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CR-114915

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R-8445

FINAL REPORT

GENERALIZED PROPULSION SYSTEM MODEL
FOR
NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

NOT REPRODUCIBLE

CONTRACT NO. NAS9-10319

FACILITY FORM 602

N71-20173	
(ACCESSION NUMBER)	(THRU)
225	G3
(PAGES)	(CODE)
CR-114915	28
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

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NO. OF PAGES iv & 218

REVISIONS

DATE 11 March 1971

DATE	REV. BY	PAGES AFFECTED	REMARKS

FORM R18-G REV. 5-69

FOREWORD

The Generalized Propulsion System Model is a digital computer program designed to study transient performance of pressure fed rocket engine systems. This is the final report of the work performed for the NASA Manned Spacecraft Center, Houston, Texas under Contract NAS9-10319. This report covers the work accomplished during the period 12 January 1970 to 12 January 1971.

SUMMARY

This program was accomplished in three phases. In the initial phase analytical techniques which could be used to characterize the behavior of pressure-fed rocket engines were evaluated. The selected techniques were programmed for solution on a digital computer in the second phase, and after debugging the necessary manuals and guides were written to allow use of the program. In the third phase the program was demonstrated by modeling the Apollo Ascent and Descent Engines, and the pressurization system of Rocketdyne's SE5-5 engine system. The program was concluded with the successful operation of the program on the NASA, Houston Univac 1108 computer.

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ILLUSTRATIONS

INTRODUCTION

The purpose of the Generalized Propulsion System Model program is to provide a general purpose, modular, digital computer program for simulating transient operation in pressure-fed rocket engine systems. In order to accomplish this, an existing Rocketdyne digital computer program was modified so that it met the requirements of the contract. The effort in this program was divided into three phases. In the first phase an evaluation of the analytical techniques used to characterize the dynamic behavior of pressure-fed rocket propulsion systems was made. In Phase II the techniques selected in Phase I were programmed and the program instruction documents written. In Phase III the use of the program was demonstrated by modeling the Apollo Ascent and Descent engines and the Rocketdyne SE5-5 Propulsion System.

The digital model, resulting from completion of this program, is flexible and has options for calculating the performance of a number of different components. It describes the propellant line dynamics using the wave equations and calculates the pressure and flow conditions when a portion of a line is being filled. The model allows a system to be broken down into a number of segments, and by proper combination, many different plumbing configurations may be simulated.

In between segments, components used in rocket engine feed systems can be installed by use of the input data and since the performance of these components is calculated entirely in subroutines, it is an easy task to add new components or change the existing ones.

The model which was developed in this program was based on an existing Rocketdyne pressure-fed rocket engine model which has been used to calculate the performance of various rocket engine systems. In order to make this program meet the requirements of this contract several modifications were necessary. The most commonly used features had to be built into the program so that they could be called out by input data. In addition, several new features were added as follows:

1. A simplified pressurization system which includes a propellant-gas heat exchanger and allows calculation of gas flow, pressure and temperature.

2. Changes in feed line representation to include effects of two-phase flow.

3. Improvement of thrust chamber and injector response, including the addition of injection stream ballistic dynamics and injector orifice inertance.

4. Injector-thrust chamber blowdown after propellant valve closure.

5. Built-in components which include valves, cavitating venturis, capped lines, accumulators, etc.

The use of subroutines, to calculate the performance of different types of components, was continued and improved by proper grouping of calculations so that maintenance and modifications of the functions will be simplified. The mathematical basis of the various program functions, a description of the digital computer model, and the results of the demonstration phase are given in the following sections. A list of symbols used is presented in Table I.

RESULTS AND CONCLUSIONS

This program has demonstrated that the Generalized Propulsion System Model, described by this report, can be successfully used to model the transient operation of pressure-fed rocket engine systems. In addition, the program has been satisfactorily run on the NASA, Houston, Univac 1108 computer. The operation of the program was demonstrated using four different transient simulations:

1. Apollo Ascent Engine On-Off Pulse
   The model simulated this transient quite accurately. The predicted thrust chamber ignition spike agreed with the test data within 6% and the shape of all transients agreed quite well with the data. The small differences seen have been attributed to instrumentation line phenomena which were not simulated in the model.

2. Apollo Descent Engine Start Transient
   The purpose of simulating this transient was to demonstrate model operation with two phase propellant flow. The results of this simulation showed good agreement with the test data; by adjusting the rate at which pressurant gas comes out of solution - from saturated propellants - it should be possible to obtain almost exact agreement between the test data and model results. Difficulty in obtaining operation of the model with two phase flow was experienced during the initial simulation of this system. The problem was traced to a computational instability due to a rapid increase in acoustic velocity which occurs after the feed system primes and the pressure increases, causing pressurant gas to go back into solution. The problem was solved by using a fixed value for the density of the pressurant gas in the model.

3. Apollo Descent Engine LM-3 Flight Anomaly
   Analysis of flight data from the Apollo 9 flight showed that a period of rough burning, which occurred during the second burn of the Descent Engine, was caused by pressurant gas bubbles in the fuel and oxidizer feed system.

The modeling of this transient required modifications to the program deck and demonstrated the flexibility of the program. Agreement between model results and test data were only qualitative. The model simulated this problem by assuming that there was only one discrete bubble in each of the systems. After running the problem it became apparent that several bubbles separated by propellant must have been in each feedline, and since the model was not set up to simulate this condition, it was not possible to obtain good correlation.

SE5-5 Pressurization System

This model of a Rocketdyne propulsion system was made to demonstrate the operation of the model's pressurization system simulation. The system simulated the pressurization of a fuel and oxidizer propellant tank from a high pressure storage bottle through a regulator. As the propellant pressure increased, burst diaphragms in the tank outlet broke and propellant filled the engine feed lines. After the feed lines were full of propellant, the propellant tank pressure increased to the regulator lockup pressure. The model provided a realistic simulation of all events occurring during pressurization.

RECOMMENDATIONS

The two phase flow description in the model is designed to handle small bubbles of pressurant gas uniformly mixed with liquid propellant. The description used has been demonstrated to be adequate to describe the Apollo Descent Engine start transient. However, to develop confidence in the method used to model this phenomena, additional correlating test data should be obtained.

The present model has not been designed to handle pump fed, regeneratively cooled, cryogenic propellant engines, although it forms a good base to build such a model. Since it is planned to use these engines as maneuvering engines in future space flights, a program should be started to prepare the subroutines needed for this use. This would require the addition of routines to provide performance of turbopumps, heat transfer to propellants, and additional propellant property data to handle the problem of phase changes.

Since one of the areas of proposed use of the model was the study of feed system coupled instabilities, the model should be used to study a known instability of this type. In so doing, its use as a tool to help solve these instabilities could be proven.

MATHEMATICAL CHARACTERIZATION

FEED SYSTEM DYNAMICS

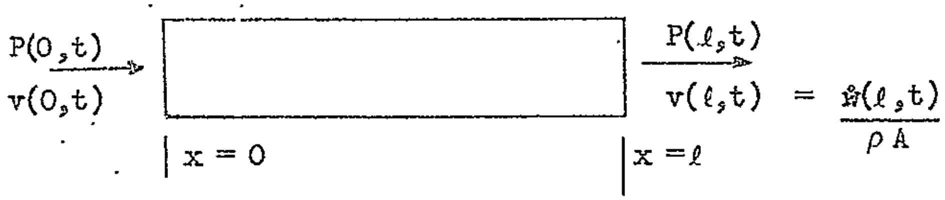
Wave Equation

In order to simulate the dynamics of a pressure fed rocket engine system, it is necessary to consider the dynamics of all of its components. The rocket engine feedline dynamics are involved in the start and cutoff transients and in feed system coupled instabilities, therefore, their correct representation in a dynamic model is both necessary and important. In general, two different methods of simulating feedlines are used; (1) lumped parameters, and (2) distributed parameters. In the first method, it is assumed that the liquid in a line moves as a solid lump; the fact that the fluid is compressible is handled by a storage term in the analytical expression. The distributed parameter representation assumes a continuous media and shows that disturbances are propagated by waves at the speed of sound in the fluid. Both methods can be used to give an adequate dynamic representation of the feedlines, however, it is felt that the wave equations (distributed parameter) are more practical for a general purpose model. The wave equations have theoretically unlimited frequency response, whereas the response of a lumped parameter system will depend on the number of elements into which it is broken. The wave equations are utilized in this model because they yield accurate frequency response independent of the line length assigned to the segment.

he equations used are the normal water hammer equations:

$$\frac{\partial P}{\partial x} = -K_1 \frac{\partial v}{\partial t} \quad \text{and} \quad \frac{\partial v}{\partial x} = -K_2 \frac{\partial P}{\partial t}$$

The solution of these equations involves terms which include past, present, and future values of velocity and pressure. By using Laplace transformation techniques and the equation of continuity, the above expressions may be solved for the pipe segment shown below



The resultant equations are:

$$\mathring{w}(\ell,t) = \rho A v(t) = \mathring{w}(t) \tag{1}$$

$$P(\ell,t) = -\frac{a}{Ag}\,\mathring{w}(\ell,t) + 2P(0,t-\tau) + \frac{a}{Ag}\,\mathring{w}(\ell,t-2\tau) - P(\ell,t-2\tau) \tag{2}$$

$$P(0,t) = P(t) \tag{3}$$

$$\mathring{w}(0,t) = \frac{Ag}{a}\,P(0,t) + 2\mathring{w}(\ell,t-\tau) - \frac{Ag}{a}\,P(0,t-2\tau) + \mathring{w}(0,t-2\tau) \tag{4}$$

and since this solution involves only past history, we may solve for the flow and pressure at each end of a pipe segment directly.

