1-10)	(no. of cylinders)	(4 times L(1))	(strokes per cycle)	(no. of differential equa.)	(no. of intake manifolds)	(counter)	(counter)	(counter)	(counter)	
L(11-20)	(mode)	(mode)	(mode)	(mode)	(mode)	(flag)	(flag)	(counter)	(counter)	(counter)

U(1-1 TO 15) T_c(°R) T_{in}(°R) Q_w(in-lbf/sec) A_{iv}(in^2) A_{ev}(in^2) V_c(in^3) A_c(in^2) $dm_{iv}/d\theta$(lbm/rad) $dm_{ev}/d\theta$(lbm/rad

$dm_{fb}/d\theta$(lbm/rad) S(in) S'(in/rad) S"(in/rad^2) $dm_{fi}/d\theta$(lbm/rad) T_{em}(°R)

U(2-1 TO 15)

U(3-1 TO 15)

U(4-1 TO 15) Same as U(1 - 1 to 15)

U(5-1 TO 15)

U(6-1 TO 15)

U(7-1 TO 15)

U(8-1 TO 15)

U(9-1 TO 15)

U(10-1 TO 15)

U(11-1 TO 15)

U(12-1 TO 15)

U(13-1 TO 15)

```
U(14-1 TO 15)
                                        Same as U(1 - 1 to 15)

U(15-1 TO 15)


U(16-1 TO 15)
```

```
CYLINDER M(I)     M1(I)     M2(I)     M3(I)     M4(I)       X(I)
   1       1        1         2         0         0       45.00000
   2       4        2         1         0         0      585.00000
   3       1        1         2         0         0      135.00000
   4       2        2         1         0         0      315.00000
   5       5        1         1         0         0      675.00000
   6       4        2         1         0         0      495.00000
   7       2        2         1         0         0      225.00000
   8       3        2         1         4         2      405.00000
   9       3        2         1         4         4      441.09000
  10       2        2         1         0         0      261.09000
  11       4        2         1         0         0      531.09000
  12       5        1         1         0         0      711.09000
  13       3        2         1         2         1      351.09000
  14       1        1         1         0         0      171.09000
  15       4        1         1         0         0      621.09000
  16       1        1         1         0         0       81.09000
```

PART 4 - TURBOCHARGER

X	to sec									
F(1- 1)	Derivative of Y(1)									
Y(1- 1)	ω_t(rad/sec)									
B(1-10)	T_c(ft-lbf)	τ_t(ft-lbf)	$\dot{m}_c$(lbm/sec)	$\dot{m}_t$(lbm/sec)	T_c(°R)	T_e(°R)				η_c
B(11-20)	P_{c1}(lbf/in^2)	$\dot{m}_{c1}$(lbm/sec)	T_{c1}(°R)	τ_{c1}(ft-lbf)	P_{c2}(lbf/in^2)	$\dot{m}_{c2}$(lbm/sec)	T_{c2}(°R)	τ_{c2}(ft-lbf)	P_{em1}(lbf/in^2)	$\dot{m}_{t1}$(lbm/sec
B(21-30)	T_{em1}(°R)	τ_{t1}(ft-lbf)	T_{e1}(°R)	P_{em2}(lbf/in^2)	$\dot{m}_{t2}$(lbm/sec)	T_{em2}(°R)	τ_{t2}(ft-lbf)	T_{e2}(°R)	P_{em3}(lbf/in^2)	$\dot{m}_{t3}$(lbm/sec
B(31-40)	T_{em3}(°R)	τ_{t3}(ft-lbf)	T_{e3}(°R)	P_{em4}(lbf/in^2)	$\dot{m}_{t4}$(lbm/sec)	T_{em4}(°R)	τ_{t4}(ft-lbf)	T_{e4}(°R)	P_{em5}(lbf/in^2	$\dot{m}_{t5}$(lbm/sec
B(41-48) X	T_{em5}(°R)	τ_{t5}(ft-lbf)	T_{e5}(°R)	P_{em6}(lbf/in^2)	$\dot{m}_{t6}$(lbm/sec)	T_{em6}(°R)	τ_{t6}(ft-lbf)	T_{e6}(°R)		
B(1- 6)	E_1 (volt)	E_2(volt)	E_3(volt)	θ_1(volt)	Δf(Hz)					
F(1- 9)	Derivatives of Y(1-9)									
Y(1- 9)	e_1(volts)	$\dot{e}_2$(volts/sec)	e_2(volts)	$\ddot{e}_3$ (volts/sec^2)	$\dot{e}_3$(volts/sec)	e_3(volts)	f_2(volys)	g_1(volts)	g_2(volts)	

8.4 CLASSIFIED DATA HANDLING

Previous use of the computer program involved classified input data describing the ambient conditions during an overpressure simulation. These data only appear in the positions A(38) to A(50) in the MAIN input stream for use in Subroutine AMB12, and only for airshock simulation as flagged by L(7)=2. Subroutine INPM is programmed to omit printing any input values located in positions A(38) to A(50). Subroutine PRTM is programmed to normalize the ambient pressure at inlet, G(10), and exhaust, G(11), when simulating an overpressure condition as flagged by L(7)=2. The normalization is based on unity being an overpressure equal to the difference between the peak ambient overpressure and the initial ambient pressure. Therefore, a normalized value of zero is printed prior to the airshock, and a value of unity is printed at the time of peak overpressure regardless of its actual magnitude.

9. OPERATOR INSTRUCTIONS

The operator need only place the proper control cards with the source deck, set up the input data as outlined in paragraph 7, and execute. Any error messages that appear will be program generated and are described in Subsection 10.

10. PROGRAM ERROR MESSAGES

Table 14 (page 79) shows all messages coded in LSV-16. Other information listed include the name of the subroutine that detected the diagnostic, the severity of the diagnostic, and an explanatory comment. Fatal errors terminate the program by calling EXIT. Informative messages are not necessarily errors, and execution is allowed to proceed.

During real execution, many of the diagnostic messages include values of variables relating to the problem. Table 14 illustrates where these values would be printed by underscoring the FORTRAN FORMAT in which these values would be printed.

11. VARIABLE DEFINITIONS

EXPLANATION: The leftmost column heading is the variable name as coded in FORTRAN with the subscript positions tabulated below. The column "INTERNAL EQUIVALENT" contains variable names which take the same storage position in the computer memory. This column is blank when no internal equivalent is assigned. "LOCATION SET" tabulates the number of the

TABLE 14

DIAGNOSTIC MESSAGES

MESSAGE*	ORIGIN	SEVERITY	COMMENT
BAD DATA - CARD A1 VECTOR A1 I3 I3	INPM, INP1, INP2, INP3, INP4, INP5	FATAL	The subsystem from which the error originated will be obvious from the printout. The A1, A1, I3, I3 format designates the data card in error.
BAD PRINT INSTRUCTION - VARIABLE A1	PRTM, PRT1, PRT2, PRT3, PRT4, PRT5	FATAL	The subsystem from which the error originated will be obvious from the printout. The error indicates that the variable A1 is not a valid one for output.
110 E18.7 E18.7 E18.7 E18.7 E18.7 BAD MODE	ANGL	FATAL	Printed values indicate cylinder number, crank angle of that cylinder, crank angle of last valve event, degrees from next valve event, and degrees between valving events. Error message indicates that an impossible combination of valving events occurred within a cylinder.
TROUBLE I5	SUB3	FATAL	I5 — Explanation 4 Negative integration step calculated by ANGLE 5 More than 200 attempts have been made to converge on integration step required by PTDSL 6 Integration step array, DD(20), size has been exceeded by PTDSL 7 Integration step array, DD(20), size has been exceeded by ANGLE 8 Peak cylinder temperature array, TM(100), size has been exceeded 9 Peak cylinder pressure array, PX(100), size has been exceeded 10 Negative integration step calculated by PTDSL
2013 TROUBLE 3 E15.5 E15.5 E15.5	YP3	FATAL	2013 - MODE STRUCTURE IN SUBSYSTEM 3, SEE TABLE 19 Printed values indicate the gas charge in the cylinder, the gas charge in the inlet manifold, and the gas charge in the exhaust manifold. Error message indicates that there is a negative mass of gas in a cylinder or manifold.
CALCULATED PRESSURE RATIO OF F10.4 FOR INPUT SPEED F10.0 BELOW 1.0 -- SET PRESSURE RATIO = 1.0 IN CHAP	CHAP	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.

* A, F, E indicate format of printed information.

TABLE 14 (Cont'd.)

MESSAGE*	ORIGIN	SEVERITY	COMMENT
INPUT SPEED F10.0 BELOW 6000 RPM -- 6000 DATA USED IN CHAP	CHAP	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.
INPUT SPEED F10.0 ABOVE 18100 RPM -- 18100 DATA USED IN CHAP	CHAP	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.
DATA IN SURGE -- SET CORRECTED MASS = 0.0 IN CHAP	CHAP	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.
CORRECTED MASS OF F10.2 FOR INPUT SPEED OF F10.0 EXCEEDS 16500 CFM -- SET CORRECTED MASS = 16500	CHAP	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.
INPUT SPEED F10.0 ABOVE 14000 RPM -- 14000 RPM DATA USED TO CALCULATE EFFICIENCY	CHAP	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.
INPUT SPEED E10.4 EXCEEDS LIMITS OF DATA IN POLYE	POLYE	FATAL	Input speed check. PRT4 prints a dump of subsystem 4's information before exiting.
LEAST SQUARES CALCULATION IN POLYE YIELDS EFFICIENCY LESS THAN 0.1 AT SPEED LINE I7 FOR INPUT SPEED E10.4 AND INPUT PRESSURE RATIO E10.4 0.1 EFFICIENCY HAS BEEN ASSIGNED	POLYE	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.
LEAST SQUARES CALCULATION IN POLYE YIELDS EFFICIENCY GREATER THAN .84 AT SPEED LINE I7 FOR INPUT SPEED E10.4 AND INPUT PRESSURE RATIO E10.4 .84 EFFICIENCY HAS BEEN ASSIGNED	POLYE	INFORMATIVE	This message indicates an engineering approximation necessary for simulation.
NO SOLUTION FOR TURBINE PARAMETERS EXIST AFTER 100 ITERATIONS	THAP	FATAL	Computation will not converge for turbine parameters.

* A, F, E indicate format of printed information.

Subsystem where the variable is assigned a value either as input data or computed. "INPUT (SOURCE)" contains current input value and letter note for source (see key below). This column is blank for variables which are computed rather than input. The "DESCRIPTION" column briefly defines the variable and gives information helpful to the user. Corresponding "ALGEBRAIC SYMBOLS" and "UNITS" are presented for variables which have engineering application.

If a variable is required as input, a value and/or source letter appears under the "INPUT (SOURCE)" column. If this column is blank, then the user does not input this variable. Additional footnotes are presented to clarify variables not input; however, this information is not necessary unless the user intends to alter the FORTRAN coding.

INPUT (SOURCE) KEY for following table of variable definitions:

(a) Arthur D. Little, Inc. (ADL) - by I. W. Dingwell (ADL) at Cooper-Bessemer on June 4, 1971.

(b) Cooper-Bessemer (C-B) - drawing LSV-24-19, labeled as A2. 12.6.

(c) Value selected by user of computer program.

(d) Initial conditions - computed using equations of motion, see section 9.B.2 in the Program Description of this manual.

(e) Cooper-Bessemer Logsheet - tests on LSV-16, Model No. 8002, June 24, 1971.

(f) Standard mathematical or engineering constant.

(g) Cooper-Bessemer Test - corrected by B. M. Allen (ADL) for correct application in program.

(h) Arthur D. Little, Inc. - computed from Cooper-Bessemer Engine Specifications.

(i) Cooper-Bessemer - drawing labeled A2.12.2.

(j) Arthur D. Little, Inc. - measured during tests on LSV-16, Model No. 8002, at Cooper-Bessemer, June 24, 1971.

(k) Cooper-Bessemer - C-B specifications, verified by H. B. Zackrison of the Office of the Chief of Engineers (OCE), February 3, 1971.

(l) Arthur D. Little, Inc. - for Dodecane, ($C_{12}H_{26}$).

(m) Arthur D. Little, Inc. - to match steady-state conditions.

(n) Arthur D. Little, Inc. - estimated value.

(o) Arthur D. Little, Inc. - from Heat Balance computed using C-B log sheets from tests of June 24, 1971.

(p) Arthur D. Little Inc. - first run input value estimated program calculated refined value for later runs.

(q) Arthur D. Little, Inc. - computed from C-B drawing LSV-24-19, labeled as A2.12.6.

(r) Arthur D. Little, Inc. - computed by J. L. Coggins (ADL) on theoretical considerations.

(s) Arthur D. Little, Inc. - computed from air flow measurements on C-B log sheet for LSV-16, Model No. 8002, May 29, 1971.

(t) Cooper-Bessemer - heat balance from R. M. Grene (C-B) on September 7, 1968.

(u) Arthur D. Little, Inc. - standard diesel cycle, refer to Table 19 in this manual.

(v) Arthur D. Little, Inc. - figured from firing order, Reference (i) above, and kinematics of crankshaft, C-B drawing and equations labeled G.C. #19.

(w) Cooper-Bessemer - given to J. L. Coggins via telephone.

(x) Arthur D. Little, Inc. - computed for analytical function to fit fuel control responses as measured at Cooper-Bessemer June 24, 1971.

(y) Arthur D. Little, Inc. - values determined by extensive operation of program to control numerical instabilities.

(z) Arthur D. Little, Inc. - values first computed by hand to satisfy initial condition that all time derivatives equal zero. Refined values obtained by operating program at steady-state (constant load and environment) then using output values as input to later runs at the same load.

MAIN

ICM (20), COMMUNICATION VARIABLES

ICM	INTERNAL EQUIVALENT	LOCATION SET	INPUT (SOURCE)	DESCRIPTION
1	L(5),L5,L7	3	2(a)	number of intake manifolds
2	L(22),L22,L8	3	6(b)	number of exhaust manifolds
3	L(26)	3		total number of manifolds, both intake and exhaust
4		5		end of run flag, =0 goes to next =1, CALLS EXIT

5-20 NOT USED

MAIN

G(90), COMMUNICATION AND PLOTTING VARIABLES

G	ALGEBRAIC SYMBOL	UNITS	LOCATION SET	INPUT (SOURCE)	DESCRIPTION
1	t	sec	1		time
2	ω	rad/sec	1		crankshaft speed
3	$\dot{\omega}$	rad/sec^2	1		crankshaft acceleration
4	f	Hz	2		electrical frequency
5	Δf_d	%	5		frequency deviation displayed
6	τ_d	in-lbf	3		developed torque
7	τ_s	in-lbf	2		alternator torque required
8	KW	Kw	ENVIR		generated power
9	Z	inches	5		injector lift
10	P_{ai}	lbf/in^2	ENVIR		ambient pressure at inlet
11	P_{ae}	lbf/in^2	ENVIR		ambient pressure at exhaust
12	T_{ai}	°R	ENVIR		ambient temperature at inlet
13	θ	rad	1		crankshaft angle
14	Δf	%	5		true frequency deviation
15	P_{cmax}	lbf/in^2	3		peak cylinder pressure
16	T_{cmax}	°F	3		peak cylinder temperature
17	P_{im}/P_{ai}	-	4		compressor pressure ratio
18	W_c^*	lbm/sec	4		corrected mass flow

G(30), COMMUNICATION AND PLOTTING VARIABLES (Cont'd.)

G	ALGEBRAIC SYMBOL	UNITS	LOCATION SET	INPUT (SOURCE)	DESCRIPTION
19	$\dot{m}_f$	lbm/hr	3		instantaneous fuel rate
20	N_t	RPM	4		turbocharger shaft speed
21	τ_d	ft-lbf	3		developed torque
22	θ	deg	MAIN	0.(c)	crankshaft angle
23	T_e	°F	4		exhaust temperature
24	a	in-lbf	3	986400.(d)	equation of motion coefficient
25	b	in-lbf-sec/rad	3	262.3(d)	equation of motion coefficient
26	c	$\text{in-lbf-sec}^2/\text{rad}^2$	3	19.36(d)	equation of motion coefficient
27	d	$\text{in-lbf-sec}^2/\text{rad}$	3	346300(d)	equation of motion coefficient
28	P_{c1}	lbf/in^2	3		cylinder 1 pressure
29	T_{c1}	°R	3		cylinder 1 temperature
30	$\Delta\theta$	deg	MAIN		clock step, set = A(3) of MAIN
31	$\dot{Q}_w$	BTU/sec	3		power loss to cylinder walls
32	$\dot{Q}_f$	BTU/sec	3		power loss to friction
33	$\dot{Q}_{in}$	BTU/sec	3		power content of fuel
34	$\dot{Q}_{ex}$	BTU/sec	3		power loss to exhaust
35	$\dot{Q}_{ic}$	BTU/sec	3		power loss to intercooler
36	$\dot{Q}_s$	BTU/sec	3		shaft power to generator

G(90), COMMUNICATION AND PLOTTING VARIABLES (Cont'd.)

G	ALGEBRAIC SYMBOL	UNITS	LOCATION SET	INPUT (SOURCE)	DESCRIPTION
37	$\dot{Q}_{em}$	BTU/sec	3		power loss to water jacket
38	Q_w/Q_{in}	%	1		% fuel energy lost to cylinder walls
39	Q_f/Q_{in}	%	1		% fuel energy lost to friction
40	Q_{ex}/Q_{in}	%	1		% fuel energy lost to exhaust
41	Q_{ic}/Q_{in}	%	1		% fuel energy lost to intercoder
42	Q_s/Q_{in}	%	1		% fuel energy to shaft
43	Q_{em}/Q_{in}	%	1		% fuel energy lost to water jacket
44	Q_{in}	BTU	1		fuel energy
45	$\Sigma\ Q_{out}$	BTU	1		sum of energy dissipated
46	BHP	HP	1		brake horsepower
47	IHP	HP	1		indicated horsepower
48	BMEP	lbf/in^2	1		brake mean effective pressure
49	IMEP	lbf/in^2	1		indicated mean effective pres.
50	FR	lbm/hr	1		fuel rate
51	BSFC	lbm/HP/hr	1		brake specific fuel consumption
52	$\dot{Q}_{aux}$	BTU/Sec	3		shaft power to auxiliaries
53	T_{aux}	in-lbf	3		torque required to drive auxiliaries
54	Q_{aux}/Q_{in}	%	1		% fuel energy to drive auxiliaries

G(90), COMMUNICATION AND PLOTTING VARIABLES (Cont'd.)

G	ALGEBRAIC SYMBOL	UNITS	LOCATION SET	INPUT (SOURCE)	DESCRIPTION
55	$\dot{m}_e$	lbm/sec	4		turbine total mass flow
56	T_{com}	°R	4		compressor exit temperature (average value for more than one compressor)
57	T_e	°R	4		exhaust (stack) temperature
58	$\dot{m}_i$	lbm/sec	4		total mass flow at all compressors
59	ω_t	rad/sec	4		turbocharger shaft speed
60	T_{ic}	°R	4		intercooler exit temperature (average value for more than one intercooler)
61	P_{im1}	lbf/in^2	3	22.65(e)	inlet manifold (#1) pressure
62	$\dot{m}_{i1}$	lbm/sec	4		mass flow from compressor to inlet manifold (#1)
63	T_{im1}	°R	3		inlet manifold (#1) temperature.
64	P_{im1}	lbf/in^2	3	22.65(e)	inlet manifold (#2) pressure
65	$\dot{m}_{12}$	lbm/sec	4		mass flow from compressor to inlet
66	T_{im2}	°R	3		inlet manifold (#2) temperature
67	P_{em1}	lbf/in^2	3		exhaust manifold (#1) pressure
68	$\dot{m}_{e1}$	lbm/sec	4	19.3(e)	exhaust manifold (#1) mass flow
69	T_{em1}	°R	3		exhaust manifold (#1) temperature

G(90), COMMUNICATION AND PLOTTING VARIABLES (Cont'd.)

G	ALGEBRAIC SYMBOL	UNITS	LOCATION SET	INPUT (SOURCE)	DESCRIPTION
70	P_{em2}	lbf/in^2	3		exhaust manifold (#2) pressure
71	$\dot{m}_{e2}$	lbm/sec	4		exhaust manifold (#2) mass flow
72	T_{em2}	°R	3		exhaust manifold (#2) temperature
73	P_{em3}				
74	$\dot{m}_{e3}$				
75	T_{em3}				
76	P_{em4}				
77	$\dot{m}_{e4}$				
78	T_{em4}				
79	P_{em5}				
80	$\dot{m}_{e5}$				
81	T_{em5}				
82	P_{em6}				
83	$\dot{m}_{e6}$				
84	T_{em6}				

85-90] Reserved for two more manifolds

NOTE: The G array is arranged to accept any combination of inlet plus exhaust manifolds up to ten in number.

MAIN

A(100), CONSTANT COEFFICIENTS

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1 --NOT USED					
2		θ_{max}	deg	2880.(c)	length of run, LSV-16 turns 2160° per sec
3		$\Delta\theta$	deg	5.(y)	computation mesh
4-37 - NOT USED					
A(38)-A(50) input for std. air shock (AMB12)					
38		T_{ai}	°R	(c)	ambient temp. about inlet before shock
39			sec	(c)	time at beginning of inlet shock
40			sec	(c)	time inlet shock reaches peak value
41			sec	(c)	time at beginning of inlet shock decay
42			sec	(c)	time at end of inlet positive phase
43		P_{ai}	lbf/in^2	(c)	ambient pressure about inlet before shock
44		P_{ai}	lbf/in^2	(c)	peak pressure of inlet shock
45			sec	(c)	time at beginning of exhaust shock
46			sec	(c)	time exhaust shock reaches peak value
47			sec	(c)	time at beginning of exhaust shock decay
48			sec	(c)	time at end of exhaust positive phase

A(100), CONSTANT COEFFICIENTS (Cont'd.)

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUTS (SOURCE)	DESCRIPTION
49		P_{ae}	lbf/in^2	(c)	ambient pressure about exhaust before shock
50		P_{ae}	lbf/in^2	(c)	peak pressure of exhaust shock
A(51)-A(98)	input for shock tube simulation (AMB10)				
51			sec	(c)	time-first data point
52		P_{ai}	lbf/in^2	(c)	inlet pressure-first data point
53		T_{ai}	°R	(c)	inlet temperature-first data point
54		P_{ae}	lbf/in^2	(c)	exhaust pressure-first data point
55			sec	(c)	time-second data point
56		P_{ai}	lbf/in^2	(c)	inlet pressure-second data point
57		T_{ai}	°R	I(c)	inlet temperature-second data point
58		P_{ae}	lbf/in^2	I(c)	exhaust pressure-second data point

A(59)-A(98) repeats this pattern (time, inlet pressure, inlet temperature, exhaust pressure) for a total of 12 data points.

A(99)-A(100)- NOT USED

MAIN

B(60), NON-CONSTANT COEFFICIENTS

B	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		P_{ai}	lbf/in^2	*AMB10	ambient pressure about inlet
2		T_{ai}	°R	*AMB10	ambient temperature about inlet
3		P_{ae}	lbf/in^2	*AMB10	ambient pressure about exhaust
4		T_{ai}	°R	*AMB12	ambient temperature about inlet
5			lbf/in^2-sec	*AMB12	rate of ambient pressure change
6				*AMB12	intermediate variables used to compute ambient temperature at inlet
7				*AMB12	
8-60	NOT USED				

*Subroutine name, value not input.

MAIN
L(30), COUNTERS

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
1	NOT USED		
2		1.0(c)	frequency for printing title with MAIN output
3	NOT USED		
4		1.0(c)	tape 8 printout frequency, unity for every A(3) degrees
5		9.0(c)	MAIN printing frequency, prints at every L(5)*A(3) degrees
6		0.0(c)	= 0 skip subsystem detailed printout; ≠ 0 calls print routines for all subsystems every time MAIN prints, see L(5) above
7		0.0(c)	= 0 steady-state environment; = 1 AMB10; = 2 AMB12
8	NOT USED		
9	NOT USED		
10			
11			counter for printing titles
12	NOT USED		
13			
14		1.0(c)	> 0 calls PUN3 at end of run
15			set ≠ 0 after data is read in AMB12
16		0.0(c)	> 0 writes G(1-48) on logical unit 4 for plotting
17-20	NOT USED		

L(30), COUNTERS (Cont'd.)

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
21			counter for print (total count)
22			counter for plot (total count)
23 24	NOT USED		
25			counter for print frequency
26			counter for plot frequency
27-30	NOT USED		

SUBSYSTEM 1 - EQUATION OF MOTION
A(20), CONSTANT COEFFICIENTS

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		$\Delta\theta$	rad	.8726646(y)	computation mesh, current value = MAIN A(3) converted to radians*
2		$\pi/180$	rad/deg	.017453291(f)	
3	EC	LHV	in-lbf/lbm	$.68327 \times 10^8$(g)	fuel lower heating value
4	JO	J	in/lbf/BTU	9338.0(f)	dimensional constant
5	CID	V_D	in^3	67041.41(h)	total displacement
6	PI		-	3.14159265(f)	
7	KO	K	in-lbf/sec-HP	6600.0(f)	dimensional constant

*NOTE: user may select computation mesh ≠ A(3)

SUBSYSTEM 1 - EQUATION OF MOTION
B(19), NON-CONSTANT COEFFICIENTS

B	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		Q_w	BTU		energy loss to cylinder walls
2		Q_f	BTU		energy loss to friction
3		Q_{in}	BTU		energy content of fuel
4		Q_{ex}	BTU		energy loss to exhaust
5		Q_{ic}	BTU		energy loss to intercooler
6		Q_s	BTU		energy to shaft
7		Q_{em}	BTU		energy loss to water jacket
8		Q_w/Q_{in}	%		% fuel energy lost to cylinder walls
9		Q_f/Q_{in}	%		% fuel energy lost to friction
10		Q_{in}/Q_{in}	%		100% (Check)
11		Q_{ex}/Q_{in}	%		% fuel energy lost to exhaust
12		Q_{ic}/Q_{in}	%		% fuel energy lost to intercooler
13		Q_s/Q_{in}	%		% fuel energy to shaft
14		Q_{em}/Q_{in}	%		% fuel energy lost to water jacket
15		Q_{aux}	BTU		energy loss to auxiliaries
16-19	NOT USED				

SUBSYSTEM 1 - EQUATION OF MOTION
L(20), COUNTERS

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
1	NE	10.0(c)	number of equations to integrate in Subroutine YPR1
2		1.0(c)	frequency for printing title, unity prints title above every printout for this Subsystem
3	NOT USED		
4			
5			
6			
7			
8	NSC	4.0(i)	number of strokes per cycle
9		-2.0(c)	counter for determining end of cycle, input value never changes
10			counter for PRT1 calls, used to determine when title frequency is reached
11-20	NOT USED		

SUBSYSTEM 1 - EQUATION OF MOTION
Y(10), DEPENDENT VARIABLES

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		ω	rad/sec		crankshaft speed
2		t	sec		time
3		Q_w	BTU		energy to cylinder walls
4		Q_f	BTU		energy loss to friction
5		Q_{in}	BTU		energy content of fuel
6		Q_{ex}	BTU		energy loss to exhaust
7		Q_{ic}	BTU		energy loss to intercooler
8		Q_s	BTU		energy to generator through shaft
9		Q_{em}	BTU		energy loss to water jacket
10		Q_{aux}	BTU		energy to auxiliaries

SUBSYSTEM 2

A(20), CONSTANT COEFFICIENTS

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		Δt	sec	.0025(y)	computation mesh*
2		f_o/ω_o	Hz-sec/rad	1.591549(h)	alternator frequency over crank speed
3		E_o	in-lbf/sec	2.6995 10 (h)	rated shaft power
4		t_o	sec	20.0(c)	time when load changes
5		E/E_o		1.10(j)	fraction of rated shaft power before load change
6		E/E_o		.606(j)	fraction of rated shaft power after load change
7		KW_o	Kw	2950.0(k)	rated electrical load
8		KW/KW_o	Kw	1.10(j)	fraction of rated electrical load before load change
9		KW/KW_o	Kw	.600(j)	fraction of rated electrical load after load change

10-20 - NOT USED

*NOTE: Computation mesh ≈ A(3) of MAIN converted to seconds by 2160 deg/sec; however, the computation meshes of different subsystems may differ. See explanation in Section 5.2.1, Basic Organization.

SUBSYSTEM 2
L(20), CONTROL INTEGERS

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
1		0.0(c)	= 0 torque set in SUB2; ≠ 0 torque set in ENVIR from test data*
2		1.0(c)	frequency for printing title; unity prints title above every Subsystem 2 printout
3-9	NOT USED		
10			counter for PRT2 calls
11-20	NOT USED		

*NOTE: Torque data for the LSV-16 diesel is not currently coded in Subroutine ENVIR. To use the option L(1) ≠ 0 the FORTRAN coding must be revised.

SUBSYSTEM 3

A(100), CONSTANT COEFFICIENTS

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1			deg.	35.(i)	exhaust valve closes
2			deg.	200.(i)	inlet valve closes
3			deg.	338.(i)	fuel injection begins
4			deg.	475.(i)	exhaust valve opens
5			deg.	640.(i)	inlet valve opens
6	*NOT USED				
7	AF		-	15.(1)	stoichiometric air-fuel ratio
8	AI	I	in-lbf-sec^2	344455.(k)	rotary moment of inertia
9	C1	h_c	lbf/in-sec-°R	0.5(m)	cylinder wall heat transfer coefficient
10	BRR	K_3	1/sec	105.(m)	burning rate constant
11	EC	LHV	in-lbf/lbm	1.682148×10^8(g)	lower heating value of fuel
12	AD	A_p	in^2	188.6917(h)	piston cross-sectional area
13	FIM	m'_{fi}	lbm/rad	Subroutine RACK	maximum fuel injection rate
14	R	R	in-lbf/lbm-°R	640.(f)	gas constant
15	TW	T_w	°R	900.(n)	cylinder wall temperature
16	VO	V_o	in^3	415.122(h)	cylinder clearance volume
17	CID	V_D	in^3	67041.41(h)	total displacement volume
18	W10	$\pi D/90$	rad		
19	W11	$\pi/180$	rad/deg	.017453293(f)	
20	W12	k	-	1.4(f)	ratio of specific heats for air
21	W13	kR	lb-lbf/lbm-°R	896.(f)	

*NOTE: FORTRAN coding contains EQUIVALENCE statements for variables not used in the Cooper-Bessemer LSV-16 simulation.

A(100), CONSTANT COEFFICIENTS (Cont'd.)

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
22 - 24	*NOT USED				
25	PD	πd	in	48.6946(h)	piston perimeter
26 - 28	*NOT USED				
29	PI	π		3.14159265(f)	
30	W29		deg	720.(i)	degrees per cycle
31	NOT USED				
32	PM	M_p	$lbf\text{-}sec^2/in$	1.7779(k)	single piston mass for cylinders NC/2 to NC
33	PM	M_p	$lbf\text{-}sec^2/in$	1.928(k)	single piston mass for cylinders #1 to NC/2
34		J	in-lbf/BTU	9338.(f)	conversion factor
35		C_p	in-lbf/lbm-°R	2250.(f)	specific heat
36	FC	f_o	lbf-sec/in	3.0(m)	friction coefficient
37		$\dot{Q}_{fo}$	%	6.0(h)	energy loss to friction at steady-state
38		$\dot{Q}_{wo}$	%	4.1(o)	energy loss to walls at steady-state
39		m_{co}	lbm	.254(p)	air mass trapped in cylinder at steady-state
40		ω_o	rad/sec	37.6991(k)	rated engine speed
41	DXC	$\Delta\theta_c$	deg	1.25(y)	combination integration step
42	NOT USED				
43	DX		deg	5.0(y)	normal integration step
44		P_{imn}	lbf/in^2	22.65(e)	nominal inlet manifold pressure
45		θ_d	deg	10.0(m)	nominal ignition delay
46			deg	.001(y)	tolerance angles for ANGLE, IMODE

*NOTE: FORTRAN coding contains EQUIVALENCE statements for variables not used in the Cooper-Bessemer LSV-16 simulation.

A(100), CONSTANT COEFFICIENTS (Cont'd.)

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
47			deg	.001(y)	tolerance on angles for CHANG
48			lbf/in^2	.001(y)	tolerance on pressure for TDSL
49			lbf/in^2	.001(y)	tolerance on pressure for CHANG
50			lbm	.000005(y)	tolerance on fuel for PTDSL
51			lbm	.000005(y)	tolerance on fuel for CHANG
52		h_{em}	lbf/in-sec-°R	.46(m)	h.t. coefficient of exhaust manifold
53		A_{em}	in^2	4112.(q)	h.t. area of single exhaust manifold (taken as average value for all exhausts)
54		T_{wem}	°R	700.(n)	temperature of exhaust manifold wall
55		T_b	°R	540.(n)	base temperature for LHV
56		a	in-lbf/lbm-°R	197.6(r)	temperature coefficient of LHV
57		a	in-lbf/lbm-°R^2	.6381(r)	temperature coefficient of LHV
58		c_{ev}	-	1.8(n)	orifice coefficient for exhaust valve
59		c_{iv}	-	1.8(n)	orifice coefficient for inlet valve
60		f_{ev}	-	0.5(n)	exhaust valve backflow coefficient
61		f_{iv}	-	0.5(n)	inlet valve backflow coefficient
62		k_{ev}	-	1.15(f)	ratio of specific heat in exh. man.
63		P_{amb}	lbf/in	14.1(e)	nominal ambient pressure
64		$\dot{m}_{eo}$	lbm/sec	2.412(s)	nominal exhaust manifold flow (for a single manifold)
65		$\dot{Q}_{aux}$	BTU/sec	73.61(t)	power loss to auxiliaries

A(100), CONSTANT COEFFICIENTS (Cont'd.)

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
66-90	NOT USED				
91	VI(1)		in^3	44490. (a)	volume of manifold #1
92	VI(2)		in^3	44490. (a)	volume of manifold #2
93	VI(3)		in^3	5894. (b)	volume of manifold #3
94	VI(4)		in^3	3561. (b)	volume of manifold #4
95	VI(5)		in^3	6670. (b)	volume of manifold #5
96	VI(6)		in^3	5037. (b)	volume of manifold #6
97	VI(7)		in^3	5980. (b)	volume of manifold #7
98	VI(8)		in^3	5835. (b)	volume of manifold #8
99-100			in^3		reserved for manifold volumes #9-#10

SUBSYSTEM 3

B(100), NON-CONSTANT COEFFICIENTS

B	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		θ	deg	0.(c)	crankshaft angle, =G(22) in MAIN
2		τ_f	in-lbf		friction torque
3		τ_i	in-lbf		intertia torque
4		τ_d	in-lbf		developed shaft torque
5		c	in-lbf-sec^2/rad^2		coefficient for equation of motion
6			in-lbf-sec^2/rad		used to compute coeff. for eq. of motion
7		$\bar{m}_c$	lbm		average mass in cylinder
8 - 9	NOT USED				
10					
11		$\dot{Q}_w$	BTU/sec		power loss to cylinder walls
12		$\dot{Q}_f$	BTU/sec		power loss to friction
13		$\dot{Q}_{in}$	BTU/sec		power content of injected fuel
14		$\dot{Q}_{ex}$	BTU/sec		power loss to exhaust
15		$\dot{Q}_{ic}$	BTU/sec		power loss to intercooler
16		$\dot{Q}_s$	BTU/sec		shaft power to generator
17		$\dot{Q}_{em}$	BTU/sec		power loss to water jacket
18		$\dot{Q}_{aux}$	BTU/sec		shaft power to auxiliaries
19 - 23	NOT USED				
24		τ_g, a	in-lbf		developed gas torque, for eq. of motion
25		$\dot{m}_{fi}$	lbm/hr		instantaneous fuel rate
26		θ_1	deg		fuel injection begins
27		Z	in		rack position (injector lift)
28 - 29	NOT USED				

B(100), NON-CONSTANT COEFFICIENTS (Cont'd.)

B	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
30		θ_d	deg		combustion begins
31	W14(1)	θ_2	deg		See Figure 2
32	W14(2)	θ_3	deg		See Figure 2
33	W14(3)	θ_4	deg		See Figure 2
34		$\Delta\theta_2$	deg		$\theta_3 - \theta_2$
35	NOT USED				
36		f_o	lbf-sec/in		steady-state friction coefficient
37		f_c	lbf-sec/in	3.54(m)	instantaneous friction coefficient
38		h_{co}	lbf/in-sec-°R		steady-state heat transfer coefficient for cylinder walls
39		h_c	lbf/in-sec-°R	.50(m)	instantaneous heat transfer coefficient for cylinder walls
40		$\Delta\theta_1$	deg		$\theta_2 - \theta_1$
41		$\Delta\theta_3$	deg		$\theta_4 - \theta_3$
42		h_{em1}	lbf/in-sec-°R		heat transfer coefficient for exh. man. #1
43		h_{em2}	lbf/in-sec-°R		heat transfer coefficient for exh. man. #2
44 - 47					heat transfer coefficient for exh. man. #3 - #6
48 - 50					reserved for exhaust manifolds #7 - #9
51	FLIM(1)		lbm/rad		flow through manifold #1
52	FLIM(2)		lbm/rad		flow through manifold #2
53 - 58	FLIM(3-8)		lbm/rad		flow through manifolds #3 - #8
59 - 60	FLIM(9-10)		lbm/rad		reserved for manifolds #9 and #10
61- 80					used to store values of UO(I,1)
81 - 100					used to store values of YO(I4)

SUBSYSTEM 3

L(99), COUNTERS

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
1	NC	16.0(k)	number of cylinders
2	NC4	64.0(k)	4 times number of cylinders
3	NSC	4.0(i)	number of strokes per cycle (2 or 4)
4	NE	*INP3	number of equations to be integrated (NE = 2+NC*4+L522*3)
5	L5	2.0(a)	number of intake manifolds
6			counter for calls to PTDSL
7			number of times ANGLE computes D
8			number of times PTDSL computes D
9			counter for calls to CHANG
10	NOT USED		
11		1.0(u)	mode, M(I), following angle A(1); intake
12		2.0(u)	mode, M(I), following angle A(2); compression
13		3.0(u)	mode, M(I), following angle A(3); combustion
14		4.0(u)	mode, M(I), following angle A(4); exhaust
15		5.0(u)	mode, M(I), following angle A(5); scavenge
16		0.0(c)	≠ 0 automatically adjusts h_c and f_o at the end of each cycle for steady-state tuning; = 0 uses input values A(9) and A(36)
17			flag set = 99 after C1 and FC are stored in B(36) and B(38)
18		7.0(c)	counter for PMAX, TMAX dum=(NSC*180)/(NC*G(30))-2
19	JT		counter for peak temperatures calculated
20	JP		counter for peak pressures calculated
21			
22		6.0(b)	number of exhaust manifolds

*Computed in Subroutine INP3.

L(99), COUNTERS (Cont'd.)