To include the effect of fluid resistance, the segment pressure drop is lumped at the downstream end of the pipe. Thus:

$$P\ \ (\ell,t) = P(\ell,t) + R\,\mathring{w}(\ell,t)\cdot|\mathring{w}(\ell,t)| \tag{5}$$

Acoustic Velocity

The acoustic velocity of the fluid enters into the above calculation in two places; (1) directly in the constant relating flow to pressure, and (2) indirectly in the time delay value τ which equals $\frac{\ell}{a}$ seconds. The acoustic velocity of a fluid is a property of that fluid, however, its effective value is reduced by the elastic walls of a pipe or entrainment of gas and vapor in the liquid-two phase flow. Vapor in the liquid can come from two places. One is direct entrainment from mixing of gas and liquid in the propellant tank, and the second results from evolution of dissolved gas if the liquid is supersaturated.

Dissolved pressurant gas in liquids obeys Henry's law which says that the amount of dissolved gas at equilibrium is a linear function of pressure. Thus the equilibrium value of dissolved gas will decrease as pressure is reduced. Because of the pressure drop in the feedlines, the pressure will decrease as the propellant flows toward the engine, and there is a tendency for gas to be evolved. The rate at which the gas is evolved appears to be at a rate proportional to its excess. Thus

$$\frac{d}{dt} G(t) = - \gamma (G(t) - G_s) \tag{6}$$

Knowing the amount of gas in the liquid, the effective acoustic velocity of the mixture may be calculated. A number of different approaches exist for this calculation, as presented in Ref. (a). The one used in this model assumes isentropic compression of the gas. The change in volume of the liquid can be written:

$$dV_\ell = - \frac{V_\ell}{B} \; dP \tag{7}$$

and for the gas

$$dV_g = -\frac{v_g}{kP}\ dP \tag{8}$$

Defining a constant α as

$$\alpha = \frac{V_g}{V_\ell} \tag{9}$$

the following relation is obtained

$$\frac{dVt}{Vt} = \frac{-dP}{\left[\dfrac{1+\alpha}{\dfrac{1}{\beta} + \dfrac{\alpha}{kP}}\right]} \tag{10}$$

The bracketed term is the compressibility of the mixture. The density of the mixture can be shown to be:

$$\rho_m = \frac{\alpha \rho_g + \rho_\ell}{(1 + \alpha)} \tag{11}$$

The acoustic velocity of a liquid in an elastic pipe is

$$a = \sqrt{\frac{1}{\dfrac{\rho}{g}\left(\dfrac{1}{\beta} + \dfrac{Dc}{eE}\right)}} \tag{12}$$

Using the above expressions for density, compressibility, and acoustic velocity, we obtain:

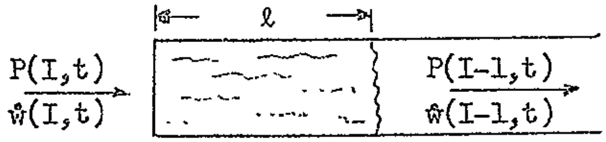
$$a = \left[\frac{1}{\dfrac{\rho_m}{1+} \quad \dfrac{\alpha}{\rho_\ell\ a_\ell{}^2} + \dfrac{}{\rho_g a_g{}^2} + \dfrac{1+\alpha}{g} \cdot \dfrac{Dc}{eE}}\right]^{\frac{1}{2}} \tag{13}$$

This expression is used along with the wave equations to define the characteristics of a feed system with two phase flow. For an all liquid system, $\alpha = 0$ and the same equation can be used.

Priming

The priming transient is that one during which the empty feed system lines are filled with propellant. When a propellant valve is opened or a burst diaphragm ruptures, the liquid is forced into the empty line segments. The model assumes that no flow leaves a segment until it is filled. This is not completely true in reality, but the assumption greatly simplifies the modeling and correlates well with test data. In a vacuum start, the propellant will vaporize in the unfilled portions of the manifold and a certain amount of this vapor will flow out of the engine. Again this effect is neglected in the present model as the gas outflow is only a small percentage of the liquid inflow.

The priming equations consider the forces acting on an incompressible "slug" of liquid. The slug has the same cross sectional area as the pipe segment being filled and the length of the slug is determined from the amount of fluid in the partially filled element.



Writing a force balance on the fluid slug as,

$$P(I,t) - P = \frac{\ell}{Ag} \frac{d}{dt} \dot{w} \qquad (14)$$

where P is a dummy pressure which represents a net value acting on the slug. P is related to the actual downstream pressure by the effective resistance R of the segment. R is obtained from the expression

$$R = \frac{\ell}{L_{act}} R_{act} \qquad (15)$$

where L_{act} is the true length of the segment and R_{act} is the lumped resistance of the segment. Thus

$$P(I-1,t) = P-R\left[\mathring{w}(I-1,t)\right]^2 \tag{16}$$

and using the water hammer equation at the junction of the two segments gives;

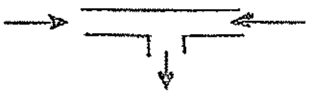
$$\begin{aligned} P(I,t) = {} & \frac{a}{Ag}\left[\mathring{w}(I,t-2\tau) - \mathring{w}(I,t)\right] + 2P(I+1,t-\tau) \\ & -R\left[\mathring{w}(I,t-2\tau)^2 + \mathring{w}(I,t)^2\right] \end{aligned} \tag{17}$$

The downstream pressure is assumed to be given and thus the above equations can be solved for the flows and pressures in the segment being filled. The flow into the segment is integrated to determine if the segment is full, and flags the start of flow into the next downstream segment when filling has been completed.

Branch Lines

The equations derived thus far consider only the flow from one pipe into another and has not covered the problem of branched lines. Branched lines can be classified in three categories, (1) outward flow, (2) inward flow, and (3) a combination of both. To handle branched lines it is assumed that the branch has zero internal volume and that its flow is incompressible. Thus the pressures of all segments which meet at a branch are set equal, and the continuity of flow is used to provide the necessary equations to allow the calculations of flow and pressure in each


Outward Flow


Inward Flow

branch. For the outward flow branch, priming of the system will work as the single feed line will fill normally and when it is full, the downstream branches can be filled as long as some initial split of the flow is provided. The inward flow branch will have a problem in priming if one of the feed lines primes before the other. The model is set up to provide a normal direction of flow in a segment and this information is used in the priming of lines. To handle the inward flow branch, the program prevents flow out of a branch until enough propellant has been accumulated to fill all segments which normally feed the branch. Thus all segments upstream of the branch are primed before fluid flows out of the branch.

PRESSURIZATION SYSTEM

In a pressure fed rocket system the propellant tank pressurization system has a direct effect on the performance of the system. For this reason, two different pressurization schemes are provided with this model. In one, the tank pressure may be programmed as a function of time; in the second a simplified pressurization system is simulated. The first system needs no further explanation. In the second, the basic elements of the system consist of the storage tank, pressure regulator, heat exchangers, propellant tank ullage volume, and general items such as valves, fittings, and a filter. Equations used for the various components are derived below.

Tank Equations

Figure 1 shows a typical tank with gas flow in and out, liquid outflow, and heat addition. The scheme of subscripts shown there is generally applicable to any series of tanks or other significant volumes in which compressibility is important, although the final model will have only one propellant tank.