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
23		2.0(c)	set > 0 to print U array shown on page 109, and Mode variables described in Table 19, page 247.
24		1.0(c)	frequency for writing TITLE in PRT3
25			counter for PRT3 calls
26	L522	*INP3	total number of manifolds, inlet plus exhaust, L(26) = L(5) + L(22)
27 - 30	NOT USED		
31	INL(1)	1. (a)	cylinder 1 inlet manifold connection
32	INL(2)	1. (a)	cylinder 2 inlet manifold connection
33	INL(3)	1. (a)	cylinder 3 inlet manifold connection
34	INL(4)	1. (a)	cylinder 4 inlet manifold connection
35	INL(5)	1. (a)	cylinder 5 inlet manifold connection
36	INL(6)	1. (a)	cylinder 6 inlet manifold connection
37	INL(7)	1. (a)	cylinder 7 inlet manifold connection
38	INL(8)	1. (a)	cylinder 8 inlet manifold connection
39	INL(9)	2. (a)	cylinder 9 inlet manifold connection
40	INL(10)	2. (a)	cylinder 10 inlet manifold connection
41	INL(11)	2. (a)	cylinder 11 inlet manifold connection
42	INL(12)	2. (a)	cylinder 12 inlet manifold connection
43	INL(13)	2. (a)	cylinder 13 inlet manifold connection
44	INL(14)	2. (a)	cylinder 14 inlet manifold connection
45	INL(15)	2. (a)	cylinder 15 inlet manifold connection
46	INL(16)	2. (a)	cylinder 16 inlet manifold connection
47 - 50			reserved for inlet manifold connections

*Computed in Subroutine INP3.

L(99), COUNTERS (Cont'd.)

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
51	IEX(1)	2.	cylinder 1 exhaust manifold connection
52	IEX(2)	5.	cylinder 2 exhaust manifold connection
53	IEX(3)	5.	cylinder 3 exhaust manifold connection
54	IEX(4)	4.	cylinder 4 exhaust manifold connection
55	IEX(5)	4.	cylinder 5 exhaust manifold connection
56	IEX(6)	6.	cylinder 6 exhaust manifold connection
57	IEX(7)	1.0(b)	cylinder 7 exhaust manifold connection
58	IEX(8)	3.0(b)	cylinder 8 exhaust manifold connection
59	IEX(9)	1.0(b)	cylinder 9 exhaust manifold connection
60	IEX(10)	2.0(b)	cylinder 10 exhaust manifold connection
61	IEX(11)	2.0(b)	cylinder 11 exhaust manifold connection
62	IEX(12)	1.0(b)	cylinder 12 exhaust manifold connection
63	IEX(13)	5.0(b)	cylinder 13 exhaust manifold connection
64	IEX(14)	3.0(b)	cylinder 14 exhaust manifold connection
65	IEX(15)	3.0(b)	cylinder 15 exhaust manifold connection
66	IEX(16)	6.0(b)	cylinder 16 exhaust manifold connection
67 - 70			reserved for exhaust manifold connections
71 - 99	NOT USED		

SUBSYSTEM 3

U(20, 15), NON-CONSTANT COEFFICIENTS AS U(i,j) FOR ith CYLINDER

i	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		T_c	°R		cylinder temperature (cylinder I)
2		T_{im}	°R		inlet manifold temperature
3		Q_w	in-lbf/sec		heat transfer to cylinder wall
4		A_{iv}	in^2		effective inlet valve open area (includes coefficient A(59))
5		A_{ev}	in^2		effective exhaust valve open area (includes coefficient A(58))
6		V_c	in^3		cylinder volume
7		A_c	in^2		cylinder heat transfer area
8		$dm_{iv}/d\theta$	lbm/rad		mass flow through inlet valve
9		$dm_{ev}/d\theta$	lbm/rad		mass flow through exhaust valve
10		$dm_{fb}/d\theta$	lbm/rad		fuel burning rate
11		S	in		cylinder position
12		S'	in/rad		cylinder velocity
13		S"	in/rad^2		cylinder acceleration
14		$dm_{fi}/d\theta$	lbm/rad		fuel injection rate
15		T_{em}	°R		exhaust manifold temperature

SUBSYSTEM 3

X(20), INDEPENDENT VARIABLES

X	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1			deg	0. (v)	value of crankshaft angle for cylinder 1
2			deg	540. (v)	value of crankshaft angle for cylinder 2
3			deg	90. (v)	value of crankshaft angle for cylinder 3
4			deg	270. (v)	value of crankshaft angle for cylinder 4
5			deg	630. (v)	value of crankshaft angle for cylinder 5
6			deg	450. (v)	value of crankshaft angle for cylinder 6
7			deg	180. (v)	value of crankshaft angle for cylinder 7
8			deg	360. (v)	value of crankshaft angle for cylinder 8
9			deg	396.09(v)	value of crankshaft angle for cylinder 9
10			deg	216.09(v)	value of crankshaft angle for cylinder 10
11			deg	486.09(v)	value of crankshaft angle for cylinder 11
12			deg	666.09(v)	value of crankshaft angle for cylinder 12
13			deg	306.09(v)	value of crankshaft angle for cylinder 13
14			deg	126.09(v)	value of crankshaft angle for cylinder 14
15			deg	576.09(v)	value of crankshaft angle for cylinder 15
16			deg	36.09(v)	value of crankshaft angle for cylinder 16
17 - 20					reserved for cylinders 17 - 20

SUBSYSTEM 3
Y(100), DEPENDENT VARIABLES

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT(SOURCE)	DESCRIPTION
1					
2		ω	rad/sec	37.739(p)	crankshaft angular speed
3		m_{f1}	lbm	0.(p)	unburned fuel in cylinder 1
4		P_{c1}	lbf/in^2	23.121(p)	pressure in cylinder 1
5		m_{c1}	lbm	.019718(p)	gas charge in cylinder 1
6		x_{c1}	-	.11192(p)	comb. prod./charge in cylinder 1
7		m_{f2}	lbm	0.(p)	unburned fuel in cylinder 2
8		P_{c2}	lbf/in^2	43.659(p)	pressure in cylinder 2
9		m_{c2}	lbm	.17051(p)	gas charge in cylinder 2
10		x_{c2}	-	.53061(p)	comb. prod./charge in cylinder 2
11		m_{f3}	lbm	0.(p)	etc., for cylinders 3 through 20
12		P_{c3}	lbf/in^2	22.718(p)	
13		m_{c3}	lbm	.5941(p)	
14		x_{c3}	-	.012052(p)	
15		m_{f4}	lbm	0.(p)	
16		P_{c4}	lbf/in^2	47.733(p)	
17		m_{c4}	lbm	.26642(p)	
18		x_{c4}	-	.006794(p)	

Y(100), DEPENDENT VARIABLES (Cont'd.)

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
19		m_{f5}	lbm	0.(p)	
20		P_{c5}	lbf/in^2	23.64(p)	
21		m_{c5}	lbm	.0675(p)	
22		x_{c5}		.5310(p)	
23		m_{p6}		0.(p)	
24		P_{c6}		181.97(p)	
25		m_{c6}		.27392(p)	
26		x_{c6}		.52844(p)	
27		m_{f7}		0.(p)	
28		P_{c7}		22.39(p)	
29		m_{c7}		.26613(p)	
30		x_{c7}		.0074077(p)	
31		m_{f8}		.0034275(p)	
32		P_{c8}		760.36(p)	
33		m_{c8}		.26583(p)	
34		x_{c8}		.047484(p)	
35		m_{f9}		.0035155(p)	
36		P_{c9}		562.48(p)	
37		m_{c9}		.27202(p)	
38		x_{c9}		.32952(p)	
39		m_{f10}		0.(p)	
40		P_{c10}		24.976(p)	
41		m_{c10}		.26724(p)	
42		x_{c10}		0.(p)	
43		m_{f11}		0.(p)	

Y(100), DEPENDENT VARIABLES (Cont'd.)

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT(SOURCE)	DESCRIPTION
44		P_{c11}		108.66(p)	
45		m_{c11}		.27705(p)	
46		x_{c11}		.52353(p)	
47		m_{f12}		0.(p)	
48		P_{c12}		22.549(p)	
49		m_{c12}		.0035353(p)	
50		x_{c12}		.53188(p)	
51		m_{f13}		0.	
52		P_{c13}		120.34(p)	
53		m_{c13}		.26781(p)	
54		x_{c13}		.011716(p)	
55		m_{f14}		0.(p)	
56		P_{c14}		22.808(p)	
57		m_{c14}		.23121(p)	
58		x_{c14}		.0090832(p)	
59		m_{f15}		0.(p)	
60		P_{c15}		28.946(p)	
61		m_{c15}		.12197(p)	
62		x_{c15}		.53393(p)	
63		m_{f16}		0.(p)	
64		P_{c16}		23.192(p)	
65		m_{c16}		.0049902(p)	
66		x_{c16}		.37940(p)	
67		P_{m1}	lbf/in^2	23.586(p)	manifold #1 pressure
68		m_{m1}	lbm	2.8509(p)	gas charge in manifold #1

Y(100), DEPENDENT VARIABLES (CONT'd)

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT(SOURCE)	DESCRIPTION
69		x_{m1}	-	$2.2723\text{x}10^{-5}$(p)	combustion product/charge in manifold #1
70		P_{m2}	lbf/in^2	23.739(p)	manifold #2 pressure
71		m_{m2}	lbm	2.868(p)	gas charge in manifold #2
72		x_{m2}	-	$3.9813\text{x}10^{-4}$(p)	combustion product/charge in manifold #2
73		P_{m3}	lbf/in^2	21.71(p)	manifold #3 pressure
74		m_{m3}	lbm	.15321(1)	gas charge in manifold #3
75		x_{m3}	-	.51688(p)	combustion product/charge in manifold #3
76		P_{m4}		17.652(p)	
77		m_{m4}		.090482(p)	
78		x_{m4}		.45036(p)	
79		P_{m5}		28.193(p)	
80		m_{m5}		.19057(p)	
81		x_{m5}		.51092(p)	
82		P_{m6}		22.661(p)	
83		m_{m6}		.13140(p)	
84		x_{m6}		.51631(p)	
85		P_{m7}		33.293(p)	
86		m_{m7}		.18372(p)	
87		x_{m7}		.50134(p)	
88		P_{m8}		15.046(p)	
89		m_{m8}		.12953(p)	
90		x_{m8}		.46174(p)	

Y(100), DEPENDENT VARIABLES (Cont'd.)

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT(SOURCE)	DESCRIPTION
90 - 96					reserved for manifolds #9 and #10
97 - 100	NOT USED				

NOTE: The Y array is set up for any combination of inlet plus exhaust manifolds not to exceed ten. For the Cooper-Bessemer LSV-16 Diesel Simulation:

Manifold #1 = inlet manifold #1
#2 = inlet manifold #2
#3 = exhaust manifold #1
#4 = exhaust manifold #2

Manifold #5 = exhaust manifold #3
#6 = exhaust manifold #4
#7 = exhaust manifold #5
#8 = exhaust manifold #6

SUBSYSTEM 4

A(5), CONSTANT COEFFICIENTS

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		Δt	sec	.001(y)	integration mesh
2		I_t	ft-lbf-sec^2	.643(w)	turbine's moment of inertia
3	FF		---	.65(m)	turbine efficiency adjustment factor
4	FACT		---	.87(m)	compressor flow adjustment factor
5	NOT USED				

SUBSYSTEM 4

B(59), NON-CONSTANT COEFFICIENTS

B	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		τ_c	ft-lbf		total compressor torque
2		τ_t	ft-lbf		total turbine torque
3		$\dot{m}_c$	lbm/sec		total compressor mass flow
4		$\dot{m}_t$	lbm/sec		total turbine mass flow
5		T_c	°R		average compressor discharge temperature
6		T_e	°R		exhaust stack temperature
7		ΣT_e	°R		sum of turbine exhaust stack temperatures
8 - 9	NOT USED				
10		η_c	-		compressor efficiency
11		P_{c1}	lbf/in^2		compressor 1 discharge pressure
12		$\dot{m}_{c1}$	lbm/sec		compressor 1 mass flow rate
13		T_{c1}	°R		compressor 1 discharge temperature
14		τ_{c1}	ft-lbf		compressor 1 torque
15		P_{c2}	lbf/in^2		compressor 2 discharge pressure
16		$\dot{m}_{c2}$	lbm/sec		compressor 2 mass flow
17		T_{c2}	°R		compressor 2 discharge temperature
18		τ_{c2}	ft-lbf		compressor 2 torque
19		P_{em1}	lbf/in^2		exhaust manifold 1 pressure
20		$\dot{m}_{t1}$	lbm/sec		exhaust manifold 1 flow
21		T_{em1}	°R		exhaust manifold 1 temperature
22		τ_{t1}	ft-lbf		turbine 1 torque
23		T_{e1}	°R		turbine 1 exit temperature

B(59), NON-CONSTANT COEFFICIENTS (Cont'd.)

B	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
24		P_{em2}	lbf/in^2		exhaust manifold 2 pressure
25		$\dot{m}_{t2}$	lbm/sec		exhaust manifold 2 flow
26		T_{em2}	°R		exhaust manifold 2 temperature
27		τ_{t2}	ft-lbf		turbine 2 torque
28		T_{e2}	°R		turbine 2 exit temperature
29 - 48		$P_{em}, \dot{m}_t, T_{em}, \tau_t, T_e$			for exhaust manifolds 3 - 6
49 - 59					reserved for more exhaust manifolds

SUBSYSTEM 4
L(10), COUNTERS

L	INTERNAL EQUIVALENT	INPUT (SOURCE)	DESCRIPTION
1		1.0(c)	number of differential equations in Subroutine YPR4
2		1.0(c)	frequency for printing title with Subsystem 4 printout
3 - 9	NOT USED		
10			count of calls to print routine, PRT5, since last time title was printed

SUBSYSTEM 4

Y(5), DEPENDENT VARIABLES

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		ω_t	rad/sec	1319.47(e)	turbocharger shaft speed
2 - 5	NOT USED				

SUBSYSTEM 5

A(30), CONSTANT COEFFICIENTS

A	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT(SOURCE)	DESCRIPTION
1		$\Delta\tau$	sec	.005(y)	integration mesh
2		f_o	Hz	60.0(k)	frequency setpoint
3		k/m	lbf/lbm-volt	900.(x)	ratio of spring constant to mass for fuel linkage
4		F/m	lbf/lbm	200.(x)	constant friction force term for fuel linkage equation, Section 5.3.7 in Part I (p. 47).
5		τ	sec	.2(x)	time constant for frequency error display
6		γ_1	Hz/volt	-.77(j)	frequency error conversion factor
7	A1	A_1		.671029(x)	2301 amplifier's transfer function constant
8	A2	A_2		.454837(x)	2301 amplifier's transfer function constant
9	A3	A_3		3.41375(x)	2301 amplifier's transfer function constant
10	A4	A_4		1006.72(x)	2301 amplifier's transfer function constant
11	A5	A_5		20.9821(x)	2301 amplifier's transfer function constant
12	A6	A_6		616.105(x)	2301 amplifier's transfer function constant
13		K_1			2301 amplifier's transfer function constant
14		K_2			2301 amplifier's transfer function constant
15		K_3			2301 amplifier's transfer function constant
16		K		.0559(x)	load sensor's transfer function constant
17		T_1		1.2(x)	load sensor's transfer function constant
18		T_2		0.3(x)	load sensor's transfer function constant
19		KW_o	kilowatts	2950.(x)	electrical load at 110% operating condition
20		U_1		807.167(x)	hydraulic actuator's transfer function constant
21		U_2		97.9718(x)	hydraulic actuator's transfer function constant
22		U_3		11.4239(x)	hydraulic actuator's transfer function constant
23			volts	2.614(x)	2301 amplifier's output for Zero frequency error
24			volts	7.5(x)	upper stop value for actuator output
25			volts	-.2(x)	lower stop value for actuator output
26			sec	.025(J)	transport delay time for hydraulic actuator

SUBSYSTEM 5

B(10), NON-CONSTANT COEFFICIENTS

B	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		E_1	volt		error voltage input to 2301 amplifier
2		E_3	volt		error voltage output from 2301 amplifier
3		E_2	volt		voltage from load sensor
4		θ_1	volt		hydraulic actuator position via potentiometer before transport
5		(E_2+E_3)	volt		hydraulic actuator input
6		Δf	Hz		frequency error
7		θ_2	volt		fuel door position via potentiometer
8		$\frac{k}{m}(\theta_1^*-\theta_{1d})$	lbf/lbm		spring force term in fuel linkage equation, Section 5.3.7 (p. 47).
9		F/m	lbf/lbm		friction force term in fuel linkage equation, Section 5.3.7
10		θ_1^*	volt		hydraulic actuator position via potentiometer after transport

SUBSYSTEM 5

L(10), COUNTERS

L	INTERNAL EQUIVALENT	INPUT(SOURCE)	DESCRIPTION
1		12.(c)	number of equations to integrate
2		1.0(c)	frequency for printing title with Subsystem 5 output
3			set ≠ 0 after transfer function constants are calculated
4 - 9	NOT USED		
10			counter for PRT5 calls

SUBSYSTEM 5

Y(13), DEPENDENT VARIABLES

Y	INTERNAL EQUIVALENT	ALGEBRAIC SYMBOL	UNITS	INPUT (SOURCE)	DESCRIPTION
1		e_1	volts	0.(z)	see transfer function analysis
2		$\dot{e}_2$	volts/sec	0.(z)	see transfer function analysis
3		e_2	volts	0.(z)	see transfer function analysis
4		$\ddot{e}_3$	volts/sec	0.(z)	see transfer function analysis
5		$\dot{e}_3$	volts/sec	0.(z)	see transfer function analysis
6		e_3	volts	0.(z)	see transfer function analysis
7		f_2	volts	-18.000(z)	*see transfer function analysis
8		g_1	volts	-.904(z)	*see transfer function analysis
9		g_2	volts	7.75(z)	*see transfer function analysis
10		$\dot{\theta}_{1_d}$	volts/sec	0.(z)	see fuel linkage mechanics analysis
11		θ_{1_d}	volts	6.85(z)	*fuel linkage position including mechanics of spring mass system during a transient
12		Δf_d	Hz	0.(z)	frequency error displayed including time constant effect in sensor, see page

*NOTE: To determine initial values hand calculate Y's to have corresponding F's=0. Refer to FORTRAN coding of YPR5, page 232. Example for Y(7) initial value:

```
F(7) = (XKL*(1.0-TID2) - Y(7))/A(18) = 0  to satisfy initial condition
      constants  TID2 = A(17)/A(18) = 1.2/0.3 = 4.0
                 A(18) = 0.3
      for specific load  XKL = A(16)*PERCT  where PERCT = % electrical load
       110% load yields  XKL = .0559*110 = 6.149
      solving  F(7) = 0  equation for Y(7)
               (6.149*(-3.0) - Y(7))/0.3 = 0
                    (-18.447 - Y(7))/0.3 = 0
                                   Y(7) = -18.447
```

Example for Y(8) initial value:

```
        F(8) = AA*B(5) - A(21)*Y(8) = 0
              constants   AA = -A(20)/(A(21) - A(22)) = -807.167/(97.9718 - 11.4239) = -9.32624
                       A(21) = 97.9718
              variables B(5) = B(2) + B(3)
                        B(2) = A(7)*B(1) + Y(1) + Y(3) + Y(6) + A(23)
                        Y(1) = Y(3) = Y(6) = 0 for initial conditions  F(1) = F(3) = F(6) = 0
                        B(1) = B(6)/A(6)  however B(6) is Δf which must = 0 initially, so
                        B(1) = 0
                  thus, B(2) = A(23) = 2.614
                        B(3) = T1D2*XKL + Y(7) = 4.0*6.149 - 18.447 = 6.149
             evaluating F(8) = -9.32624*(2.614 + 6.149) - 97.9718*Y(8) = 0
                        Y(8) = -.8342
```

Note that the values presented as INPUT for Y(7), Y(8), Y(9), and Y(11) resulted from output of a steady-state run at 110% load. Since this run did not have the frequency error exactly equal to zero, the hand calculated initial values differ slightly.

Example for Y(9) initial value:

F(9) = BB*B(5) - A(22)*Y(9) = 0

constants BB = -AA = 9.32624
A(22) = 11.4239

variables B(5) = B(2) + B(3) = 8.763 See Y(8) calculations.

evaluating F(9) = 9.3264*8.763 - 11.4239*Y(9) = 0
Y(9) = 7.1540

Example for Y(11) initial value:

Each run must start with the hydraulic actuator's position after transport equal to before transport.

$$\theta_1^* = \theta_1$$

B(10) = B(4)
B(4) = Y(8) + Y(9)
from above B(4) = -.8342 + 7.1540 = 6.3198

Initially, the fuel linkage system must be unloaded so that the dynamic position must equal the position being demanded by the hydraulic actuator.

$$\theta_{1_d} = \theta_1^*$$

Y(11) = B(4) = 6.3198

12. EXAMPLE CASE

The following computer printout displays the results of a sample simulation of the Cooper-Bessemer LSV-16 Diesel Engine, run under steady-state conditions at 110% load.

```
                INPUT DATA FOR MAIN -
               COOPER-BESSEMER LSV-16 DIESEL,110 PERCENT LD.
I A  2  3   1.8000E+02  5.0000E+00 -0.          -0.          -0.          -0.
I A 38 39   5.4100E+02 -0.         -0.          -0.          -0.          -0.
I L  2  7   1.0000E+00  0.          6.0000E+00  1.0000E+00  9.0000E+00  0.
I L  4  4   1.0000E+00 -0.         -0.          -0.          -0.          -0.
I L  5  5   9.0000E+00 -0.         -0.          -0.          -0.          -0.
I L 14 16   1.0000E+00  0.          0.          -0.          -0.          -0.
I G 22 27   0.          8.5000E+02  9.8640E+05  2.6230E+02  1.9360E+01  3.4630E+05
I G 57 57   1.3100E+03 -0.         -0.          -0.          -0.          -0.
I G 60 60   5.7250E+02 -0.         -0.          -0.          -0.          -0.
I G 61 65   2.2650E+01  7.0150E+00  5.7200E+02  2.2650E+01  7.0150E+00  5.7200E+02
I G 67 72   1.9300E+01 -0.          1.3910E+03  1.9300E+01 -0.           1.3780E+03
I G 73 78   1.9300E+01 -0.          1.2930E+03  1.9300E+01 -0.           1.3450E+03
I G 79 84   1.9300E+01 -0.          1.3650E+03  1.9300E+01 -0.           1.3280E+03
P G  1 90  -0.         -0.         -0.          -0.          -0.          -0.
R   -0 -0  -0.         -0.         -0.          -0.          -0.          -0.
```

INPUT DATA FOR SUB1 -
PART 1 - EQUATION OF MOTION

```
I A  1  6   8.7266E-02  1.7453E-02  1.6833E+08  9.3380E+03  6.7041E+04  3.1416E+00
I A  7  7   6.6000E+03 -0.         -0.         -0.         -0.         -0.
I L  1  2   1.0000E+01  1.0000E+00 -0.         -0.         -0.         -0.
I L  8  9   4.0000E+00 -2.0000E+00 -0.         -0.         -0.         -0.
I X  1  1   0.         -0.         -0.         -0.         -0.         -0.
I Y  1  2   3.7699E+01  0.         -0.         -0.         -0.         -0.
P X  1  1  -0.         -0.         -0.         -0.         -0.         -0.
P L  1 10  -0.         -0.         -0.         -0.         -0.         -0.
P R  1 15  -0.         -0.         -0.         -0.         -0.         -0.
P F  1 10  -0.         -0.         -0.         -0.         -0.         -0.
P Y  1 10  -0.         -0.         -0.         -0.         -0.         -0.
R   -0 -0  -0.         -0.         -0.         -0.         -0.         -0.
```

```
                 INPUT DATA FOR SUB2 -
                PART 2 - ALTERNATOR
I A  4  4   4.5000E-02 -0.         -0.        -0.        -0.        -0.
I A  1  4   2.5000E-03  1.5915E+00  2.6995E+07  2.0000E+01 -0.        -0.
I A  5  6   1.0760E+00  6.0290E-01 -0.        -0.        -0.        -0.
I A  7  7   2.9500E+03 -0.         -0.        -0.        -0.        -0.
I A  8  9   1.0780E+00  5.9660E-01 -0.        -0.        -0.        -0.
I L  1  2   0.          1.0000E+00 -0.        -0.        -0.        -0.
I X  1  1   0.         -0.         -0.        -0.        -0.        -0.
P X  1  1  -0.         -0.         -0.        -0.        -0.        -0.
P L  1 10  -0.         -0.         -0.        -0.        -0.        -0.
R   -0 -0  -0.         -0.         -0.        -0.        -0.        -0.
```

```
                 INPUT DATA FOR SUB3 -
                PART 3 - DIESEL ENGINE, SIXTEEN CYLINDERS
I A  1  5   3.5000E+01  2.0000E+02  3.3800E+02  4.7500E+02  6.4000E+02 -0.
I A  7 12   1.5000E+01  3.4445E+05  4.2000E-01  9.0000E+01  1.6821E+08  1.8869E+02
I A  9 10   5.0000E-01  1.0500E+02 -0.          -0.          -0.          -0.
I A 14 17   6.4000E+02  9.0000E+02  4.1512E+02  6.7041E+04 -0.          -0.
I A 19 21   1.7453E-02  1.4000E+00  8.9600E+02 -0.          -0.          -0.
I A 25 25   4.8695E+01 -0.          -0.          -0.          -0.          -0.
I A 29 30   3.1416E+00  7.2000E+02 -0.          -0.          -0.          -0.
I A 32 36   1.7779E+00  1.9280E+00  9.3380E+03  2.2500E+03  3.0000E+00 -0.
I A 37 42   6.0000E+00  4.1000E+00  1.8866E-01  3.7699E+01  2.5000E+00  2.5000E+00
I A 41 41   1.2500E+00 -0.          -0.          -0.          -0.          -0.
I A 43 48   5.0000E+00  2.2650E+01  1.0000E+01  1.0000E-03  1.0000E-03  1.0000E-03
I A 49 54   1.0000E-03  5.0000E-06  5.0000E-06  1.4500E+00  2.4350E+03  7.0000E+02
I A 52 53   4.6000E-01  4.1120E+03 -0.          -0.          -0.          -0.
I A 55 60   5.4000E+02  1.9760E+02  6.3810E-01  1.8000E+00  1.8000E+00  5.0000E-01
I A 61 65   5.0000E-01  1.1500E+00  1.4100E+01  2.4120E+00  7.3610E+01 -0.
I A 91 92   4.4490E+04  4.4490E+04 -0.          -0.          -0.          -0.
I A 93 98   5.8940E+03  3.5610E+03  6.6700E+03  5.0370E+03  5.9800E+03  5.8350E+03
I B  1  1   0.          -0.          -0.          -0.          -0.          -0.
```

```
I B 37 37   3.0000E+00 -0.          -0.          -0.          -0.          -0.
I B 39 39   5.0000E-01 -0.          -0.          -0.          -0.          -0.
I L  1  5   1.6000E+01  6.4000E+01  4.0000E+00  3.5000E+01  2.0000E+00 -0.
I L 11 16   1.0000E+00  2.0000E+00  3.0000E+00  4.0000E+00  5.0000E+00  0.
I L 16 16   1.0000E+00 -0.          -0.          -0.          -0.          -0.
I L 18 18   2.2000E+01 -0.          -0.          -0.          -0.          -0.
I L 21 24   0.          6.0000E+00  2.0000E+00  1.0000E+00 -0.          -0.
I L 31 36   1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
I L 37 42   1.0000E+00  1.0000E+00  2.0000E+00  2.0000E+00  2.0000E+00  2.0000E+00
I L 43 46   2.0000E+00  2.0000E+00  2.0000E+00  2.0000E+00 -0.          -0.
I L 51 56   2.0000E+00  5.0000E+00  5.0000E+00  9.0000E+00  4.0000E+00  6.0000E+00
I L 57 62   1.0000E+00  3.0000E+00  1.0000E+00  2.0000E+00  2.0000E+00  1.0000E+00
[illegible]
I X  1  6   0.          5.4000E+02  9.0000E+01  2.7000E+02  6.3000E+02  4.5000E+02
I X  7 12   1.8000E+02  3.6000E+02  3.9609E+02  2.1609E+02  4.8609E+02  6.6609E+02
I X 13 16   3.0609E+02  1.2609E+02  5.7609E+02  3.6090E+01 -0.          -0.
I Y  1  6   0.          3.7739E+01  0.          2.3121E+01  1.9718E-02  1.1192E-01
I Y  7 12   0.          4.3659E+01  1.7051E-01  5.3061E-01  0.          2.2718E+01
I Y 13 18   1.5941E-01  1.2052E-02  0.          4.7733E+01  2.6642E-01  6.7940E-03
I Y 19 24   0.          2.3642E+01  6.7529E-02  5.3100E-01  0.          1.8197E+02
I Y 25 30   2.7392E-01  5.2844E-01  0.          2.2390E+01  2.6613E-01  7.4077E-03
I Y 31 36   3.4275E-03  7.6036E+02  2.6583E-01  4.7484E-02  3.5155E-03  5.6248E+02
```

```
I Y 37 42   2.7202E-01  3.2952E-01  0.          2.4976E+01  2.6724E-01  1.2242E-02
I Y 43 48   0.          1.0866E+02  2.7705E-01  5.2353E-01  0.          2.2549E+01
I Y 49 54   3.5353E-02  5.2188E-01  0.          1.2034E+02  2.6781E-01  1.1716E-02
I Y 55 60   0.          2.2808E+01  2.3121E-01  9.0832E-03  0.          2.8946E+01
I Y 61 66   1.2197E-01  5.3393E-01  0.          2.3192E+01  4.9902E-02  3.7940E-02
I Y 67 72   2.3586E+01  2.8509E+00  2.2723E-05  2.3739E+01  2.8680E+00  3.9813E-04
I Y 73 78   2.1710E+01  1.5321E-01  5.1688E-01  1.7652E+01  9.0482E-02  4.5036E-01
I Y 79 84   2.8193E+01  1.9057E-01  5.1092E-01  2.2661E+01  1.3140E-01  5.1631E-01
I Y 85 90   3.3293E+01  1.8372E-01  5.0134E-01  1.5046E+01  1.2953E-01  4.6174E-01
P B  1 60  -0.         -0.         -0.         -0.         -0.         -0.
P F  1 90  -0.         -0.         -0.         -0.         -0.         -0.
P Y  1 90  -0.         -0.         -0.         -0.         -0.         -0.
P L  1 20  -0.         -0.         -0.         -0.         -0.         -0.
R   -0 -0  -0.         -0.         -0.         -0.         -0.         -0.
```

```
                    INPUT DATA FOR SUB4 -
                    PART A - TURBOCHARGER
I A  1  2   1.0000E-03  6.4300E-01 -0.          -0.          -0.          -0.
I A  3  4   6.5000E-01  8.7000E-01 -0.          -0.          -0.          -0.
I L  1  1   1.0000E+00 -0.          -0.          -0.          -0.          -0.
I X  1  1   0.         -0.          -0.          -0.          -0.          -0.
I Y  1  1   1.3195E+03 -0.          -0.          -0.          -0.          -0.
P X  1  1  -0.          -0.          -0.          -0.          -0.          -0.
P F  1  1  -0.          -0.          -0.          -0.          -0.          -0.
P Y  1  1  -0.          -0.          -0.          -0.          -0.          -0.
P B  1 10  -0.          -0.          -0.          -0.          -0.          -0.
P B 11 20  -0.          -0.          -0.          -0.          -0.          -0.
P B 21 30  -0.          -0.          -0.          -0.          -0.          -0.
P B 31 40  -0.          -0.          -0.          -0.          -0.          -0.
P B 41 48  -0.          -0.          -0.          -0.          -0.          -0.
R   -0 -0  -0.          -0.          -0.          -0.          -0.          -0.
```

```
                    INPUT DATA FOR SUBS -
                   PART 5. - FUEL CONTROLLER
I A  1  5   1.0000E-02  6.0000E+01  1.0000E+03  1.2600E+01  2.0000E-01 -0.
I A  6  6  -7.7000E-01 -0.         -0.         -0.         -0.         -0.
I A  7 12   6.7103E-01  4.5484E-01  3.4137E+00  1.0067E+03  2.0982E+01  6.1610E+02
I A 16 19   6.4100E-02  8.0000E-01  4.0000E-01  2.9600E+03 -0.         -0.
I A 17 17   1.2000E+00 -0.         -0.         -0.         -0.         -0.
I A 20 22   8.0717E+02  9.7972E+01  1.1424E+01 -0.         -0.         -0.
I A 23 25   2.6140E+00  7.5000E+00 -2.0000E-01 -0.         -0.         -0.
I L  1  2   1.2000E+01  1.0000E+00 -0.         -0.         -0.         -0.
I X  1  1   0.         -0.         -0.         -0.         -0.         -0.
I Y  1  6   0.          0.          0.          0.          0.          0.
I Y  7  9  -6.8843E+00 -9.0400E-01  7.7500E+00 -0.         -0.         -0.
I Y  7  9  -6.9200E+00 -8.8900E-01  7.6200E+00 -0.         -0.         -0.
I Y  7  7  -1.3849E+01 -0.         -0.         -0.         -0.         -0.
I Y 11 11   6.8500E+00 -0.         -0.         -0.         -0.         -0.
P X  1  1  -0.         -0.         -0.         -0.         -0.         -0.
P B  1  7  -0.         -0.         -0.         -0.         -0.         -0.
P Y  1 12  -0.         -0.         -0.         -0.         -0.         -0.
P F  1 12  -0.         -0.         -0.         -0.         -0.         -0.
Z   -0 -0  -0.         -0.         -0.         -0.         -0.         -0.
```

```
                  COOPER-BESSEMER LSV-16 DIESEL,110 PERCENT LD.


     TIME =       0.000000
     ANGLE =       0.000000

  G( 1-10)  0.         3.770E+01  2.740E+00  6.000E+01  0.         8.353E+05  7.705E+05  3.180F+03  4.535E-02  1.410E+01
  G(11-20)  1.390E+01  5.410E+02  0.        -2.666E-05  0.         0.         1.606E+00  1.217E+04  1.583E+03  1.260E+04
  G(21-30)  6.961E+04  0.         8.355E+02  9.803E+05  2.982E+03  1.936E+01  3.463E+05  2.312E+01  7.606E+02  5.000E+00
  G(31-40)  3.906F+02  4.539E+02  7.919E+03  1.830E+03  2.585E+02  3.299E+03  5.824E+02  0.         0.         0.
  G(41-50)  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
  G(51-60)  0.         7.361E+01  1.823E+04  0.         1.007E+01  6.462E+02  1.295E+03  1.427E+01  1.319E+03  5.711E+02
  G(61-70)  2.359E+01  7.135E+00  5.751E+02  2.374E+01  7.135E+00  5.754E+02  2.171E+01  1.655E+00  1.305E+03  1.765E+01
  G(71-80)  1.662E+00  1.085E+03  2.819E+01  1.710E+00  1.542E+03  2.266E+01  1.680E+00  1.357E+03  3.329E+01  1.669E+00
  G(81-90)  1.693E+03  1.505E+01  1.690E+00  1.059E+03  0.         0.         0.         0.         0.         0.
```

```
                        PART 1 - EQUATION OF MOTION
X                0.000000
L( 1-10)    10         1          0          0          0          0          0          4          0          1
B( 1-10) 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
B(11-15) 0.         0.         0.         0.         0.
F( 1-10) 7.269E-02  2.653E-02  0.         0.         0.         0.         0.         0.         0.         0.
Y( 1-10) 3.770E+01  0.         0.         0.         0.         0.         0.         0.         0.         0.


                       PART 2 - ALTERNATOR
X                 .002500
L( 1-10)    0          1          0          0          0          0          0          0          0          1


                       PART 3 - DIESEL ENGINE, SIXTEEN CYLINDERS
B( 1-10) 0.         1.124E+05  3.255E+04  8.353E+05  1.936E+01  1.840E+03  1.883E-01  0.         0.         0.
B(11-20) 3.906E+02  4.539E+02  7.919E+03  1.830E+03  2.585E+02  3.299E+03  5.824E+02  7.361E+01  0.         0.
B(21-30) 0.         0.         0.         9.803E+05  1.583E+03  3.441E+02  0.         0.         0.         3.536E+02
B(31-40) 3.481E+02  3.746E+02  3.786E+02  2.649E+01  0.         3.000E+00  3.000E+00  5.000E-01  4.991E-01  4.000E+00
B(41-50) 4.000E+00  3.403E-01  3.415E-01  3.493E-01  3.445E-01  3.427E-01  3.460E-01  0.         0.         0.
B(51-60) 1.893E-01  1.893E-01  4.390E-02  4.409E-02  4.535E-02  4.457E-02  4.428E-02  4.482E-02  0.         0.
F( 1-10) 0.         0.         0.         2.202E+00  1.093E-02 -2.354E-01  0.        -5.283E+01 -1.427E-01  0.
```

```
F(11-20)  0.         3.885E-01  1.268E-01 -9.572E-03  0.         5.767E+01  0.         0.         0.        -3.631E+00
F(21-30) -5.683E-02  0.         0.        -1.998E+02  0.         0.         0.         1.066E+00  4.652E-03 -1.291E-04
F(31-40)  9.511E-03  1.236E+03  7.698E-03  4.619E-01 -6.700E-03 -7.705E+02  6.700E-03  3.860E-01  0.         8.935E+00
F(41-50)  0.         0.         0.        -6.701E+01 -7.719E-03  0.         0.        -3.700E+00 -4.753E-02 -6.499E-02
F(51-60)  0.         2.265E+02  0.         0.         0.        -2.333E-01  8.883E-02 -3.337E-03  0.        -9.260E+00
F(61-70) -5.346E-02  0.         0.        -4.956E-01  8.695E-02 -6.541E-02  1.732E-01  1.629E-02 -1.509E-06  8.867E-02
F(71-80)  9.078E-03 -2.627E-05  9.115E-01  8.030E-03  1.695E-03 -3.189E+00 -5.826E-03 -1.080E-01  1.883E-01  8.101E-03
F(81-90)  6.434E-03  2.212E+00  1.226E-02  6.353E-03  2.535E+01  9.844E-02  2.274E-02 -8.218E+00 -4.482E-02  0.
Y( 1-10)  0.         3.770E+01  0.         2.312E+01  1.972E-02  1.119E-01  0.         4.366E+01  1.705E-01  5.306E-01
Y(11-20)  0.         2.272E+01  1.594E-01  1.205E-02  0.         4.773E+01  2.664E-01  6.794E-03  0.         2.364E+01
Y(21-30)  6.753E-02  5.310E-01  0.         1.820E+02  2.739E-01  5.284E-01  0.         2.239E+01  2.661E-01  7.408E-03
Y(31-40)  3.427E-03  7.604E+02  2.658E-01  4.748E-02  3.516E-03  5.625E+02  2.720E-01  3.295E-01  0.         2.498E+01
Y(41-50)  2.672E-01  1.224E-02  0.         1.087E+02  2.770E-01  5.235E-01  0.         2.255E+01  3.535E-02  5.219E-01
Y(51-60)  0.         1.263E+02  2.678E-01  1.172E-02  0.         2.281E+01  2.312E-01  9.083E-03  0.         2.895E+01
Y(61-70)  1.220E-01  5.339E-01  0.         2.319E+01  4.990E-02  3.794E-02  2.359E+01  2.851E+00  2.272E-05  2.374E+01
Y(71-80)  2.458E+00  3.981E-04  2.171E+01  1.532E-01  5.169E-01  1.765E+01  9.048E-02  4.504E-01  2.819E+01  1.906E-01
Y(81-90)  5.139E-01  2.266E+01  1.314E-01  5.163E-01  3.329E+01  1.837E-01  5.013E-01  1.505E+01  1.295E-01  4.617E-01
L( 1-10)     16         64          4         90          2          0          0          0          0          0
L(11-20)      1          2          3          4          5          1         99          1          0          0
U( 1-1 TO 15)    7.6057E+02  5.7512E+02 -3.3719E+04  1.0443E+01  4.5551E+00  4.1512E+02  4.8451E+02  4.1472E-02
 3.0543E-02  0.          0.          0.          1.3200E+01  0.          1.0855E+03
```

```
U( 2-1 TO 15)   1.8269E+03   5.7512E+02   7.1977E+05   0.           1.7450E+01   4.5663E+03   1.5558E+03   0.
 1.4272E-01   0.           2.2000E+01   1.0701E-04  -8.8000E+00   0.           1.6932E+03

U( 3-1 TO 15)   6.0132E+02   5.7512E+02  -1.6015E+05   2.3600E+01   0.           2.7004E+03   1.0743E+03   1.2685E-01
 0.           0.           1.2111E+01   1.1000E+01  -2.2453E+00   0.           1.6932E+03

U( 4-1 TO 15)   7.5597E+02   5.7512E+02  -7.7230E+04   0.           0.           2.7004E+03   1.0743E+03   0.
 0.           0.           1.2111E+01  -1.1000E+01  -2.2454E+00   0.           1.3573E+03

U( 5-1 TO 15)   1.4772E+03   5.7512E+02   3.0951E+05   0.           2.3742E+01   2.7004E+03   1.0743E+03   0.
 5.6830E-02   0.           1.2111E+01  -1.1000E+01  -2.2455E+00   0.           1.3573E+03

U( 6-1 TO 15)   2.8030E+03   5.7512E+02   1.0204E+06   0.           0.           2.7004E+03   1.0743E+03   0.
 0.           0.           1.2111E+01   1.1000E+01  -2.2453E+00   0.           1.0590E+03

U( 7-1 TO 15)   6.0027E+02   5.7512E+02  -2.3275E+05   7.4320E-01   0.           4.5663E+03   1.5558E+03   4.6524E-03
 0.           0.           2.2000E+01   3.5672E-05  -8.8000E+00   0.           1.3050E+03

U( 8-1 TO 15)   1.8553E+03   5.7512E+02   2.3102E+05   0.           0.           4.1512E+02   4.8451E+02   0.
 0.           7.6976E-03   4.3393E-10  -1.0701E-04   1.3200E+01   1.7209E-02   1.5418E+03

U( 9-1 TO 15)   2.9546E+03   5.7539E+02   5.9064E+05   0.           0.           8.8354E+02   6.0539E+02   0.
 0.           6.7000E-03   2.4824E+00   7.5198E+00   9.6250E+00   0.           1.3050E+03

U(10-1 TO 15)   6.3098E+02   5.7539E+02  -2.0040E+05   0.           0.           4.3209E+03   1.4924E+03   0.
 0.           0.           2.0699E+01  -5.5294E+00  -8.5876E+00   0.           1.0855E+03
```

```
U(11-1 TO 15)   2.3791E+03  5.7539E+02  1.0183E+06  0.            2.4587E-01  3.8822E+03  1.3793E+03  0.
 7.7186E-03  0.          1.8375E+01  8.1135E+00 -7.5725E+00  0.              1.0855E+03

U(12-1 TO 15)   1.4117E+03  5.7539E+02  1.8976E+05  7.0324E-01  2.3415E+01  1.4165E+03  7.4294E+02  4.4058E-03
 5.1931E-02  0.          5.3072E+00 -1.01 5E+01  5.2433E+00  0.              1.3050E+03

U(13-1 TO 15)   9.9457E+02  5.7539E+02  3.5070E+04  0.            0.            1.4166E+03  7.4295E+02  0.
 0.          0.          5.3072E+00 -1.0105E+01  5.2432E+00  0.              1.6932E+03

U(14-1 TO 15)   5.9839E+02  5.7539E+02 -2.0764E+05  1.5933E+01  0.            3.8822E+03  1.3792E+03  8.8835E-02
 0.          0.          1.8374E+01  8.1136E+00 -7.5724E+00  0.              1.5418E+03

U(15-1 TO 15)   1.6022E+03  5.7539E+02  5.2311E+05  0.            2.3742E+01  4.3209E+03  1.4924E+03  0.
 5.3456E-02  0.          2.0699E+01 -5.5204E+00 -8.5876E+00  0.              1.5418E+03

U(16-1 TO 15)   6.4159E+02  5.7539E+02 -7.8983E+04  2.0163E+01  0.            8.8353E+02  6.0539E+02  8.6947E-02
 0.          0.          2.4824E+00  7.5197E+00  9.6251E+00  0.              1.0590E+03
```

```
CYLINDER M(I)      M1(I)      M2(I)      M3(I)      M4(I)       X(I)
    1       5        1          1          0          0       0.00000
    2       4        2          1          0          0     540.00000
    3       1        1          2          0          0      90.00000
    4       2        2          1          0          0     270.00000
    5       4        2          1          0          0     630.00000
    6       3        2          1          4          4     450.00000
    7       1        1          1          0          0     180.00000
    8       3        2          1          2          2     360.00000
    9       3        2          1          4          2     396.09000
   10       2        2          1          0          0     216.09000
   11       4        2          1          0          0     486.09000
   12       5        1          1          0          0     606.09000
   13       2        2          1          0          0     306.09000
   14       1        1          2          0          0     126.09000
   15       4        2          1          0          0     576.09000
   16       1        1          1          0          0      36.09000


                    PART 4 - TURBOCHARGER
X             0.000000

F( 1- 1) -2.041E+02

Y( 1- 1)  1.319E+03

B( 1-10)  2.142E+02  6.296E+01  1.427E+01  1.007E+01  6.462E+02  1.295E+03  0.         0.         0.         7.463E-01

B(11-20)  2.265E+01  7.135E+00  6.462E+02  1.071E+02  2.265E+01  7.135E+00  6.462E+02  1.071E+02  1.930E+01  1.655E+00
```

```
B(21-30)  1.391E+03  1.412E+01  1.335E+03  1.930E+01  1.662E+00  1.378E+03  1.403E+01  1.323E+03  1.930E+01  1.710E+00
B(31-40)  1.293E+03  1.341E+01  1.241E+03  1.930E+01  1.680E+00  1.345E+03  1.379E+01  1.291E+03  1.930E+01  1.669E+00
B(41-48)  1.365E+03  1.394E+01  1.310E+03  1.930E+01  1.690E+00  1.328E+03  1.367E+01  1.275E+03

                                PART 5 - FUEL CONTROLLER
X                   0.000000
B( 1- 7)  2.077E-05  2.614E+00  6.811E+00  6.731E+00  9.425E+00 -1.600E-05  1.130E+01
Y( 1-10)  0.         0.         0.         0.         0.         0.        -1.385E+01 -8.890E-01  7.620E+00  0.
Y(11-12)  6.850E+00  0.
F( 1-10)  1.379F-02 -2.437E-01  0.        -8.477E+00  0.         0.         1.883E-01 -8.059E-01  8.527E-01 -1.190E+02
F(11-12)  0.        -7.998E-05
```

```
                         COUPER-BESSEMER LSV-16 DIESEL,110 PERCENT LD.

     TIME =         .083325
     ANGLE =      180.000000

 G( 1-10)  8.333E-02  3.770E+01  1.281E-01  6.000E+01  3.332E-03  8.583E+05  7.704E+05  3.180E+03  4.440E-02  1.410E+01
 G(11-20)  1.390E+01  5.410E+02  3.142E+00  5.973E-03  8.961E+02  2.652E+03  1.725E+00  1.124E+04  1.529E+03  1.260E+04
 G(21-30)  7.152E+04  1.800E+02  8.683E+02  9.984E+05  2.982E+03  1.936E+01  3.463E+05  2.236E+01  6.034E+02  5.000E+00
 G(31-40)  3.831E+02  4.540E+02  7.652E+03  2.492E+03  2.639E+02  3.392E+03  7.785E+02  0.         0.         0.
 G(41-50)  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
 G(51-60)  0.         7.361E+01  1.823E+04  0.         1.313E+01  6.517E+02  1.328E+03  1.328E+01  1.320E+03  5.692E+02
 G(61-70)  2.348E+01  6.649E+00  5.734E+02  2.365E+01  6.589E+00  8.738E+02  2.859E+01  3.206E+00  1.513E+03  2.149E+01
 G(71-80)  2.231E+00  1.245E+03  3.371E+01  3.574E+00  1.640E+03  1.391E+01  0.         1.006E+03  1.863E+01  1.687E+00
 G(81-90)  1.167E+03  2.325E+01  2.436E+00  1.366E+03  0.         0.         0.         0.         0.         0.
```

```
                                  PART 1 - EQUATION OF MOTION
X                   3.141593
L( 1-10)  10          1           0           0           0           0           0           4           36          1
B( 1-10)  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
B(11-15)  0.          0.          0.          0.          0.
F( 1-10)  3.399E-03   2.652E-02   1.014E+01   1.204E+01   2.030E+02   6.693E+01   6.999E+00   8.724E+01   2.095E+01   1.952E+00
Y( 1-10)  3.770E+01   8.333E-02   3.311E+01   3.789E+01   6.496E+02   2.094E+02   2.196E+01   2.630E+02   6.610E+01   6.134E+00

                                  PART 2 - ALTERNATOR
X                   .092500
L( 1-10)  0           1           0           0           0           0           0           0           0           1

                                  PART 3 - DIESEL ENGINE, SIXTEEN CYLINDERS
B( 1-10)  1.800E+02   1.124E+05   2.775E+04   8.583E+05   1.936E+01   1.840E+03   1.888E-01   0.          0.          0.
B(11-20)  3.831E+02   4.540E+02   7.652E+03   2.492E+03   2.639E+02   3.392E+03   7.785E+02   7.361E+01   0.          0.
B(21-30)  0.          0.          0.          9.984E+05   1.529E+03   3.445E+02   4.440E-02   0.          0.          3.540E+02
B(31-40)  3.495E+02   3.740E+02   3.780E+02   2.554E+01   0.          3.000E+00   3.000E+00   5.000E-01   5.003E-01   4.000E+00
B(41-50)  4.000E+00   5.777E-01   4.321E-01   6.301E-01   0.          3.456E-01   4.637E-01   0.          0.          0.
B(51-60)  1.774E-01   1.748E-01   8.505E-02   5.916E-02   9.480E-02   0.          4.475E-02   6.462E-02   0.          0.
```

```
F( 1-10)  0.         0.         0.         1.043E+00  4.502E-03 -1.138E-04  0.         1.309E+00  1.102E-02 -2.858E-01
F(11-20)  0.         5.207E+01  0.         0.         0.        -1.956E+02  0.         0.         0.         1.995E-01
F(21-30)  1.257E-01 -9.403E-03  0.        -2.868E+00 -5.755E-02  0.         9.567E-03  1.219E+03  7.597E-03  4.533E-01
F(31-40)  0.        -5.122E+01 -1.414E-01  0.         0.        -9.349E+00 -5.539E-02  0.        -6.203E-03 -8.613E+02
F(41-50)  6.203E-03  3.555E-01  0.        -3.346E+00 -4.820E-02 -6.588E-02  0.        -3.911E-01  8.766E-02 -3.330E-03
F(51-60)  0.        -6.583E+01 -7.641E-03  0.         0.         2.283E+02  0.         0.         0.        -8.620E-01
F(61-70)  8.652E-02 -1.253E-01  0.         8.951E+00  0.         0.         7.904E-02  8.126E-03 -1.169E-06 -6.248E-02
F(71-80) -4.007E-03 -2.004E-05 -9.812E+00 -2.966E-02  8.606E-03 -3.205E+00 -6.368E-03  2.074E-03  9.207E+00  4.655E-02
F(81-90)  1.909E-02  0.         0.         0.        -3.004E+00 -9.086E-03 -6.103E-02 -3.024E+00 -7.075E-03  6.959E-03
Y( 1-10)  0.         3.770E+01  0.         2.236E+01  2.644E-01  6.705E-03  0.         2.357E+01  1.897E-02  1.389E-01
Y(11-20)  0.         4.812E+01  2.655E-01  7.244E-03  0.         1.782E+02  2.754E-01  5.290E-01  0.         2.263E+01
Y(21-30)  1.586E-01  1.188E-02  0.         2.421E+01  7.028E-02  5.284E-01  3.348E-03  7.741E+02  2.673E-01  4.988E-02
Y(31-40)  0.         4.349E+01  1.735E-01  5.359E-01  0.         2.937E+01  1.262E-01  5.295E-01  3.095E-03  5.858E+02
```

```
Y(41-50)  2.730E-01  3.515E-01  0.         2.235E+01  3.606E-02  5.171E-01  0.         2.274E+01  2.298E-01  9.057E-03
Y(51-60)  0.         1.068E+02  2.763E-01  5.367E-01  0.         1.213E+02  2.700E-01  7.835E-03  0.         2.311E+01
Y(61-70)  4.658E-02  6.780E-02  0.         2.501E+01  2.685E-01  7.358E-03  2.348E+01  2.847E+00  1.876E-05  2.365E+01
Y(71-80)  2.865E+00  3.285E-04  2.659E+01  1.740E-01  5.075E-01  2.149E+01  9.603E-02  5.133E-01  3.371E+01  2.142E-01
Y(81-90)  5.070E-01  1.391E+01  1.089E-01  4.513E-01  1.863E+01  1.492E-01  4.794E-01  2.325E+01  1.551E-01  5.097E-01
L( 1-10)     16         64         4          90         2          0          224        192        224        0
L(11-20)     1          2          3          4          5          1          99         7          1          1
U( 1-1 TO 15)   6.0344E+02  5.7339E+02 -2.3075E+05  7.4320E-01  0.          4.5663E+03  1.5558E+03  4.5018E-03
 0.          0.          2.2000E+01  3.5672E-05 -8.8000E+00  0.          1.2454E+03


U( 2-1 TO 15)   7.9862E+02  5.7339E+02 -2.4990E+04  1.0443E+01  4.5551E+00  4.1512E+02  4.8451E+02  3.9045E-02
 2.8025E-02  0.          2.2737E-13 -4.6935E-11  1.3200E+01  0.          1.1667E+03


U( 3-1 TO 15)   7.0465E+02  5.7339E+02 -7.2717E+04  0.          0.            2.7004E+03  1.0743E+03  0.
 0.          0.          1.2111E+01 -1.1000E+01 -2.2454E+00  0.          1.1667E+03


U( 4-1 TO 15)   2.7302E+03  5.7339E+02  9.8329E+05  0.          0.            2.7004E+03  1.0743E+03  0.
 0.          0.          1.2111E+01  1.1000E+01 -2.2453E+00  0.          1.0056E+03


U( 5-1 TO 15)   6.0186E+02  5.7339E+02 -1.6018E+05  2.3600E+01  0.            2.7004E+03  1.0743E+03  1.2573E-01
 0.          0.          1.2111E+01  1.1000E+01 -2.2453E+00  0.          1.0056E+03
```

```
U( 6-1 TO 15)   1.4536E+03  5.7339E+02  2.9742E+05  0.          2.3742E+01  2.7004E+03  1.0743E+03  0.
 5.7545E-02  0.            1.2111E+01 -1.1000E+01 -2.2455E+00  0.          1.3664E+03

U( 7-1 TO 15)   1.8787E+03  5.7339E+02  2.3715E+05  0.          0.          4.1512E+02  4.8451E+02  0.
 0.          7.5965E-03  4.3383E-10 -1.0701E-04  1.3200E+01  1.7164E-02  1.5133E+03

U( 8-1 TO 15)   1.7887E+03  5.7339E+02  6.9146E+05  0.          1.7450E+01  4.5663E+03  1.5558E+03  0.
 1.4135E-01  0.            2.2000E+01  1.0701E-04 -8.8000E+00  0.          1.6398E+03

U( 9-1 TO 15)   1.5713E+03  5.7384E+02  5.0105E+05  0.          2.3742E+01  4.3209E+03  1.4924E+03  0.
 5.5338E-02  0.            2.0699E+01 -5.5294E+00 -8.5876E+00  0.          1.5133E+03

U(10-1 TO 15)   2.9618E+03  5.7384E+02  6.2425E+05  0.          0.          8.8354E+02  6.0539E+02  0.

 0.          6.2025E-03  2.4824E+00  7.5198E+00  9.6250E+00  0.          1.2454E+03

U(11-1 TO 15)   1.3718E+03  5.7384E+02  1.7529E+05  7.0324E-01  2.3415E+01  1.4165E+03  7.4294E+02  4.5963E-03
 5.2794E-02  0.            5.3072E+00 -1.0105E+01  5.2433E+00  0.          1.2454E+03

U(12-1 TO 15)   6.0035E+02  5.7384E+02 -2.0669E+05  1.5933E+01  0.          3.8822E+03  1.3792E+03  8.7661E-02
 0.          0.            1.8374E+01  8.1136E+00 -7.5724E+00  0.          1.5133E+03

U(13-1 TO 15)   2.3452E+03  5.7384E+02  9.9686E+05  0.          2.4587E-01  3.8822E+03  1.3793E+03  0.
 7.6413E-03  0.            1.8375E+01  8.1135E+00 -7.5725E+00  0.          1.1667E+03

U(14-1 TO 15)   9.9435E+02  5.7384E+02  3.5055E+04  0.          0.          1.4166E+03  7.4295E+02  0.
 0.          0.            5.3072E+00 -1.0105E+01  5.2432E+00  0.          1.6398E+03
```

```
U(15-1 TO 15)   6.8482E+02  5.7384E+02 -6.5150E+04  2.0163E+01  0.           8.8353E+02  6.0539E+02  8.6521E-02
 0.          0.          2.4824E+00  7.5197E+00  9.6251E+00  0.          1.6398E+03

U(16-1 TO 15)   6.2886E+02  5.7384E+02 -2.0238E+05  0.          0.           4.3209E+03  1.4924E+03  0.
 0.          0.          2.0699E+01 -5.5294E+00 -8.5876E+00  0.          1.3664E+03


          CYLINDER M(I)     M1(I)     M2(I)     M3(I)     M4(I)       X(I)
             1       1        1         1         0         0     180.00000
             2       5        1         1         0         0      -.00000
             3       2        2         1         0         0     270.00000
             4       3        2         1         4         4     450.00000
             5       1        1         1         0         0      90.00000
             6       4        2         1         0         0     630.00000
             7       3        2         1         2         2     360.00000
             8       4        2         1         0         0     540.00000
             9       4        2         1         0         0     576.09000
            10       3        2         1         4         2     396.09000
            11       5        1         1         0         0     666.09000
            12       1        1         2         0         0     126.09000
            13       4        2         1         0         0     486.09000
            14       2        2         1         0         0     306.09000
            15       1        1         2         0         0      36.09000
            16       2        2         1         0         0     216.09000
```

```
                          PART 4 - TURBOCHARGER
X                 .083000

F( 1- 1)  1.376E+01

Y( 1- 1)  1.320E+03

B( 1-10)  2.097E+02  2.185E+02  1.328E+01  1.313E+01  6.517E+02  1.328E+03  0.         0.         0.         8.220E-01

B(11-20)  2.414E+01  6.689E+00  6.514E+02  1.053E+02  2.432E+01  6.589E+00  6.520E+02  1.043E+02  2.946E+01  3.206E+00

B(21-30)  1.536E+03  6.559E+01  1.402E+03  2.175E+01  2.231E+00  1.254E+03  2.345E+01  1.185E+03  3.275E+01  3.574E+00

B(31-40)  1.627E+03  8.552E+01  1.470E+03  1.391E+01  0.         1.006E+03  0.         1.006E+03  1.892E+01  1.687E+00

B(41-48)  1.180E+03  1.103E+01  1.137E+03  2.352E+01  2.436E+00  1.377E+03  3.293E+01  1.288E+03


                          PART 5 - FUEL CONTROLLER
X                 .080000

B( 1- 7) -4.654E-03  2.474E+00  6.825E+00  6.727E+00  9.298E+00  3.584E-03  1.107E+01

Y( 1-10) -4.139E-01  1.978E+00  1.322E-01  6.880E+01  4.599E+00  1.446E-01 -1.383E+01 -8.836E-01  7.610E+00 -1.443E+00

Y(11-12)  6.689E+00  1.999E-03

F( 1-10) -3.091E+00 -6.842E+01  1.982E+00 -2.380E+03  6.895E+01  4.597E+00  1.542E-01 -2.033E-01 -2.185E-01  5.623E+01

F(11-12) -1.451E+00  7.924E-03
```

```
TAPE 8  PRINTOUT

  TIME       ANGLE   FREQ        PCYL     TCYL     PIM      PEM     TEXH     TCS    RCOM     MASS       FUEL     M4D
  SEC         DEG     PC         PSIA     DEG F    PSIA     PSIA    DEG F    RPM              CFM       LB/HR   LB/SEC

 0.0000        0.0  -.0000       0.00      0.0    23.586   21.710   835.5   12600  1.606 12171.444   1582.5   10.066
  .0023        5.0  -.0000       0.00      0.0    23.590   21.486   875.6   12600  1.733 11122.626   1582.5   13.076
  .0046       10.0  -.0000       0.00      0.0    23.599   21.240   872.4   12600  1.730 11164.621   1582.5   12.945
  .0069       15.0   .0058       0.00      0.0    23.609   20.983   865.5   12600  1.729 11173.612   1580.7   12.871
  .0093       20.0   .0058       0.00      0.0    23.619   20.718   858.0   12599  1.728 11185.419   1580.7   12.850
  .0116       25.0   .0058       0.00      0.0    23.628   20.446   855.1   12599  1.727 11198.582   1580.7   12.885
  .0139       30.0   .0058       0.00      0.0    23.632   20.168   859.7   12598  1.726 11214.469   1580.7   12.963
  .0162       35.0   .0158       0.00      0.0    23.632   19.878   870.5   12598  1.724 11232.558   1575.6   13.132
  .0185       40.0   .0158       0.00      0.0    23.628   19.566   883.7   12599  1.723 11252.349   1575.6   13.394
  .0208       45.0   .0158    1762.24   3644.1    23.621   19.215   884.2   12599  1.722 11270.267   1575.6   13.501
  .0231       50.0   .0158    1762.24   3644.1    23.611   18.812   880.0   12600  1.721 11283.601   1575.6   13.674
  .0255       55.0   .0091    1762.24   3644.1    23.599   18.359   875.2   12600  1.721 11290.189   1568.2   13.942
  .0278       60.0   .0091    1762.24   3644.1    23.584   17.872   869.4   12601  1.721 11291.379   1568.2   14.221
  .0301       65.0   .0091    1762.24   3644.1    23.566   17.372   864.5   12602  1.721 11287.550   1568.2   14.384
  .0324       70.0   .0091    1762.24   3644.1    23.548   16.879   862.4   12602  1.722 11281.506   1568.2   14.417
  .0347       75.0   .0091    1762.24   3644.1    23.531   16.407   864.3   12603  1.722 11276.381   1568.2   14.395
  .0370       80.0   .0013    1762.24   3644.1    23.517   15.976   869.5   12604  1.723 11271.990   1559.5   14.355
  .0393       85.0   .0013    1762.24   3644.1    23.512   15.659   870.8   12604  1.723 11269.550   1559.5   14.180
  .0417       90.0   .0013    1762.24   3644.1    23.514   15.472   868.7   12605  1.723 11270.454   1559.5   13.938
  .0440       95.0   .0013     911.76   2655.8    23.521   15.569   865.9   12606  1.723 11273.534   1559.5   13.705
  .0463      100.0   .0067     911.76   2655.8    23.531   16.096   860.0   12606  1.722 11278.792   1550.5   13.498
  .0486      105.0   .0067     911.76   2655.8    23.542   17.100   850.4   12605  1.722 11285.456   1550.5   13.336
  .0509      110.0   .0067     911.76   2655.8    23.551   18.649   839.4   12605  1.721 11293.487   1550.5   13.219
  .0532      115.0   .0067     911.76   2655.8    23.559   20.757   831.1   12604  1.720 11302.896   1550.5   13.162
  .0556      120.0   .0209     911.76   2655.8    23.564   23.361   828.5   12603  1.719 11312.877   1542.1   13.125
  .0579      125.0   .0209     911.76   2655.8    23.565   26.328   832.0   12602  1.718 11325.580   1542.1   13.125
  .0602      130.0   .0209     911.76   2655.8    23.564   29.467   840.2   12602  1.717 11338.544   1542.1   13.165
  .0625      135.0   .0209     911.76   2655.8    23.560   31.052   850.7   12601  1.716 11349.815   1542.1   13.245
  .0648      140.0   .0209     911.76   2655.8    23.553   32.314   854.4   12601  1.716 11354.452   1542.1   13.201
  .0671      145.0   .0144     896.05   2652.2    23.544   33.306   857.5   12601  1.716 11350.005   1534.8   13.205
  .0694      150.0   .0144     896.05   2652.2    23.533   33.705   860.8   12601  1.717 11336.786   1534.8   13.255
  .0718      155.0   .0144     896.05   2652.2    23.519   33.386   863.9   12601  1.719 11316.114   1534.8   13.306
  .0741      160.0   .0144     896.05   2652.2    23.505   32.524   866.9   12601  1.721 11286.065   1534.8   13.322
  .0764      165.0   .0060     896.05   2652.2    23.491   31.462   870.5   12602  1.723 11261.484   1529.2   13.310
  .0787      170.0   .0060     896.05   2652.2    23.482   30.422   873.6   12602  1.724 11247.380   1529.2   13.357
  .0810      175.0   .0060     896.05   2652.2    23.479   29.459   871.3   12603  1.725 11240.841   1529.2   13.251
  .0833      180.0   .0060     896.05   2652.2    23.482   28.587   868.3   12603  1.725 11240.190   1529.2   13.135
  .0833      180.0   .0060     896.05   2652.2    23.482   28.587   868.3   12603  1.725 11240.190   1529.2   13.135


     END OF RUN
```

13. JOB PROCESSING AND OUTPUT TIMES

The Cooper-Bessemer LSV-16 computer program requires approximately 900 seconds of central processing time on the CDC 6400 for each second of real time simulated. Input/Output time required is approximately equal to 1/30 of the central processing time used. Output usually amounts to 10,000 lines of printing for each second of real time simulated.

PART III - FILE DOCUMENTATION

1. REVISION LOG

Date	Changes	Comments

2. SHORT TITLE

LSV-16

3. SOURCE PROGRAM LISTING AND SYMBOL TABLE

The following MAIN program and subroutines constitute a FORTRAN listing of the LSV-16 program. They are arranged alphabetically within each subsystem.