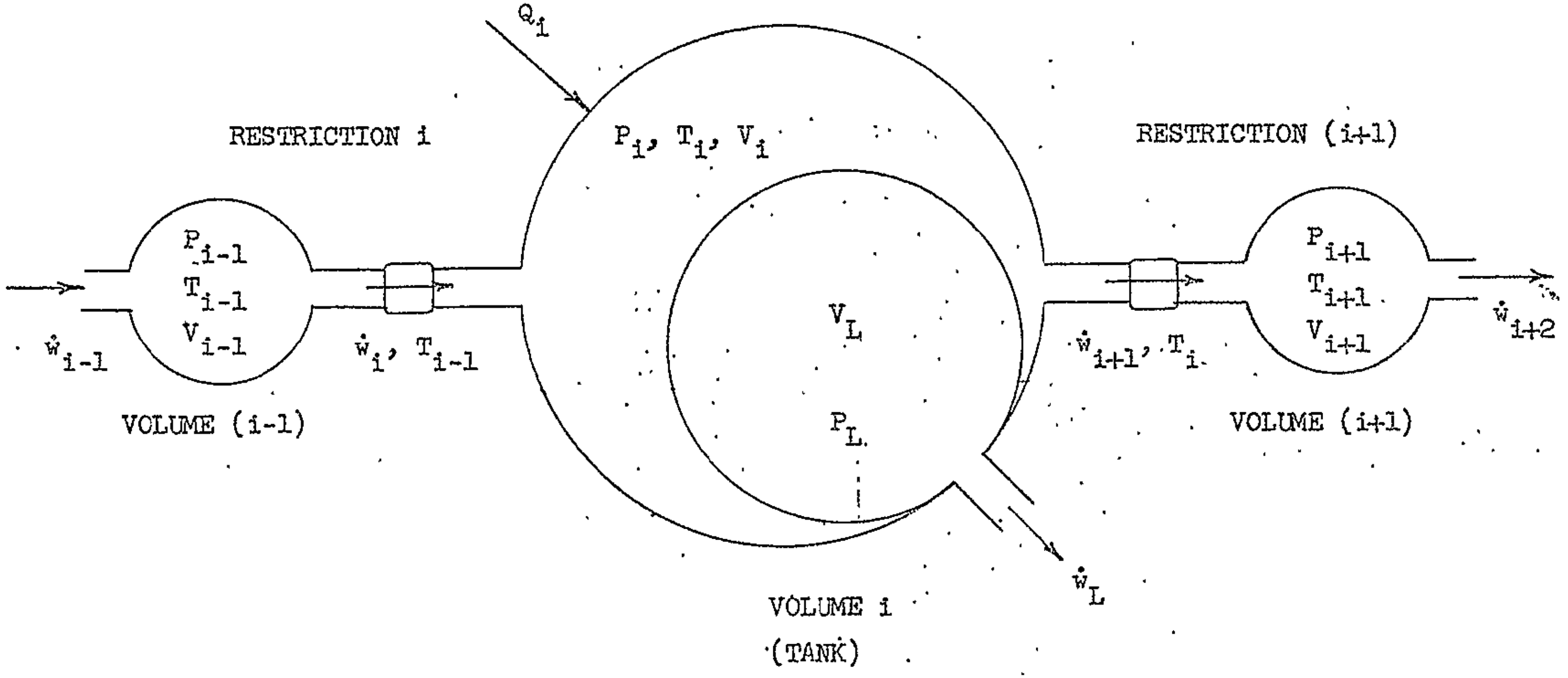


FIGURE 1 - SCHEMATIC SHOWING GENERALIZED FEEDSYSTEM TANK (COMPRESSIBLE VOLUME) AND IDENTIFICATION

Application of mass conservation, energy conservation, and the equation of stage relationships will yield the desired thermodynamic conditions within such a tank at any instant.

By conservation of mass for the gas system,

$$\frac{d}{dt} \quad \mathring{W}_i = \mathring{w}_i - \mathring{w}_{i+1} \tag{18}$$

where $\mathring{W}_i$ is the stored weight, and $\mathring{w}_i$ and $\mathring{w}_{i+1}$ are gas inflow and outflow respectively. Integration of this equation yields the instantaneous stored weight of gas in the i^{th} tank or compressible volume.

By conservation of energy with respect to the gas system in this tank, (ref. b), neglecting potential and kinetic energy,

$$\frac{d}{dt} \quad U_{TOT} = - \Delta H\mathring{w} + Q_i - W_i \tag{19}$$

where U_{TOT} is the total internal energy of the gas mass. H represents the enthalpy per unit weight, and the Δ represents the change from inlet to outlet. Q_i is heat added, including convection from the walls or liquid interface, mass transfer from the liquid interface, or from an immersed heat exchanger. W_i is the external work, i.e. the work done by the gas on the liquid surface.

The external work is

$$W_i = P_i \frac{d}{dt} V_i = P_i \frac{\mathring{w}_{\ell i}}{\rho} \tag{20}$$

where it is noted that the rate of change of gas volume, V_i, is simply the negative of the rate of change of liquid volume.

Substituting equation (20) into (19) and applying the relationships

$$U_{TOT} = C_V W T$$

$$H = C_p T$$

$$k = C_p/C_V$$

it is found that,

$$\frac{d}{dt} T_i = \frac{1}{W_i} \left[\dot{w}_i (kT_{i-1} - T_i) - (k-1)\, \dot{w}_{i+1} T_i - \frac{P_i \dot{w}_\ell}{\rho_\ell C_V} + \frac{Q_i}{C_V} \right] \quad (21)$$

This equation can be integrated to yield the instantaneous temperature of the gas within the i^{th} tank. Note that the absence of liquid outflow or inflow, or heat addition can be represented simply by striking out the associated term in equation (21).

The instantaneous volume occupied by the gas is found from

$$\frac{d}{dt} V_i = \frac{\dot{w}_\ell}{\rho_\ell} \quad (22)$$

Equations (18 and (22) are sufficient to determine the density of the gas in the tank, which is a thermodynamic property. A second thermodynamic property, temperature, is obtained from equation (21). Assuming a single phase, these two properties are sufficient to determine all other properties, specifically pressure. That is

$$P_i = P_i \left(\frac{W_i}{V_i}, \quad T_i \right) \quad (23)$$

which is an equation of state.

If it is assumed at this point that the gas is at a temperature sufficiently above its critical temperature, the equation of state can be approximated by an ideal gas form. That is;

$$P_i = Z \frac{W_i}{V_i} \frac{R_o}{M} T_i \qquad (24)$$

where Z is a compressibility factor. The compressibility factor can be taken as constant for a sufficiently small change in temperature and pressure, such as would be expected during an engine start period. The validity of this approximation must be examined in each case, making reference to reduced properties charts, or other representations of actual gas behavior. The alternative would be to include an equation of state in tabular form. The remainder of this development will employ equation (24).

Flow Device Equations

Many flow devices can be represented by the compressible flow orifice equation. A convenient form of this equation is, for the flowrate through the i^{th} device

$$\dot{w}_i = \frac{C_i P_{i-1} A_i}{\sqrt{T_{i-1}}} \Phi\left(\frac{P_i}{P_{i-1}}\right) \qquad (25)$$

where Φ is the compressible flow function. Letting the pressure ratio be α, Φ can be expressed as,

$$\Phi = \left[\frac{2kg}{R(k-1)} \left(\alpha^{\frac{2}{k}} - \alpha^{\frac{k+1}{k}}\right)\right]^{\frac{1}{2}}, \quad \alpha \geq \alpha_c \qquad (26)$$

$$\Phi = \Phi_M = \Phi(\alpha_c) \qquad , \quad \alpha < \alpha_c$$

$$\alpha_c = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \qquad (27)$$

In this equation k and R are the specific heat ratio and gas constant for the gas being used in this system.

Filters in the gas flow system are generally laminar flow devices, and therefore obey a linear flow-pressure loss relationship. This can be expressed as

$$\dot{w}_i = K \rho \Delta P_i$$

Assuming an ideal gas density

$$\rho = \frac{P}{RT}$$

results in

$$\dot{w}_i = \frac{K_i \; P_i}{R \; T_{i-1}} \quad (P_{i-1} - P_i) \tag{28}$$

The proportionality constant K_i can be evaluated if the flow temperature and pressure conditions are known at any nominal point, i.e.

$$K_i = \left(\frac{\dot{w} \; RT}{P \Delta P} \right)_n \tag{29}$$

Pressure loss through a heat exchanger core is generally expressed in a square-law relationship (Ref. b), i.e.

$$\dot{w}_i = \left(\dot{w} \sqrt{\frac{T}{P \Delta P}} \right)_n \left(\frac{P_{i-1} \quad (P_{i-1} - P_i)}{T_{i-1}} \right)^{\frac{1}{2}} \tag{30}$$

Again, the proportionality constant has been evaluated by reference to some nominal point at which the pressure, temperature, and flowrate are all known.

A pressure regulator in the system can be simulated with equation (25), if it is noted that the flow area is a variable dependent on diaphragm or reference pressure. This relationship can be developed by equating diaphragm force, F_d, to the force exerted by the reference spring, F_r. If it is assumed that the spring has a force deflection curve which is linear over the range of poppet travel, the reference spring force is

$$F_R = F_{RO} + K_1 X, \quad 0 \leq X \leq X_{MAX} \tag{31}$$

where F_{ro} is the spring force when the regulator is closed, and X is the poppet position, measured from the closed position. The local spring slope is K_1, and diaphragm force is represented as;

$$F_d = (P_R - P_a)\ A_e \tag{32}$$

where P_r and P_a are the reference and ambient pressures respectively, and A_e is the effective diaphragm area. For small poppet travel, the seat area is a linear function of X, i.e.

$$A_S = K_2\ X, \quad 0 \leq X \leq X_{MAX} \tag{33}$$

By equating diaphragm and spring forces, and substituting equation (33), there results,

$$A_S = \left(P_R - P_a - \frac{F_{RO}}{A_e}\right) \frac{K_2 A_e}{K_1}, \quad 0 \leq A_S \leq A_{MAX} \tag{34}$$

In a simple system, the reference pressure is the pressure immediately downstream of the seat, but it could as well be supplied from some other downstream point by means of a sensing line.