MAIN page

SUBSYSTEM 1

SUBSYSTEM 2

SUBSYSTEM 3

page

SUBSYSTEM 4

SUBSYSTEM 5

```
      PROGRAM DIESEL(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2=
     1PUNCH,TAPE4,TAPE8)
      COMMON ICM(20),G(90)
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),
     1IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
C     MAIN FOR COOPER-BESSEMER LSV-16 DIESEL
C     L(1) =1 AFTER TEST DATA READ INTO INAUX,=0 BEFORE
C     L(2) IS NUMBER OF PRINTS PER PAGE
C     L(4) IS THE PLOTTING FREQUENCY
C     L(5) IS THE PRINTING FREQUENCY
C     L(6) .NE. 0 WILL CALL ALL THE PRINT ROUTINES
C     L(7)=0 GIVES NEMA CONDITIONS, =1 CALLS AMB10 (SHOCK TUBE SIM.),
C        =2 CALLS AMB12 (STD. AIR SHOCK), =3 READS TEST DATA OFF TAPE
C         UNIT 4 FROM IVAUX.
C     L(10) IS A COUNTER OF NUMBER OF PRINTS PER PAGE
C     L(14) =0 FOR NO PUNCHING, =1 FOR PUNCHING
C     L(15)=0 BEFORE DATA READ INTO AMB12
C     L(16) GREATER THAN ZERO WRITES  G VECTOR FOR PLOTTING
C     L(21) IS A COUNTER FOR THE NUMBER OF PRINTS PER PAGE
C     L(22) IS THE COUNTER FOR PLOT
C     L(25) IS THE PRINT COUNT
C     L(26) IS THE PLOT COUNT
C     A(2) IS THE FINAL ANGLE
C     A(3) IS THE ANGLE INCREMENT
    1 REWIND 4
      REWIND 8
      MF18=1
      CALL ZRDSL
      CALL INPM
      CALL INP1
      CALL INP2
      CALL INP3
      CALL INP4
      CALL INP5
      L(21)=1
      L(25)=1
      G(30)=A(3)
      CALL SUB1
      CALL YPR1
      CALL SUB1
      CALL ENVIR
      CALL SUB2
      CALL SUB4
      CALL YPR4
      CALL SUB4
      CALL SUB5
      CALL YPR5
      CALL SUB5
      CALL IMODE
      CALL SUB3
      CALL YP3
      CALL SUB3
      CALL PRIM
      CALL PRT1
      CALL PRT2
      CALL PRT3
      CALL PRT4
      CALL PRT5
```

```
      CALL PLOT(MF18)                                                   DSL 0060
      L(26)=1                                                           DSL 0061
      L(22)=1                                                           DSL 0062
  100 G(22)=G(22)+A(3)                                                  DSL 0063
      CALL SUB1                                                         DSL 0064
      CALL ENVIR                                                        DSL 0065
      CALL SUB2                                                         DSL 0066
      CALL SUB4                                                         DSL 0067
      CALL SUB5                                                         DSL 0068
      CALL SUB3                                                         DSL 0069
      IF(L(5)-L(25))11,11,12                                            DSL 0070
   11 L(21)=L(21)+1                                                     DSL 0071
      CALL PRTM                                                         DSL 0072
      L(25)=1                                                           DSL 0073
      IF(L(6)) 20,20,5                                                  DSL 0074
    5 CALL PRT1                                                         DSL 0075
      CALL PRT2                                                         DSL 0076
      CALL PRT3                                                         DSL 0077
      CALL PRT4                                                         DSL 0078
      CALL PRT5                                                         DSL 0079
      GO TO 20                                                          DSL 0080
   12 L(25)=L(25)+1                                                     DSL 0081
   20 IF(L(4)-L(26))21,21,22                                            DSL 0082
   21 L(22)=L(22)+1                                                     DSL 0083
      CALL PLOT(MF18)                                                   DSL 0084
      L(26)=1                                                           DSL 0085
      GO TO 30                                                          DSL 0086
   22 L(26)=L(26)+1                                                     DSL 0087
   30 IF(G(22)+0.01*A(3)-A(2))100,13,13                                 DSL 0088
   13 CALL PRT8(MF18)                                                   DSL 0089
      IF(L(14))1000,1000,1001                                           DSL 0090
 1001 CALL PUN3                                                         DSL 0091
 1000 IF(ICM(4))1,1,999                                                 DSL 0092
  999 WRITE(MLP,1010)                                                   DSL 0093
      CALL EXIT                                                         DSL 0094
 1010 FORMAT(1H1,10X,10HEND OF RUN)                                     DSL 0095
      END                                                               DSL 0096
```

```
      SUBROUTINE AMB10
      COMMON ICM(20),G(90)
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),IA
     12(7),IC(19),ID(19),IE(19)
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
C     DIESEL SHOCK TUBE SIMULATION
      DO 10 I=51,100,4
      IF (A(I)-G(1)) 10,20,40
   10 CONTINUE
   20 DO 30 J=1,3
      IPJ=I+J
   30 B(J)=A(IPJ)
      GO TO 70
   40 IF (I-51) 50,20,50
   50 DO 60 J=1,3
      IPJ=I+J
      IPJM4=I+J-4
   60 B(J)=(A(IPJ)-A(IPJM4))/(A(I)-A(I-4))*(G(1)-A(I-4))+A(IPJM4)
   70 G(10)=B(1)
      G(12)=B(2)
      G(11)=B(3)
      RETURN
      END
```

```
      SUBROUTINE AMB12
      COMMON ICM(20),G(90)
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),IA
     12(7),IC(19),ID(19),IE(19)
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
C     STANDARD AIR SHOCK FOR DIESEL ENGINE
      DIMENSION P(2,2), N(2), U(2,4), T(2,4)
      IF (L(15)) 20,10,20
10    T(1,1)=A(39)
      T(1,2)=A(40)
      T(1,3)=A(41)
      T(1,4)=A(42)
      P(1,1)=A(43)
      P(1,2)=A(44)
      T(2,1)=A(45)
      T(2,2)=A(46)
      T(2,3)=A(47)
      T(2,4)=A(48)
      P(2,1)=A(49)
      P(2,2)=A(50)
      B(4)=A(38)
      L(15)=9999
20    DO 40 I=1,2
      DO 30 J=1,4
      N(I)=J
      IF (T(I,J)-G(1)) 30,40,40
30    CONTINUE
40    CONTINUE
      DO 110 I=1,2
      K=N(I)
      GO TO (60,70,80,90,60), K
60    U(I,4)=P(I,1)
      U(I,3)=B(4)
      GO TO 110
70    B(5)=(P(I,2)-P(I,1))/(T(I,2)-T(I,1))
      U(I,4)=P(I,1)+B(5)*(G(1)-T(I,1))
      GO TO 100
80    U(I,4)=P(I,2)
      GO TO 100
90    U(I,4)=(P(I,2)-P(I,1))*(T(I,4)-G(1))*EXP((T(I,3)-G(1))/(T(I,4)-T(I
     1,3)))/(T(I,4)-T(I,3))
      U(I,4)=U(I,4)+P(I,1)
100   B(6)=U(I,4)/P(I,1)
      B(7)=1.+6.*B(6)
      U(I,3)=B(4)*B(6)*(6.+B(6))/B(7)
110   CONTINUE
      G(12)=U(1,3)
      G(10)=U(1,4)
      G(11)=U(2,4)
      RETURN
      END
```

```
      SUBROUTINE ENVIR
      DIMENSION GG(4,1464), IG(4)
      COMMON ICM(20),G(90)
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),IA
     12(7),IC(19),ID(19),IE(19)
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
      DATA IG/9,11,12,13/
C
C     AMBIENT CONDITIONS FOR LSV-16
C     WRITTEN BY BRUCE ALLEN 11/71
C     REFERENCE   BOOPER-BESSEMER LOG SHEET
C
C     L(7)=0  SETS STEADY STATE CONDITIONS FOR ENVIRONMENT,
C     L(7)=1 CALLS AMB10 (SHOCK TUBE SIMULATION),
C     L(7)=2 CALLS AMB12 (STANDARD AIR SHOCK)
      L7=L(7)+1
      GO TO (30,10,20,40), L7
10    CALL AMB10
      GO TO 40
20    CALL AMB12
      GO TO 40
C     AMBIENT CONDITIONS FOR COOPER-BESSEMER LSV-16 DIESEL TESTS AT
C     GROVE CITY,PA. ON JUNE 24,1971
30    G(10)=14.10
      G(11)=13.90
      G(12)=541.
40    RETURN
      END
```

```
      SUBROUTINE INPM
      DIMENSION Z(6)
      COMMON ICM(20),G(90)
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),IA
     12(7),IC(19),ID(19),IE(19)
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
C     IC CONTAINS VARIABLE NAMES TO BE PRINTED
C     ID CONTAINS LOWER INDEX OF VARIABLE TO BE PRINTED
C     IE CONTAINS UPPER INDEX OF VARIABLE TO BE PRINTED
C     TITT WILL BE PRINTED AT THE TOP OF EACH PAGE OF OUTPUT
C     HED WILL BE PRINTED AT THE TOP OF THE 11 COLUMNS OF THE TAPE PRINT
      MCR=5
      MLP=6
      IA1(1)=1HI
      IA1(2)=1HP
      IA1(3)=1HR
      IA2(1)=1HA
      IA2(2)=1HB
      IA2(3)=1HF
      IA2(4)=1HL
      IA2(5)=1HX
      IA2(6)=1HY
      IA2(7)=1HG
      DO 10 I=1,30
   10 L(I)=0
      M=0
      READ (MCR,180) TITLE
      WRITE (MLP,190) TITLE
      READ (MCR,180) HEAD
   20 READ (MCR,200) II1,II2,I1,I2,Z
      IF(II2-IA2(1))30,21,30
   21 IF(I1-38)30,31,31
   30 WRITE(MLP,210)II1,II2,I1,I2,Z
   31 KKY=1
      DO 40 I=1,3
      IF (II1-IA1(I)) 40,50,40
   40 CONTINUE
   50 GO TO (60,130,140,160), I
   60 DO 70 I=1,7
      IF (II2-IA2(I)) 70,80,70
   70 CONTINUE
   80 CONTINUE
      GO TO (90,100,150,110,150,150,120,160), I
   90 CALL STORE (I1,I2,Z,A,100,KKY)
      GO TO (20,160), KKY
  100 CALL STORE (I1,I2,Z,B,60,KKY)
      GO TO (20,160), KKY
  110 CALL STORI (I1,I2,Z,L,30,KKY)
      GO TO (20,160), KKY
  120 CALL STORE (I1,I2,Z,G,90,KKY)
      GO TO (20,160), KKY
  130 M=M+1
      IC(M)=II2
      IC(M)=I1
      IE(M)=I2
      GO TO 20
  140 L14=M
      RETURN
  150 WRITE (MLP,170)
```

```
160    WRITE (MLP,220) III,II2,I1,I2                                  INM 580
       CALL EXIT                                                      INM 590
C                                                                     INM 600
170    FORMAT (//,20X,28HMAIN DOES NOT HAVE X, Y OR F)                INM 610
180    FORMAT (20A4)                                                  INM 620
190    FORMAT (1H1,20X,22HINPUT DATA FOR MAIN - ,/,20X,20A4)          INM 630
200    FORMAT (A1,1X,A1,2I3,1X,6F10.5)                                INM 640
210    FORMAT (/,1X,A1,1X,A1,2I3,1X,6E12.4)                           INM 650
220    FORMAT (17H1BAD DATA - CARD ,A1,8H VECTOR ,A1,2I3)             INM 660
       END                                                            INM 670-
```

```
      SUBROUTINE PLOT (IF8)                                             PLO  10
      COMMON ICM(20),G(90)                                              PLO  20
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),IAPLO  30
     12(7),IC(19),ID(19),IE(19)                                         PLO  40
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)    PLO  50
      WRITE (8) G                                                       PLO  60
      IF (L(16)) 10,10,20                                               PLO  70
   10 RETURN                                                            PLO  80
   20 MPU=4                                                             PLO  90
      WRITE (MPU,30) (G(I),I=1,10)                                      PLO 100
      WRITE (MPU,30) (G(I),I=11,20)                                     PLO 110
      WRITE (MPU,30) (G(I),I=21,30)                                     PLO 120
      WRITE (MPU,30) (G(I),I=31,40)                                     PLO 130
      WRITE (MPU,30) (G(I),I=41,48)                                     PLO 140
      RETURN                                                            PLO 150
C                                                                       PLO 160
   30 FORMAT (10E11.4)                                                  PLO 170
      END                                                               PLO 180-
```

```
      SUBROUTINE PRT8 (IF8)
      COMMON ICM(20),G(90)
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),IA
     12(7),IC(19),ID(19),IE(19)
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
      WRITE (MLP,20)
      WRITE (MLP,30) HEAD
      WRITE (MLP,40)
      WRITE (8) G
      N=L(22)+1
      REWIND 8
      DO 10 J=1,N
      READ (8) G
      WRITE (MLP,50) G(1),G(22),G(14),G(15),G(16),G(61),G(67),G(23),G(20
     1),G(17),G(18),G(19),G(55)
C
10    CONTINUE
      RETURN
C
20    FORMAT (18H1 TAPE 8  PRINTOUT)
30    FORMAT (1H0,20(2X,A4))
40    FORMAT (5X,4HTIME,7X,5HANGLE,3X,4HFREQ,9X,4HPCYL,5X,4HTCYL,4X,3HPI
     1M,6X,3HPEM,6X,4HTEXH,5X,3HTCS,4X,4HRCOM,5X,4HMASS,5X,4HFUEL,5X,4HM
     24C ,/,5X,3HSEC,9X,3HDEG,5X,2HPC,10X,4HPSIA,4X,5HDEG F,4X,4HPSIA,5X
     3,4HPSIA,5X,5HDEG F,4X,3HRPM,12X,6H CFM  ,4X,5HLB/HR,3X,6HLB/SEC,//
     4)
50    FORMAT (2X,F9.4,F10.1,F9.4,F10.2,F9.1,2F9.3,F8.1,F9.0,F8.3,F10.3,F
     19.1,F9.3)
      END
```

```
      SUBROUTINE PRTM
      COMMON ICM(20),G(90)                                              PRM  10
      COMMON A(100),B(60),TITLE(20),HEAD(20),L(30),MCR,MLP,L14,IA1(3),IAPRM  20
     12(7),IC(19),ID(19),IE(19)                                         PRM  30
      COMMON DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)    PRM  40
      IF (L(10)) 10,20,10                                               PRM  50
10    IF (L(10)-L(2)) 30,20,20                                          PRM  60
20    L(10)=0                                                           PRM  70
      WRITE (MLP,130) TITLE                                             PRM  80
30    L(10)=L(10)+1                                                     PRM  90
      WRITE (MLP,170) G(1)                                              PRM 100
      WRITE (MLP,180) G(22)                                             PRM 110
C                                                                       PRM 120
C     NORMALIZE AMBIENT PRESSURES FOR STANDARD AIR SHOCK                PRM 121
C                                                                       PRM 122
      IF(L(7)-2)32,31,32                                                PRM 123
   31 G(10)=(G(10)-A(43))/(A(44-A(43))                                  PRM 124
      G(11)=(G(11)-A(49))/(A(50)-A(49))                                 PRM 125
   32 DO 120 I=1,L14                                                    PRM 130
      I1=ID(I)                                                          PRM 135
      I2=IE(I)                                                          PRM 140
      DO 40 J=1,7                                                       PRM 150
      IF (IC(I)-IA2(J)) 40,70,40                                        PRM 160
40    CONTINUE                                                          PRM 170
50    WRITE (MLP,140) IC(I)                                             PRM 180
      CALL EXIT                                                         PRM 190
60    I1=I4+1                                                           PRM 200
      IF (I1-I2) 70,70,120                                              PRM 210
70    I4=MINO(I1+9,I2)                                                  PRM 220
      GO TO (80,90,50,100,50,50,110), J                                 PRM 230
80    WRITE (MLP,150) IC(I),I1,I4,(A(K),K=I1,I4)                        PRM 240
      GO TO 60                                                          PRM 250
90    WRITE (MLP,150) IC(I),I1,I4,(B(K),K=I1,I4)                        PRM 260
      GO TO 60                                                          PRM 270
100   WRITE (MLP,160) IC(I),I1,I4,(L(K),K=I1,I4)                        PRM 280
      GO TO 60                                                          PRM 290
110   WRITE (MLP,150) IC(I),I1,I4,(G(K),K=I1,I4)                        PRM 300
      GO TO 60                                                          PRM 310
120   CONTINUE                                                          PRM 320
      RETURN                                                            PRM 330
C                                                                       PRM 340
130   FORMAT (1H1,25X,20A4)                                             PRM 350
140   FORMAT (34H1BAD PRINT INSTRUCTION - VARIABLE ,A1)                 PRM 360
150   FORMAT (/,1X,A1,1H(,I2,1H-,I2,1H),10E11.3)                        PRM 370
160   FORMAT (/,1X,A1,1H(,I2,1H-,I2,1H),1X,9(I5,6X),I5)                 PRM 380
170   FORMAT (///,5X,6HTIME =,F15.6)                                    PRM 390
180   FORMAT (5X,7HANGLE =,F15.6,/)                                     PRM 400
      END                                                               PRM 410
                                                                        PRM 420-
```

```
      SUBROUTINE STORE (I1,I2,Z,A,NDA,KKY)                              STE  10
      DIMENSION Z(6), A(1)                                              STE  20
C     NO COMMON                                                         STE  30
      I4=I2-I1+1                                                        STE  40
      DO 10 I=1,I4                                                      STE  50
      I3=I-1+I1                                                         STE  60
      IF (I3-NDA) 10,10,20                                              STE  70
   10 A(I3)=Z(I)                                                        STE  80
      RETURN                                                            STE  90
   20 KKY=2                                                             STE 100
      RETURN                                                            STE 110
      END                                                               STE 120-
```

```
      SUBROUTINE STORI (I1,I2,Z,N,NDN,KKY)
      DIMENSION Z(6), N(1)
      I4=I2-I1+1
      DO 10 I=1,I4
      I3=I-1+I1
      IF (I3-NDN) 10,10,.
10    N(I3)=Z(I)
      RETURN
20    KKY=2
      RETURN
      END
```

```
      SUBROUTINE ZRDSL
      COMMON L(110)
      COMMON I(2793)
      DO 10 J=1,110
10    L(J)=0
      DO 20 J=1,2793
20    I(J)=0
      RETURN
      END
```

```
      SUBROUTINE INP1
      DIMENSION Z(6)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300)
      COMMON X,Y(10),F(10),Q(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MC
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
C     IC CONTAINS VARIABLE NAMES TO BE PRINTED
C     ID CONTAINS LOWER INDEX OF VARIABLE TO BE PRINTED
C     IE CONTAINS UPPER INDEX OF VARIABLE TO BE PRINTED
C     TITT WILL BE PRINTED AT THE TOP OF EACH PAGE OF OUTPUT
C     HED WILL BE PRINTED AT THE TOP OF THE 11 COLUMNS OF THE TAPE PRINT
      MCR=5
      MLP=6
      IA1(1)=1HI
      IA1(2)=1HP
      IA1(3)=1HR
      IA2(1)=1HA
      IA2(2)=1HB
      IA2(3)=1HF
      IA2(4)=1HL
      IA2(5)=1HX
      IA2(6)=1HY
      DO 10 I=1,20
   10 L(I)=0
      M=0
      READ (MCR,180) TITLE
      WRITE (MLP,190) TITLE
      READ (MCR,180) HEAD
   20 READ (MCR,200) II1,II2,I1,I2,Z
      WRITE (MLP,210) II1,II2,I1,I2,Z
      KKY=1
      DO 40 I=1,3
      IF (II1-IA1(I)) 40,50,40
   40 CONTINUE
   50 GO TO (60,150,160,170), I
   60 DO 70 I=1,6
      IF (II2-IA2(I)) 70,80,70
   70 CONTINUE
   80 GO TO (90,100,110,120,130,140,170), I
   90 CALL STORE (I1,I2,Z,A,20,KKY)
      GO TO (20,170), KKY
  100 CALL STORE (I1,I2,Z,B,19,KKY)
      GO TO (20,170), KKY
  110 CALL STORE (I1,I2,Z,F,10,KKY)
      GO TO (20,170), KKY
  120 CALL STORI (I1,I2,Z,L,20,KKY)
      GO TO (20,170), KKY
  130 CALL STORE (I1,I2,Z,X,1,KKY)
      GO TO (20,170), KKY
  140 CALL STORE (I1,I2,Z,Y,10,KKY)
      GO TO (20,170), KKY
  150 M=M+1
      IC(M)=II2
      ID(M)=I1
      IE(M)=I2
      GO TO 20
  160 L14=M
      RETURN
```

```
170   WRITE (MLP,220) II1,II2,I1,I2                                     IN1 600
      CALL EXIT                                                         IN1 610
C                                                                       IN1 620
180   FORMAT (20A4)                                                     IN1 630
190   FORMAT (1H1,20X,22HINPUT DATA FOR SUB1 - ,/,20X,20A4)             IN1 640
200   FORMAT (A1,1X,A1,2I3,1X,6F10.5)                                   IN1 650
210   FORMAT (/,1X,A1,1X,A1,2I3,1X,6E12.4)                              IN1 660
220   FORMAT (17H1BAD DATA - CARD ,A1,8H VECTOR ,A1,2I3)                IN1 670
      END                                                               IN1 680-
```

```
      SUBROUTINE PRT1
      COMMON ICM(20),G(90)                                              PR1  10
      COMMON DMAIN(300)                                                 PR1  20
      COMMON X,Y(10),F(10),Q(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MCPR1  30
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)                      PR1  40
      COMMON DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)               PR1  50
      IF (L(10)) 10,20,10                                               PR1  60
   10 IF (L(10)-L(2)) 30,20,20                                          PR1  70
   20 L(10)=0                                                           PR1  80
      WRITE (MLP,150) TITLE                                             PR1  90
   30 L(10)=L(10)+1                                                     PR1 100
      DO 140 I=1,L14                                                    PR1 110
      I1=IC(I)                                                          PR1 120
      I2=IE(I)                                                          PR1 130
      DO 40 J=1,6                                                       PR1 140
      IF (IC(I)-IA2(J)) 40,60,40                                        PR1 150
   40 CONTINUE                                                          PR1 160
      WRITE (MLP,160) IC(I)                                             PR1 170
      CALL EXIT                                                         PR1 180
   50 I1=I4+1                                                           PR1 190
      IF (I1-I2) 60,60,140                                              PR1 200
   60 I4=MIN0(I1+9,I2)                                                  PR1 210
      GO TO (70,80,90,100,110,120,130), J                               PR1 220
   70 WRITE (MLP,170) IC(I),I1,I4,(A(K),K=I1,I4)                        PR1 230
      GO TO 50                                                          PR1 240
   80 WRITE (MLP,170) IC(I),I1,I4,(B(K),K=I1,I4)                        PR1 250
      GO TO 50                                                          PR1 260
   90 WRITE (MLP,170) IC(I),I1,I4,(F(K),K=I1,I4)                        PR1 270
      GO TO 50                                                          PR1 280
  100 WRITE (MLP,180) IC(I),I1,I4,(L(K),K=I1,I4)                        PR1 290
      GO TO 50                                                          PR1 300
  110 WRITE (MLP,190) X                                                 PR1 310
      GO TO 140                                                         PR1 320
  120 WRITE (MLP,170) IC(I),I1,I4,(Y(K),K=I1,I4)                        PR1 330
      GO TO 50                                                          PR1 340
  130 WRITE (MLP,170) IC(I),I1,I4,(G(K),K=I1,I4)                        PR1 350
      GO TO 50                                                          PR1 360
  140 CONTINUE                                                          PR1 370
      RETURN                                                            PR1 380
C                                                                       PR1 390
  150 FORMAT (1H1,25X,20A4)                                             PR1 400
  160 FORMAT (34H1BAD PRINT INSTRUCTION - VARIABLE ,A1)                 PR1 410
  170 FORMAT (/,1X,A1,1H(,I2,1H-,I2,1H),10E11.3)                        PR1 420
  180 FORMAT (/,1X,A1,1H(,I2,1H-,I2,1H),1X,9(I5,6X),I5)                 PR1 430
  190 FORMAT (1X,1H<,10X,F12.6)                                         PR1 440
      END                                                               PR1 450
                                                                        PR1 460-
```

```
      SUBROUTINE RNG1 (H1,N1)                                           RN1  10
      COMMON ICM(20),G(90)                                              RN1  20
      COMMON CMAIN(300)                                                 RN1  30
      COMMON X,Y(10),F(10),Q(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MCRN1  40
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)                      RN1  50
      COMMON DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)               RN1  60
   10 H=H1                                                              RN1  70
      HH=.5*H                                                           RN1  80
      N=N1                                                              RN1  90
      DO 20 I=1,N                                                       RN1 100
   20 Q(I)=0.0                                                          RN1 110
      CALL YPR1                                                         RN1 120
      DO 30 I=1,N                                                       RN1 130
      S=F(I)*H                                                          RN1 140
      T=.5*(S-2.*Q(I))                                                  RN1 150
      Y(I)=Y(I)+T                                                       RN1 160
   30 Q(I)=Q(I)+3.*T-.5*S                                               RN1 170
      X=X+HH                                                            RN1 180
      CALL YPR1                                                         RN1 190
      DO 40 I=1,N                                                       RN1 200
      S=F(I)*H                                                          RN1 210
      T=.29289322*(S-Q(I))                                              RN1 220
      Y(I)=Y(I)+T                                                       RN1 230
   40 Q(I)=Q(I)+3.*T-.29289322*S                                        RN1 240
      CALL YPR1                                                         RN1 250
      DO 50 I=1,N                                                       RN1 260
      S=F(I)*H                                                          RN1 270
      T=1.7071067*(S-Q(I))                                              RN1 280
      Y(I)=Y(I)+T                                                       RN1 290
   50 Q(I)=Q(I)+3.*T-1.707106*S                                         RN1 300
      X=X+HH                                                            RN1 310
      CALL YPR1                                                         RN1 320
      DO 60 I=1,N                                                       RN1 330
      S=F(I)*H                                                          RN1 340
      T=(S-2.*Q(I))/6.                                                  RN1 350
      Y(I)=Y(I)+T                                                       RN1 360
   60 Q(I)=Q(I)+3.*T-.5*S                                               RN1 370
      RETURN                                                            RN1 380
      END                                                               RN1 390-
```

```
      SUBROUTINE SUB1
      REAL IHP,IMEP,JO,KO
      COMMON ICM(20),G(90)
      COMMON DMAIN(300)
      COMMON X,Y(10),F(10),Q(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MC
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
      EQUIVALENCE (NSC,L(8)), (EC,A(3)), (JO,A(4)), (CID,A(5)), (PI,A(6)
     1), (KO,A(7)), (BHP,G(46)), (IHP,G(47)), (BMEP,G(48)), (IMEP,G(49))
     2, (FR,G(50)), (BSFC,G(51))
C     EQUATION OF MOTION
      G(13)=A(2)*G(22)
   10 IF (G(13)-(X+A(1)*0.5)) 20,60,60
   20 G(1)=Y(2)
      G(2)=Y(1)
      G(3)=F(1)*Y(1)
      L(9)=L(9)+1
      IDX=IFIX(G(30))
      IF (L(9)-NSC*180/IDX) 50,30,30
   30 L(9)=0
      B(3)=Y(5)
      B(15)=Y(10)
      DO 40 J=3,9
      B(J-2)=Y(J)
      B(J+5)=Y(J)*100.0/B(3)
   40 Y(J)=0.0
      Y(10)=0.0
      G(38)=B(8)
      G(39)=B(9)
      G(40)=B(11)
      G(41)=B(12)
      G(42)=B(13)
      G(43)=B(14)
      G(44)=B(3)
      G(45)=B(1)+B(2)+B(4)+B(5)+B(6)+B(7)+B(15)
      G(54)=B(15)*100.0/B(3)
      BHP=B(6)*Y(1)*JO/(PI*KO*NSC)
      IHP=(B(2)+B(6))*Y(1)*JO/(PI*KO*NSC)
      BMEP=B(6)*JO/CID
      IMEP=(B(2)+B(6))*JO/CID
      FR=B(3)*Y(1)*JO*3600./(PI*NSC*EC)
      BSFC=FR/BHP
   50 RETURN
   60 CALL RNG1 (A(1),L(1))
      GO TO 10
      END
```

```
      SUBROUTINE YPR1
      COMMON ICM(20),G(90)
      COMMON DMAIN(300)
      COMMON X,Y(10),F(10),Q(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MC
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB2(200),DSUB3(1693),DSUB4(200),DSUB5(200)
      F(1)=(G(24)-G(25)*Y(1)-G(26)*Y(1)*Y(1)-G(7)-G(53))/(G(27)*Y(1))
      F(2)=1.0/Y(1)
      F(3)=G(31)/Y(1)
      F(4)=G(32)/Y(1)
      F(5)=G(33)/Y(1)
      F(6)=G(34)/Y(1)
      F(7)=G(35)/Y(1)
      F(8)=G(36)/Y(1)
      F(9)=G(37)/Y(1)
      F(10)=G(52)/Y(1)
      RETURN
      END
```

```
      SUBROUTINE INP2
      DIMENSION Z(6)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200)
      COMMON X,Y(10),F(10),Q(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MC
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB3(1693),DSUB4(200),DSUB5(200)
C     IC CONTAINS VARIABLE NAMES TO BE PRINTED
C     ID CONTAINS LOWER INDEX OF VARIABLE TO BE PRINTED
C     IE CONTAINS UPPER INDEX OF VARIABLE TO BE PRINTED
C     TITT WILL BE PRINTED AT THE TOP OF EACH PAGE OF OUTPUT
C     HED WILL BE PRINTED AT THE TOP OF THE 11 COLUMNS OF THE TAPE PRINT
      MCR=5
      MLP=6
      IA1(1)=1HI
      IA1(2)=1HP
      IA1(3)=1HR
      IA2(1)=1HA
      IA2(2)=1HB
      IA2(3)=1HF
      IA2(4)=1HL
      IA2(5)=1HX
      IA2(6)=1HY
      DO 10 I=1,20
   10 L(I)=0
      M=0
      READ (MCR,180) TITLE
      WRITE (MLP,190) TITLE
      READ (MCR,180) HEAD
   20 READ (MCR,200) II1,II2,I1,I2,Z
      WRITE (MLP,210) II1,II2,I1,I2,Z
      KKY=1
      DO 40 I=1,3
      IF (II1-IA1(I)) 40,50,40
   40 CONTINUE
   50 GO TO (60,150,160,170), I
   60 DO 70 I=1,6
      IF (II2-IA2(I)) 70,80,70
   70 CONTINUE
   80 GO TO (90,100,110,120,130,140,170), I
   90 CALL STORE (I1,I2,Z,A,20,KKY)
      GO TO (20,170), KKY
  100 CALL STORE (I1,I2,Z,B,19,KKY)
      GO TO (20,170), KKY
  110 CALL STORE (I1,I2,Z,F,10,KKY)
      GO TO (20,170), KKY
  120 CALL STORI (I1,I2,Z,L,20,KKY)
      GO TO (20,170), KKY
  130 CALL STORE (I1,I2,Z,X,1,KKY)
      GO TO (20,170), KKY
  140 CALL STORE (I1,I2,Z,Y,10,KKY)
      GO TO (20,170), KKY
  150 M=M+1
      IC(M)=II2
      ID(M)=I1
      IE(M)=I2
      GO TO 20
  160 L14=M
      RETURN
```

```
170   WRITE (MLP,220) II1,II2,I1,I2                                        IN2 600
      CALL EXIT                                                            IN2 610
C                                                                          IN2 620
180   FORMAT (20A4)                                                        IN2 630
190   FORMAT (1H1,20X,22HINPUT DATA FOR SUB2 - ,/,20X,20A4)                IN2 640
200   FORMAT (A1,1X,A1,2I3,1X,6F10.5)                                      IN2 650
210   FORMAT (/,1X,A1,1X,A1,2I3,1X,6E12.4)                                 IN2 660
220   FORMAT (17H1BAD DATA - CARD ,A1,8H VECTOR ,A1,2I3)                   IN2 670
      END                                                                  IN2 680-
```

```
      SUBROUTINE PRT2
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200)
      COMMON X,Y(10),F(10),Q(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MC
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB3(1693),DSUB4(200),DSUB5(200)
      IF (L(10)) 10,20,10
   10 IF (L(10)-L(2)) 30,20,20
   20 L(10)=0
      WRITE (MLP,150) TITLE
   30 L(10)=L(10)+1
      DO 140 I=1,L14
      I1=ID(I)
      I2=IE(I)
      DO 40 J=1,6
      IF (IC(I)-IA2(J)) 40,60,40
   40 CONTINUE
      WRITE (MLP,160) IC(I)
      CALL EXIT
   50 I1=I4+1
      IF (I1-I2) 60,60,140
   60 I4=MIN0(I1+9,I2)
      GO TO (70,80,90,100,110,120,130), J
   70 WRITE (MLP,170) IC(I),I1,I4,(A(K),K=I1,I4)
      GO TO 50
   80 WRITE (MLP,170) IC(I),I1,I4,(B(K),K=I1,I4)
      GO TO 50
   90 WRITE (MLP,170) IC(I),I1,I4,(F(K),K=I1,I4)
      GO TO 50
  100 WRITE (MLP,180) IC(I),I1,I4,(L(K),K=I1,I4)
      GO TO 50
  110 WRITE (MLP,190) X
      GO TO 140
  120 WRITE (MLP,170) IC(I),I1,I4,(Y(K),K=I1,I4)
      GO TO 50
  130 WRITE (MLP,170) IC(I),I1,I4,(G(K),K=I1,I4)
      GO TO 50
  140 CONTINUE
      RETURN
C
  150 FORMAT (1H1,25X,20A4)
  160 FORMAT (34H1BAD PRINT INSTRUCTION - VARIABLE ,A1)
  170 FORMAT (/,1X,A1,1H(,I2,1H-,I2,1H),10E11.3)
  180 FORMAT (/,1X,A1,1H(,I2,1H-,I2,1H),1X,9(I5,6X),I5)
  190 FORMAT (1X,1HX,10X,F12.6)
      END
```

```
      SUBROUTINE SUB2                                                   SU2  10
      COMMON ICM(20),G(90)                                              SU2  20
      COMMON DMAIN(300),DSUB1(200)                                      SU2  30
      COMMON X,Y(10),F(10),O(10),A(20),B(19),TITLE(20),HEAD(20),L(20),MCSU2  40
     1R,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)                      SU2  50
      COMMON DSUB3(1693),DSUB4(200),DSUB5(200)                          SU2  60
C     DUMMY ALTERNATOR                                                  SU2  70
C     L(1)=0 SETS TORQUE SUB2,INSTEAD OF IN ENVIR                       SU2  80
      IF (G(1)-(X+A(1)*0.5)) 10,20,20                                   SU2  90
10    IF (G(1)) 70,20,70                                                SU2 100
20    IF (L(1)) 60,30,60                                                SU2 110
30    IF (G(1)-A(4)) 40,50,50                                           SU2 120
40    G(7)=A(3)*A(5)/G(2)                                               SU2 130
      G(8)=A(7)*A(8)                                                    SU2 140
      GO TO 60                                                          SU2 150
50    G(7)=A(3)*A(6)/G(2)                                               SU2 160
      G(8)=A(7)*A(9)                                                    SU2 170
60    G(4)=A(2)*G(2)                                                    SU2 180
      X=X+A(1)                                                          SU2 190
70    RETURN                                                            SU2 200
      END                                                               SU2 210-
```

```
      FUNCTION AEV (THETA,COEF)
C
C     EXHAUST VALVING FOR LSV-16
C     WRITTEN BY BRUCE ALLEN 11/71
C     REFERENCE    COOPER-BESSEMER GRAPHS
C
C
C    EXHAUST VALVE AREA FOR LSV-16
      X=THETA
      IF (X-35.) 10,240,30
10    IF (X-15.) 210,220,20
20    IF (X-25.) 220,220,230
30    IF (X-475.) 240,240,40
C    TEST IF BEFORE DWELL
40    IF (X-575.) 50,250,110
50    IF (X-485.) 130,130,60
60    IF (X-495.) 140,140,70
70    IF (X-535.) 150,150,80
80    IF (X-555.) 160,160,90
90    IF (X-565.) 170,170,100
100   IF (X-575.) 180,250,110
110   IF (X-655.) 250,250,120
120   IF (X-665.) 190,190,200
130   Y=.00986*(X-475.)
      GO TO 260
140   X=X-360.
      Y=31.240698+X*(-.53065826+X*.22521731E-2)
      GO TO 260
150   X=X-360.
      Y=122.01975+X*(-.22952127E+1+X*(.13494418E-1+X*(-.23350869E-4)))
      GO TO 260
160   X=X-360.
      Y=-149.23379+X*(.15401395E+1+X*(-.36511332E-2))
      GO TO 260
170   X=X-720.
      Y=-67.141347+X*(-.10817768E+1+X*(-.36397647E-2))
      GO TO 260
180   Y=13.0887+.01015*(X-565.)
      GO TO 260
190   Y=13.1902-.01014*(X-655.)
      GO TO 260
200   X=X-720.
210   Y=2.5306121+X*(-.17628683+X*(.35793348E-2+X*(.16580119E-4+X*(-.164
     163877E-5+X*(-.15538472E-7)))))
      GO TO 260
220   Y=2.3160373+X*(-.14500998+X*.22524997E-2)
      GO TO 260
230   Y=.0986-.00986*(X-25.)
      GO TO 260
240   AEV=0.
      GO TO 270
250   Y=13.1902
260   AEV=Y*COEF
270   RETURN
      END
```

```
      FUNCTION AIV (THETA,COEF)
C
C      INLET VALVING LSV-16
C      WRITTEN BY BRUCE ALLEN 11/71
C      REFERENCE   COOPER-BESSEMER GRAPHS
C
C
C     INLET VALVE AREA FOR LSV-16
      X=THETA
      IF (X-200.) 20,170,10
10    IF (X-640.) 170,170,70
20    IF (X-64.) 100,100,30
30    IF (X-92.) 110,110,40
40    IF (X-140.) 120,120,50
50    IF (X-176.) 130,130,60
60    IF (X-188.) 140,140,150
C     LEAST SQUARES CURVE FITS AND LINEAR INTERPOLATION
70    X=THETA-720.
      IF (THETA-656.) 80,80,90
80    Y=2.6130778+X*(.65789682E-1+X*.41407765E-3)
      GO TO 160
90    Y=5.8133347+X*(.16043559+X*(.88374677E-3+X*(-.76256847E-5+X*(-.635
     148363E-7))))
      GO TO 180
100   Y=5.8017106+X*(.1611841+X*(.88399514E-03+X*(-.43754881E-04+X*.2877
     1331E-06)))
      GO TO 180
110   Y=88.82831+X*(-.39886968E+1+X*(.77776331E-01+X*(-.66515297E-3+X*.2
     11059899E-05)))
      GO TO 180
120   Y=73.762577+X*(-.21190414E+1+X*(.24725009E-01+X*(-.73792507E-4+X*(
     1-.44715408E-6+X*.22006886E-8))))
      GO TO 180
130   Y=53.449592+X*(-.30777121+X*(-.11955116E-2+X*(.40134812E-5+X*(.332
     129148E-7+X*(-.90964446E-10)))))
      GO TO 180
140   Y=62.293526+X*(-.63532565+X*.16196907E-2)
      GO TO 180
150   Y=29.196687+X*(-.29254434+X*.73280356E-3)
160   IF (Y) 170,170,180
C
170   AIV=0.
      GO TO 190
180   AIV=Y*COEF
190   RETURN
      END
```

```
      SUBROUTINE ANGLE (LX)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)
      COMMON X(20),XO(20),Y(100),YO(100),Q(100),F(100),A(100),B(100)
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON DD(20)
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON DSUB4(200),DSUB5(200)
      EQUIVALENCE (AE,A(6)), (AF,A(7)), (AI,A(8)), (C1,A(9)), (BRR,A(10)
     1)
      EQUIVALENCE (EC,A(11)), (AD,A(12)), (FIM,A(13)), (R,A(14)), (TW,A(
     115))
      EQUIVALENCE (VO,A(16)), (CID,A(17)), (W10,A(18)), (W11,A(19))
      EQUIVALENCE (W12,A(20)), (W13,A(21)), (W19,A(22)), (W20,A(23))
      EQUIVALENCE (W21,A(24)), (PD,A(25)), (BORE,A(26)), (STROK,A(27))
      EQUIVALENCE (ROD,A(28)), (PI,A(29)), (W29,A(30))
      EQUIVALENCE (PM,A(33)), (CP,A(35)), (DXC,A(41)), (DXS,A(42))
      EQUIVALENCE (DX,A(43)), (PINIM,A(44)), (NC,L(1)), (NC4,L(2))
      EQUIVALENCE (NSC,L(3)), (NE,L(4)), (FC,A(36))
      LX=0
      DO 290 I=1,NC
      IF (IY(I)-1) 290,10,290
   10 K=M(I)
      K1=M1(I)
      K2=M2(I)
      K3=M3(I)
      K4=M4(I)
      IF (K-3) 20,140,20
C     SELECT A(I) TO CHECK A(I+1) FOR MODE K
   20 DO 110 K9=1,5
      IF (L(K9+10)-K) 110,30,110
   30 KK=K9+1-5*(K9/5)
      IF (A(KK)-X(I)) 50,40,40
   40 DAX=A(KK)-X(I)
      GO TO 60
   50 DAX=A(KK)+NSC*180.0-X(I)
   60 IF (ABS(X(I)-A(K9))-A(46)) 120,120,70
   70 IF (A(KK)-A(K9)) 90,80,80
   80 DA=A(KK)-A(K9)
      GO TO 100
   90 DA=A(KK)+NSC*180.0-A(K9)
  100 IF (DA-DAX) 110,120,120
  110 CONTINUE
      WRITE (MLP,310)
      WRITE (MLP,300) I,X(I),A(K9),DAX,DA
      CALL PRT3
      CALL EXIT
  120 IF (DAX-D) 130,290,290
  130 LX=LX+1
      DD(LX)=DAX
      GO TO 290
  140 GO TO (160,150,160,160), K4
  150 LX=LX+1
      DD(LX)=DXC
  160 IF (M3(I)-4) 170,220,220
  170 IF (W14(K3)-X(I)) 190,180,180
  180 DWX=W14(K3)-X(I)
      GO TO 200
```

```
 190    DWX=W14(K3)+NSC*180-X(I)                                             ANG 600
 200    IF (DWX-D) 210,220,220                                               ANG 610
 210    LX=LX+1                                                              ANG 620
        DD(LX)=DWX                                                           ANG 630
 220    GO TO (230,270,270,270), K4                                          ANG 640
 230    IF (B(30)-X(I)) 250,240,240                                          ANG 650
 240    DDX=B(30)-X(I)                                                       ANG 660
        GO TO 260                                                            ANG 670
 250    DDX=B(30)+NSC*180.-X(I)                                              ANG 680
 260    IF (DDX-D) 280,270,270                                               ANG 690
 270    IF (M3(I)-4) 290,20,20                                               ANG 700
 280    LX=LX+1                                                              ANG 710
        DD(LX)=DDX                                                           ANG 720
 290    CONTINUE                                                             ANG 730
        RETURN                                                               ANG 740
C                                                                            ANG 750
 300    FORMAT (I10,5E18.7)                                                  ANG 760
 310    FORMAT (1H1,10X,8HBAD MODE)                                          ANG 770
        END                                                                  ANG 780-
```

```
      SUBROUTINE CHANG (LX)
      DIMENSION INL(20), IEX(20), VI(10)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)
      COMMON X(20),XO(20),Y(100),YO(100),W(100),F(100),A(100),B(100)
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON DD(20)
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON DSUB4(200),DSUB5(200)
      EQUIVALENCE (AE,A(6)), (AF,A(7)), (AI,A(8)), (C1,A(9)), (BRR,A(10)
     1)
      EQUIVALENCE (EC,A(11)), (AD,A(12)), (FIM,A(13)), (R,A(14)), (TW,A(
     115))
      EQUIVALENCE (VO,A(16)), (CID,A(17)), (W10,A(18)), (W11,A(19))
      EQUIVALENCE (W12,A(20)), (W13,A(21)), (W19,A(22)), (W20,A(23))
      EQUIVALENCE (W21,A(24)), (PD,A(25)), (BORE,A(26)), (STROK,A(27))
      EQUIVALENCE (ROD,A(28)), (PI,A(29)), (W29,A(30))
      EQUIVALENCE (PM,A(33)), (CP,A(35)), (DXC,A(41)), (DXS,A(42))
      EQUIVALENCE (DX,A(43)), (PINIM,A(44)), (NC,L(1)), (NC4,L(2))
      EQUIVALENCE (NSC,L(3)), (NE,L(4)), (FC,A(36))
      EQUIVALENCE (L(31),INL(1)), (L(51),IEX(1)), (A(91),VI(1))
      EQUIVALENCE (L(5),L5)
      LX=0
      DO 490 I=1,NC
      II=NC4+3*INL(I)
      IX=NC4+3*L5+3*IEX(I)
      I4=4*I
      IF (IY(I)-1) 490,20,490
   20 K=M(I)
      K1=M1(I)
      K2=M2(I)
      K3=M3(I)
      K4=M4(I)
      DO 60 K9=1,5
      IF (L(K9+10)-K) 60,30,60
   30 KK=K9+1-5*(K9/5)
      IF (A(KK)-A(K9)) 40,50,50
   40 IF (X(I)-A(K9)) 50,200,200
C     CHANGE BASIC MODE
   50 IF (ABS(X(I)-A(KK))-A(47)) 70,70,60
   60 CONTINUE
      GO TO 200
   70 M(I)=L(KK+10)
      K=M(I)
      M1(I)=0
      M2(I)=0
      M3(I)=0
      M4(I)=0
      LX=1
      GO TO (140,140,90,80,140), K
C     UNBURNED FUEL IS PURGED WHEN EXHAUST VALVE OPENS.
   80 Y(I4-1)=0.
      GO TO 140
   90 DO 100 N=1,3
      IF (ABS(W14(N)-A(KK))-A(47)) 100,100,110
  100 CONTINUE
  110 M3(I)=N
      IF (ABS(B(30)-A(KK))-A(47)) 120,120,130
```

```
120   M4(I)=2                                            CHA 600
      GO TO 140                                          CHA 610
130   M4(I)=1                                            CHA 620
140   IF (Y(I4)-Y(IX)) 160,150,150                       CHA 630
150   M2(I)=1                                            CHA 640
      GO TO 170                                          CHA 650
160   M2(I)=2                                            CHA 660
170   IF (Y(I4)-Y(II)) 180,180,190                       CHA 670
180   M1(I)=1                                            CHA 680
      GO TO 490                                          CHA 690
190   M1(I)=2                                            CHA 700
      GO TO 490                                          CHA 710
C     CHANGE SUB MODE                                    CHA 720
200   GO TO (350,350,210,350,350), K                     CHA 730
C     CHANGE COMBUSTION MODE                             CHA 740
210   GO TO (220,230,230,280), K3                        CHA 750
220   W1=A(3)                                            CHA 760
      GO TO 240                                          CHA 770
230   W1=W14(K3-1)                                       CHA 780
240   IF (W14(K3)-W1) 250,260,260                        CHA 790
250   IF (X(I)-W1) 260,280,280                           CHA 800
260   IF (ABS(X(I)-W14(K3))-A(47)) 270,270,280           CHA 810
270   K3=K3+1                                            CHA 820
      M3(I)=K3                                           CHA 830
      LX=1                                               CHA 840
      GO TO 210                                          CHA 850
280   GO TO (310,290,490,490), K4                        CHA 860
290   IF (Y(I4-1)-A(51)) 300,300,490                     CHA 870
300   Y(I4-1)=0.                                         CHA 880
      M4(I)=4                                            CHA 890
      LX=1                                               CHA 900
      GO TO 350                                          CHA 910
310   IF (B(30)-A(3)) 320,330,330                        CHA 920
320   IF (X(I)-A(3)) 330,490,490                         CHA 930
330   IF (ABS(X(I)-B(30))-A(47)) 340,340,490             CHA 940
340   M4(I)=2                                            CHA 950
      LX=1                                               CHA 960
      GO TO 350                                          CHA 970
C     CHANGE EXHAUST VALVE MODE                          CHA 980
350   IF (ABS(Y(I4)-Y(IX))-A(49)) 360,360,420            CHA 990
360   LX=1                                               CHA1000
      GO TO (370,380), K2                                CHA1010
370   M2(I)=2                                            CHA1020
      Y(I4)=Y(IX)-2.*A(49)                               CHA1030
      GO TO 390                                          CHA1040
380   M2(I)=1                                            CHA1050
      Y(I4)=Y(IX)+2.*A(49)                               CHA1060
390   IF (Y(I4)-Y(II)) 400,400,410                       CHA1070
400   M1(I)=1                                            CHA1080
      GO TO 490                                          CHA1090
410   M1(I)=2                                            CHA1100
      GO TO 490                                          CHA1110
C     CHANGE INTAKE VALVE MODE.                          CHA1120
420   IF (ABS(Y(I4)-Y(II))-A(49)) 430,430,490            CHA1130
430   LX=1                                               CHA1140
      GO TO (440,450), K1                                CHA1150
440   M1(I)=2                                            CHA1160
      Y(I4)=Y(II)+2.*A(49)                               CHA1170
      GO TO 460                                          CHA1180
```

```
450   M1(I)=1                                                          CHA1190
      Y(I4)=Y(I1)-2.*A(49)                                             CHA1200
460   IF (Y(I4)-Y(IX)) 480,470,470                                     CHA1210
470   M2(I)=1                                                          CHA1220
      GO TO 490                                                        CHA1230
480   M2(I)=2                                                          CHA1240
490   CONTINUE                                                         CHA1250
      RETURN                                                           CHA1260
      END                                                              CHA1270-
```

```
      FUNCTION CM (P1,P2,A,T,C)                                         CM 00001
      IF(ABS(P1-P2)-.005)50,50,40                                       CM 00002
   50 CM=0.                                                             CM 00003
      RETURN                                                            CM 00004
   40 W1=P2/P1                                                          CM 00005
      IF (W1-.53) 10,20,20                                              CM 00006
10    W2=.531246608                                                     CM 00007
      GO TO 30                                                          CM 00008
20    W3=W1**(1./C)                                                     CM 00009
      W2=2.05*W3*SQRT(ABS(1.-W1/W3))                                    CM 00010
30    CM=W2*A*P1/SQRT(T)                                                CM 00011
      RETURN                                                            CM 00012
      END                                                               CM 00013
```

```
      SUBROUTINE DMFB (WBR,M4,WF,XC,AMC,BRR)
C     COMBUSTION MODEL
      GO TO (10,20,10,10), M4
   10 WBR=0.
      RETURN
   20 IF (WF) 10,10,30
   30 WBR=BRR*WF*(1.-EXP((XC-1.)*AMC/(45.*WF)))
      IF (WBR-0.18850) 40,50,50
   40 WBR=0.18850
   50 RETURN
      END
```

```
      FUNCTION EXMAN (HEM,AEM,TWEM,GAMMA,VEM,TGEM,OMEGA)               EXM  10
C     COMPUTES HEAT LOSS TO EXHAUST MANIFOLD WATER JACKET              EXM  20
      EXMAN=-HEM*AEM*(TGEM-TWEM)*(GAMMA-1.)/(VEM*OMEGA)                EXM  30
      RETURN                                                           EXM  40
      END                                                              EXM  50-
```

```
      SUBROUTINE FI (WF,M1,WFM,A1,A2,A3,A4,XCYL)
C  **  FUEL INJECTOR SCHEDULE
      GO TO (10,20,30,40), M1
10    WF=WFM*(XCYL-A1)/(A2-A1)
      RETURN
20    WF=WFM
      RETURN
30    WF=WFM*(1.-(XCYL-A3)/(A4-A3))
      RETURN
40    WF=0.0
      RETURN
      END
```

```
      SUBROUTINE IMODE
      DIMENSION INL(20), IEX(20), VI(10)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)
      COMMON X(20),XO(20),Y(100),YO(100),Q(100),F(100),A(100),B(100)
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON DD(20)
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON DSUB4(200),DSUB5(200)
      EQUIVALENCE (AE,A(6)), (AF,A(7)), (AI,A(8)), (C1,A(9)), (BRR,A(10)