Heat Exchangers

Heat exchangers in the pressurization system can be simulated most easily by the effectiveness vs net-transfer-unit method described in Ref. (c). Figure 2 shows a typical heat exchanger. In a pressurization system, the gas is the colder fluid and is being heated by a secondary flow. Therefore the gas inlet and outlet temperatures are referred to as $T_{c\ in}$ and $T_{c\ out}$, and the cooling fluid inlet and outlet temperatures are $T_{h\ in}$ and $T_{h\ out}$, following the terminology of Ref. (b). The secondary or heating fluid flowrate is designated $\mathring{w}_h$, whereas the gas flowrate is designated $\mathring{w}_g$. The method is independent of the type of the two flows. That is, the heating flow can be either liquid or gaseous.

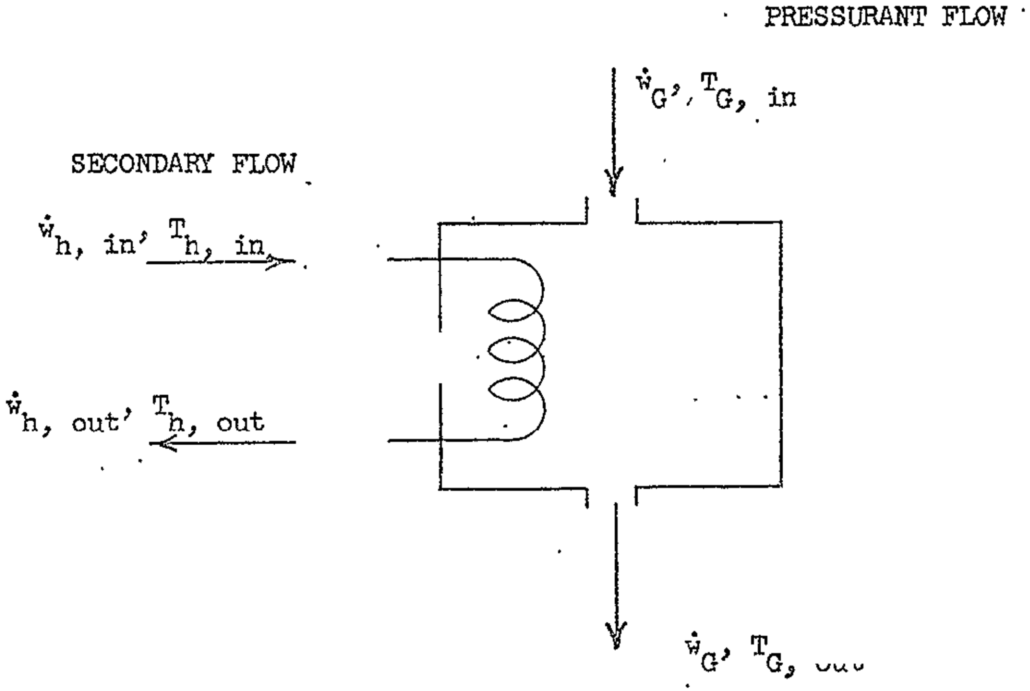


FIGURE 2 - GENERALIZED HEAT EXCHANGER

Capacity rates are defined for both flows as

$$C_h = \dot{w}_h \, C_{Pn} \quad \text{(hot fluid)} \tag{35}$$

$$C_c = \dot{w}_G \, C_{PG} \quad \text{(cold fluid)}$$

It is necessary to distinguish between the C which is maximum and that which is minimum is assessing the heat exchanger performance. Therefore, let,

$$C_m = \text{MIN}\ (C_h, C_c) \tag{36}$$
$$C_M = \text{MAX}\ (C_n, C_c)$$

where the functions MIN(a,b) and MAX(a,b) are defined as the minimum and maximum of the arguments (a,b) respectively. These functions are standard library functions for most digital programming languages.

The number of transfer units, or NTU, is defined as

$$\text{NTU} = \frac{A_h U_h}{C_m} = \frac{A_c \ U_c}{C_m} \tag{37}$$

where AU is the transfer area times the average over-all conductance between the two flows. It can be evaluated either for the hot or the cold fluid side, since conservation of evergy requires them to be equal.

Finally, the heat exchanger effectiveness, ξ, can be determined from charts (Ref. c), or can be approximated by closed-form expressions. In general,

$$\xi = \xi(\text{NTU}, C_m/C_M, \text{Flow arrangement}) \tag{38}$$

For many systems, the hot fluid will be liquid and the cold fluid gas, in which case, due to the low mass flowrate and C_p of the gas relative to the liquid,

$$\frac{C_m}{C_M} \ll 1$$

and ξ becomes

$$\xi = 1 - e^{-NTU} \tag{39}$$

for all flow arrangements. This is also the case for a heat exchanger submerged in a constant temperature fluid, since C_M is then essentially infinite.

Once the effectiveness of the heat exchanger is known, the heat transferred is found from

$$Q = C_m (T_{h\ in} - T_{c\ in})\ \xi \tag{40}$$

The outlet temperature of the two flows is then

$$T_{c\ out} = T_{c\ in} + \frac{Q}{C_c} \tag{41}$$

$$T_{h\ out} = T_{h\ in} + \frac{Q}{C_h} \tag{42}$$

If the heat exchanger is submerged in a propellant or pressurant tank, the Q determined from equation (40) is employed in the tank temperature equation, rather than in equation (42).

From the above it is apparent that the heat supplied from a particular heat exchanger to the pressurant flow is easily determined from upstream temperatures, fluid flowrates, and fluid properties. That is, functionally,

$$Q = f(\dot{w}_h, C_{Ph}, \dot{w}_c, C_{PC}, AU, T_{h\ in}, T_{c\ in}) \tag{43}$$

which can most efficiently be developed as a digital subroutine program.

Solution for Particular System

The equations developed above can be applied to any combination of elements, thereby describing a large number of different pressurization systems. A typical system is shown in Fig. 3 . This system has three heat exchangers, the second of which is submerged in the storage tank. The propellant tank has a liquid outflow, $\mathring{w}_L$, which is assumed to be given. Other known data include the initial conditions in the two tanks, the flowrate for heat exchangers, system geometry and pressurant properties.

Since gas storage volumes in the flow system are small relative to the two tanks, storage will be neglected in the flow system. This implies that all flow devices have the same instantaneous flowrate, $\mathring{w}_G$. Thus equation (25) is applied at the start valve, regulator, and fittings, equation (28) is applied at the filter, and equation (21) at the heat exchangers, all with the same flowrate. The occurrence of this single variable in all of these equations makes it necessary to solve the equations iteratively.

COMBUSTION CHAMBER

The combustion chamber model describes the reaction of the propellant, their storage in the combustion chamber, and the continuity between flow in and out. This can be expressed mathematically as

$$M = \int (\mathring{w}_{in} - \mathring{w}_{out})\, dt \qquad (44)$$

The mass M, of reacted propellant is related to the chamber pressure by the perfect gas law