     1)
      EQUIVALENCE (EC,A(11)), (AD,A(12)), (FIM,A(13)), (R,A(14)), (TW,A(
     115))
      EQUIVALENCE (VO,A(16)), (CID,A(17)), (W10,A(18)), (W11,A(19))
      EQUIVALENCE (W12,A(20)), (W13,A(21)), (W19,A(22)), (W20,A(23))
      EQUIVALENCE (W21,A(24)), (PD,A(25)), (BORE,A(26)), (STROK,A(27))
      EQUIVALENCE (ROD,A(28)), (PI,A(29)), (W29,A(30))
      EQUIVALENCE (PM,A(33)), (CP,A(35)), (DXC,A(41)), (DXS,A(42))
      EQUIVALENCE (DX,A(43)), (PINIM,A(44)), (NC,L(1)), (NC4,L(2))
      EQUIVALENCE (NSC,L(3)), (NE,L(4)), (FC,A(36))
      EQUIVALENCE (L(31),INL(1)), (L(51),IEX(1)), (A(91),VI(1))
      EQUIVALENCE (L(5),L5), (L(22),L22)
      CALL RACK (A(3),W14(1),W14(2),W14(3),FIM,G(9),G(2),NSC,NC)
      DX2=DX/2.0
      DO 350 I=1,NC
      II=NC4+3*INL(I)
      IX=NC4+3*L5+3*IEX(I)
      IY(I)=1
      I4=I*4
      DO 70 J=1,5
      JJ=J+1-5*(J/5)
      IF (A(JJ)-A(J)) 50,10,10
 10   IF (ABS(X(I)-A(J))-A(46)) 80,80,20
 20   IF (X(I)-A(J)) 70,80,30
 30   IF (ABS(X(I)-A(JJ))-A(46)) 90,90,40
 40   IF (A(JJ)-X(I)) 70,70,80
 50   IF (ABS(X(I)-A(J))-A(46)) 30,60,60
 60   IF (X(I)-A(J)) 30,80,80
 70   CONTINUE
      J=5
 80   M(I)=L(J+10)
      GO TO 100
 90   M(I)=L(JJ+10)
 100  K=M(I)
      IF (Y(I4)-Y(II)) 120,120,130
 120  M1(I)=1
      GO TO 140
 130  M1(I)=2
 140  IF (Y(I4)-Y(IX)) 160,150,150
 150  M2(I)=1
      GO TO 170
 160  M2(I)=2
 170  GO TO (350,350,180,350,350), K
 180  W2=A(3)
      DO 230 J=1,3
      IF (ABS(W14(J)-W2)-A(46)) 230,230,190
 190  IF (W14(J)-W2) 200,210,210
 200  IF (X(I)-W2) 220,240,240
```

```
210    IF (X(I)-W2) 230,240,220                                     IMO 600
220    IF (W14(J)-X(I)) 230,230,240                                 IMO 610
230    W2=W14(J)                                                    IMO 620
       M3(I)=4                                                      IMO 630
       GO TO 250                                                    IMO 640
240    M3(I)=J                                                      IMO 650
250    W4=A(3)+A(45)*A(44)/Y(I)                                     IMO 660
       B(30)=W4                                                     IMO 670
       IF (B(30)-NSC*180.) 270,260,260                              IMO 680
260    B(30)=B(30)-180.*NSC                                         IMO 690
270    W4=B(30)                                                     IMO 700
       IF (W4-A(3)) 280,280,290                                     IMO 710
280    IF (W4-X(I)) 300,300,320                                     IMO 720
290    IF (W4-X(I)) 310,310,300                                     IMO 730
300    IF (X(I)-A(3)) 310,320,320                                   IMO 740
310    IF (Y(14-1)) 340,340,330                                     IMO 750
320    M4(I)=1                                                      IMO 760
       GO TO 350                                                    IMO 770
330    M4(I)=2                                                      IMO 780
       GO TO 350                                                    IMO 790
340    M4(I)=4                                                      IMO 800
350    CONTINUE                                                     IMO 810
       RETURN                                                       IMO 820
       END                                                          IMO 830-
```

```
      SUBROUTINE INP3
      DIMENSION Z(6)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)
      COMMON X(20),XO(20),Y(100),YO(100),U(100),F(100),A(100),B(100)
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON DD(20)
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON DSUB4(200),DSUB5(200)
C   IC CONTAINS VARIABLE NAMES TO BE PRINTED
C   ID CONTAINS LOWER INDEX OF VARIABLE TO BE PRINTED
C   IE CONTAINS UPPER INDEX OF VARIABLE TO BE PRINTED
C   TITT WILL BE PRINTED AT THE TOP OF EACH PAGE OF OUTPUT
C   HED WILL BE PRINTED AT THE TOP OF THE 11 COLUMNS OF THE TAPE PRINT
      MCR=5
      MLP=6
      IA1(1)=1HI
      IA1(2)=1HP
      IA1(3)=1HR
      IA2(1)=1HA
      IA2(2)=1HB
      IA2(3)=1HF
      IA2(4)=1HL
      IA2(5)=1HX
      IA2(6)=1HY
      DO 10 I=1,25
10    L(I)=0
      L14=0
      READ (MCR,240) TITLE
      WRITE (MLP,250) TITLE
      READ (MCR,240) HEAD
20    READ (MCR,260) II1,II2,I1,I2,Z
      WRITE (MLP,270) II1,II2,I1,I2,Z
      KKY=1
      DO 40 I=1,3
      IF (II1-IA1(I)) 40,50,40
40    CONTINUE
50    GO TO (60,150,160,210), I
60    DO 70 I=1,6
      IF (II2-IA2(I)) 70,80,70
70    CONTINUE
80    GO TO (90,100,110,120,130,140,210), I
90    CALL STORE (I1,I2,Z,A,100,KKY)
      GO TO (20,210), KKY
100   CALL STORE (I1,I2,Z,B,100,KKY)
      GO TO (20,210), KKY
110   CALL STORE (I1,I2,Z,F,100,KKY)
      GO TO (20,210), KKY
120   CALL STORE (I1,I2,Z,L,99,KKY)
      GO TO (20,210), KKY
130   CALL STORE (I1,I2,Z,X,20,KKY)
      GO TO (20,210), KKY
140   CALL STORE (I1,I2,Z,Y,100,KKY)
      GO TO (20,210), KKY
150   L14=L14+1
      IC(L14)=II2
      ID(L14)=I1
      IE(L14)=I2
```

```
      GO TO 20                                                          IN3 600
  160 CONTINUE                                                          IN3 610
C                                                                       IN3 620
      L(26)=L(5)+L(22)                                                  IN3 630
      IF (L(26)-10) 170,170,190                                         IN3 640
  170 L(2)=4*L(1)                                                       IN3 650
      L(4)=2+L(2)+3*L(26)                                               IN3 660
      ICM(1)=L(5)                                                       IN3 670
      ICM(2)=L(22)                                                      IN3 680
      ICM(3)=L(26)                                                      IN3 690
      IF (L(4)-100) 180,180,200                                         IN3 700
  180 RETURN                                                            IN3 710
C                                                                       IN3 720
  190 WRITE (MLP,220)                                                   IN3 730
      CALL EXIT                                                         IN3 740
C                                                                       IN3 750
  200 WRITE (MLP,230)                                                   IN3 760
      CALL EXIT                                                         IN3 770
C                                                                       IN3 780
  210 WRITE (MLP,280) II1,II2,I1,I2                                     IN3 790
      CALL EXIT                                                         IN3 800
C                                                                       IN3 810
  220 FORMAT (//64H PROGRAM WILL NOT ACCEPT A TOTAL NO. OF MANIFOLDS MORIN3 820
     1E THAN TEN )                                                      IN3 830
  230 FORMAT (//52H NUMBER OF EQUATIONS TO INTEGRATE EXCEEDS DIMENSION )IN3 840
  240 FORMAT (20A4)                                                     IN3 850
  250 FORMAT (1H1,20X,22HINPUT DATA FOR SUB3 - ,/,20X,20A4)             IN3 860
  260 FORMAT (A1,1X,A1,2I3,1X,6F10.5)                                   IN3 870
  270 FORMAT (/,1X,A1,1X,A1,2I3,1X,6E12.4)                              IN3 880
  280 FORMAT (17H1BAD DATA - CARD ,A1,8H VECTOR ,A1,2I3)                IN3 890
      END                                                               IN3 900-
```

```
      SUBROUTINE PEAK (Y1,Y2,Y3,YMAX,YMIN,XX,XY,XZ,IPEAK,NSC)
      X1=XX
      X2=XY
      X3=XZ
      IF (Y2-YMIN) 100,100,10
 10   DY12=Y2-Y1
      DY23=Y3-Y2
      IF (X2-X1) 20,100,20
 20   IF (X2-X3) 30,100,30
 30   IF (DY12) 100,100,40
 40   IF (DY23) 50,100,100
 50   IF ((X3-X2)*(X2-X1)) 60,60,90
 60   IF (X2-X1) 70,70,80
 70   X2=X2+NSC*180.
 80   X3=X3+NSC*180.
 90   XY12=(Y1-Y2)/(X1-X2)
      XY23=(Y2-Y3)/(X2-X3)
      C=(XY12-XY23)/(X1-X3)
      B=XY12-C*(X1+X2)
      A=Y2-B*X2-C*X2*X2
      XMAX=-B/(2.*C)
      YMAX=A+B*XMAX+C*XMAX*XMAX
      IPEAK=1
      RETURN
 100  IPEAK=0
      RETURN
      END
```

```
      SUBROUTINE PRT3
      COMMON  ICM(20),G(90)
      COMMON  CMAIN(300),DSUB1(200),DSUB2(200)
      COMMON  X(20),XO(20),Y(100),YO(100),Q(100),F(100),A(100),B(100)
      COMMON  U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON  CD(20)
      COMMON  IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON  M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON  DSUB4(200),DSUB5(200)
      EQUIVALENCE (AE,A(6)),(AF,A(7)),(AI,A(8)),(C1,A(9)),(BRR,A(10))
      EQUIVALENCE (EC,A(11)),(AD,A(12)),(FIM,A(13)),(R,A(14)),(TW,A(15))
      EQUIVALENCE (VO,A(16)),(CID,A(17)),(W10,A(18)),(W11,A(19))
      EQUIVALENCE (W12,A(20)),(W13,A(21)),(W19,A(22)),(W20,A(23))
      EQUIVALENCE (W21,A(24)),(PD,A(25)),(BORE,A(26)),(STROK,A(27))
      EQUIVALENCE (ROD,A(28)),(PI,A(29)),(W29,A(30))
      EQUIVALENCE (PM,A(33)),(CP,A(35)),(DXC,A(41)),(DXS,A(42))
      EQUIVALENCE (DX,A(43)),(PINIM,A(44)),(NC,L(1)),(NC4,L(2))
      EQUIVALENCE (NSC,L(3)),(NE,L(4)),(FC,A(36))
      IF(L(25))111,1,111
  111 IF(L(25)-L(24))2,1,1
    1 L(25)=0
      WRITE(MLP,200)TITLE
    2 L(25)=L(25)+1
      DO 13 I=1,L14
      I1=ID(I)
      I2=IE(I)
      DO 3 J=1,7
      IF(IC(I)-IA2(J))3,5,3
    3 CONTINUE
      WRITE(MLP,201) IC(I)
      CALL EXIT
    4 I1=I4+1
      IF(I1-I2) 5,5,13
    5 I4=MIN0(I1+9,I2)
      GO TO (6,7,8,9,10,11,12), J
    6 WRITE(MLP,202)IC(I),I1,I4,(A(K),K=I1,I4)
      GO TO 4
    7 WRITE(MLP,202)IC(I),I1,I4,(B(K),K=I1,I4)
      GO TO 4
    8 WRITE(MLP,202)IC(I),I1,I4,(F(K),K=I1,I4)
      GO TO 4
    9 WRITE(MLP,203)  IC(I),I1,I4,(L(K),K=I1,I4)
      GO TO 4
   10 WRITE(MLP,202) IC(I),I1,I4,(X(K),K=I1,I4)
      GO TO 4
   11 WRITE(MLP,202) IC(I),I1,I4,(Y(K),K=I1,I4)
      GO TO 4
   12 WRITE(MLP,202)IC(I),I1,I4,(G(K),K=I1,I4)
      GO TO 4
   13 CONTINUE
      IF(L(23))14,14,15
   14 RETURN
   15 DO 20 I=1,NC
   20 WRITE(MLP,205)I,(U(I,J),J=1,15)
      WRITE(MLP,206)
      DO 25 I=1,NC
   25 WRITE(MLP,207)I,M(I),M1(I),M2(I),M3(I),M4(I),X(I)
      GO TO 14
  200 FORMAT(///,25X,20A4)
```

```
  201 FORMAT(34H1BAD PRINT INSTRUCTION - VARIABLE ,A1)                      PR3 0060
  202 FORMAT(/,1X,A1,1H(,I2,1H-,I2,1H),10E11.3)                             PR3 0061
  203 FORMAT(/,1X,A1,1H(,I2,1H-,I2,1H),1X,9(I5,6X),I5)                      PR3 0062
  204 FORMAT(1X,1HX,10X,F12.6)                                              PR3 0063
  205 FORMAT(/,1X,2HU(,I2,9H-1 TO 15),1X,8E12.4,/,7E12.4,//)                PR3 0064
  206 FORMAT(///,22X,8HCYLINDER,1X,4HM(I),5X,5HM1(I),5X,5HM2(I),5X,5HM3(PR3 0065
     1I),5X,5HM4(I),6X,4HX(I))                                              PR3 0065
  207 FORMAT(20X,I5,3X,I5, 4I10,F13.5)                                      PR3 0067
      END                                                                   PR3 0068
```

```
      SUBROUTINE PTDSL (LX)
      DIMENSION INL(20), IEX(20), VI(10)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)
      COMMON X(20),XO(20),Y(100),YO(100),Q(100),F(100),A(100),B(100)
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON DD(20)
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON DSUB4(200),DSUB5(200)
      EQUIVALENCE (AE,A(6)), (AF,A(7)), (AI,A(8)), (CI,A(9)), (BRR,A(10)
     1)
      EQUIVALENCE (EC,A(11)), (AD,A(12)), (FIM,A(13)), (R,A(14)), (TW,A(
     115))
      EQUIVALENCE (VO,A(16)), (CID,A(17)), (W10,A(18)), (W11,A(19))
      EQUIVALENCE (W12,A(20)), (W13,A(21)), (W19,A(22)), (W20,A(23))
      EQUIVALENCE (W21,A(24)), (PD,A(25)), (BORE,A(26)), (STROK,A(27))
      EQUIVALENCE (ROD,A(28)), (PI,A(29)), (W29,A(30))
      EQUIVALENCE (PM,A(33)), (CP,A(35)), (DXC,A(41)), (DXS,A(42))
      EQUIVALENCE (DX,A(43)), (PINIM,A(44)), (NC,L(1)), (NC4,L(2))
      EQUIVALENCE (NSC,L(3)), (NE,L(4)), (FC,A(36))
      EQUIVALENCE (L(31),INL(1)), (L(51),IEX(1)), (A(91),VI(1))
      EQUIVALENCE (L(5),L5)
   10 LX=0
      DO 20 I=1,20
   20 DD(I)=0.
      DO 160 I=1,NC
      II=NC4+3*INL(I)
      IX=NC4+3*L5+3*IEX(I)
      I4=4*I
      IF (IY(I)-1) 160,30,160
   30 K=M(I)
      K1=M1(I)
      K2=M2(I)
      K3=M3(I)
      K4=M4(I)
      GO TO (50,60), K1
   50 IF (Y(I4)-Y(II)-A(48)) 80,80,70
   60 IF (Y(I4)-Y(II)+A(48)) 70,80,80
   70 LX=LX+1
      DD(LX)=D/(1.-(Y(I4)-Y(II))/(YO(I4)-YO(II)))
      IY(I)=1
   80 GO TO (90,100), K2
   90 IF (Y(I4)-Y(IX)+A(48)) 110,150,150
  100 IF (Y(I4)-Y(IX)-A(48)) 150,150,110
  110 LX=LX+1
      DD(LX)=D/(1.-(Y(I4)-Y(IX))/(YO(I4)-YO(IX)))
      IY(I)=1
      GO TO (160,160,120,160,160), K
  120 GO TO (150,130,150,150), K4
  130 IF (Y(I4-1)+A(50)) 140,150,150
  140 LX=LX+1
      DD(LX)=D*YO(I4-1)/(YO(I4-1)-Y(I4-1))
      IY(I)=1
      GO TO 160
  150 IY(I)=1
  160 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PUN3                                                   PUN  10
      COMMON ICM(20),G(90)                                              PUN  20
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)                           PUN  30
      COMMON X(20),X0(20),Y(100),Y0(100),Q(100),F(100),A(100),B(100)   PUN  40
      COMMON U(20,15),U0(20,15),W14(3),F0(100),D,HEAD(20),TITLE(20)     PUN  50
      COMMON DD(20)                                                     PUN  60
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)PUN  70
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)                          PUN  80
      COMMON DSUB4(200),DSUB5(200)                                      PUN  90
      DATA MPP/2/                                                       PUN 100
      WRITE (MPP,60) TITLE                                              PUN 110
      WRITE (MPP,60) HEAD                                               PUN 120
      KLO=1                                                             PUN 130
      KHI=6                                                             PUN 140
C     PUNCHES Y ARRAY USED FOR INTEGRATION OF EQUATIONS                 PUN 150
      XCARD=L(4)/6                                                      PUN 160
      YCARD=FLOAT(L(4))/6.00                                            PUN 170
      IF (YCARD-XCARD) 20,20,10                                         PUN 180
10    NCARD=XCARD+1.0                                                   PUN 190
      GO TO 30                                                          PUN 200
20    NCARD=XCARD                                                       PUN 210
30    DO 40 I=1,NCARD                                                   PUN 220
      WRITE (MPP,50) IA1(1),IA2(6),KLO,KHI,(Y(K),K=KLO,KHI)             PUN 230
      KLO=KLO+6                                                         PUN 240
40    KHI=KHI+6                                                         PUN 250
C                                                                       PUN 260
      RETURN                                                            PUN 270
C                                                                       PUN 280
50    FORMAT (A1,1X,A1,2I3,1X,6E10.4)                                   PUN 290
60    FORMAT (20A4)                                                     PUN 300
      END                                                               PUN 310-
```

```
      SUBROUTINE RACK(A1,A2,A3,A4,WFM,ZEE,OMEGA,NSC,NC)                 RAC 0000
      DATA DPR/57.29578/,REVPR/.1591549/,UP/4.0/                        RAC 0001
C                                                                       RAC 0002
C     FUEL INJECTOR SCHEDULE FOR LSV-16 DIESEL                          RAC 0003
C      RETURNS ANGLES(DEGREES) FOR INJECTION TIMING, AND FUEL RATE(LB/RADRAC 0004
C      ) FOR ONE CYLINDER AS FUNCTIONS OF INJECTOR LIFT                 RAC 0005
C      WRITTEN BY BRUCE ALLEN 11/71                                     RAC 0006
C      REFERENCE   COOPER-BESSEMER GRAPHS                               RAC 0007
C      REFERENCE   GROVE CITY TESTS,JUNE 1971                           RAC 0008
C      FUEL SCHEDULE RAMPS,UP AND DOWN,DEDUCED FROM TEST DATA,JUNE 1971 RAC 0009
C                                                                       RAC 0010
      Z=ZEE*1000.                                                       RAC 0011
      SPEED=OMEGA*REVPR                                                 RAC 0012
      DOWN=.34225*Z-2.1099                                              RAC 0013
    4 A1=-5.4947008+Z*(-.54174284E-1+Z*(-.38790261E-2))+360.            RAC 0014
      A4=-5.6130359+Z*(.10240623E+1+Z*(-.37867378E-1+Z*(.92115294E-3+Z* RAC 0015
     1 (-.71644789E-5))))+360.                                          RAC 0016
      A2=A1+UP                                                          RAC 0017
      A3=A4-DOWN                                                        RAC 0018
      WFM=-.02027+4.55788*ZEE+123.07835*ZEE*ZEE                         RAC 0019
  100 WFM=DPR*WFM*0.5*FLOAT(NSC)/(FLOAT(NC)*SPEED*(A3-A2+0.5*(A2-A1+A4  RAC 0020
     1 -A3)))                                                           RAC 0021
      RETURN                                                            RAC 0022
      END                                                               RAC 0023
```

```
      SUBROUTINE RK3
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)
      COMMON X(20),XO(20),Y(100),YO(100),Q(100),F(100),A(100),B(100)
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON CD(20)
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON DSUB4(200),DSUB5(200)
      EQUIVALENCE (AE,A(6)), (AF,A(7)), (AI,A(8)), (C1,A(9)), (BRR,A(10)
     1)
      EQUIVALENCE (EC,A(11)), (AD,A(12)), (FIM,A(13)), (R,A(14)), (TW,A(
     115))
      EQUIVALENCE (VO,A(16)), (CID,A(17)), (W10,A(18)), (W11,A(19))
      EQUIVALENCE (W12,A(20)), (W13,A(21)), (W19,A(22)), (W20,A(23))
      EQUIVALENCE (W21,A(24)), (PD,A(25)), (BORE,A(26)), (STROK,A(27))
      EQUIVALENCE (ROD,A(28)), (PI,A(29)), (W29,A(30))
      EQUIVALENCE (PM,A(33)), (CP,A(35)), (DXC,A(41)), (DXS,A(42))
      EQUIVALENCE (DX,A(43)), (PINIM,A(44)), (NC,L(1)), (NC4,L(2))
      EQUIVALENCE (NSC,L(3)), (NE,L(4)), (FC,A(36))
      W1=.5*D
      H=D*W11
      N=NE
      DO 10 I=1,N
   10 Q(I)=0.0
      CALL YP3
      DO 20 I=1,N
      S=F(I)*H
      T=.5*(S-2.*Q(I))
      Y(I)=Y(I)+T
   20 Q(I)=Q(I)+3.*T-.5*S
      DO 40 I=1,NC
      X(I)=X(I)+W1
      IF (X(I)-W29+.001) 40,30,30
   30 X(I)=X(I)-W29
   40 CONTINUE
      CALL YP3
      DO 50 I=1,N
      S=F(I)*H
      T=.29289322*(S-Q(I))
      Y(I)=Y(I)+T
   50 Q(I)=Q(I)+3.*T-.29289322*S
      CALL YP3
      DO 60 I=1,N
      S=F(I)*H
      T=1.7071067*(S-Q(I))
      Y(I)=Y(I)+T
   60 Q(I)=Q(I)+3.*T-1.707106*S
      DO 80 I=1,NC
      X(I)=X(I)+W1
      IF (X(I)-W29+.001) 80,70,70
   70 X(I)=X(I)-W29
   80 CONTINUE
      CALL YP3
      DO 90 I=1,N
      S=F(I)*H
      T=(S-2.*Q(I))/6.
      Y(I)=Y(I)+T
   90 Q(I)=Q(I)+3.*T-.5*S
      RETURN
      END
```

```
      SUBROUTINE SUB3
C     SUBROUTINE SUB3 FOR COOPER-BESSEMER LSV-16
      DIMENSION MX(20),MX1(20),MX2(20),MX3(20),MX4(20)
      DIMENSION       X2(20),PX(100),IM(100)
      DIMENSION F1(2),F2(2),F3(2),F4(2),F5(2)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)
      COMMON X(20),XO(20),Y(100),YO(100),Q(100),F(100),A(100),B(100)
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)
      COMMON CD(20)
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)
      COMMON DSUB4(200),DSUB5(200)
      EQUIVALENCE (AE,A(6)),(AF,A(7)),(AI,A(8)),(C1,A(9)),(BRR,A(10))
      EQUIVALENCE (EC,A(11)),(AD,A(12)),(FIM,A(13)),(R,A(14)),(TW,A(15))
      EQUIVALENCE (VO,A(16)),(CID,A(17)),(W10,A(18)),(W11,A(19))
      EQUIVALENCE (W12,A(20)),(W13,A(21)),(W19,A(22)),(W20,A(23))
      EQUIVALENCE (W21,A(24)),(PD,A(25)),(BORE,A(26)),(STRCK,A(27))
      EQUIVALENCE (ROD,A(28)),(PI,A(29)),(W29,A(30))
      EQUIVALENCE             (CP,A(35)),(DXC,A(41)),(DXS,A(42))
      EQUIVALENCE (DX,A(43)),(PINIM,A(44)),(NC,L(1)),(NC4,L(2))
      EQUIVALENCE (NSC,L(3)),(NE,L(4)),(FC,A(36))
      EQUIVALENCE (L(20),JP),(L(19),JT)
      EQUIVALENCE (L(5),L5),(L(22),L22),(L(26),L522)
      Y(2)=G(2)
      L7OLD=L(7)
C
C     COMPUTE EXHAUST MANIFOLD HEAT COEFFICIENTS
      DO 1001 J=1,L22
      J1=59+3*L5+J*3
 1001 B(J+41)=A(52)*(G(J1)/A(64))**0.8
      DO 1002 J=1,L522
      J1=62+(J-1)*3
 1002 B(J+50)=G(J1)/Y(2)
  100 IF(G(22)-(B(1)+0.5*DX))6,5,5
    6 DO 515 J=2,25
  515 B(J)=0.0
      DO 7 I=1,NC
C     SPECIAL LOGIC FOR LSV-16 * KINEMATICS AS FUNCTION OF MASTER(RIGHT)
      I4=4*I
      IF(I-NC/2)60,60,61
   60 IR=I
      IL=IR+NC/2
      CALL TABLE(X(IR),F1,F2,F3,F4,F5,VO,AD,PD)
      U(IR,11)=F1(1)
      U(IL,11)=F1(2)
      U(IR,12)=F2(1)
      U(IL,12)=F2(2)
      U(IR,13)=F3(1)
      U(IL,13)=F3(2)
      U(IR,6)=F4(1)
      U(IL,6)=F4(2)
      U(IR,7)=F5(1)
      U(IL,7)=F5(2)
C  MASTER(RIGHT) PISTON AND SLAVE(LEFT) HAVE DIFFERENT MASSES
      PM=A(33)
      GO TO 63
   61 PM=A(32)
   63 B(24)=B(24)+(Y(I4)-A(63))*U(I,12)
```

```
      U12=U(I,12)*U(I,12)
      B(2)=B(2)+U12
      B(5)=B(5)+U(I,12)*U(I,13)*PM
      B(6)=B(6)+U12*PM
      B(7) = B(7) + Y(I4+1)
      B(11)=B(11)+U(I,3)
    7 CONTINUE
      B(7) = B(7)/NC
      B(24)=B(24)*AD
      B(2)=B(2)*B(37)
      B(3)=B(6)*G(3)+G(2)*G(2)*B(5)
      G(24)=B(24)
      G(25)=B(2)
      G(26)=B(5)
      G(27)=B(6)+AI
      B(2)=B(2)*G(2)
      B(4)=B(24)-B(2)-B(3)
C     HEAT BALANCE FOR ENTERPRISE DIESEL
      B(11)=B(11)/A(34)
      B(12)=B(2)*G(2)/A(34)
      B(14)=A(35)*G(55)*(G(57)-G(12))/A(34)
      B(15)=A(35)*G(58)*(G(56)-G(60))/A(34)
      B(18)=A(65)
      B(16)=B(4)*G(2)/A(34)-B(18)
      B(17)=0.
C     HEAT TO EXHAUST MANIFOLDS
      DO 1003 J=1,L22
      J1=60+3*L5+3*J
      J2=J+41
 1003 B(17)=B(17)+A(53)*B(J2)*(G(J1)-A(54))/A(34)
      G(31)=B(11)
      G(32)=B(12)
      G(34)=B(14)
      G(35)=B(15)
      G(36)=B(16)
      G(37)=B(17)
      G(52)=B(18)
      G(53)=B(18)*A(34)/G(2)
      L(18)=L(18)+1
      IDX=IFIX(G(30))
      IF(L(18)-((NSC*180)/(NC*IDX)+1))43,39,39
   39 L(18)=0
      IF(JP)40,40,41
   41 PMAX=0.
      DO 42 IJ=1,JP
   42 PMAX=AMAX1(PMAX,PX(IJ))
 9999 FORMAT(10E13.6)
      G(15)=PMAX
      JP=0
   40 IF(JT)43,43,44
   44 TMAX=0.
      DO 45 IJ=1,JT
   45 TMAX=AMAX1(TMAX,TM(IJ))
      G(16)=TMAX-459.7
      JT=0
   43 G(6)=B(4)
      G(21)=B(4)/12.
C     SET MANIFOLD PRESSURES
      DO 1004 J=1,L5
```

```
         J1=58+3*J
         J2=NC4+3*J
 1004    G(J1)=Y(J2)
         DO 1005 J=1,L22
         J1=58+3*L5+3*J
         J2=NC4+3*L5+3*J
 1005    G(J1)=Y(J2)
         CALL RACK(B(26),B(31),B(32),B(33),FIM,G(9),G(2),NSC,NC)
         B(34)=B(32)-B(31)
         IF(B(34))12,13,13
   12    B(34)=B(34)+NSC*180.
   13    B(40)=B(31)-B(26)
         IF(B(40))730,735,735
  730    B(40)=B(40)+NSC*180.
  735    B(41)=B(33)-B(32)
         IF(B(41))740,745,745
  740    B(41)=B(41)+NSC*180.
C        INSTANT TOTAL FUEL CONSUMPTION(LB/HR)
  745    B(25)=(B(34)+(B(40)+B(41))/2.0)*FIM*G(2)*20.*FLCAT(NC)/FLCAT(NSC)
C        CONSTANT ABOVE,20.0,IS 2REV/INJECT*3600SEC/HR*1REV/360DEGREES
         G(19)=B(25)
         B(13)=B(25)*EC/(3600.*A(34))
         G(33)=B(13)
         IF(L(17))17,14,17
   14    B(36)=FC
         B(38)=CI
         L(17)=99
C   L(16) NOT EQUAL ZERO COMPUTES HEAT TRANSFER AND FRICTION COEFFICIENTS
   17    IF(L(16))10,16,10
   10    IF(B(1)+A(46)-180.*NSC)16,111,111
  111    IF(ABS(X(1))-A(46))15,15,16
   15    B(36)=B(36)*A(37)/G(39)
         B(38)=B(38)*A(38)/G(38)
         B(37)=B(36)
   16    B(39)=B(38)*(B(7)*Y(2)/(A(39)*A(40)))**0.8
         G(28)=Y(4)
         G(29)=U(1,1)
         RETURN
    5    D=DX
         DP=DX
         CALL RACK(A(3),W14(1),W14(2),W14(3),FIM,G(9),G(2),NSC,NC)
         B(27)=G(9)
         CALL IMODE
   50    DO 51 I=1,NC
         IY(I)=1
         B(I+60)=U0(I,1)
         U0(I,1)=U(I,1)
         I4=4*I
         B(I+80)=Y0(I4)
         X2(I)=X0(I)
   51    X0(I)=X(I)
         DO 102 I=1,NE
         F0(I)=F(I)
  102    Y0(I)=Y(I)
         CALL ANGLE(LX)
         IF (LX)109,109,104
  104    DO 119 K=1,LX
  119    D=AMIN1(D,DD(K))
         L(7)=L(7)+1
```

```
      IF(LX-20)109,109,802                                              SU3 0178
  802 KON=7                                                             SU3 0179
      GO TO 800                                                         SU3 0180
C     CHECK L(7),ANGLE COUNTER                                          SU3 0181
  109 IF(L(7)-L7OLD-500)230,230,200                                     SU3 0182
  200 WRITE(MLP,997)(A(II),II=1,5)                                      SU3 0183
  997 FORMAT(//2X,14H ANGLE COUNTER /,1X,5E15.8)                        SU3 0184
      WRITE(MLP,998) (DD(II),II=1,LX)                                   SU3 0185
      WRITE(MLP,999) W14,B(30)                                          SU3 0186
      WRITE(MLP,999)X                                                   SU3 0187
      WRITE(MLP,999)Y                                                   SU3 0188
      IF(L(7)-L7OLD-505)230,230,225                                     SU3 0189
  225 KON=11                                                            SU3 0190
      GO TO 800                                                         SU3 0191
  230 IF(C)130,130,300                                                  SU3 0192
  130 KON=4                                                             SU3 0193
  800 WRITE(MLP,25)KON                                                  SU3 0194
   25 FORMAT ( 8H1TROUBLE I5)                                           SU3 0195
  999 FORMAT(10F13.8)                                                   SU3 0196
      WRITE(MLP,899)M,M1,M2,M3,M4                                       SU3 0197
      WRITE(MLP,899)MX,MX1,MX2,MX3,MX4                                  SU3 0198
      WRITE(MLP,999)D,(DD(II),II=1,LX),DP                               SU3 0199
      WRITE(MLP,999)(A(II),II=1,5),W14,B(30)                            SU3 0200
      WRITE(MLP,999)X,X0,X2,Y,Y0,F                                      SU3 0201
  899 FORMAT(20I3)                                                      SU3 0202
      CALL PRT3                                                         SU3 0203
      CALL EXIT                                                         SU3 0204
  300 CALL RK3                                                          SU3 0205
      CALL PTCSL(LX)                                                    SU3 0206
      IF(LX)400,500,400                                                 SU3 0207
  400 DO 461 I=1,LX                                                     SU3 0208
 1919 FORMAT(I5,E20.5)                                                  SU3 0209
  461 D=AMIN1(D,DD(I))                                                  SU3 0210
      IF(D)805,805,469                                                  SU3 0211
  805 KON=10                                                            SU3 0212
      GO TO 800                                                         SU3 0213
  469 IF(LX-20)468,468,801                                              SU3 0214
  801 KON=6                                                             SU3 0215
      GO TO 800                                                         SU3 0216
  468 L(8)=L(8)+1                                                       SU3 0217
      L(6)=L(6)+1                                                       SU3 0218
 1999 FORMAT(16I5)                                                      SU3 0219
 1467 CONTINUE                                                          SU3 0220
      IF(L(6)-100)466,466,467                                           SU3 0221
  467 KON=5                                                             SU3 0222
      GO TO 800                                                         SU3 0223
  466 DO 464 I=1,NC                                                     SU3 0224
  464 X(I)=X0(I)                                                        SU3 0225
      DO 465 I=1,NE                                                     SU3 0226
  465 Y(I)=Y0(I)                                                        SU3 0227
      GO TO 300                                                         SU3 0228
  500 B(1)=B(1)+D                                                       SU3 0229
      DP=DP-D                                                           SU3 0230
      D=DP                                                              SU3 0231
      L(6)=0                                                            SU3 0232
      L(9)=L(9)+1                                                       SU3 0233
      DO 530 I=1,NC                                                     SU3 0234
      MX(I)=M(I)                                                        SU3 0235
      MX1(I)=M1(I)                                                      SU3 0236
```

```
      MX2(I)=M2(I)                                                      SU3 0237
      MX3(I)=M3(I)                                                      SU3 0238
  530 MX4(I)=M4(I)                                                      SU3 0239
      CALL CHANG(LX)                                                    SU3 0240
      DO 520 I=1,NC                                                     SU3 0241
      I4=4*I                                                            SU3 0242
      CALL PEAK(B(I+80),YO(I4),Y(I4),PMM,500.,X2(I),XO(I),X(I),IPEAK,NSCSU3 0243
     1)                                                                 SU3 0244
      IF(IPEAK)511,511,512                                              SU3 0245
  512 JP=JP+1                                                           SU3 0246
      PX(JP)=PMM                                                        SU3 0247
      IF(JP-100)511,511,803                                             SU3 0248
  803 KCN=9                                                             SU3 0249
      WRITE(MLP,998)PX                                                  SU3 0250
  998 FORMAT(10E13.6)                                                   SU3 0251
      GO TO 800                                                         SU3 0252
  511 CALL PEAK(B(I+60),UO(I,1),U(I,1),TMM,2500.,X2(I),XO(I),X(I),IPEAK,SU3 0253
     1NSC)                                                              SU3 0254
      IF(IPEAK)520,520,514                                              SU3 0255
  514 JT=JT+1                                                           SU3 0256
      TM(JT)=TMM                                                        SU3 0257
      IF(JT-100)520,520,804                                             SU3 0258
  804 KCN=8                                                             SU3 0259
      WRITE(MLP,998)TM                                                  SU3 0260
      GO TO 800                                                         SU3 0261
  520 CONTINUE                                                          SU3 0262
      IF(DP-.001)100,100,50                                             SU3 0263
      END
```

```
      SUBROUTINE TABLE (CO,F1,F2,F3,F4,F5,VO,AD,PD)
      DIMENSION F1(2), F2(2), F3(2), F4(2), F5(2)
C    SUBSCRIPTS  ARE 1 = MASTER  , AND  2 = SLAVE
      DATA C1,C2,C4,C5,C6,C8,C9/11.,5.,11.75,55.,43.211,0.628319,0.04/
      DATA W5,W6,W7,W8,W9/-.11754,.99307,.58779,.80902,.235/
C
C     ENGINE CRANKING KINEMATICS FOR LSV-16
C     WRITTEN BY BRUCE ALLEN 11/71
C     REFERENCE   COOPER-BESSEMER EQUATION (SECTION 9.8.4 OF PROGRAM
C                 DOCUMENTATION FOR COOPER-BESSEMER LSV-16,DIESEL)
C
      C=CO*.01745327
      W1=SIN(C)
      W2=COS(C)
      W11=W1*W1
      C55=C5*C5
      C11=C1*C1
      W22=W2*W2
      W3=SIN(C+C8)
      W4=COS(C+C8)
C    MASTER PISTON KINEMATICS
      F1(1)=C1+C5-C1*W2-SQRT(C55-C11*W11)
      F2(1)=C1*W1+0.5*C11*SIN(2.0*C)/SQRT(C55-C11*W11)
      F3(1)=C1*W2+C11*COS(2.0*C)/SQRT(C55-C11*W11)+C11*C11*W11*W22/(C55-
     1C11*W11)**1.50
C    ARTICULATED(SLAVE) PISTON KINEMATICS
      X1=C1*W4
      DX1=-C1*W3
      DDX1=-C1*W4
      X2=C4*(W6*SQRT(1.0-C9*W11)+W5*W1/C2)
      DX2=-W9*W6*SIN(2.*C)/SQRT(1.-C9*W11)+C4*W5*W2/C2
      DDX2=-W9*W6*(0.5*C9*(1.0-C9*W11)**(-1.5)*(SIN(2.0*C))**2+2.*COS(2.
     1*C)/SQRT(1.-C9*W11))-(C4*W5*W1/C2)
      Z=C1*W8*W1+C1*W7*W2+C4*W5*SQRT(1.0-C9*W11)-C4*W6*W1/C2
C
      W10=C6*C6-Z*Z
C
      E=Z/SQRT(W10)
      X3=C6/SQRT(1.0+E*E)
      DZ=C1*W8*W2-C1*W7*W1-W9*W5*SIN(2.*C)/SQRT(1.-C9*W11)-C4*W6*W2/C2
      DDZ=-C1*W1-C1*W7*W2-W9*W5*(0.5*C9*(1.-C9*W11)**(-1.5)*(SIN(2.*C))*
     1*2+2.*COS(2.*C)*SQRT(1.-C9*W11))
C
      U1=Z*Z*DZ
      DU1=Z*Z*DDZ+2.*Z*DZ*DZ
      DE=U1*W10**(-1.5)+DZ/SQRT(W10)
      DDE=DU1*W10**(-1.5)+U1*3.*Z*W10**(-2.5)*DZ+DDZ/SQRT(W10)+DZ*DZ*Z*W
     110**(-1.5)
      DX3=-C6*E*(1.+E*E)**(-1.5)*DE
      U3=E*DE
      DU3=E*DDE+DE*DE
      DDX3=-C6*(-3.*(1.+E*E)**(-2.5)*U3*U3+DU3*(1.+E*E)**(-1.5))
C
C  DISPLACEMENT FROM T.D.C. , ARTICULATED PISTON
      F1(2)=C1+C4+C6-X1-X2-X3
      F2(2)=-DX1-DX2-DX3
      F3(2)=-DDX1-DDX2-DDX3
C COMPUTES VOLUMES AND HEAT TRANSFER AREAS
      DO 10 J=1,2
      F4(J)=VO+F1(J)*AD
10    F5(J)=2.*AD+F1(J)*PD+VO*PD/AD
      RETURN
      END
```

```
      SUBROUTINE YP3
      DIMENSION INL(20), IEX(20), VI(10), TIM(10), FLIM(10)             YP3  10
      DIMENSION F1(2), F2(2), F3(2), F4(2), F5(2)                       YP3  20
      COMMON ICM(20),G(90)                                              YP3  30
      COMMON DMAIN(300),DSUB1(200),DSUB2(200)                           YP3  40
      COMMON X(20),XO(20),Y(100),YO(100),Q(100),F(100),A(100),B(100)    YP3  50
      COMMON U(20,15),UO(20,15),W14(3),FO(100),D,HEAD(20),TITLE(20)     YP3  60
      COMMON CD(20)                                                     YP3  70
      COMMON IA1(3),IA2(7),MCR,MLP,L14,IC(19),ID(19),IE(19),L(99),IY(20)YP3  80
      COMMON M(20),M1(20),M2(20),M3(20),M4(20)                          YP3  90
      COMMON DSUB4(200),DSUB5(200)                                      YP3 100
      EQUIVALENCE (AE,A(6)), (AF,A(7)), (AI,A(8)), (C1,A(9)), (BRR,A(10)YP3 110
     11)                                                                YP3 120
      EQUIVALENCE (EC,A(11)), (AD,A(12)), (FIM,A(13)), (R,A(14)), (TW,A(YP3 130
     115))                                                              YP3 140
      EQUIVALENCE (VO,A(16)), (CID,A(17)), (W10,A(18)), (W11,A(19))     YP3 150
      EQUIVALENCE (W12,A(20)), (W13,A(21)), (W19,A(22)), (W20,A(23))    YP3 160
      EQUIVALENCE (W21,A(24)), (PD,A(25)), (BORE,A(26)), (STROK,A(27))  YP3 170
      EQUIVALENCE (ROD,A(28)), (PI,A(29)), (W29,A(30))                  YP3 180
      EQUIVALENCE (PM,A(33)), (CP,A(35)), (DXC,A(41)), (DXS,A(42))      YP3 190
      EQUIVALENCE (DX,A(43)), (PINIM,A(44)), (NC,L(1)), (NC4,L(2))      YP3 200
      EQUIVALENCE (NSC,L(3)), (NE,L(4)), (FC,A(36))                     YP3 210
      EQUIVALENCE (L(31),INL(1)), (L(51),IEX(1)), (A(91),VI(1))         YP3 220
      EQUIVALENCE (B(51),FLIM(1)), (L(5),L5), (L(22),L22), (L(26),L522) YP3 230
C     MAKE ANGLES LESS THAN NSC*180.                                    YP3 240
C     CALCULATE MANIFOLD TEMPERATURES                                   YP3 250
      Y(2)=G(2)                                                         YP3 260
C     COMPUTE MANIFOLD TEMPERATURES                                     YP3 270
      DO 10 J=1,L522                                                    YP3 280
      J1=60+J*3                                                         YP3 290
      J2=NC4+3*J                                                        YP3 300
      TIM(J)=Y(J2)*VI(J)/(R*Y(J2+1))                                    YP3 310
   10 G(J1)=TIM(J)                                                      YP3 320
C                                                                       YP3 330
      DO 240 I=1,NC                                                     YP3 340
      IMI=INL(I)                                                        YP3 350
      IME=IEX(I)+L5                                                     YP3 360
      II=NC4+3*INL(I)                                                   YP3 370
      IX=NC4+3*L5+3*IEX(I)                                              YP3 380
      U(I,2)=TIM(IMI)                                                   YP3 390
      U(I,15)=TIM(IME)                                                  YP3 400
      I4=4*I                                                            YP3 410
      IF (Y(I4+1)*Y(II+1)*Y(IX+1)) 30,40,40                             YP3 420
   30 KON=3                                                             YP3 430
      WRITE (MLP,430) KON,Y(I4+1),Y(II+1),Y(IX+1)                       YP3 440
      WRITE (MLP,440) M,M1,M2,M3,M4                                     YP3 450
      WRITE (MLP,450) X,F,Y                                             YP3 460
      CALL EXIT                                                         YP3 470
C     LSV-16 * KINEMATICS AS FUNCTION OF MASTER(RIGHT) BANK             YP3 480
   40 IF (I-NC/2) 50,50,60                                              YP3 490
   50 IR=I                                                              YP3 500
      IL=IR+NC/2                                                        YP3 510
      CALL TABLE (X(IR),F1,F2,F3,F4,F5,VO,AD,PD)                        YP3 520
      U(IR,11)=F1(1)                                                    YP3 530
      U(IL,11)=F1(2)                                                    YP3 540
      U(IR,12)=F2(1)                                                    YP3 550
      U(IL,12)=F2(2)                                                    YP3 560
      U(IR,13)=F3(1)                                                    YP3 570
      U(IL,13)=F3(2)                                                    YP3 580
                                                                        YP3 590
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      U(IR,6)=F4(1)                                                     YP3 600
      U(IL,6)=F4(2)                                                     YP3 610
      U(IR,7)=F5(1)                                                     YP3 620
      U(IL,7)=F5(2)                                                     YP3 630
60    U(I,1)=Y(I4)*U(I,6)/(R*Y(I4+1))                                   YP3 640
      U(I,10)=0.                                                        YP3 650
      U(I,14)=0.                                                        YP3 660
      MODE=M(I)                                                         YP3 670
      U(I,3)=B(39)*U(I,7)*(U(I,1)-TW)                                   YP3 680
      F(I4)=(W12-1.)*(-U(I,3))/Y(2)-W12*Y(I4)*U(I,12)*AD                YP3 690
      F(I4-1)=0.                                                        YP3 700
      F(I4+1)=0.                                                        YP3 710
      F(I4+2)=0.                                                        YP3 720
      U(I,4)=AIV(X(I),A(59))                                            YP3 730
      IF (U(I,4)-0.0001) 80,80,90                                       YP3 740
80    U(I,8)=0.0                                                        YP3 750
      GO TO 130                                                         YP3 760
90    IF (M1(I)-1) 100,100,110                                          YP3 770
100   U(I,8)=DM(Y(II),Y(I4),U(I,4),U(I,2),W12)/Y(2)                     YP3 780
      F(I4)=F(I4)+W13*U(I,2)*U(I,8)                                     YP3 790
      F(I4+2)=F(I4+2)+(Y(II+2)-Y(I4+2))*U(I,8)/Y(I4+1)                  YP3 800
      GO TO 120                                                         YP3 810
110   U(I,8)=-DM(Y(I4),Y(II),U(I,4),U(I,1),W12)*A(61)/Y(2)              YP3 820
      F(I4)=F(I4)+W13*U(I,1)*U(I,8)                                     YP3 830
120   F(I4+1)=F(I4+1)+U(I,8)                                            YP3 840
130   GO TO (170,170,140,170,170), MODE                                 YP3 850
140   IF (M3(I)-4) 150,160,160                                          YP3 860
150   CALL FI (U(I,14),M3(I),FIM,A(3),W14(1),W14(2),W14(3),X(I))        YP3 870
      F(I4-1)=U(I,14)                                                   YP3 880
160   CALL OMFB (U(I,10),M4(I),Y(I4-1),Y(I4+2),Y(I4+1),BRR)             YP3 890
      U(I,10)=U(I,10)/Y(2)                                              YP3 900
      F(I4-1)=F(I4-1)-U(I,10)                                           YP3 910
      F(I4+2)=(1.+AF-Y(I4+2))*U(I,10)/Y(I4+1)+F(I4+2)                   YP3 920
      F(I4+1)=U(I,10)+F(I4+1)                                           YP3 930
C     SECOND ORDER CORRECTION TO LHV                                    YP3 940
      F(I4)=F(I4)+(W12-1.)*U(I,10)*(EC+(U(I,1)-A(55))*(A(56)-A(57)*(U(I,YP3 950
     11)-A(55))))                                                       YP3 960
170   U(I,5)=AEV(X(I),A(58))                                            YP3 970
      IF (U(I,5)-0.0001) 180,180,190                                    YP3 980
180   U(I,9)=0.0                                                        YP3 990
      GO TO 230                                                         YP31000
190   IF (M2(I)-1) 200,200,210                                          YP31010
200   U(I,9)=DM(Y(I4),Y(IX),U(I,5),U(I,1),A(62))/Y(2)                   YP31020
      F(I4)=F(I4)-W13*U(I,1)*U(I,9)                                     YP31030
      GO TO 220                                                         YP31040
210   U(I,9)=-DM(Y(IX),Y(I4),U(I,5),U(I,15),A(62))*A(60)/Y(2)           YP31050
      F(I4)=F(I4)-W13*U(I,15)*U(I,9)                                    YP31060
      F(I4+2)=F(I4+2)-U(I,9)*(Y(IX+2)-Y(I4+2))/Y(I4+1)                  YP31070
220   F(I4+1)=F(I4+1)-U(I,9)                                            YP31080
230   F(I4)=F(I4)/U(I,6)                                                YP31090
240   CONTINUE                                                          YP31100
      DO 280 I=1,L5                                                     YP31110
      II=NC4+3*I                                                        YP31120
      IF (FLIM(I)) 260,260,250                                          YP31130
250   WB=G(60)                                                          YP31140
      F(II+2)=-FLIM(I)*Y(II+2)                                          YP31150
      GO TO 270                                                         YP31160
260   WB=TIM(I)                                                         YP31170
      F(II+2)=0.                                                        YP31180
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 270    F(II)=W8*FLIM(I)                                                        YP31190
 280    F(II+1)=FLIM(I)                                                         YP31200
        DO 320 I=1,L22                                                          YP31210
        J1=I+L5                                                                 YP31220
        IX=NC4+L5*3+3*I                                                         YP31230
        IF (FLIM(J1)) 300,300,290                                               YP31240
 290    W9=TIM(J1)                                                              YP31250
        F(IX+2)=0.                                                              YP31260
        GO TO 310                                                               YP31270
 300    W9=G(57)                                                                YP31280
        F(IX+2)=FLIM(J1)*Y(IX+2)                                                YP31290
 310    F(IX)=-W9*FLIM(J1)                                                      YP31300
 320    F(IX+1)=-FLIM(J1)                                                       YP31310
        DO 400 I=1,NC                                                           YP31320
        I4=4*I                                                                  YP31330
        K=M(I)                                                                  YP31340
        K1=M1(I)                                                                YP31350
        IMI=INL(I)                                                              YP31360
        IME=IEX(I)+L5                                                           YP31370
        II=NC4+3*IMI                                                            YP31380
        IX=NC4+3*L5+3*IEX(I)                                                    YP31390
        K2=M2(I)                                                                YP31400
        K3=M3(I)                                                                YP31410
        K4=M4(I)                                                                YP31420
        F(II+1)=F(II+1)-U(I,8)                                                  YP31430
        F(IX+1)=U(I,9)+F(IX+1)                                                  YP31440
        GO TO (340,350), K1                                                     YP31450
 340    F(II)=F(II)-U(I,2)*U(I,8)                                               YP31460
        GO TO 360                                                               YP31470
 350    F(II)=F(II)-U(I,1)*U(I,8)                                               YP31480
        F(II+2)=F(II+2)+(Y(II+2)-Y(I4+2))*U(I,8)                                YP31490
 360    GO TO (370,380), K2                                                     YP31500
 370    F(IX)=F(IX)+U(I,1)*U(I,9)                                               YP31510
        IF (FLIM(IME)) 400,400,390                                              YP31520
 380    F(IX)=F(IX)+U(I,15)*U(I,9)                                              YP31530
        IF (FLIM(IME)) 390,400,400                                              YP31540
 390    F(IX+2)=F(IX+2)+(Y(I4+2)-Y(IX+2))*U(I,9)                                YP31550
 400    CONTINUE                                                                YP31560
        DO 410 J=1,L5                                                           YP31570
        II=NC4+J*3                                                              YP31580
        F(II)=F(II)*W13/VI(J)                                                   YP31590
 410    F(II+2)=F(II+2)/Y(II+1)                                                 YP31600
        DO 420 J=1,L22                                                          YP31610
        J1=J+L5                                                                 YP31620
        IX=NC4+L5*3+J*3                                                         YP31630
        F(IX)=F(IX)*W13/VI(J1)                                                  YP31640
        F(IX+2)=F(IX+2)/Y(IX+1)                                                 YP31650
C       MANIFOLD HEAT LOSS CORRECTION TO EXHAUST MANIFOLD PRESSURE              YP31660
 420    F(IX)=F(IX)+EXMAN(B(41+J),A(53),A(54),W12,VI(J1),TIM(J1),Y(2))          YP31670
        RETURN                                                                  YP31680
C                                                                               YP31690
 430    FORMAT (8H1TROUBLEI5,2X,3E15.5)                                         YP31700
 440    FORMAT (20I3)                                                           YP31710
 450    FORMAT (10F13.8)                                                        YP31720
        END                                                                     YP31730-
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 SUBROUTINE CMAP (FLOC,TORC,TC,YO,XO,ETA,SPEED,TAI,PAI,PC,MLP,FACT)
 DIMENSION X(18,20), XA(18,3), XB(18,3), XC(18,3), XD(18,3), XE(18,
13), XF(18,3), XG(18,2)
 DIMENSION Y(18,20), YA(18,3), YB(18,3), YC(18,3), YD(18,3), YE(18,
13), YF(18,3), YG(18,2)
 DIMENSION NPC(18), X1(20), Y1(20), Z(18)
 EQUIVALENCE (XA(1,1),X(1,1)), (XB(1,1),X(1,4)), (XC(1,1),X(1,7)),
1(XD(1,1),X(1,10)), (XE(1,1),X(1,13)), (XF(1,1),X(1,16)), (XG(1,1),
2X(1,19))
 EQUIVALENCE (YA(1,1),Y(1,1)), (YB(1,1),Y(1,4)), (YC(1,1),Y(1,7)),
1(YD(1,1),Y(1,10)), (YE(1,1),Y(1,13)), (YF(1,1),Y(1,16)), (YG(1,1),
2Y(1,19))
 DATA NPC/18*20/
 DATA NC/18/
 DATA XA/1804.,2100.,2585.,3050.,3761.,6050.,7534.,8286.,8950.,9350
1.,9850.,10380.,11100.,12200.,12630.,13000.,13400.,13726.,2289.,239
20.,3146.,3445.,5000.,6345.,8087.,8500.,9155.,9615.,10065.,10750.,1
31390.,12415.,12750.,13125.,13500.,13872.,2774.,2660.,3707.,3840.,6
4000.,6640.,8640.,9000.,9360.,9880.,10280.,11000.,11680.,12630.,129
500.,13350.,13620.,14018./
 DATA XB/3259.,2970.,4268.,4235.,7000.,6935.,9193.,9500.,9565.,1014
15.,10495.,11250.,11970.,12845.,13200.,13575.,13860.,14164.,3744.,3
2260.,4829.,4630.,7500.,7230.,9341.,10000.,9770.,10410.,10710.,1150
30.,12260.,13060.,13350.,13800.,13980.,14310.,4229.,3550.,5390.,592
45.,8000.,7525.,9746.,10500.,9975.,10675.,10925.,11750.,12550.,1327
55.,13500.,14000.,14100.,14456./
 DATA XC/4714.,3840.,5951.,5420.,8500.,7820.,10299.,11000.,10180.,1
10940.,11140.,12000.,12840.,13490.,13800.,14025.,14340.,14602.,5199
2.,4130.,6512.,5815.,9000.,8000.,10852.,11500.,10385.,11205.,11355.
3,12250.,13130.,13705.,13950.,14250.,14460.,14746.,5684.,4420.,7073
4.,6210.,9500.,8115.,11173.,12000.,10590.,11470.,11570.,12500.,1342
50.,13920.,14100.,14475.,14580.,14894./
 DATA XD/6169.,4710.,7634.,6605.,10000.,8410.,11405.,12500.,10795.,
111735.,11785.,12750.,13710.,14135.,14400.,14700.,14820.,15040.,665
24.,5000.,8195.,7000.,10500.,8705.,11958.,13000.,11000.,12000.,1247
33.,13000.,14100.,14350.,14550.,14925.,14940.,15186.,7139.,6670.,87
456.,9000.,11000.,9430.,12511.,13500.,12000.,12455.,12964.,13250.,1
54230.,14565.,14700.,15000.,15060.,15332./
 DATA XE/7624.,7000.,9317.,9205.,11500.,11000.,13064.,14000.,12300.
1,12940.,13000.,13500.,14460.,14780.,15000.,15150.,15300.,15478.,81
209.,7560.,9878.,9940.,12000.,11575.,13243.,14250.,12875.,13000.,13
3455.,13750.,14690.,14995.,15150.,15375.,15420.,15624.,8594.,8450.,
410439.,10675.,12500.,12000.,13657.,14500.,13450.,13425.,13946.,140
500.,14920.,15210.,15300.,15600.,15540.,15770./
 DATA XF/9079.,9340.,11000.,11410.,13000.,12290.,14071.,14750.,1402
15.,13910.,14437.,14500.,15150.,15425.,15600.,15825.,15780.,15916.,
29564.,10230.,11561.,12141.,13500.,13005.,14485.,15000.,14600.,1439
35.,14928.,15000.,15380.,15640.,15750.,16000.,15900.,16060.,10049.,
411120.,12122.,12880.,14000.,13720.,14899.,15250.,15000.,14880.,150
500.,15500.,15610.,15855.,15900.,16050.,16020.,16208./
 DATA XG/10534.,12010.,12683.,14000.,14500.,14435.,14922.,15500.,15
1175.,15365.,15419.,15750.,15840.,16070.,16200.,16275.,16260.,16354
2.,11504.,12900.,13805.,14350.,14961.,15150.,15313.,15600.,15750.,1
35850.,15910.,16000.,16300.,16500.,16500.,16500.,16500.,16500./
 DATA YA/1.1603,1.2177,1.2932,1.3835,1.5130,1.6391,1.7232,1.8450,1.
19373,2.0279,2.1172,2.2310,2.3170,2.5232,2.6178,2.7168,2.7828,2.869
24,1.1591,1.2176,1.2877,1.3815,1.5100,1.6370,1.7177,1.8430,1.9346,2
3.0243,2.1152,2.2300,2.3140,2.5203,2.6176,2.7133,2.7818,2.8633,1.15
480,1.2172,1.2842,1.3795,1.5020,1.6344,1.7151,1.8380,1.9316,2.0200,
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     52.1126,2.2290,2.3084,2.5154,2.6156,2.7035,2.7792,2.8558/
      DATA YB/1.1570,1.2167,1.2821,1.3778,1.4930,1.6312,1.7137,1.8340,1.
     19282,2.0151,2.1096,2.2250,2.3002,2.5079,2.6059,2.6896,2.7698,2.846
     29,1.1558,1.2160,1.2812,1.3761,1.4860,1.6275,1.7133,1.8280,1.9244,2
     3.0098,2.1061,2.2210,2.2910,2.4973,2.5981,2.6715,2.7630,2.8367,1.15
     444,1.2151,1.2808,1.3746,1.4790,1.6233,1.7120,1.8200,1.9204,2.0038,
     52.1022,2.2190,2.2810,2.4830,2.5884,2.6518,2.7540,2.8251/
      DATA YC/1.1527,1.2141,1.2804,1.3731,1.4700,1.6187,1.7084,1.8080,1.
     19160,1.9972,2.0979,2.2170,2.2690,2.4645,2.5633,2.6492,2.7340,2.812
     22,1.1503,1.2128,1.2796,1.3719,1.4590,1.6155,1.7013,1.7890,1.9112,1
     3.9901,2.0931,2.2120,2.2590,2.4410,2.5479,2.6258,2.7215,2.7977,1.14
     473,1.2115,1.2778,1.3707,1.4490,1.6135,1.6949,1.7660,1.9062,1.9825,
     52.0879,2.2070,2.2420,2.4122,2.5306,2.5922,2.7076,2.7820/
      DATA YD/1.1434,1.2099,1.2746,1.3697,1.4350,1.6078,1.6892,1.7390,1.
     19008,1.9743,2.0822,2.1990,2.2120,2.3773,2.4901,2.5576,2.6756,2.764
     29,1.1385,1.2081,1.2694,1.3687,1.4230,1.6015,1.6704,1.7030,1.8950,1
     3.9654,2.0607,2.1890,2.1540,2.3359,2.4670,2.5186,2.6574,2.7464,1.13
     424,1.2077,1.2619,1.3636,1.4100,1.5948,1.6434,1.6580,1.8693,1.9527,
     52.0501,2.1720,2.1310,2.2872,2.4420,2.5046,2.6378,2.7266/
      DATA YE/1.1250,1.2042,1.2514,1.3603,1.3920,1.5627,1.6065,1.5850,1.
     18684,1.9409,2.0486,2.1490,2.0790,2.2309,2.3862,2.4755,2.5945,2.705
     24,1.1162,1.1966,1.2376,1.3418,1.3710,1.5508,1.5964,1.5410,1.8530,1
     3.9383,2.0170,2.1180,2.0110,2.1662,2.3554,2.4283,2.5706,2.6828,1.10
     457,1.1798,1.2198,1.3134,1.3410,1.5345,1.5578,1.4890,1.8069,1.9092,
     51.9468,2.0680,1.9080,2.0926,2.3227,2.3769,2.5454,2.6588/
      DATA YF/1.0935,1.1572,1.1976,1.2749,1.3020,1.5188,1.4891,1.4200,1.
     17150,1.8446,1.8247,1.9150,1.8150,2.0095,2.2515,2.3213,2.4907,2.633
     25,1.0793,1.1288,1.1706,1.2263,1.2570,1.4589,1.3600,1.3210,1.5610,1
     3.7342,1.6361,1.7000,1.6645,1.9163,2.2130,2.2752,2.4612,2.6067,1.06
     431,1.0946,1.1382,1.1678,1.1970,1.3618,1.2202,1.2090,1.4111,1.5651,
     51.6019,1.3680,1.5258,1.8125,2.1727,2.2616,2.4303,2.5787/
      DATA YG/1.0446,1.0546,1.0999,1.0593,1.1060,1.2179,1.2096,1.0750,1.
     13323,1.3245,1.3663,1.1810,1.3716,1.6975,2.0861,2.1977,2.3643,2.549
     22,1.0003,1.0088,1.0037,1.0207,1.0000,1.0178,0.9996,1.0000,1.0109,0
     3.9995,1.0006,1.0000,1.0165,1.4314,1.9919,2.1296,2.2925,2.5183/
      DATA Z/6000.,7000.,8000.,9000.,10000.,11000.,12000.,12450.,13000.,
     113500.,14000.,14540.,15000.,16000.,16620.,17000.,17500.,18100./
      DATA PI30/9.549296585/
C
C
C     TURBOCHARGER COMPRESSOR MAP FOR LSV-16
C     WRITTEN BY LUIS FERRARESSO11/71
C     REFERENCE   COOPER-BESSEMER DATA
C
C     COMPRESSOR FLOW MAP FOR COOPER - BESSEMER DIESEL LSV-16
C
C
C     MAP DATA FOR TOTAL MASS FLOW THROUGH ENGINE AS A FUNCTION
C     OF OPERATING CONDITIONS
C
C
C     FLOC = MASS FLOW CALCULATED IN LBS./SEC.
C     TORC = TORQUE CALCULATED IN LBM/SEC
C     TC = COMPRESSOR DISCHARGE TEMPERATURE CALCULATED IN DEG. R
C     YO = COMPRESSOR PRESSURE RATIO CALCULATED
C     XO = CORRECTED MASS CALCULATED IN CFM
C
C     SPEEC = CONSTANT SPEED INPUT IN RAD./SEC.
C     TAI = AMBIENT TEMPERATURE AT COMPRESSOR INLET INPUT, DEG. R
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C      PAI = AMBIENT PRESSURE AT COMPRESSOR INLET INPUT, PSIA
C      PC = COMPRESSOR DISCHARGE PRESSURE INPUT, PSIA
C
C      CALCULATE PRESSURE RATIO
C      CORRECT TEMPERATURE BY 540.0 DEG.R
C      ADJUST SPEED TO RPM
C
       IT=0
       Y0=PC/PAI
       S=Y0**0.286-1.
       T1=TAI/540.0
       ST1=SQRT(T1)
       Z0=SPEED*PI30/ST1
C
C      IF PRESSURE RATIO IS LESS THAN 1.0, SET PRESSURE RATIO = 1.0
C
       IF (Y0-1.) 10,20,20
10     WRITE (MLP,350) Y0,Z0
       Y0=1.0
       S=0.0
C
C      Z(N+1) MUST BE GREATER THAN Z(N)
C      Y(I,J) MUST BE GREATER THAN Y(I,J+1)
C      FIND ADJACENT Z CURVES
C      IF SPEED IS LESS THAN 6000 RPM, SET SPEED = 6000 RPM
C
20     IF (Z0-Z(1)) 30,40,40
30     WRITE (MLP,360) Z0
       Z0=Z(1)
       GO TO 60
C
C      IF SPEED IS GREATER THAN 18100 RPM, SET SPEED = 18100 RPM
C
40     IF (Z0-Z(NC)) 60,60,50
50     WRITE (MLP,370) Z0
       Z0=Z(NC)
60     DO 70 I=1,NC
       IF (Z(I)-Z0) 70,90,80
70     CONTINUE
       GO TO 250
80     IZ1=I
       IZ2=I-1
       GO TO 150
C
C      IF Z EQUALS ONE OF THE INPUT CURVES, FIND ADJACENT Y=S AND
C      INTERPOLATE BETWEEN THEM FOR X
C
90     K=NPC(I)
       DO 100 J=1,K
C
C      TEST IF IN SURGE REGION
C
       IF (Y(I,J)-Y0) 120,110,100
100    CONTINUE
       DY=3200.0-0.4*Z0-96000.0/Z0
       X0=X(I,K)-(Y(I,K)-Y0)*DY
       GO TO 250
110    X0=X(I,J)
       GO TO 250
```

```
  120 IY1=J
      IY2=J-1                                                           CMA1770
      IF (IY2) 140,130,140                                              CMA1780
  130 IT=130                                                            CMA1790
      GO TO 250                                                         CMA1800
  140 X0=X(I,IY2)+((Y(I,IY2)-Y0)/(Y(I,IY2)-Y(I,IY1)))*(X(I,IY1)-X(I,IY2)CMA1810
     1)                                                                 CMA1820
      GO TO 250                                                         CMA1830
  150 K=NPC(IZ1)                                                        CMA1840
      IF (K-NPC(IZ2)) 170,170,160                                       CMA1850
  160 K=NPC(IZ2)                                                        CMA1860
C                                                                       CMA1870
C     FIND THE INDICES OF THE FOUR INTERPOLATING POINTS.                CMA1880
C                                                                       CMA1890
  170 DO 180 K1=1,K                                                     CMA1900
      KBUG=K1                                                           CMA1910
      Y1(K1)=(Z0-Z(IZ2))/(Z(IZ1)-Z(IZ2))*(Y(IZ1,K1)-Y(IZ2,K1))+Y(IZ2,K1)CMA1920
C                                                                       CMA1930
C     TEST IF IN SURGE REGION                                           CMA1940
C                                                                       CMA1950
      IF (Y1(K1)-Y0) 200,190,180                                        CMA1960
  180 CONTINUE                                                          CMA1970
      K1=KBUG                                                           CMA1980
      IT=250                                                            CMA1990
  190 X0=X(IZ2,K1)+((Y1(K1)-Y(IZ2,K1))/(Y(IZ1,K1)-Y(IZ2,K1)))*(X(IZ1,K1)CMA2000
     1-X(IZ2,K1))                                                       CMA2010
  200 IND1=K1                                                           CMA2020
      IND2=K1-1                                                         CMA2030
      IF (IND2) 220,210,220                                             CMA2040
  210 IT=130                                                            CMA2050
      GO TO 250                                                         CMA2060
  220 DO 230 M=IND2,IND1                                                CMA2070
  230 X1(M)=X(IZ2,M)+((Y1(M)-Y(IZ2,M))/(Y(IZ1,M)-Y(IZ2,M)))*(X(IZ1,M)-X(CMA2080
     1IZ2,M))                                                           CMA2090
      X0=X1(IND2)+((Y0-Y1(IND2))/(Y1(IND1)-Y1(IND2)))*(X1(IND1)-X1(IND2)CMA2100
     1)                                                                 CMA2110
      IF (IT-250) 250,240,250                                           CMA2120
  240 DY=3200.0-0.35*Z0-96000.0/Z0                                      CMA2130
      X0=X0-(Y1(K)-Y0)*DY                                               CMA2140
C                                                                       CMA2150
C     IF IN SURGE REGION, SET CORRECTED MASS = 0.0                      CMA2160
C                                                                       CMA2170
  250 IF (IT-130) 270,260,270                                           CMA2180
  260 X0=0.0                                                            CMA2190
      WRITE (MLP,380)                                                   CMA2200
C                                                                       CMA2210
C     IF CORRECTED MASS EXCEEDS 16500 CFM,SET CORRECTED MASS = 16500 CFMCMA2220
C     INCLUDES NORMALIZATION PLUS COMPUTATION OF MASS FLOW (LBM/SEC)    CMA2230
C     FROM (CFM) AT COMPRESSOR EXIT                                     CMA2240
C                                                                       CMA2250
C     DIVIDE MASS FLOW BY 2.0 SINCE TWO INTAKE MANIFOLDS                CMA2260
  270 IF (X0-16500) 290,290,280                                         CMA2270
  280 WRITE (MLP,390) X0,Z0                                             CMA2280
      X0=16500.                                                         CMA2290
C                                                                       CMA2300
  290 X0=X0*FACT                                                        CMA2310
      FLOW=X0*PAI*SQRT(540.0/TAI)/(842.8*14.243*ST1)                    CMA2320
      FLOC=FLOW/2.0                                                     CMA2330
C                                                                       CMA2340
                                                                        CMA2350
```

```
C     PRINT MASS FLOW FOR PRESSURE RATIO OF 1.0                         CMA2351
      IF(YO-1.0)295,295,296                                             CMA2352
  295 WRITE(MLP,410)XO                                                  CMA2353
C                                                                       CMA2354
C     CALCULATE EFFICIENCY FROM SPEED AND PRESSURE RATIO                CMA2360
C     IF SPEED GREATER THAN 14000 RPM, CALCULATE EFFICIENCY FOR SPEED   CMA2370
C     OF 14000 RPM                                                      CMA2380
C     CALCULATE TORQUE AND COMPRESSOR DISCHARGE TEMPERATURE             CMA2390
C                                                                       CMA2400
  296 IF(ZO-Z(11))310,310,300                                           CMA2410
300   WRITE (MLP,400) ZO                                                CMA2420
      AN=Z(11)                                                          CMA2430
      GO TO 320                                                         CMA2440
310   AN=ZO                                                             CMA2450
320   CALL POLYE (AN,YO,MLP,ETA)                                        CMA2460
      TSUR=103.0*(YO-1)                                                 CMA2470
      TORC=188.2*FLOC*TAI*S/(ETA*SPEED)                                 CMA2480
      IF (IT-130) 340,330,340                                           CMA2490
330   TORC=TSUR                                                         CMA2500
340   TMIN=1.0E-07*ZO*ZO                                                CMA2510
      TORC=AMAX1(TORC,TMIN)                                             CMA2520
      TC=TAI*(1+S/ETA)                                                  CMA2530
      RETURN                                                            CMA2540
C                                                                       CMA2550
C     DIAGNOSTIC MESSAGES                                               CMA2560
C                                                                       CMA2570
C                                                                       CMA2580
350   FORMAT (10X,28HCALCULATED PRESSURE RATIO OF,F10.4,16H FOR INPUT SPCMA2590
     1EED,F10.0,46H BELOW 1.0 -- SET PRESSURE RATIO = 1.0 IN CMAP)      CMA2600
360   FORMAT (10X,11HINPUT SPEED,F10.0,41H BELOW 6000 RPM -- 6000 DATA UCMA2610
     1SED IN CMAP)                                                      CMA2620
370   FORMAT (10X,11HINPUT SPEED,F10.0,43H ABOVE 18100 RPM -- 18100 DATACMA2630
     1 USED IN CMAP)                                                    CMA2640
380   FORMAT (10X,49HDATA IN SURGE -- SET CORRECTED MASS = 0.0 IN CMAP) CMA2650
390   FORMAT (10X,17HCORRECTED MASS OF,F10.2,19H FOR INPUT SPEED OF,F10.CMA2660
     10,48H EXCEEDS 16500 CFM -- SET CORRECTED MASS = 16500)            CMA2670
400   FORMAT (10X,11HINPUT SPEED,F10.0,63H ABOVE 14000 RPM -- 14000 RPM CMA2680
     1DATA USED TO CALCULATE EFFICIENCY)                                CMA2690
  410 FORMAT(10X,25HCORRECTED MASS FLOW(CFM)=,F10.2)                    CMA2691
      END                                                               CMA2700-
```

```
      FUNCTION DPIC (AIRM)
C                                                                       DPI  10
C     INTERCOOLER PRESSURE DROP FOR LSV-16                              DPI  20
C     WRITTEN BY BRUCE ALLEN 11/71                                      DPI  30
C     REFERENCE   EXPERIMENTAL DATA FROM JUNE 23,1971 TESTS             DPI  40
C                                                                       DPI  50
C     COMPUTES PRESSURE DROP ACROSS INTERCOOLER FROM CURVEFIT           DPI  60
      DPIC=AIRM*(.06907338-.001432273*AIRM)                             DPI  70
      RETURN                                                            DPI  80
      END                                                               DPI  90
                                                                        DPI 100-
```

```
      SUBROUTINE INP4
      DIMENSION Z(6)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693)
      COMMON X,Y(5),F(5),Q(5),A(5),B(59),TITLE(20),HEAD(20),L(10),MCR,ML
     1P,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB5(200)
C    IC CONTAINS VARIABLE NAMES TO BE PRINTED
C    ID CONTAINS LOWER INDEX OF VARIABLE TO BE PRINTED
C    IE CONTAINS UPPER INDEX OF VARIABLE TO BE PRINTED
C    TITT WILL BE PRINTED AT THE TOP OF EACH PAGE OF OUTPUT
C    HED WILL BE PRINTED AT THE TOP OF THE 11 COLUMNS OF THE TAPE PRINT
C      L(14)  CONTAINS THE NUMBER OF PRINT INSTRUCTIONS
C      L(10)  CONTAINS THE NUMBER OF CALLS TO PRINT
C      L(2)  CONTAINS PRINTING FREQUENCY FOR PAR14 ONLY
C
      MCR=5
      MLP=6
      IA1(1)=1HI
      IA1(2)=1HP
      IA1(3)=1HR
      IA2(1)=1HA
      IA2(2)=1HB
      IA2(3)=1HF
      IA2(4)=1HL
      IA2(5)=1HX
      IA2(6)=1HY
      DO 10 I=1,10
10    L(I)=0
      M=0
      READ (MCR,180) TITLE
      WRITE (MLP,190) TITLE
      READ (MCR,180) HEAD
20    READ (MCR,200) I11,I12,I1,I2,Z
      WRITE (MLP,210) I11,I12,I1,I2,Z
      KKY=1
      DO 40 I=1,3
      IF (I11-IA1(I)) 40,50,40
40    CONTINUE
50    GO TO (60,150,160,170), I
60    DO 70 I=1,6
      IF (I12-IA2(I)) 70,80,70
70    CONTINUE
80    GO TO (90,100,110,120,130,140,170), I
90    CALL STORE (I1,I2,Z,A,5,KKY)
      GO TO (20,170), KKY
100   CALL STORE (I1,I2,Z,B,59,KKY)
      GO TO (20,170), KKY
110   CALL STORE (I1,I2,Z,F,5,KKY)
      GO TO (20,170), KKY
120   CALL STORE (I1,I2,Z,L,10,KKY)
      GO TO (20,170), KKY
130   CALL STORE (I1,I2,Z,X,1,KKY)
      GO TO (20,170), KKY
140   CALL STORE (I1,I2,Z,Y,5,KKY)
      GO TO (20,170), KKY
150   M=M+1
      IC(M)=I12
      ID(M)=I1
```

```
      IE(M)=I2
      GO TO 20
 160  L14=M
      RETURN
 170  WRITE (MLP,220) II1,II2,I1,I2
      CALL EXIT
C
 180  FORMAT (20A4)
 190  FORMAT (1H1,20X,22HINPUT DATA FOR SUB4 - ,/,20X,20A4)
 200  FORMAT (A1,1X,A1,2I3,1X,6F10.5)
 210  FORMAT (/,1X,A1,1X,A1,2I3,1X,6E12.4)
 220  FORMAT (17H1BAD DATA - CARD ,A1,8H VECTOR ,A1,2I3)
      END
```

```
      SUBROUTINE POLYE (AN,P1,MLP,ETA)
C
C
C     TURBOCHARGER COMPRESSOR EFFICIENCY FOR LSV-16
C     WRITTEN BY STEPHEN PERRY 11/71
C     REFERENCE   COOPER-BESSEMER DATA
C
C     PROGRAM TO CHECK OUT TURBO-CHARGER MAPS
C
      DIMENSION A2(9), A1(9), A0(9), XM(9), YM(9), XI(8), XS(9), SL(9),
     1E(2)
      DIMENSION AM1(7), ANA(7), AM2(8), ANB(8)
      DATA A2/-25.5606,-17.6666,-9.4661,-5.1979,-3.1695,-1.9035,-1.1994,
     1-.7963,-.6944/
      DATA A1/61.7137,43.7425,25.0673,14.7776,9.7288,6.4160,4.4977,3.306
     15,2.9448/
      DATA A0/-35.7747,-26.2047,-15.7222,-9.6514,-6.6152,-4.5461,-3.3291
     1,-2.5486,-2.3149/
      DATA AM1/16.6667,14.2857,4*10.0,7.1429/
      DATA ANA/-12.9999,-10.1428,4*-4.7,.0713/
      DATA AM2/16.6667,12.5,10.0,9.3458,9.7087,9.5238,8.5470,5.3191/
      DATA ANB/-13.1667,-8.1250,-4.90,-3.9907,-4.5339,-4.2381,-2.5726,3.
     13086/
      DATA XM/1.14,1.2,1.27,1.37,1.47,1.57,1.67,1.81,2.01/
      DATA YM/8*.84,.8/
      DATA XI/1.15,1.21,1.29,1.39,1.497,1.6,1.705,1.822/
      DATA XS/1.18,1.23,1.297,1.39,1.497,1.6,1.705,1.822,2.01/
      DATA SL/2*.78,.79,6*.8/
C
C     CHECK INPUT SPEED WITH RANGE OF DATA
C
      IF ((AN-6000.0)*(14000.0-AN)) 10,20,20
10    WRITE (MLP,350) AN
      GO TO 340
C
C     FIND LOWER SPEED LINE
C
20    IG=0
      N=AN/1000.0-5.0
C
C     CALCULATE LOWER AND UPPER SPEED LINE EFFICIENCIES
C
      DO 270 I=1,2
      IF (N-10) 30,300,300
C
C     ZONE 1
C
30    IF (P1-XM(N)) 40,260,90
C
C     CALCULATE EFFICIENCY BY LEAST SQUARES AND VALIDATE
C
40    E(I)=A2(N)*P1**2+A1(N)*P1+A0(N)
      IF (E(I)-0.10) 50,80,60
50    E(I)=0.10
      N1=(N+5)*1000
C     WRITE (MLP,360) N1,AN,P1
      GO TO 80
60    IF (E(I)-0.84) 80,80,70
70    E(I)=0.84
```

```
      N1=(N+5)*1000                                                     POL 600
      WRITE (MLP,370) N1,AN,P1                                          POL 610
80    IF (IG) 270,270,280                                               POL 620
90    IF (N-8) 100,200,310                                              POL 630
C                                                                       POL 640
C     ZONE 2                                                            POL 650
C                                                                       POL 660
100   AN1=(AM1(N)*P1+ANA(N))*1000.0                                     POL 670
      IF (P1-XI(N)) 110,110,130                                         POL 680
110   IF (AN1-AN) 250,320,120                                           POL 690
120   E(2)=.84                                                          POL 700
      E(1)=SL(N)-((XI(N)-P1)*(SL(N)-YM(N))/(XI(N)-XM(N)))               POL 710
      GO TO 290                                                         POL 720
C                                                                       POL 730
C     ZONE 3                                                            POL 740
C                                                                       POL 750
130   AN2=(AM2(N)*P1+ANB(N))*1000.0                                     POL 760
      IF (P1-XM(N+1)) 140,140,170                                       POL 770
140   IF (AN-AN2) 310,310,150                                           POL 780
150   IF (AN-AN1) 160,320,250                                           POL 790
160   ETA=.84-(AN1-AN)*(.84-SL(N))/(AN1-AN2)                            POL 800
      GO TO 330                                                         POL 810
C                                                                       POL 820
C     ZONE 4                                                            POL 830
C                                                                       POL 840
170   IF (P1-XI(N+1)) 180,310,310                                       POL 850
180   IF (AN-AN2) 310,310,190                                           POL 860
190   AN1=AN2                                                           POL 870
      E(1)=SL(N)                                                        POL 880
      N=N+1                                                             POL 890
      E(2)=SL(N)-((XI(N)-P1)*(SL(N)-YM(N))/(XI(N)-XM(N)))               POL 900
      GO TO 280                                                         POL 910
C                                                                       POL 920
C     ZONE 5                                                            POL 930
C                                                                       POL 940
200   IF (P1-XI(N)) 210,240,220                                         POL 950
210   E(I)=SL(N)-((XI(N)-P1)*(SL(N)-YM(N))/(XI(N)-XM(N)))               POL 960
      GO TO 270                                                         POL 970
220   AN1=(AM2(N)*P1+ANB(N))*1000.0                                     POL 980
      IF (AN-AN1) 310,310,230                                           POL 990
C                                                                       POL1000
C     EFFICIENCIES                                                      POL1010
C                                                                       POL1020
230   IG=1                                                              POL1030
240   E(I)=SL(N)                                                        POL1040
      GO TO 270                                                         POL1050
250   E(I)=.84                                                          POL1060
      IG=1                                                              POL1070
      GO TO 270                                                         POL1080
260   E(I)=YM(N)                                                        POL1090
270   N=N+1                                                             POL1100
C                                                                       POL1110
C     FINAL EFFICIENCIES                                                POL1120
C                                                                       POL1130
      ETA=E(2)-(FLOAT((N+4)*1000)-AN)*(E(2)-E(1))*0.001                 POL1140
      GO TO 330                                                         POL1150
280   AN2=FLOAT((N+5)*1000)                                             POL1160
      ETA=E(2)-(AN2-AN)*(E(2)-E(1))/(AN2-AN1)                           POL1170
      GO TO 330                                                         POL1180
```

```
290    ETA=E(2)-(AN1-AN)*(E(2)-E(1))/(AN1-FLOAT((N+5)*1000))                 POL1190
       GO TO 330                                                             POL1200
C                                                                            POL1210
C      USE 14000 RPM SPEED LINE EFFICIENCY                                   POL1220
C                                                                            POL1230
300    ETA=E(1)                                                              POL1240
       GO TO 330                                                             POL1250
310    ETA=SL(N)                                                             POL1260
       GO TO 330                                                             POL1270
320    ETA=.84                                                               POL1280
330    RETURN                                                                POL1290
340    CALL PRT4                                                             POL1300
       CALL EXIT                                                             POL1310
C                                                                            POL1320
C      DIAGNOSTIC FORMATS                                                    POL1330
C                                                                            POL1340
C                                                                            POL1350
350    FORMAT (1H1,10X,14HINPUT SPEED    ,E10.4,32H EXCEEDS LIMITS OF DATAPOL1360
      1 IN POLYE)                                                            POL1370
360    FORMAT (10X,80HLEAST SQUARES CALCULATION IN POLYE YIELDS EFFICIENCPOL1380
      1Y LESS THAN 0.1 AT SPEED LINE,I7,2X,15HFOR INPUT SPEED,3X,E10.4/,1POL1390
      20X,26HAND INPUT PRESSURE RATIO  ,E10.4,34H  0.1 EFFICIENCY HAS BEEPOL1400
      3N ASSIGNED)                                                           POL1410
370    FORMAT (10X,83HLEAST SQUARES CALCULATION IN POLYE YIELDS EFFICIENCPOL1420
      1Y GREATER THAN .84 AT SPEED LINE,I7,2X,15HFOR INPUT SPEED,3X,E10.4POL1430
      2/,10X,26HAND INPUT PRESSURE RATIO  ,E10.4,34H  .84 EFFICIENCY HAS POL1440
      3BEEN ASSIGNED)                                                        POL1450
       END                                                                   POL1460-
```

```
      SUBROUTINE PRT4                                                   PR400001
      COMMON ICM(20),G(90)                                              PR400002
      COMMON DMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693)               PR400003
      COMMON X,Y(5),F(5),Q(5),A(5),B(59),TITLE(20),HEAD(20),L(10),      PR400004
     1MCR,MLP,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)                    PR400005
      COMMON DSUB5(200)                                                 PR400006
      IF(L(10))111,1,111                                                PR400007
  111 IF(L(10)-L(2))2,1,1                                               PR400008
    1 L(10)=0                                                           PR400009
      WRITE(MLP,200)TITLE                                               PR400010
    2 L(10)=L(10)+1                                                     PR400011
      DO 13 I=1,L14                                                     PR400012
      I1=IC(I)                                                          PR400013
      I2=IE(I)                                                          PR400014
      DO 3 J=1,6                                                        PR400015
      IF( IC(I)-IA2(J))3,5,3                                            PR400016
    3 CONTINUE                                                          PR400017
      WRITE(MLP,201) IC(I)                                              PR400018
      CALL EXIT                                                         PR400019
    4 I1=I4+1                                                           PR400020
      IF(I1-I2) 5,5,13                                                  PR400021
    5 I4=MINO(I1+9,I2)                                                  PR400022
      GO TO (6,7,8,9,10,11,12), J                                       PR400023
    6 WRITE(MLP,202)IC(I),I1,I4,(A(K),K=I1,I4)                          PR400024
      GO TO 4                                                           PR400025
    7 WRITE(MLP,202)IC(I),I1,I4,(B(K),K=I1,I4)                          PR400026
      GO TO 4                                                           PR400027
    8 WRITE(MLP,202)IC(I),I1,I4,(F(K),K=I1,I4)                          PR400028
      GO TO 4                                                           PR400029
    9 WRITE(MLP,203)  IC(I),I1,I4,(L(K),K=I1,I4)                        PR400030
      GO TO 4                                                           PR400031
   10 WRITE(MLP,204)X                                                   PR400032
      GO TO 13                                                          PR400033
   11 WRITE(MLP,202) IC(I),I1,I4,(Y(K),K=I1,I4)                         PR400034
      GO TO 4                                                           PR400035
   12 WRITE(MLP,202)IC(I),I1,I4,(G(K),K=I1,I4)                          PR400036
      GO TO 4                                                           PR400037
   13 CONTINUE                                                          PR400038
      RETURN                                                            PR400039
  200 FORMAT(///,25X,20A4)                                              PR400040
  201 FORMAT(34H1BAD PRINT INSTRUCTION - VARIABLE ,A1)                  PR400041
  202 FORMAT(/,1X,A1,1H(,I2,1H-,I2,1H),10E11.3)                         PR400042
  203 FORMAT(/,1X,A1,1H(,I2,1H-,I2,1H),1X,9(I5,6X),I5)                  PR400043
  204 FORMAT(1X,1HX,10X,F12.6)                                          PR400044
      END                                                               PR400045
```

```
      SUBROUTINE RNG4 (H1,N1)
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693)
      COMMON X,Y(5),F(5),Q(5),A(5),B(59),TITLE(20),HEAD(20),L(10),MCR,ML
     1P,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB5(200)
   10 H=H1
      HH=.5*H
      N=N1
      DO 20 I=1,N
   20 Q(I)=0.0
      CALL YPR4
      DO 30 I=1,N
      S=F(I)*H
      T=.5*(S-2.*Q(I))
      Y(I)=Y(I)+T
   30 Q(I)=Q(I)+3.*T-.5*S
      X=X+HH
      CALL YPR4
      DO 40 I=1,N
      S=F(I)*H
      T=.29289322*(S-Q(I))
      Y(I)=Y(I)+T
   40 Q(I)=Q(I)+3.*T-.29289322*S
      CALL YPR4
      DO 50 I=1,N
      S=F(I)*H
      T=1.7071067*(S-Q(I))
      Y(I)=Y(I)+T
   50 Q(I)=Q(I)+3.*T-1.707106*S
      X=X+HH
      CALL YPR4
      DO 60 I=1,N
      S=F(I)*H
      T=(S-2.*Q(I))/6.
      Y(I)=Y(I)+T
   60 Q(I)=Q(I)+3.*T-.5*S
      RETURN
      END
```

```
      SUBROUTINE SUB4
C
C     SUBROUTINE SUB4 IS A GENERAL ROUTINE FOR CALCULATING TURBCCHARGER
C     PERFORMANCE
C
      COMMON ICM(20),G(90)
      COMMON DMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693)
      COMMON X,Y(5),F(5),Q(5),A(5),B(59),TITLE(20),HEAD(20),L(10),MCR,ML
     1P,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB5(200)
      EQUIVALENCE (L7,ICM(1)), (L8,ICM(2))
      DATA PI30/9.549296/
      IF (G(1)) 80,80,10
   10 N=0
   20 IF (G(1)-(X+A(1)*0.5)) 110,30,30
   30 IF (N) 70,40,70
C
C     SET COMPRESSOR AND TURBINE DATA FROM G ARRAY
C
   40 N=1
      DELP=DPIC(G(58))
      DO 50 J=1,L7
      J1=3*J+58
      J3=4*J+7
   50 B(J3)=G(J1)+DELP
      DO 60 J=1,L8
      J5=3*L7+3*J+58
      J7=4*L7+5*J+6
      B(J7)=G(J5)
   60 B(J7+2)=G(J5+2)
   70 CALL RNG4 (A(1),L(1))
      GO TO 20
C
C     SET INITIAL VALUES
   80 DELP=DPIC(G(58))
      DO 90 J=1,L7
      J1=3*J+58
      J3=4*J+7
   90 B(J3)=G(J1)+DELP
      DO 100 J=1,L8
      J5=3*L7+3*J+58
      J7=4*L7+5*J+6
      B(J7)=G(J5)
  100 B(J7+2)=G(J5+2)
C     RETURN CALCULATED INLET AND EXHAUST MANIFOLD DATA TO G ARRAY
C
  110 DO 120 J=1,L7
      J2=3*J+59
      J4=4*J+8
  120 G(J2)=B(J4)
      DO 130 J=1,L8
      J6=3*L7+3*J+59
      J8=4*L7+5*J+7
  130 G(J6)=B(J8)
      G(20)=PI30*Y(1)
      G(59)=Y(1)
      G(58)=B(3)
      G(55)=B(4)
      G(56)=B(5)
      G(57)=B(6)
      G(23)=B(6)-460.0
      G(60)=TIC(B(3))
      RETURN
      END
```

```
      FUNCTION TIC (AIRM)
C
C     INTERCOOLER TEMPERATURE FOR LSV-16
C     WRITTEN BY BRUCE ALLEN 11/71
C     REFERENCE   EXPERIMENTAL DATA FROM JUNE 23,1971 TESTS
C
C     INTERCOOLER TEMPERATURE FROM CURVEFIT TEST DATA
      TIC=560.28+AIRM*(-.39692+.08074449*AIRM)
      RETURN
      END
```

```
      SUBROUTINE TMAP (FLOW,TORQ,TEXH,SPEED,T1,P1,P3,MLP,FF)
C
C     TURBOCHARGER TURBINE FOR LSV-16
C     WRITTEN BY JAMES COGGINS 11/71
C     REFERENCE   COOPER-BESSEMER DATA
C
C
C     SUBROUTINE TMAP CALCULATES TURBINE PERFORMANCE PARAMETERS FOR THE
C     COOPER-BESSEMER DIESEL ENGINE.
C
      N=0
      RATIO=P3/P1
      IF (RATIO-0.999) 20,10,10
   10 FLOW=0.0
      TORQ=0.0
      TEXH=T1
      GO TO 100
   20 U=0.627*SPEED
      ST1=SQRT(T1)
      PST1=P1/ST1
      R=RATIO**0.2658-1.0
      ETA=0.76*FF
      GO TO 50
   30 ETAO=ETA
      PHI=U/V2
      PARA=SQRT(1.4706-PHI*(1.8608-PHI))
      COR=PHI*(0.1813*PHI-0.180)
      ETA=1.229*PHI*(0.9304-PHI+0.8526*PARA)+COR
      ETA=ETA*FF
      N=N+1
      IF (N-100) 40,90,90
   40 TEST=(ETA-ETAO)*100.0/ETAO
      IF (ABS(TEST)-0.5) 80,80,50
   50 P21=(0.7158*ETA*R+1)**3.762
      IF (P21-0.534) 60,70,70
   60 FL=5.04*PST1
      V2=44.49*ST1
      GO TO 30
   70 R21=1.0-P21**0.2658
      FL=20.39*PST1*SQRT(R21*P21**1.467)
      V1=4.20*FL*T1/P1
      V22=V1**2+12270.0*T1*R21
      V2=SQRT(V22)
      GO TO 30
   80 R=-R
      FLOW=FL
      TORQ=200.7*FL*T1*ETA*R/SPEED
      TEXH=T1*(1-ETA*R)
      GO TO 100
   90 WRITE (MLP,110)
      WRITE (MLP,120) N,FLOW,TORQ,TEXH,SPEED,T1,P1,P3,ETA,PHI,P21,V2,V1
  100 RETURN
C
  110 FORMAT (65H1 NO SOLUTION FOR TURBINE PARAMETERS EXISTS AFTER 100 I
     1TERATIONS )
  120 FORMAT (I5,12E10.3)
      END
```

```
      SUBROUTINE YPR4
C
C     SUBROUTINE YPR4 IS A GENERAL ROUTINE FOR CALCULATING TURBOCHARGER
C     PERFORMANCE
C
      COMMON ICM(20),G(90)
      COMMON CMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693)
      COMMON X,Y(5),F(5),Q(5),A(5),B(59),TITLE(20),HEAD(20),L(10),MCR,ML
     1P,L14,IA1(3),IA2(7),IC(19),ID(19),IE(19)
      COMMON DSUB5(200)
      EQUIVALENCE (L7,ICM(1)), (L8,ICM(2))
      DO 10 J=1,10
   10 B(J)=0.0
      DO 20 J=1,L7
      JC=4*J+10
      CALL CMAP (B(JC-2),B(JC),B(JC-1),G(17),G(18),B(10),Y(1),G(12),G(10
     1),B(JC-3),MLP,A(4))
      B(1)=B(1)+B(JC)
      B(3)=B(3)+B(JC-2)
   20 B(5)=B(5)+B(JC-2)*B(JC-1)
      B(5)=B(5)/B(3)
      DO 30 J=1,L8
      JT=4*L7+5*J+10
      CALL TMAP (B(JT-3),B(JT-1),B(JT),Y(1),B(JT-2),B(JT-4),G(11),MLP,A(
     13))
      B(2)=B(2)+B(JT-1)
      B(4)=B(4)+B(JT-3)
      B(7)=B(7)+B(JT)
   30 B(6)=B(6)+B(JT-3)*B(JT)
      IF(ABS(B(4))-0.01) 50,50,40
   40 B(6)=B(6)/B(4)
      GO TO 60
   50 B(6)=B(7)/FLOAT(L7)
   60 F(1)=(B(2)-B(1))/A(2)
      RETURN
      END
```

```
      SUBROUTINE INP5
      DIMENSION Z(6)
      COMMON ICM(20),G(90)
      COMMON OMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200)
      COMMON X,Y(13),F(13),Q(13),A(29),B(10),TITLE(20),HEAD(20),L(10),MC
     1R,MLP,L14,IA1(4),IA2(7),IC(19),ID(19),IE(19)
C     IC CONTAINS VARIABLE NAMES TO BE PRINTED
C     ID CONTAINS LOWER INDEX OF VARIABLE TO BE PRINTED
C     IE CONTAINS UPPER INDEX OF VARIABLE TO BE PRINTED
C     TITT WILL BE PRINTED AT THE TOP OF EACH PAGE OF OUTPUT
C     HED WILL BE PRINTED AT THE TOP OF THE 11 COLUMNS CF THE TAPE PRINT
      MCR=5
      MLP=6
      IA1(1)=1HI
      IA1(2)=1HP
      IA1(3)=1HR
      IA1(4)=1HZ
      IA2(1)=1HA
      IA2(2)=1HB
      IA2(3)=1HF
      IA2(4)=1HL
      IA2(5)=1HX
      IA2(6)=1HY
      IA2(7)=1HG
      DO 10 I=1,10
   10 L(I)=0
      M=0
      READ (MCR,190) TITLE
      WRITE (MLP,200) TITLE
      READ (MCR,190) HEAD
   20 READ (MCR,210) II1,II2,I1,I2,Z
      WRITE (MLP,220) II1,II2,I1,I2,Z
      KKY=1
      DO 40 I=1,4
      IF (II1-IA1(I)) 40,50,40
   40 CONTINUE
   50 GO TO (60,150,170,160,180), I
   60 DO 70 I=1,6
      IF (II2-IA2(I)) 70,80,70
   70 CONTINUE
   80 GO TO (90,100,110,120,130,140,180), I
   90 CALL STORE (I1,I2,Z,A,29,KKY)
      GO TO (20,180), KKY
  100 CALL STORE (I1,I2,Z,B,10,KKY)
      GO TO (20,180), KKY
  110 CALL STORE (I1,I2,Z,F,13,KKY)
      GO TO (20,180), KKY
  120 CALL STORI (I1,I2,Z,L,10,KKY)
      GO TO (20,180), KKY
  130 CALL STORE (I1,I2,Z,X,1,KKY)
      GO TO (20,180), KKY
  140 CALL STORE (I1,I2,Z,Y,13,KKY)
      GO TO (20,180), KKY
  150 M=M+1
      IC(M)=II2
      ID(M)=I1
      IE(M)=I2
      GO TO 20
  160 ICM(4)=1
```

```
170    L14=M                                                                     IN5 600
       RETURN                                                                    IN5 610
180    WRITE (MLP,230) II1,II2,I1,I2                                             IN5 620
       CALL EXIT                                                                 IN5 630
C                                                                                IN5 640
190    FORMAT (20A4)                                                             IN5 650
200    FORMAT (1H1,20X,22HINPUT DATA FOR SUB5 - ,/,20X,20A4)                     IN5 660
210    FORMAT (A1,1X,A1,2I3,1X,6F10.5)                                           IN5 670
220    FORMAT (/,1X,A1,1X,A1,2I3,1X,6E12.4)                                      IN5 680
230    FORMAT (17H1BAD DATA - CARD ,A1,8H VECTOR ,A1,2I3)                        IN5 690
       END                                                                       IN5 700-
```

```
      SUBROUTINE PRT5
      COMMON ICM(20),G(90)
      COMMON CMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200)
      COMMON X,Y(13),F(13),Q(13),A(29),B(10),TITLE(20),HEAD(20),L(10),
     1MCR,MLP,L14,IA1(4),IA2(7),IC(19),ID(19),IE(19)
      IF(L(10))111,1,111
  111 IF(L(10)-L(2))2,1,1
    1 L(10)=0
      WRITE(MLP,200)TITLE
    2 L(10)=L(10)+1
      DO 13 I=1,L14
      I1=IC(I)
      I2=IE(I)
      DO 3 J=1,6
      IF(IC(I)-IA2(J))3,5,3
    3 CONTINUE
      WRITE(MLP,201) IC(I)
      CALL EXIT
    4 I1=I4+1
      IF(I1-I2) 5,5,13
    5 I4=MIN0(I1+9,I2)
      GO TO (6,7,8,9,10,11,12), J
    6 WRITE(MLP,202)IC(I),I1,I4,(A(K),K=I1,I4)
      GO TO 4
    7 WRITE(MLP,202)IC(I),I1,I4,(B(K),K=I1,I4)
      GO TO 4
    8 WRITE(MLP,202)IC(I),I1,I4,(F(K),K=I1,I4)
      GO TO 4
    9 WRITE(MLP,203)  IC(I),I1,I4,(L(K),K=I1,I4)
      GO TO 4
   10 WRITE(MLP,204)X
      GO TO 13
   11 WRITE(MLP,202) IC(I),I1,I4,(Y(K),K=I1,I4)
      GO TO 4
   12 WRITE(MLP,202)IC(I),I1,I4,(G(K),K=I1,I4)
      GO TO 4
   13 CONTINUE
      RETURN
  200 FORMAT(///,25X,20A4)
  201 FORMAT(34H1BAD PRINT INSTRUCTION - VARIABLE ,A1)
  202 FORMAT(/,1X,A1,1H(,I2,1H-,I2,1H),10E11.3)
  203 FORMAT(/,1X,A1,1H(,I2,1H-,I2,1H),1X,9(I5,6X),I5)
  204 FORMAT(1X,1HX,10X,F12.6)
      END
```

```
      SUBROUTINE RNG5 (H1,N1)                                           RN5  10
      COMMON ICM(20),G(90)                                              RN5  20
      COMMON DMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200)    RN5  30
      COMMON X,Y(13),F(13),Q(13),A(29),B(10),TITLE(20),HEAD(20),L(10),MCRN5  40
     1R,MLP,L14,IA1(4),IA2(7),IC(19),ID(19),IE(19)                      RN5  50
      H=H1                                                              RN5  60
      HH=.5*H                                                           RN5  70
      N=N1                                                              RN5  80
      DO 10 I=1,N                                                       RN5  90
   10 Q(I)=0.0                                                          RN5 100
      CALL YPR5                                                         RN5 110
      DO 20 I=1,N                                                       RN5 120
      S=F(I)*H                                                          RN5 130
      T=.5*(S-2.*Q(I))                                                  RN5 140
      Y(I)=Y(I)+T                                                       RN5 150
   20 Q(I)=Q(I)+3.*T-.5*S                                               RN5 160
      X=X+HH                                                            RN5 170
      CALL YPR5                                                         RN5 180
      DO 30 I=1,N                                                       RN5 190
      S=F(I)*H                                                          RN5 200
      T=.29289322*(S-Q(I))                                              RN5 210
      Y(I)=Y(I)+T                                                       RN5 220
   30 Q(I)=Q(I)+3.*T-.29289322*S                                        RN5 230
      CALL YPR5                                                         RN5 240
      DO 40 I=1,N                                                       RN5 250
      S=F(I)*H                                                          RN5 260
      T=1.7071067*(S-Q(I))                                              RN5 270
      Y(I)=Y(I)+T                                                       RN5 280
   40 Q(I)=Q(I)+3.*T-1.707106*S                                         RN5 290
      X=X+HH                                                            RN5 300
      CALL YPR5                                                         RN5 310
      DO 50 I=1,N                                                       RN5 320
      S=F(I)*H                                                          RN5 330
      T=(S-2.*Q(I))/6.                                                  RN5 340
      Y(I)=Y(I)+T                                                       RN5 350
   50 Q(I)=Q(I)+3.*T-.5*S                                               RN5 360
      RETURN                                                            RN5 370
      END                                                               RN5 380-
```

```
      SUBROUTINE SUB5
C     FUEL CONTROL FOR COOPER-BESSEMER LSV-16 DIESEL
      COMMON ICM(20),G(90)
      COMMON CMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200)
      COMMON X,Y(13),F(13),Q(13),A(29),B(10),TITLE(20),HEAD(20),L(10),
     1MCR,MLP,L14,IA1(4),IA2(7),IC(19),ID(19),IE(19)
      EQUIVALENCE(B(10),THET1),(B(7),THET2)
   10 IF(G(1)-(X+0.5*A(1)) )50,100,100
   50 CALL XLIFT(Y(11),THET2,G(9))
C     CHECK ACTUATOR STOPS RECORDED DURING TESTS ON JUNE 23,1971
      IF(THET2-12.3)30,26,26
   26 THET2=12.3
      Y(11)=THET1
      Y(10)=0.
      G(9)=.0496
   30 G(5)=100.*Y(12)/A(2)
      G(14)=100.0*B(6)/A(2)
      RETURN
C
  100 CALL RNG5(A(1),L(1))
      GO TO 10
      END
```

```
      SUBROUTINE XLIFT(THET1,THET2,ZLIFT)
C
C     FUEL INJECTOR POSITIONING FOR LSV-16
C     WRITTEN BY BRUCE ALLEN 11/71
C     REFERENCE   EXPERIMENTAL DATA FROM JUNE 23,1971 TESTS
C
C     COMPUTES FUEL DOOR POTENTIOMETER VALUE FROM ACTUATOR POTENTIOMETER
C     COMPUTES INJECTOR LIFT (INCHES) FROM FUEL DOOR POTENTIOMETER(VOLTS
C
      THET2=1.63+1.411*THET1
      ZLIFT=.007+.0041845*(THET2-2.13)
      IF(ZLIFT-.007)10,50,50
C     PILOT POSITION LIMITS LOWER VALUE OF FUEL DELIVERED BY INJECTORS
   10 ZLIFT=.007
   50 RETURN
      END
```

```
      SUBROUTINE YPR5
      DIMENSION TRANS(50)
      COMMON ICM(20),G(90)
      COMMON CMAIN(300),DSUB1(200),DSUB2(200),DSUB3(1693),DSUB4(200)
      COMMON X,Y(13),F(13),Q(13),A(29),B(10),TITLE(20),HEAD(20),L(10),MC
     1R,MLP,L14,IA1(4),IA2(7),IC(19),ID(19),IE(19)
C
C     FUEL CONTROL DIFFERENTIAL EQUATIONS FOR LSV-16
C     WRITTEN BY BRUCE ALLEN 11/71
C     REFERENCE   EXPERIMENTAL DATA FROM JUNE 23,1971 TESTS
C
      IF (L(3)) 10,10,20
C        COMPUTES COMBINED CONSTANTS FOR TRANSFER FUNCTION EVALUATION
10    A1=A(7)
      A2=A(8)
      A3=A(9)
      A4=A(10)
      A5=A(11)
      A6=A(12)
      A(13)=A2+A3+A4-A5
      A(14)=A2*A3+A2*A4+A3*A4-A6-A2*A5-A3*A5-A4*A5+A5*A5
      A(15)=A2*A3*A4-A2*A6-A3*A6-A4*A6+A5*A6
      T1D2=A(17)/A(18)
      AA=-A(20)/(A(21)-A(22))
      BB=-AA
      TCLV=0.01
      L(3)=5
      NTRAN=4.0*A(26)/A(1)
      MAX=2*NTRAN
      IF(MAX-50)14,14,1
    1 WRITE(MLP,900)MAX
  900 FORMAT(//5X,I3,36H EXCEEDS TRANS(50) DIMENSION IN YPR5  )
      CALL EXIT
C
   14 DO 15 J=1,MAX
   15 TRANS(J)=Y(8)+Y(9)
      N=MAX
C
C     2301 AMPLIFIER
20    B(6)=G(4)-A(2)
      B(1)=B(6)/A(6)
      B(2)=A(7)*B(1)+Y(1)+Y(3)+Y(6)+A(23)
      F(1)=A(7)*A(13)*B(1)
      F(2)=A(7)*A(14)*B(1)-A(11)*Y(2)-A(12)*Y(3)
      F(3)=Y(2)
      F(4)=A(7)*A(15)*B(1)-A(11)*Y(4)-A(12)*Y(5)
      F(5)=Y(4)
      F(6)=Y(5)
C
C     LOAD SENSOR
C     XKL IS CONSTANT * PERCENT ELECTRICAL LOAD
C
      PERCT=100.*G(8)/A(19)
      XKL=A(16)*PERCT
      B(3)=T1D2*XKL+Y(7)
      F(7)=(XKL*(1.0-T1D2)-Y(7))/A(18)
C
C     HYDRAULIC ACTUATOR
      B(4)=Y(8)+Y(9)
```

```
      B(5)=B(2)+B(3)                                                    YP5 0060
      F(8)=AA*B(5)-A(21)*Y(8)                                           YP5 0061
      F(9)=BB*B(5)-A(22)*Y(9)                                           YP5 0062
C                                                                       YP5 0063
C     TRANSPORT FUNCTION LOGIC FOR HYDRAULIC ACTUATOR                   YP5 0064
      TRANS(N)=B(4)                                                     YP5 0065
      IF(N-MAX)30,25,25                                                 YP5 0066
   25 B(10)=TRANS(NTRAN)                                                YP5 0067
      DO 26 J=1,NTRAN                                                   YP5 0068
   26 TRANS(J)=TRANS(J+NTRAN)                                           YP5 0069
      N=NTRAN+1                                                         YP5 0070
      GO TO 40                                                          YP5 0071
   30 B(10)=TRANS(N-NTRAN)                                              YP5 0072
      N=N+1                                                             YP5 0073
C                                                                       YP5 0074
C     CHECK ACTUATOR STOPS                                              YP5 0075
      IF(B(10)-A(24))35,34,34                                           YP5 0076
   34 B(10)=A(24)                                                       YP5 0077
      GO TO 40                                                          YP5 0078
   35 IF(B(10)-A(25))38,40,40                                           YP5 0079
   38 B(10)=A(25)                                                       YP5 0080
C                                                                       YP5 0081
C     SPRING MASS SYSTEM WITH DAMPING FOR FUEL LINKAGE                  YP5 0082
C     COULOMB DAMPING                                                   YP5 0083
   40 B(8)=A(3)*(B(10)-Y(11))                                           YP5 0084
      IF(ABS(Y(10))-TOLV)130,130,100                                    YP5 0085
  100 IF(Y(10))110,130,120                                              YP5 0086
  110 B(9)=-A(4)                                                        YP5 0087
      GO TO 160                                                         YP5 0088
  120 B(9)=A(4)                                                         YP5 0089
      GO TO 160                                                         YP5 0090
  130 IF(ABS(B(8))-A(4))140,140,150                                     YP5 0091
  140 F(10)=0.                                                          YP5 0092
      GO TO 170                                                         YP5 0093
  150 B(9)=B(8)*A(4)/ABS(B(8))                                          YP5 0094
  160 F(10)=B(8)-B(9)                                                   YP5 0095
  170 F(11)=Y(10)                                                       YP5 0096
C                                                                       YP5 0097
C                                                                       YP5 0098
C     FREQUENCY ERROR DISPLAY CIRCUITRY                                 YP5 0099
      F(12)=(B(6)-Y(12))/A(5)                                           YP5 0100
C                                                                       YP5 0101
      RETURN                                                            YP5 0102
      END                                                               YP5 0103
```