$$P_c V_c = M R_c T_c \qquad (45)$$

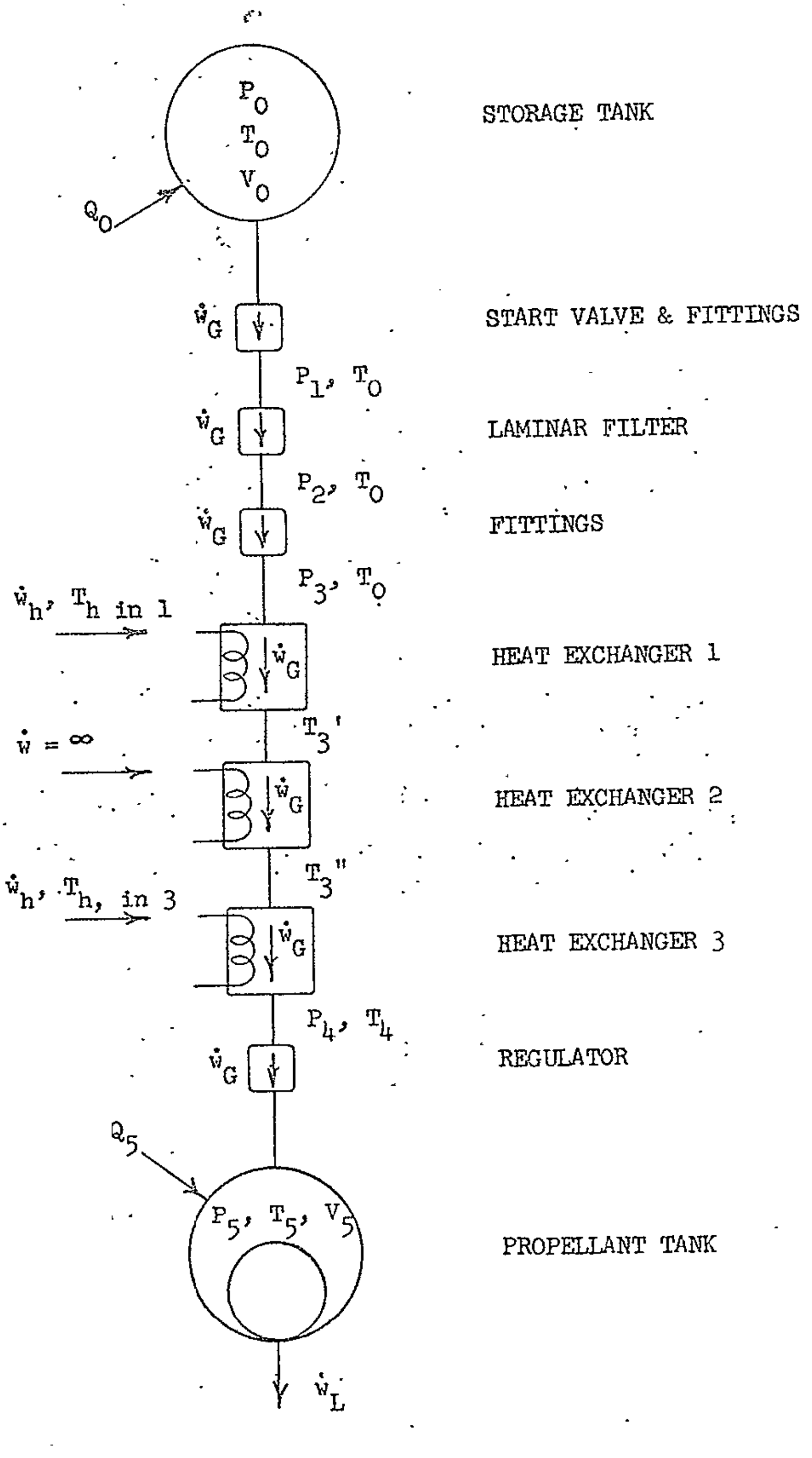


FIGURE 3 - TYPICAL PRESSURIZATION SYSTEM

The flowrate out of the chamber is also related to the chamber pressure and can be written

$$\mathring{w}_{out} = \frac{P_c \, A_T}{\eta_c{*} \, \frac{C^*}{g}} \tag{46}$$

If equations (44) and (45) are differentiated they can be combined with equation (46) to give

$$\frac{d}{dt} \, P_c = \frac{R_c \, T_c}{V_c} \, \mathring{w}_{in} - \frac{R_c \, T_c}{V_c} \cdot \frac{A_t}{\eta_c{*} \, \frac{C^*}{g}} \cdot P_c \tag{47}$$

which is the desired form.

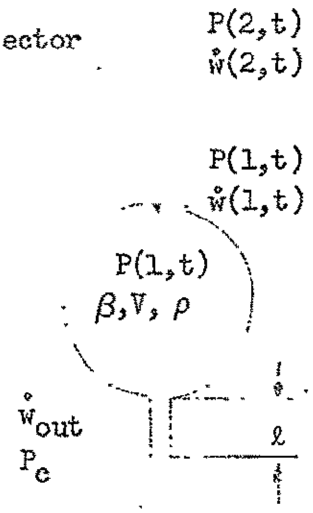
The constants in equation (47) vary with mixture ratio and chamber pressure. This variation is supplied from a table which contains R_cT_c, C^*/g, and η_c* as functions of oxidizer fraction MR/(1 + MR) and a correction factor $C_f = (P_c/P_{BASE})^{\delta}$. These constants are determined from thermochemical calculations for the propellant combination being used. The value of $\mathring{w}_{in}$ is the sum of the fuel and oxidizer flowrate which is presently being converted into combustion products, and the quotient of these values determines the mixture ratio used to find chamber properties.

The propellant presently burning is not the propellant leaving the injection orifices. Instead, it is propellant that has finally reached the combustion zone after traveling some finite distance from the injector. The time required for the propellant to travel to the combustion is known as flight time or transport time, and is often assumed to be a constant. Reference (d) discussed the transport process and shows that the flight time should be a variable dependent on the injection velocity. If it is assumed that the combustion zone is stationary the time delay can be computed from the velocity which is a function of the injector differential pressure. Thus

$$\tau_D = \frac{\ell}{v} = \frac{\ell}{\sqrt{2g\,\Delta P/\rho}} \tag{48}$$

INJECTOR

The injector dynamics are included by treating the injector as a lumped compressible volume as shown in the figure at the right. The flow and pressure at the bottom of the pipe segment are related by the equation:



$$P(1,t) = \frac{a}{Ag} \quad \mathring{w}(1,t-2\tau) - \mathring{w}(1,t) \quad + 2P(2,t-\tau) \tag{49}$$

$$-P(1,t-2\tau) - R \quad \mathring{w}(1,t)^2 + \mathring{w}(1,t-2\tau)^2$$

The flow out is controlled by the differential pressure across the injector and the resistance and inertia of the injector orifices; thus

$$P(1,t) - P_c = R\mathring{w}_{out}^2 + \frac{\ell}{Ag}\,\frac{d}{dt}\,P(1,t) \tag{50}$$

Storage of propellant in the injector manifold can be represented by the following equation.

$$\mathring{w}_{out} = \mathring{w}_{in} - \frac{V\rho}{\beta}\,\frac{d}{dt}\,P(1,t) \tag{51}$$

Since P_c is determined by flow into the combustion chamber some time prior to the present (transport time delay), it can be calculated directly. Then the above equations, which involve only 3 unknowns, may be calculated directly.

CUTOFF

Rocket engine cutoff is initiated by closing one or both of the main propellant valves. As the valves start to close the resistance of the valve segment will increase and flow will start to decrease. When the valve effective area reaches zero, the resistance is set to a value of 10^{31} to act as a flag in the program to signify valve closure. While the valve or valves are closing, the model will operate normally. When the injector manifold is finally separated from the propellant tank, the state of the propellants will be determined by the energy in the system downstream of the closed propellant valves. At valve closure, the quantities of propellant liquid, vapor, and pressurant gas may be determined from known properties of the propellant.

Flow out of the injector is represented by equation (50), and the equations of state for the gas and liquid phase can be represented as follows:

$$M = \frac{V_\ell \; \rho_\ell}{\beta} \; P_m \tag{52}$$

and

$$M_V = M_g + M_{\ell \; v} = \frac{P_g \; V_g}{R_o \; T} + \frac{P_{\ell \; v} \; V_g}{R_o \; T} \tag{53}$$

The liquid vapor pressure is a function of temperature and can be approximated by

$$\mathrm{Log}_{10} \; P_{\ell \; v} = K_1 T + K_2 \tag{54}$$

The total pressure in the injector is the sum of the partial gas pressures, thus:

$$P_m = P_g + P_{\ell \; v} = P_g + \mathrm{Log}^{-1}_{10} \left(K_1 T + K_2\right) \tag{55}$$

After engine cutoff, heat soakback will raise the temperature of the injector and there will be heat transfer to the propellant. However, as the pressure in the injector falls more of the liquid will vaporize which will tend to lower the propellant temperature in the manifold. The propellant temperature is therefore found from the following heat balance:

$$\begin{aligned} T(t)\,(C_P\, M_\ell + C_{Pg}\, M_g + C_{P\ell\, v}\, M_{\ell v})\Big|_{t=t} \\ = T_{(t-1)}\,(C_P M_\ell + C_{Pg} M_g + C_{P\ell\, v}\, M_{\ell v})\Big|_{t=t-1} \\ + Q(T_{INJ} - T_{(t-1)})\,\Delta t - (M_{\ell v}(t) - M_{\ell v}(t-1))\,H_v \end{aligned} \tag{56}$$

The concentration of dissolved pressurant gas in the propellant is determined using the same equation as used for the derivation of effective acoustic velocity

$$\frac{d}{dt}\, G = -\,\gamma(G - G_S) \tag{57}$$

To solve these equations it is assumed that the propellant mixture is homogeneous and therefore if $\mathring{w}$ is known, the mass of propellant left in the injector can be calculated. An iteration technique of the predictor-corrector variety is used to solve these equations. First P_m is estimated, and if P_c is known, $\mathring{w}$ can be calculated followed by the state of the propellants in the injector. Using these data, the pressure estimate can be checked using equation (55).