4. SYSTEM CONTROL CARD LISTING FOR CDC SCOPE OPERATING SYSTEM

The cards listed below along with a 7-8-9 delimiter card before and after the FORTRAN deck and END OF FILE cards after the data deck are all the control cards necessary to execute the Cooper-Bessemer LSV-16 program on a CDC 6400 computer. Refer to Figure 11 (page 58) for the deck setup.

```
ADLBA,C29000,T110,CM70K. A.D.LITTLE.(ALLEN)864-5770X888*
CLEAR.
RUN(P)
LGO.
```

*to be changed on individual CDC 6000 systems.

5. NUMERICAL AND LOGICAL ANALYSIS

5.1 COMPUTATIONAL TECHNIQUES

A diesel engine generating system is represented by five subsystems (the common shaft, the alternator, the diesel, the fuel control, and the turbo-supercharger). The performance of each subsystem is calculated by the numerical integration of the differential equations which represent the physical process within each subsystem. If the initial boundary conditions (or initial values) are given then a time-history of each parameter may be calculated using a 4th order Runge-Kutta (Gill's method) integration technique.

The differential equations are for the most part non-linear and have been reduced to 1st order form. The integration interval (or time step) is determined by an error analysis.

All systems represent steady flow phenomena; and, therefore, the differential equations do not change in basic form. The diesel, however, exhibits non-steady flow (intake, compression, combustion, exhaust) and, under certain conditions, exhibits flow reversal. Thus, the form of the differential equations are subject to boundaries which are not time dependent. In fact, these boundaries are governed by pressure gradients, crank angle, or the combustion process. Iteration techniques have been coded to approach these boundaries, and these techniques, in effect, vary the time integration interval.

5.2 PROGRAM STRUCTURE

5.2.1 Basic Organization

The basic program structure follows a building block procedure so that several non-linear subsystems may be analyzed as a single, interacting system. The differential equations of each subsystem are integrated by the Runge-Kutta method at an integrating step size which is commensurate with an accurate numerical solution of the subsystem. Thus, the fastest loop will not bind the entire system to a short integrating step which would require excessive computational time with little increase in accuracy.

The key building blocks in the program are the following:

Main System - Executive Function
Environment - Ambient and Load Conditions
Subsystem #1 - Equation of Motion
Subsystem #2 - Alternator
Subsystem #3 - Diesel Engine
Subsystem #4 - Turbocharger
Subsystem #5 - Fuel Control

The names of all subroutines which constitute each system are shown in Section 6. Each of the subsystems numbered 1 through 5 is a self-contained subprogram which describes, in the form of equations and stored data, a portion of the physical system. Each subsystem has its own master routine (SUB), set of input data, and differential equations.* (Sub 2 is an exception having no differential equations.) Each is controlled by the MAIN program and communicates with other subsystems through the MAIN.

For ease of programming, pre-coded input, output, and integration routines have been developed. Thus, once a logical block diagram is developed, all that is required is the statement of the differential equations (whose non-constant coefficients may require extensive algebraic calculations or tabular look-ups) and the input data.

The main program initializes the subsystem, guides the machine through the computation process, and controls the logical flow of information between the subsystems. No computations are performed by the MAIN. The flow of information between

---

*Sub 1 will be used to refer to Subsystem 1, whereas SUB1 will refer to that subroutine which controls the computation within Sub 1, and so on for each of the subsystems.

the subsystems is schematically represented in Figure 9 (page 55). The main system and subsystems communicated parameters through Common storage. All coefficients and variables are stored in a section of Common core area which is allocated to that subsystem; thus, all programs within a subsystem communicate all variables readily. See Table 15 (page 237) for Common structure. In a different subsystem the same variable might have a different meaning or value. Thus, the areas of Common exclusive to each subsystem are masked by dummy variables. Only the G(I) and ICM(I) vectors are simultaneously communicated to all systems. Crankshaft angle, G(22), is the independent variable for the entire program and is indexed by the MAIN. The environment uses time, G(1), as its independent variable. Each of the numbered subsystems has an internal independent variable, X, which may be either time or angle. These variables are as follows:

Subsystem 1 - angle in radians
Subsystem 2 - time in seconds
Subsystem 3 - angle in degrees
Subsystem 4 - time in seconds
Subsystem 5 - time in seconds

Briefly, the computation scheme works as follows:

> The MAIN first calls each of the SUB's (subsystem "mains") and YPR's (derivative computing subroutines) in order to initialize the subsystems; the MAIN then indexes the angle forward, calls SUB1 to compute the time and ENVIR to set the environmental conditions at that time, and calls the remaining SUB's in turn. Each of the SUB's checks its internal time (or angle) against the MAIN's "clock" time (or angle) to determine whether to compute or to return to MAIN. In order to compute, SUB calls RNG (the integration routine) which in turn calls YPR four times in order to compute the derivatives necessary for integrating forward in time (or angle). The independent variable (time or angle) internal to SUB is indexed forward by RNG. Depending on its computation mesh, SUB may have to call RNG several times before returning control to MAIN. The YPR subroutine may call a number of other subroutines to perform tabular look-ups or algebraic manipulations necessary to compute the non-constant coefficients in the differential equations. Before returning to MAIN, SUB updates a number of quantities in the G array, so that the latest values will be available for printing or for use by the other subsystems. Control integers determine how often (how many steps of the angular "clock" in MAIN) the results are printed or written on the disk file (logical unit 8).

TABLE 15

STRUCTURE OF COMMON

A(I)	constant coefficients
B(I)	non-constant coefficients
D*	integration step
DD(I)*	integration step array
DMAIN(I), DSUB1(I)-DSUB5(I)	dummy variables to mask out areas of common
F(I)	derivative of dependent variable
FO(I)*	storage for F array
G(I)**	engine parameters
HEAD(I)	title at top of tape printout
IA1(I), IA2(I)	alphabetic characters used by input routines
IC(I)	alphabetic characters to be printed
ICM(I)**	program control parameters
ID(I)	first subscript number to be printed
IE(I)	last subscript number to be printed
IY(I)*	available for additional program control parameters
L(I)	counters and control indices
L14	number of print instructions read from cards
M(I)*	major mode
M1(I)*	submode
M2(I)*	submode
M3(I)*	submode
M4(I)*,	submode
MCR	logical unit number of card reader
MLP	logical unit number of line printer

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*These parameters are peculiar to subsystem 3.

**Note: These are only variables common to the main and all six subsystems.

TABLE 15 (Continued)

STRUCTURE OF COMMON

Q(I)	integration parameter
TITLE(I)	titla printed at top of output page
U(I,J)[*]	non-constant coefficients
UO(I,J)[*]	storage for U array
W14(I)[*]	fuel injection schedule angles
X(I)	independent variable (angular displacement of time)
XO(I)[*]	storage for X array
Y(I)	dependent variables computed by integration
YO(I)[*]	storage for X array

---

[*] These parameters are peculiar to subsystem 3.

After the "clock" has indexed up to the prescribed angle (A(2) in MAIN), the information on logical unit 9 is printed in column form with headings and units for easy reference. Then the Y array of Sub 3 is punched into cards, if desired, to be used as input for another run. (The tedium of manually punching the Sub 3 Y array for a 20 cylinder engine led to the addition of Subroutine PUN3 to do this job automatically.) Finally, the program attempts to read in another set of input data. The "normal" exit for the program is a job abort caused by INPM reading an END OF FILE card instead of input data.

5.2.2 Environment

The Environment is a subsystem which supplies values for those parameters which characterize the engine's interaction with its environment and load. Although the Environment uses the same Common space, and input and print routines as the MAIN program, it is for all intents and purposes a separate subsystem which consists of the subroutines AMB10, AMB12, and ENVIR. The subroutine ENVIR acts as the "main" for this subsystem. The Environment is an analytically described function of time with the values being input via cards.

In describing the environment, there are three sub-options. The first is that of having constant inlet pressure and temperature, and exhaust pressure. These are set within ENVIR. The second sub-option is that of having AMB12 generate a "standard" airshock (ramp pressure rise, exponential decay). The third sub-option is to have ABM10 generate inlet pressure, inlet temperature, and exhaust pressure profiles of a prescribed arbitrary shape. Up to 12 data points for each of the above parameters may be used (as input data) to describe its profile. AMB10 interpolates in a straight line fashion between these points. Under all three of these sub-options, the generator load is set in Subsystem 2 and may be varied independently of the environmental pressures and temperatures. The input data required to implement each of these options is described in detail later.

5.2.3 Equation of Motion, Sub 1

The Equation of Motion (Sub 1) performs three functions: First, it computes the angular speed of the shaft of the engine-generator set using the equation given in Part I.5.3.3. The developed torque, τ_d, is not used directly in this equation; rather, four coefficients, G(24)-G(27), are calculated in Sub 3 then used in Sub 1 to calculate shaft speed. This transfer of information is shown symbolically in Figure 9 (page 55) as simply the transfer of τ_d from Sub 3 to Sub 1. The second function of Sub 1 is computing the time from the angular speed and the shaft angle. The third function of Sub 1, which is unrelated to the first two, is that of keeping an energy balance for the engine. The energy rates going to various functions are calculated in Sub 3 and integrated in Sub 1 in order to keep a running sum of the energy spent as shaft power, friction, etc. These sums are set to zero at the beginning of each cycle, so that the values calculated are for one complete cycle. A summary of the computation process with Sub 1 is shown in Figure 12 (page 241) and the corresponding logical control points are explained in Table 16 (page 242).

5.2.4 Alternator, Sub 2

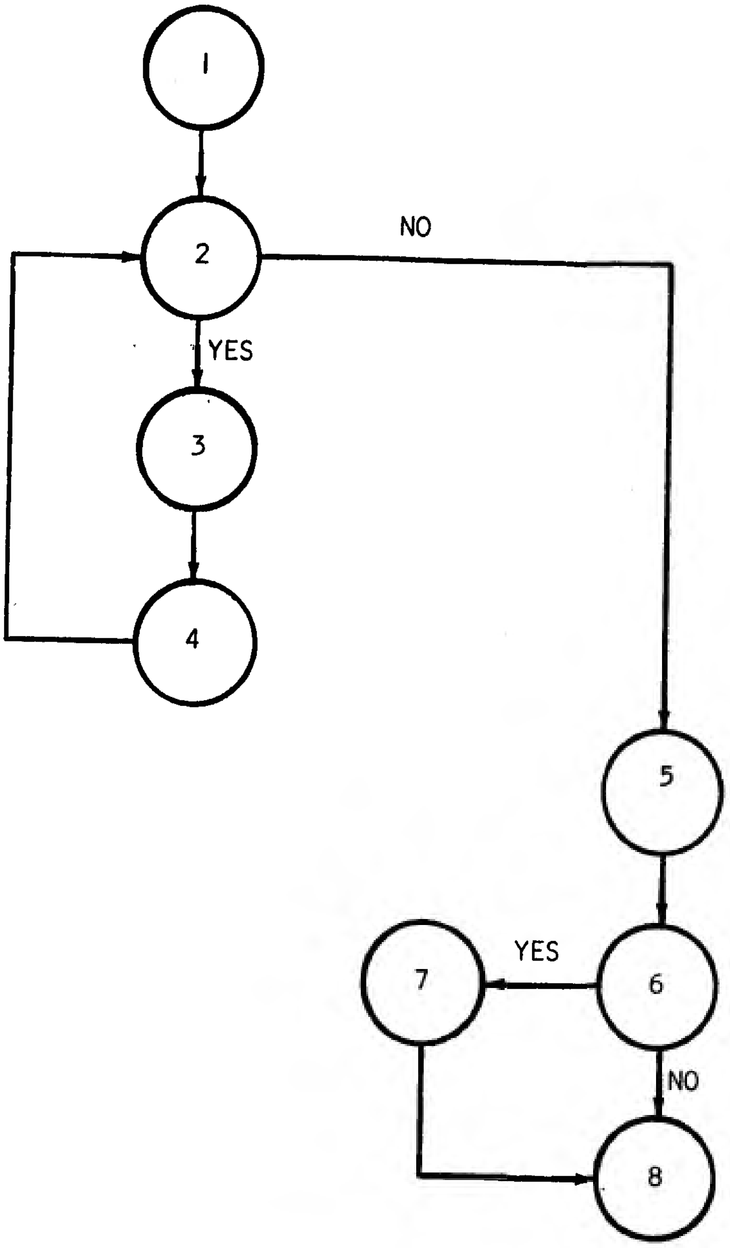
In the case of the Cooper-Bessemer diesel engine-generator set, the Alternator (Sub 2) has been represented simply as a load requiring constant power. As such, this subsystem has no differential equations or integration routines. The electrical power divided by shaft torque and generator efficiency. The shaft torque is set in Sub 2. The generator power is input data for Sub 2. It is possible, by use of other Sub 2 input data, to simulate a step load change. The logical flow of information is shown on Figure 13 (page 243) and Table 17 (page 244).

A program capable of a detailed simulation of the electrical equipment is described in Reference 2. This alternator program is designed to be used as a subsystem within the computational framework presented here.

The alternator program includes a detailed analysis of the electrical generating equipment and voltage controls. The introduction of the alternator program will extend the computer solution time by a factor of approximately 1.5. The Common area reserved for Sub 2 will have to be expanded (see Common setup of Reference 2) and the variables which must communicate with the MAIN program in the G vector (see paragraph 11, Computer Functional Description) must be properly defined in consistent units; otherwise, little recoding is required.

5.2.5 Diesel, Sub 3

Subsystem 3 is suitable, without change, for describing any of a variety of diesel engines. Those routines which require revision in order to model an engine other than the Cooper-Bessemer LSV-16 are shown in Table 18 (page 245). Sub 3 is capable of simulating a two or four cycle diesel engine with up to 20 cylinders, having up to 10 manifolds (intake plus exhaust). The cylinders may be connected in any arbitrary fashion to the manifolds, e.g., Cylinder 2 may be connected to Inlet



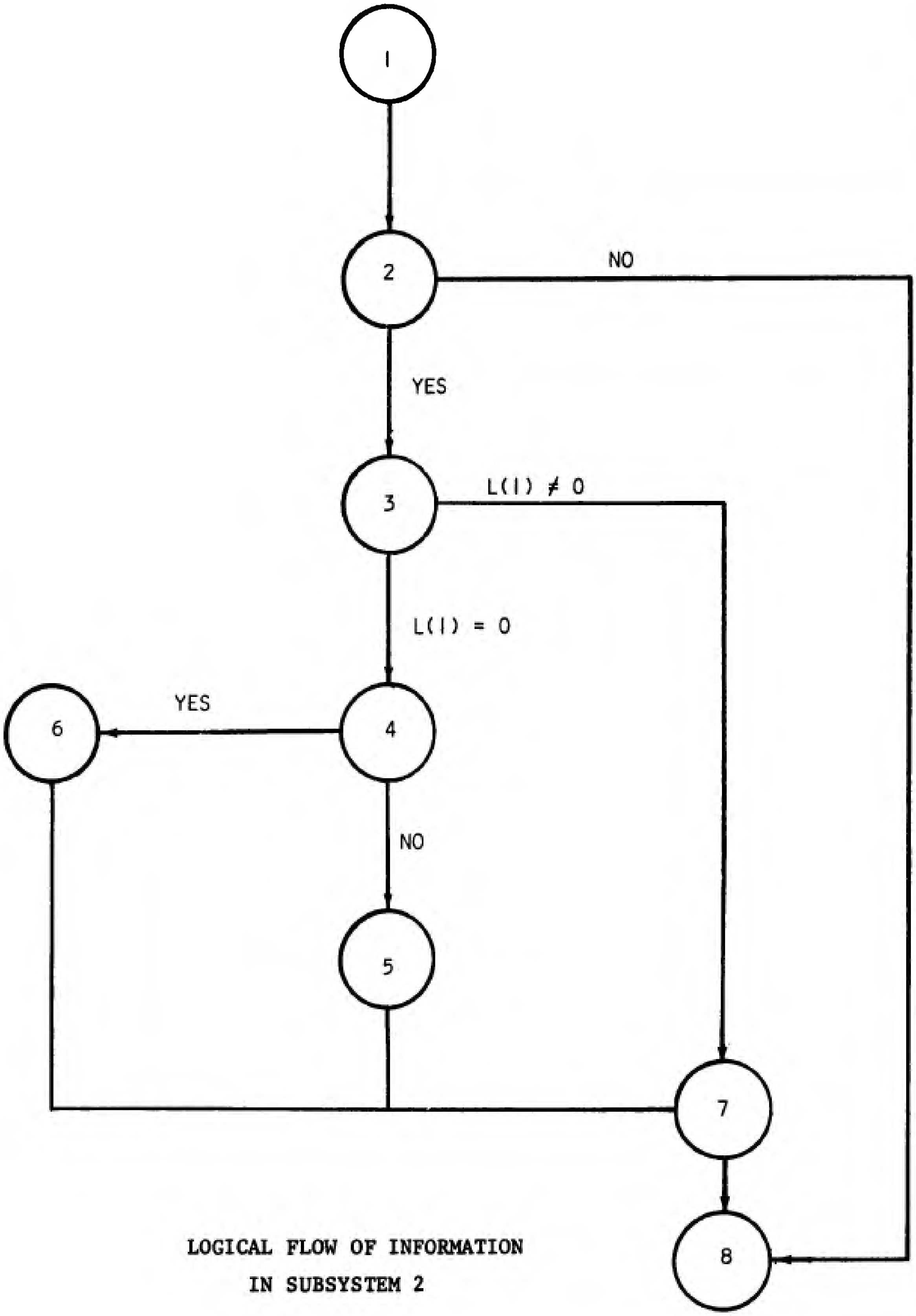
LOGICAL FLOW OF INFORMATION
IN SUBSYSTEM 1

FIGURE 12

TABLE 16

LOGICAL FLOW OF INFORMATION IN SUBSYSTEM 1

1. Enter Subsystem 1.
2. Compare external and internal crank angle to determine if integration is needed. If not, go to Step 5 before returning to MAIN.
3. Integration required: Compute all values for integrating differential equations used to describe the equation of motion.
4. Integration equations and advance internal crank angle for Subsystem 1. Go to Step 2.
5. Set communication variables (G array) for time, crankshaft speed, and acceleration.
6. Check to see if an engine cycle has been completed. If not, go to Step 8.
7. If reached the end of an engine cycle, set communication variables for energy balance and compute engine performance using values integrated during past cycle.
8. Exit Subsystem 1.



LOGICAL FLOW OF INFORMATION
IN SUBSYSTEM 2

FIGURE 13

TABLE 17

LOGICAL FLOW OF INFORMATION IN SUBSYSTEM 2

1. Enter Subsystem 2.
2. Compare external and internal time clock to determine if any calculations should be made in this Subsystem. If not, go to Step 8.
3. If so, is flag L(1) = 0? If so, go to Step 4. If not, go to Step 7.
4. Compare internal time and time of load change to determine if load has been changed. If not, go to Step 5. If so, go to Step 6.
5. Set torque for full load. Go to Step 7.
6. Set torque for changed load.
7. Calculate electrical frequency.
8. Exit Subsystem 2.

TABLE 18

SUBPROGRAMS REQUIRING RECOMPILATION FOR DIESEL SIMULATION OTHER THAN THE COOPER-BESSEMER LSV-16

SUBPROGRAM NAME	SUBSYSTEM	UNIQUE FEATURE
SUBROUTINE ENVIR	MAIN	ambient conditions
FUNCTION AEV	3	exhaust valving
FUNCTION AIV	3	inlet valving
SUBROUTINE RACK	3	fuel injection rates
SUBROUTINE TABLE	3	engine cranking kinematics
SUBROUTINE CMAP	4	turbocharger compressor map
FUNCTION DPIC	4	intercooler pressure drop
SUBROUTINE POLYE	4	turbocharger compressor efficiency
FUNCTION TIC	4	intercooler temperature
SUBROUTINE TMAP	4	turbocharger turbine
SUBROUTINE XLIFT	4	fuel injector positioning
SUBROUTINE YPR5	5	fuel control

Manifold 1 and Exhaust Manifold 4. There are no obvious limitations to size or geometry since these elements, like the number of cylinders and manifolds, are specified by input data. The valve area subroutines AEV and AIV can be set up to describe any arbitrary valve open area history, including one for "leaky" valves, where the valve area is never zero. (This feature allows the performance of a degraded or worn engine to be simulated.)

The key to keeping track of the events occurring within the cylinders and the manifolds is the set of mode numbers used in Sub 3. These numbers, the value of which are assigned by Subroutines IMODE and CHANG, are used to select the appropriate equations in YP3, and the subroutines called from YP3, to describe the physical processes occurring at that instant of time within a particular cylinder. Table 19 (page 247) summarizes the values, together with their meanings, which may be taken on by the major mode, M(I), and the submodes, M1(I), M2(I), M3(I), and M4(I). A summary of the computation process within Sub 3 is shown in Figure 14 (page 248) and in Table 20 (page 249).

5.2.6 Turbocharger and Intercooler

The processes occurring in the turbocharger and intercooler are described in Subsystem 4. The treatment of the turbocharger is similar to that of a single shaft gas turbine engine. The performance of the turbine is approximated by analytical expressions while that of the compressor is described by performance map data described earlier.

This subsystem has two general purpose routines, SUB4 and YPR4, which can apply to any turbocharger. Features peculiar to the Cooper-Bessemer turbine are contained in Subroutine TMAP. Likewise, those features peculiar to the Cooper-Bessemer compressor are contained in Subroutine CMAP. Subroutine CMAP and another map routine, POLYE, together return compressor performance data. CMAP computes mass flow, $\dot{m}_i$, torque, τ_c, and compressor exit temperature, T_e, given compressor pressure information and speed, ω_t. POLYE computes compressor efficiency, η_c, from pressure ratio and speed data. CMAP is set up to linearly interpolate between data points retrieved from the performance map. POLYE calculates efficiencies for speed lines on either side of N_t from map data and linearly interpolates between the two values. A summary of the computation process within Sub 4 is shown in Figure 15 (page 250) and the corresponding logical control points are explained in Table 21 (page 251).

TABLE 19

MODE STRUCTURE OF SUBSYSTEM 3

M(I)	=	1	Intake
		2	Compression
		3	Combustion and Expansion
		4	Exhaust
		5	Scavenge
M1(I)	=	1	$P_{im} \geq P_c$
		2	$P_{im} < P_c$
M2(I)	=	1	$P_c \geq P_{em}$
		2	$P_c < P_{em}$
M3(I)	=	0	$M(I) \neq 3$
		1	$\theta_1 \leq \theta < \theta_2$
		2	$\theta_2 \leq \theta < \theta_3$
		3	$\theta_3 \leq \theta < \theta_4$
		4	$\theta_4 \leq \theta$
M4(I)	=	0	$M(I) \neq 3$
		1	$\theta < \theta_1 + \theta_d$
		2	$\theta \geq \theta_1 + \theta_d$; combustion occurs
		4	$m_f = 0$; combustion complete

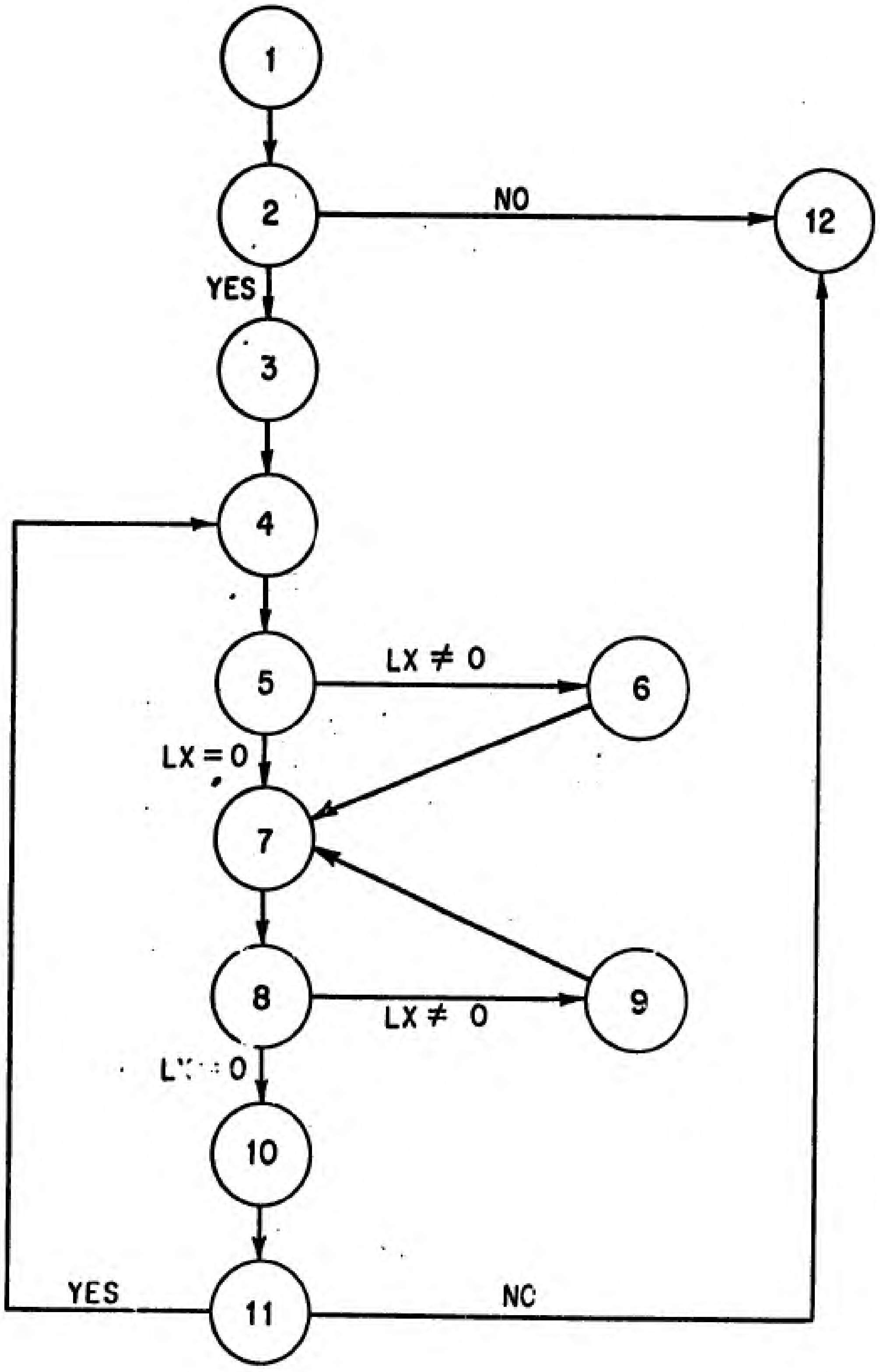
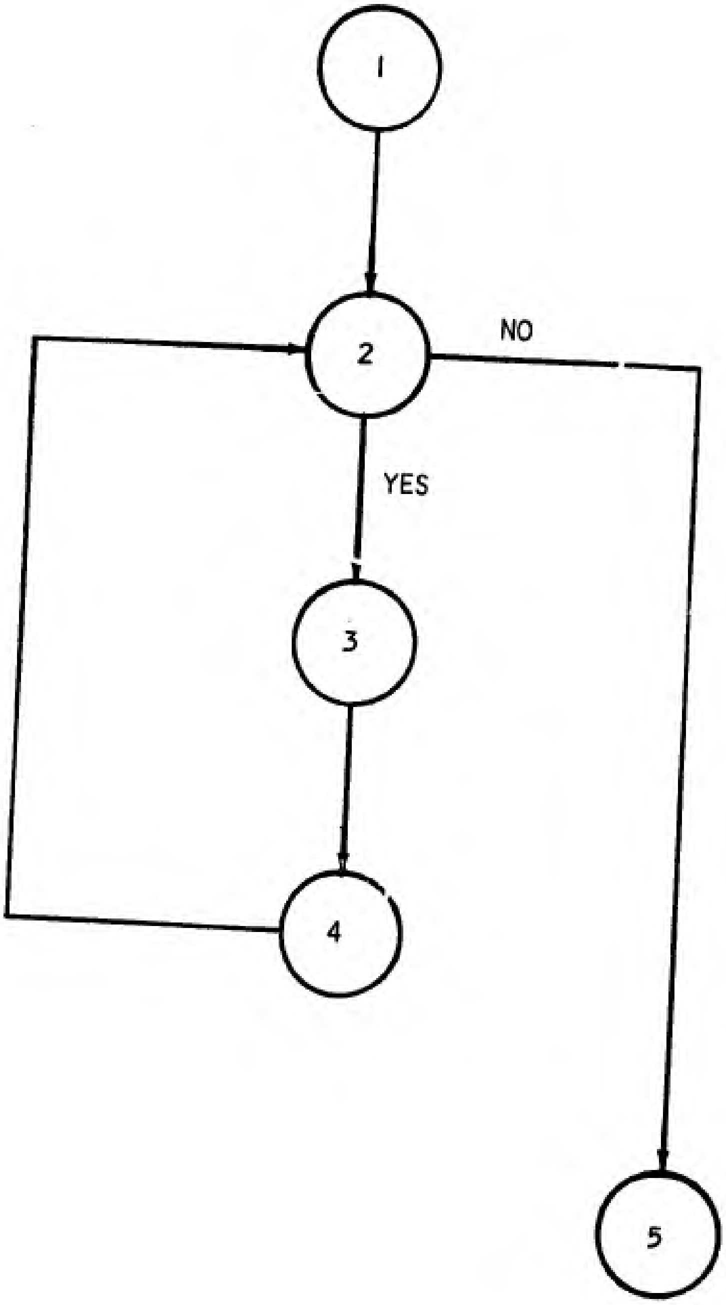


FIGURE 14 LOGICAL FLOW OF INFORMATION IN SUBSYSTEM 3

TABLE 20

LOGICAL FLOW OF INFORMATION IN SUBSYSTEM 3

1. Enter
2. Determine if integration is needed; if not, go to Step 12.
3. Call RACK and set new fuel angle setting; call IMODE and reset all major modes and submodes.
4. Store X and Y arrays into XO, YO.
5. Call ANGLE, set LX ≠ 0 if integration step is to be shortened. For intake, compression, exhaust or scavenge modes, see if angle which ends mode is exceeded in integration step, D. If so, store A(KK) - X(I) in DD(LX). For combustion mode, set D = DXC and determine if any fuel injector angles W14(KK) are exceeded; if so, store W14(KK) - X(I) in DD(LX).
6. Set D = minimum value of DD(LX).
7. Call RK3 and integrate Y array to X(I) + D.
8. Call PTDSL, set LX ≠ 0 if a critical points which defines a change in submode has been exceeded in integration of Step 7. As submodes may be changed by changes in dependent variable Y, the integration step can only be estimated; store in DD(LX).
9. If LX ≠ 0, set D equal to minimum value of DD(LX); reset X and Y arrays to original values stored in XO, YO. Go to Step 7.
10. Store M, M1, M2, M3, M4 arrays into MX, MX1, MX2, MX3, MX4 arrays; call CHANG to determine if mode change has occurred and to reset mode arrays; calculate peak temperatures and pressures.
11. Determine if integration is needed; if not, go to Step 12; if so, go to Step 4.
12. Set G array, exit.



LOGICAL FLOW OF INFORMATION
IN SUBSYSTEM 4

FIGURE 15

TABLE 21

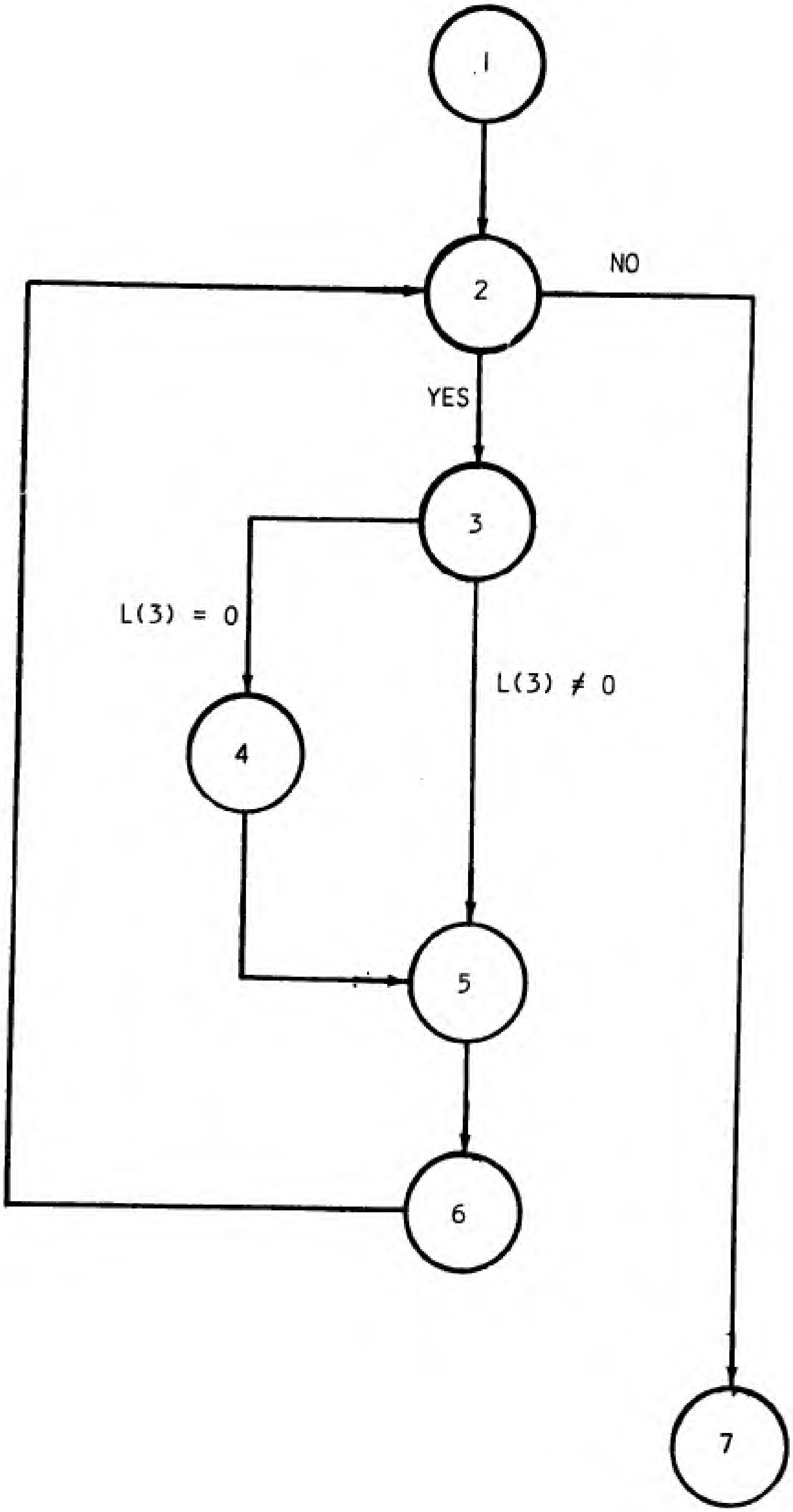
LOGICAL FLOW OF INFORMATION IN SUBSYSTEM 4

1. Enter Subsystem 4.
2. Compare external and internal time clocks to determine if integration is needed. If not, go to Step 5 before returning to MAIN.
3. Integration required: Compute all values required for integrating differential equations used to describe the turbocharger performance.
4. Integrate equations and advance internal time clock for Subsystem 4. Go to Step 2.
5. Calculate inlet and exhaust manifold data for G array. Exit Subsystem 4.

5.2.7 Fuel Control

The transfer functions which describe the response of the fuel control are reduced to time dependent first order differential equations which can be numerically integrated. These differential equations are located in Subsystem 5 of the Diesel Engine Simulation Program. Subsystem 5 contains the programming required to simulate all operations of the fuel control. The fuel control system closes the loop between sensing the engine-generator set operating point as described by electrical frequency and electrical load, and the positioning of the fuel metering device.

Subroutine YPR5 contains the differential equations for computation during the integration process. The evaluation of these equations yields the position of the hydraulic actuator. Subroutine SUB5 checks to determine if the actuator has hit a stop. Function XLIFT returns the fuel injector position measured as injector lift (analogous to rack position), as a function of actuator position. A summary of the computation process within Sub 5 is shown in Figure 16 (page 253) and the corresponding logical control points are explained in Table 22 (page 254).



LOGICAL FLOW OF INFORMATION
IN SUBSYSTEM 5

FIGURE 16

TABLE 22

LOGICAL FLOW OF INFORMATION IN SUBSYSTEM 5

1. Enter Subsystem 5.

2. Compare external and internal time clocks to determine if integration is needed. If not, go to Step 7 before returning to MAIN.

3. Integration required: Is flag L(3) = 0? If so, go to Step 4. If not, go to Step 5.

4. Compute combined constants for fuel control transfer function evaluation. Set L(3) = 5.

5. Compute all values required for integrating differential equations used to describe the fuel control.

6. Integrate equations and advance internal time clock for Subsystem 5.

7. Check to find out if actuator has hit upper or lower stops. If so, set at appropriate limit. Compute fuel door position and injector lift for actuator position.

8. Exit Subsystem 5.

6. SUBROUTINES

This section contains the complete list of all subprograms required by the C-B-LSV-16. This list includes subprogram name, arguments, and the function of each subprogram within the diesel simulation program.

6.1 SUBPROGRAMS

6.1.1 Subprograms used by the MAIN of Program DIESEL

NAME	ARGUMENTS	COMMENTS
AMB10		Simulates arbitrary air shock profile.
AMB12		Simulates standard air shock.
ENVIR		Sets environmental conditions.
INPM		Reads input data for Main.
PLOT	IF8	Writes selected variables from G array on logical unit 8 (disk) and logical unit 4 (output tape); where IF8 = no. of records.
PRT8	IF8	Prints information from logical unit 8; where IF8 = no. of records.
PRTM		Prints information from Main Common.
*STORE	I1, I2, Z, A, NDA, KKY	Stores real number input data in common; where I1 = subscript of first value to store, I2 = subscript of last value to store, Z = corresponding array values, A = Real variable array name, NDA = maximum allowed length of array, KKY = flag for exceeding max. length.
*STORI	I1, I2, Z, N, NDN, KKY	Stores integer input data in Common; where I1 = subscript of first value to store, I2 = subscript of last value to store, Z = corresponding array values, N = integer variable array name, NDN = maximum allowed length of array, KKY = flag for exceeding max. length.
ZRDSL		Zeroes Common for entire program.

*These subroutines are used by the input subroutine in each subsystem.

6.1.2 Subprograms used by Subsystem 1 (Equation of Motion)

NAME	ARGUMENTS	COMMENTS
INP1		Reads input data for Sub 1.
PRT1		Prints results of Sub 1 calculations.
RNG1	H1, N1	Integrates differential equations in YPR1; where H1 = computation mesh, N1 = number of equations.
SUB1		Controls calculations in Subsystem 1
YPR1		Calculates the derivatives associated with the equation of motion and energy balance.

6.1.3 Subprograms used by Subsystem 2 (Alternator)

INP2		Reads input data for Sub 2.
PRT2		Prints results of Sub 2 calculations.
SUB2		Calculates generator frequency and torque.

6.1.4 Subprograms used by Subsystem 3 (Diesel Engine)

AEV	THETA, COEF	Calculates exhaust valve area; where THETA = crankshaft angle, COEF = orifice coefficient for exhaust valve.
AIV	THETA, COEF	Calculates inlet valve area; where THETA = crankshaft angle, COEF = orifice coefficient for inlet valve.
ANGLE	LX	Determines integration step size based on angular-dependent events; where LX = counter (see Table 20, p. 249).
CHANG	LX	Changes major mode and submodes, as required, after successful integration; where LX = control counter (see Table 20 , p. 249).

6.1.5 Subprograms used by Subsystem 3 (Diesel Engine) (Cont.)

NAME	ARGUMENTS	COMMENTS
DM	P1, P2, A, T, C	Calculates flow through valves; where P1 = pressure before valve, P2 = pressure after valve, A = effective valve, T = temperature of fluid at valve, C = ratio of specific heat in exhaust manifold.
DMFB	WBR, M4, WF, XC, AMC, BRR	Calculates fuel burning rate; where WBR = fuel burning rate, M4 = combustion mode, WF = mass of unburned fuel in cylinder, XC = combustion products charge in cylinder, AMC = gas charge in cylinder, BRR = burning rate constant.
EXMAN	HEM, AEM, TWEM, GAMMA, VEM, TGEM, OMEGA	Calculates heat loss to exhaust manifold water jacket; where HEM = heat transfer coefficient for exhaust manifold, AEM = heat transfer area for single exhaust manifold, TWEM = temperature of exhaust manifold wall, GAMMA = ratio of specific heats for air, VEM = volume of exhaust manifold, TEEM = exhaust manifold temperature, OMEGA = crankshaft angular speed.
FI	WF, M1, WFM, A1, A2, A3, A4, XCYCL	Calculates the instantaneous fuel injection rate for a cylinder; where WF = fuel injection rate, M1 = injection schedule mode identifier, WFM = maximum fuel injection rate, A1 = crank angle when fuel injection begins, A2 = crank angle to start maximum injection rate, A3 = crank angle to end maximum injection rate, A4 = crank angle to end injection. XCYCL = cylinder crank angle.
IMODE		Sets up the major mode and submodes from the values of physical parameters.
INP3		Reads input data for Sub 3.
PEAK	Y1, Y2, Y3, YMAX, YMIN, XX, XY, XZ, 1PEAK, NSC	Calculates peak cylinder pressures and temperatures; when Y1 = cylinder temperature or pressure from last regular integration step, Y2 = cylinder temperature or pressure at current regular integration step. Y3 = cylinder temperature or pressure at intermediate integration step required to find peak value, YMAX = peak value of temperature or pressure, YMIN = minimum value to check as a peak for temperature or pressure, XX = crank angle from last regular integration step, XY = crank angles at current regular integration step, XZ = crank angle at intermediate integration step required to find peak value, 1PEAK = flag when peak value is reached, NSC = number of strokes per cycle.

6.1.6 Subprograms used by Subsystem 3 (Diesel Engine) (Cont.)

NAME	ARGUMENTS	COMMENTS
PRT3		Prints results of Sub 3 calculations.
PTDSL	LX	Determines integration step size bases on flow reversal and end of combustion; where LX = control counter.
PUN3		Punches Y array of Sub 3 into cards with input format at the end of a run.
RACK	A1, A2, A3, A4, WFM, ZEE, OMEGA, NSC, NC	Calculates the four angles associated with the fuel injection schedule and the fuel consumption rate for a single cylinder; where A1 = crank angle when fuel injection begins, A2 = crank angle to start maximum injection rate, A3 = crank angle to end maximum injection rate, A4 = crank angle when fuel injection ends, WFM = maximum fule injection rate, ZEE = injector lift, OMEGA = crankshaft speed, NSC = number of strokes per cycle, NC = number of cylinders.
RK3		Integrates the differential equations in YP3.
SUB3		Controls calculations in Subsystem 3.
TABLE	CO, F1, F2, F3, F4, F5, VO, AD, PD	Calculates kinematic relationships between crankshaft angle and piston position, velocity and acceleration; when CO = value of crankshaft angle for master (right bank) cylinder, F1(1),F1(2) = cylinder position for master and slave, F2(1),F2(2) = cylinder velocity for master and slave, F3(1),F3(2) = cylinder acceleration for master and slave, F4(1),F4(2) = cylinder volume for master and slave, F5(1),F5(2) = cylinder heat transfer area for master and slave, VO = cylinder clearance volume, AD = piston cross-sectional area, PD = piston perimeter.
YP3		Calculates the derivatives associated with the equations describing pressures and mass balances in cylinders and manifolds

6.1.7 Subprograms used by Subsystem 4 (Turbocharger)

NAME	ARGUMENTS	COMMENTS
CMAP	FLOC, TORC, TC, YO, XO, ETA, SPEED, TA1, PA1, PC, MLP. FACT	Calculates corrected mass flow through turbocharger compressor; where FLOC = compressor mass flow, TORC = compressor torque, TC = compressor discharge temperature, YO = pressure ratio, XO = corrected mass, ETA = efficiency, SPEED = turbocharger shaft speed, TA1 = ambient temperature at compressor inlet, PA1 = ambient pressure at compressor inlet, PC = compressor discharge pressure, MLP = logical unit number for output, FACT = compressor flow adjustment factor.
DPIC	AIRM	Computes pressure drop across intercooler; where AIRM = total mass flow at all compressors.
INP4		Reads input data for Sub 4.
POLYE	AN, P1, MLP, ETA	Calculates turbocharger compressor efficiency; where AN = turbocharger shaft speed, P1 = pressure ratio, MLP = logical unit number for output, ETA = efficiency.
PRT4		Prints results of Sub 4 calculations.
RNG4	H1, N1	Integrates the differential equations in YPR4; where H1 = integration mesh, N1 = number of differential equations.
SUB4		Controls calculations in Subsystem 4.
TIC	AIRM	Computes intercooler temperature; where AIRM = total compressor mass flow.
TMAP	FLOW, TORQ, TEXH, SPEED, T1, P1, P3, NLP. FF	Calculates corrected mass flow through turbocharger turbine; where FLOW = turbine mass flow, TORQ = turbine torque, TEXH = turbine exit temperature, SPEED = turbocharger shaft speed, T1 = exhaust manifold temperature, P1 = exhaust manifold pressure, P3 = ambient pressure at exhaust, MLP = logical unit number for output, FF = turbine efficiency adjustment factor.
YPR4		Calculates derivative associated with turbocharger equation of motion.

6.1.8 Subprograms used by Subsystem 5 (Fuel Control)

NAME	ARGUMENTS	COMMENTS
INP5		Reads input data for Sub 5.
PRT5		Prints results of Sub 5 calculations.
RNG5	H1, N1	Integrates differential equations in YPR5; where H1 = inter mesh, N1 = number of equations to integrate.
SUB5		Controls calculations in Subsystem 5.
XLIFT	THET1, THET2, ZLIFT	Calculates fuel injector lift; where THET1 = hydraulic actuator output, THET2 = fuel door position, ZLIFT = fuel injector lift.
YPR5		Calculates the derivatives associated with the differential equations describing the fuel control system.