At the start of the cutoff transient, the combustion chamber pressure is calculated in a normal fashion as previously described. As the propellant valves close combustion will continue down to some limiting value, which will have to be established. After combustion ceases, the thrust chamber will blow down to a pressure level which will be maintained by the vaporization rate of the propellants. Flow out of the chamber during this period will be assumed to be propellant vapor plus any pressurization gas which is present. In terms of mass storage,

$$\dot{w}_{in} - \dot{w}_{out} = \frac{V_c}{R_c\, T_c} \frac{d}{dt} P_c \tag{58}$$

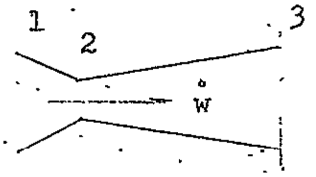
The flow in is that calculated by equation (50) above, and flow out is assumed to be either all oxidizer or all fuel. This assumption allows the calculation to be done in the combustion subprogram.

MISCELLANEOUS COMPONENTS

Cavitating Venturi

These components are used in rocket engine systems to control flowrate and their operation is based on Bernoulli's Equation given below

$$\frac{P_1}{\rho_1} + \frac{V_1^2}{2g} = \frac{P_2}{\rho_2} + \frac{V_2^2}{2g} \tag{59}$$



Using the equation of continuity equation (59) becomes,

$$\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2} = \frac{w_2^2}{2\,\rho_2^2 A_2^2 g} - \frac{\dot{w}_1^2}{2\,\rho_1^2 A_1^2 g} \tag{60}$$

For an incompressible liquid, the above equation can be simplified to

$$P_1 - P_2 = \frac{\dot{w}^2}{2g\rho}\left(\frac{1}{A_2^2} - \frac{1}{A_1^2}\right) \tag{61}$$

From this equation it may be seen that for constant geometry and inlet pressure P_1, as the flowrate increases the pressure P_2 decreases until it equals the vapor pressure of the fluid. At this point, cavitation occurs in the throat of the Venturi and further increases in flow are not possible without an increase in inlet pressure P_1. The pressure and flow on either side of the venturi may be determined by the equations (2) and (21) developed previously. Thus:

$$P_1 = f(\mathring{w}_1) \tag{62}$$

The pressure on the downstream side of the venturi for no cavitation will be

$$P_3 = f(\mathring{w}_1) \tag{63}$$

This latter function may be either the priming equation or the wave equation depending on whether the segment is filled. P_1 and P_3 are related to the pressure recovery of the venturi

$$P_3 = P_1 - K\mathring{w} \qquad (64$$

Using the above equations, the flow through the venturi and the inlet and outlet pressures may be calculated assuming no cavitation. By solving equation (61) for P_2 it can be determined if cavitation is occurring. If the calculated value of P_2 is less than the vapor pressure, cavitation is occurring and the flow and pressure must be calculated using equations (61) and (62). Using this flow, P_3 can be calculated from equation (63).

If there is gas entrained with the liquid, the gas will expand and the density can no longer be assumed to be constant. Thus, equation (60) must be used and the values of P_1 and P_2 determined as functions of pressure. If a perfect gas is assumed,

$$\rho_g = \frac{P}{RT} + \frac{W_g}{V_g} \tag{65}$$

and since the ratio of the masses of gas and liquid are known,

$$B = \frac{W_g}{W_\ell} \quad \text{and} \quad \rho_\ell = \frac{W_\ell}{V_\ell} \tag{66}$$

The equivalent density of the mixture will be

$$\rho_m = \frac{W_\ell + W_\ell}{V_\ell + V_g} \qquad \frac{(1 + B)}{\frac{1}{\rho_\ell} + \frac{BRT}{P}} \tag{67}$$

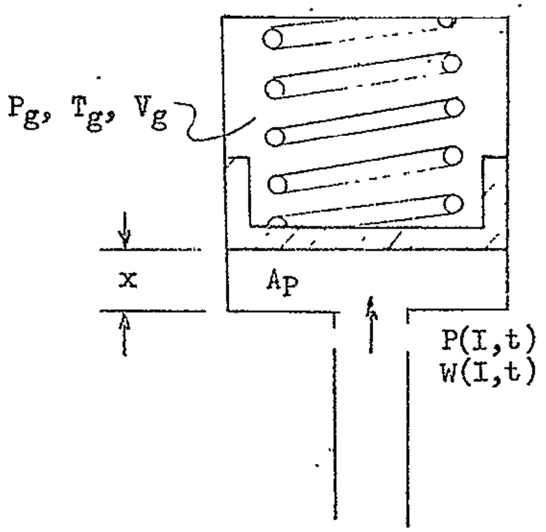
It is assumed that two phase flow in the pipe segments is isothermal but sudden transients are adiabatic. Thus,

$$\rho_1 = \frac{1 + B}{\frac{1}{\rho_\ell} + \frac{BRT_1}{P_1}} \quad \text{and} \quad \rho_2 = \frac{1 + B}{\frac{1}{\rho_\ell} + \frac{BRT_1}{P_1}\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}} . \tag{68}$$

Using these values of density, the performance of the cavitating Venturi can be calculated. The technique is similar to that used with no gas. First the pressures and flows assuming no cavitation are calculated; second, using the calculated value of P_1 and the vapor pressure for P_2, the maximum allowable flow is determined. If this flow is less than that calculated in the first step, cavitation occurs and equations (60) and (62) must be solved for the value of P_1 and $\dot{w}$. After these values are obtained, P_3 may be calculated.

ACCUMULATOR

Since accumulators are often used to lower surge pressures or smooth out pressure fluctuations, a model of a simple accumulator will be provided in the program. This element will be mounted on the end of a pipe segment as shown in the sketch. The liquid pressure in the accumulator will be the same as that at the end of the pipe. Thus, the wave equation (2) can be used to obtain



$$P(I,t) = f\left(W(I,t)\right) \tag{69}$$

The accumulator functions when liquid flows into it and moves the piston so as to compress the gas behind the piston and the spring; stops are provided to limit its motion. Depending on the initial pressure behind the piston and preload on the spring, some initial pressure level must generally be reached before the piston will move; also in some cases, the piston or the spring may be missing. The equations are derived for the most general case.

The gas pressure behind the accumulator will depend on the initial value to which it is charged and its instantaneous volume assuming isentropic compression.

$$P_g(t) = P_o\left(\frac{V_o}{V_{g(t)}}\right)^k \tag{70}$$

A force balance on the piston yields

$$W_P\,\ddot{X} = \big(P(I,t) - P_g(t)\big)A_P - K_S(X_o + X) \tag{71}$$

The gas pressure and liquid flow are related to piston position so that:

$$P_g\,(t) = P_o\left(\frac{V_o}{V_o - XA_P}\right)^k \tag{72}$$

$$\dot{X} = \frac{\dot{w}\,(I,t)}{A_P}$$

These equations can be combined to produce a non-linear second order differential equation of the form;

$$M_P\,\ddot{X} = K_1 - K_2\,\dot{X} - K_3\,\dot{X}|\dot{X}| - K_4\left(\frac{1}{1-K_5X}\right)^k \tag{73}$$

where the capital K's represent constants. There are several techniques available for solving the above equation, however, an iterative technique will be used so that no special cases develop if one or more of the constants are zero. Secondly, the results will be checked to ensure that X does not exceed its limits, and if this occurs, the flow will be set to zero.

VALVES, FITTINGS, ORIFICES, ETC.

These components are all characterized by the fluid resistance they add to the system. This resistance is handled in two different manners in the model which depends on whether an element is primed or not. For liquid filled lines, the resistance of the pipe and any other component is lumped at the downstream end of the element. Valve resistance can be varied as a function of time for ten different values in either the fuel or oxidizer feed system. When lines are being filled, the resistance of a segment is distributed along the length of an element so that the friction loss will affect the priming. If the resistance is concentrated at an orifice, the priming rate of a line will be reduced too much. This will be prevented during priming by removing the orifice resistance from that line segment until after it is primed.

COMPUTER PROGRAM

The equations described in the preceding section were programmed into a digital computer program. Figure 4 shows a block diagram of this program which contains a main program controlling the data input and output, parameter initialization, and the flow of calculations through 19 subprograms.

To use the program, the system to be modeled is broken up into segments and the required valves, cavitating venturis, orifices, etc., are noted. The model has the capability to handle 60 segments, 10 valves, 4 cavitating venturis, 4 accumulators, and 5 dead end terminations in both the fuel and oxidizer systems. Provisions are also available to handle 4 individual combustion chambers. Additional components may be added by use of subroutines.

Program operation proceeds as follows: After reading the input data, subroutine SETUP is entered. Initial conditions are stored in the proper arrays, miscellaneous constants are calculated, and the program made ready for the case to be run. Upon return to the main program, subroutine P1PRNT is called and system data and initial conditions are printed. Then the auxiliary tape headings are written and subroutine P2PRNT is called to write values of variables on the tape at time zero.

The main program then begins the sequential calculation of the transient being simulated. Subroutine DELAY is the first routine entered at each time interval. In this routine, the gas concentration, the value of effective acoustic velocity, and fluid density in each segment are

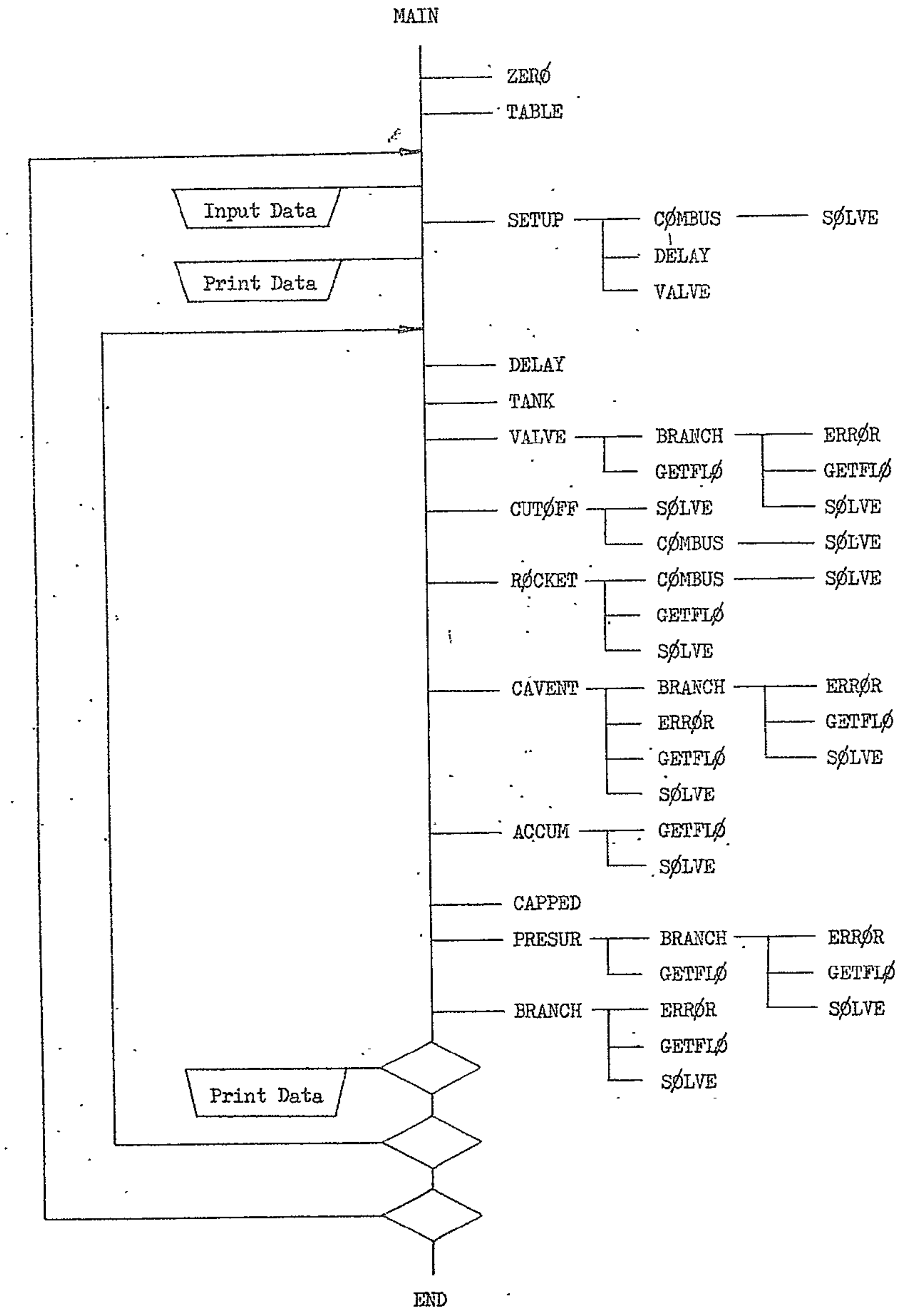


Figure 4 - Block Diagram of Main Program Showing Subprogram Structure

calculated. The time delay flow and pressure terms are then obtained from stored data so that the wave equations can be solved for pressure in each segment. Subroutine TANK calculates the pressures and flows in the pressurization system. This is done using an iterative technique. Also included in the program are provisions to program tank pressure as a function of time. Subroutine VALVE computes the propellant valve opening and closing characteristics. These data are supplied in tables of valve effective area versus time. The subroutine then computes the flow and pressure through the valves, and areas in the variable area cavitating venturis.

The dynamics of other components are next calculated in Subroutines ROCKET, CAVENT, ACCUM, and CAPPED. To simulate blowdown operation of the engine at cutoff subroutine CUTOFF is used.

The main calculation of flow and pressure in the feed system segments is done in subroutines PRESUR and BRANCH. Subroutine PRESUR calculates flow and pressure between single segments which are completely filled with propellant, and calls subroutine BRANCH to fill partially full segments. Subroutine BRANCH calculates flow and pressure in branch elements. The downstream elements can be either full or in the process of being filled. For the latter case it was necessary to include the solution of the priming equations in this subroutine, and thus all priming is done in this subroutine. At specific times during the operation subroutine P2PRNT is entered to write out selected data.

A more detailed description of the program is given in the Engineer and Programmer's Guide. To use the program, the system to be modeled must be divided into segments. The segments and components in the system must then be sequenced so that their location in the system will be known. Data on the length, area, pressure drop, and wall stiffness must be supplied by the user to describe the line segments. Data to describe the physical characteristics of the miscellaneous components, thrust chamber, and pressurization system must also be supplied. After the data describing the physical system to be modeled is supplied, information to describe the function to be simulated must be furnished. This is generally a description of a valve or valves opening or closing, change in area of a cavitating venturi, or change in tank pressure. These functions will allow simulation of engine start, shutdown, or throttling or a combination of all three.

The feed lines of a simple system and engine are shown in segmented form in Fig. 5. Several features should be noted. Segments are numbered from the downstream end to the upstream end of any branch or line. Orifices are lumped with a specific segment. Valves which are in effect variable orifices are identified as separate segments. Branch points or tees are also considered as separate segments but have no characteristics other than as connections.

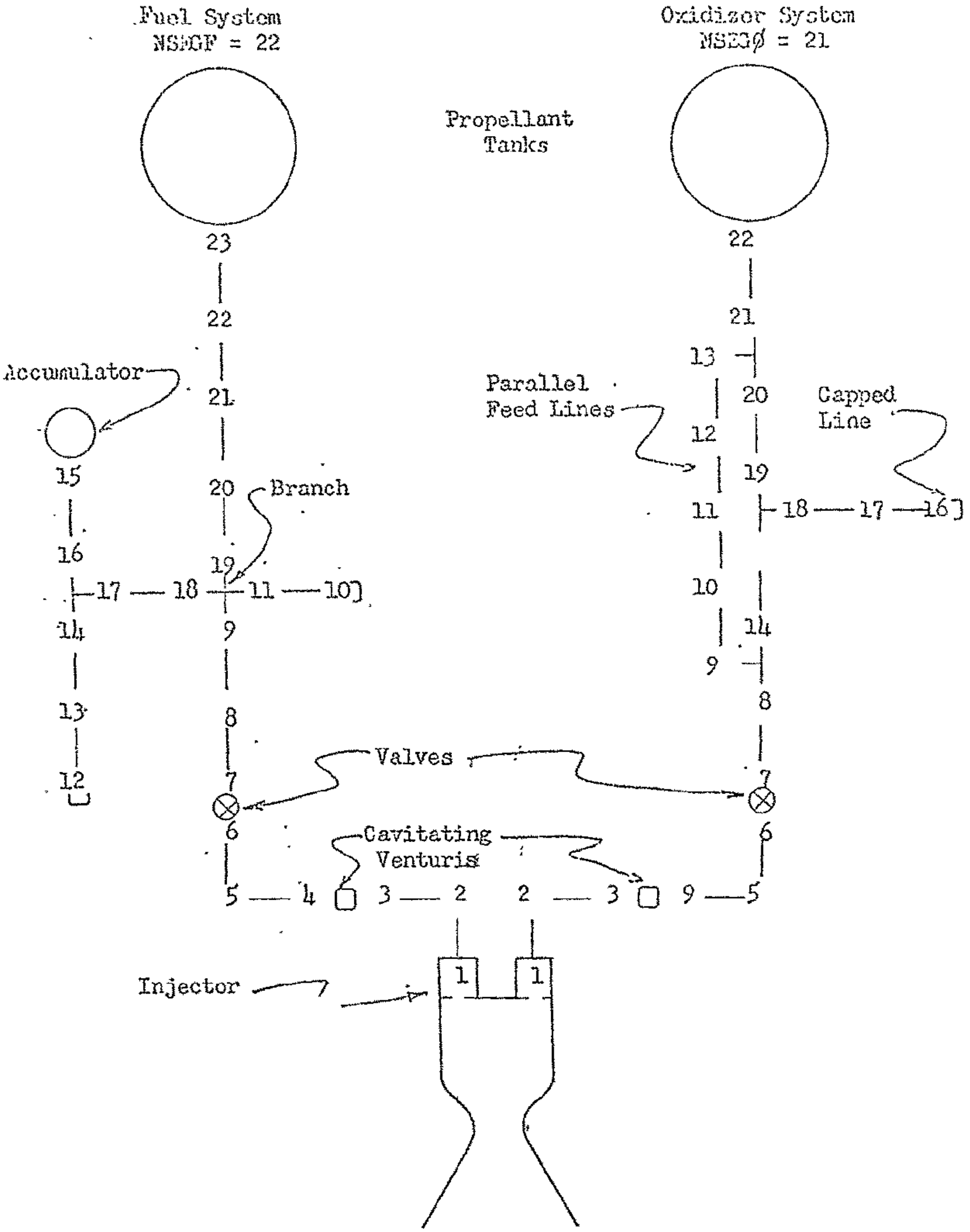


Figure 5 - Typical Rocket Engine System Showing Segment Numbers.

MODEL DEVELOPMENT

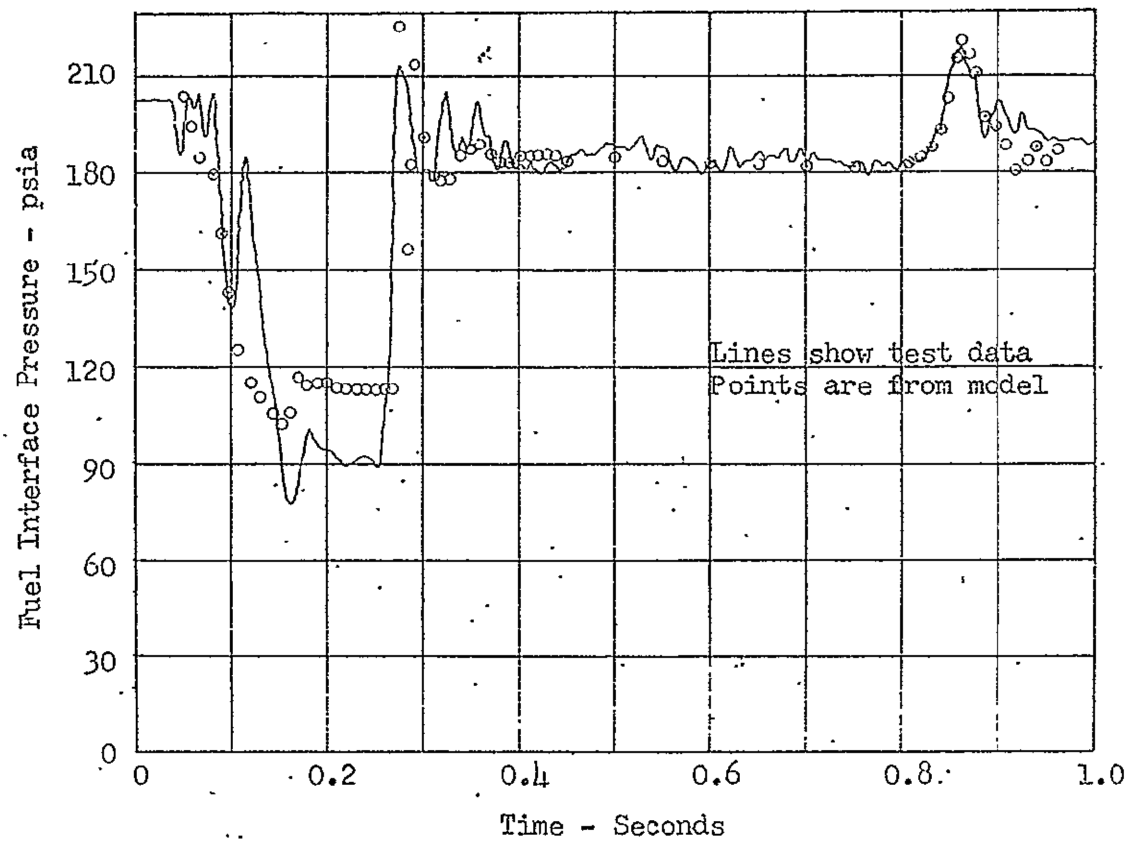
Demonstration of the model's use was accomplished by simulating four transients. These were an Apollo Ascent Engine on-off pulse, a Descent Engine start transient with helium saturated propellants, a Descent Engine throttling transient in which a pressurant gas bubble passed through the engine, and an SE5-5 Engine system pressurization transient.

ASCENT ENGINE SIMULATION

The Apollo Ascent Engine transient simulated by the model was an 0.9 second engine on-off pulse. The test simulated was run at the White Sands Test Facility and is designated as Test 006 Run 1. In order to simulate the transient, it was first necessary to prepare a data package for this engine. This required that details of the engine geometry, propellant combustion characteristics, and vehicle feed system configuration be determined and these data put into proper form for use in the model. A description of the work involved in the preparation of the data for input into the model is given in Appendix A.

The results obtained from the computer simulation are shown plotted with the test data in Fig. 6, 7, and 8. Three separate features of the model are demonstrated in this run. First, a start transient is simulated. In this mode, segments downstream of the propellant valve are initially empty. When the valves are opened propellants start to flow, the empty propellant lines fill and when both fuel and oxidizer reach the engine, ignition occurs. Second, when the flow and pressure transients die out a period of steady state performance exists. Third, the propellant valves close and an engine cutoff transient occurs.

The agreement between the test data and model results is good except for the oxidizer injector pressure rise at start and the decay in thrust chamber pressure after the propellant valves close. The variation seen in the oxidizer injector pressure rise is most likely caused by the instrumentation line being empty at the start of the test. This hypothesis is supported by two facts:



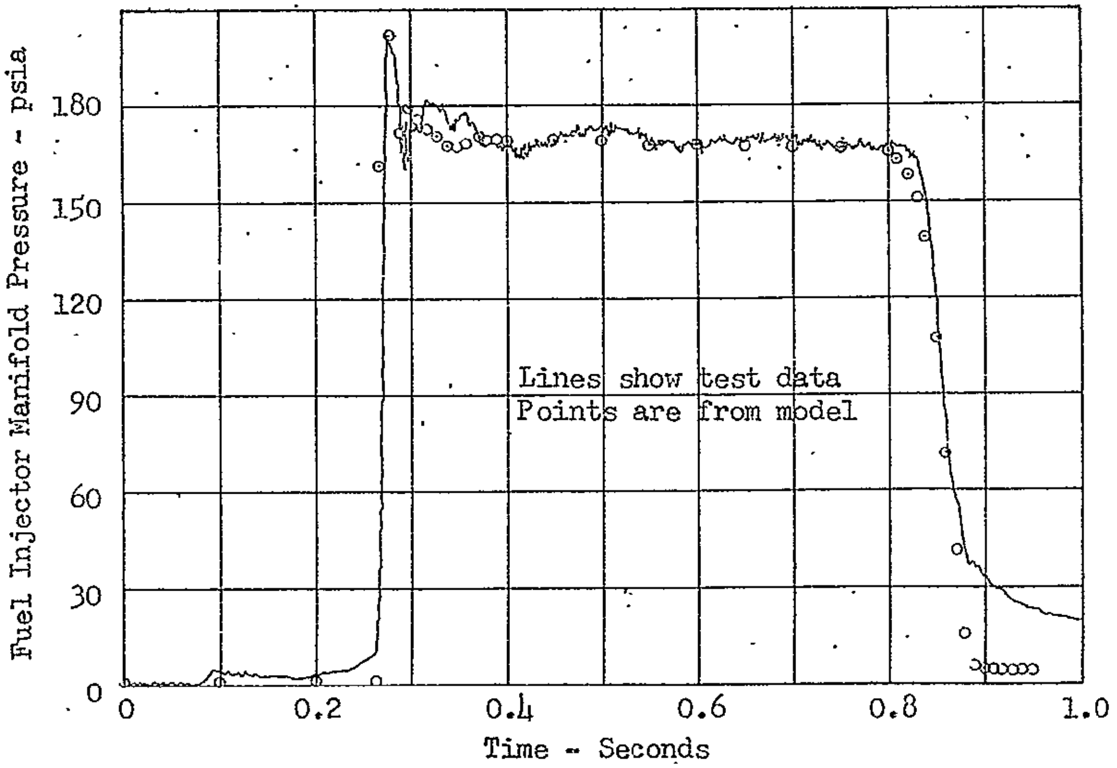


Figure 6 - Apollo Ascent Engine Data Correlation - Fuel System Pressures Subsystem PA-1, Series 7B, Test 006, Run 1

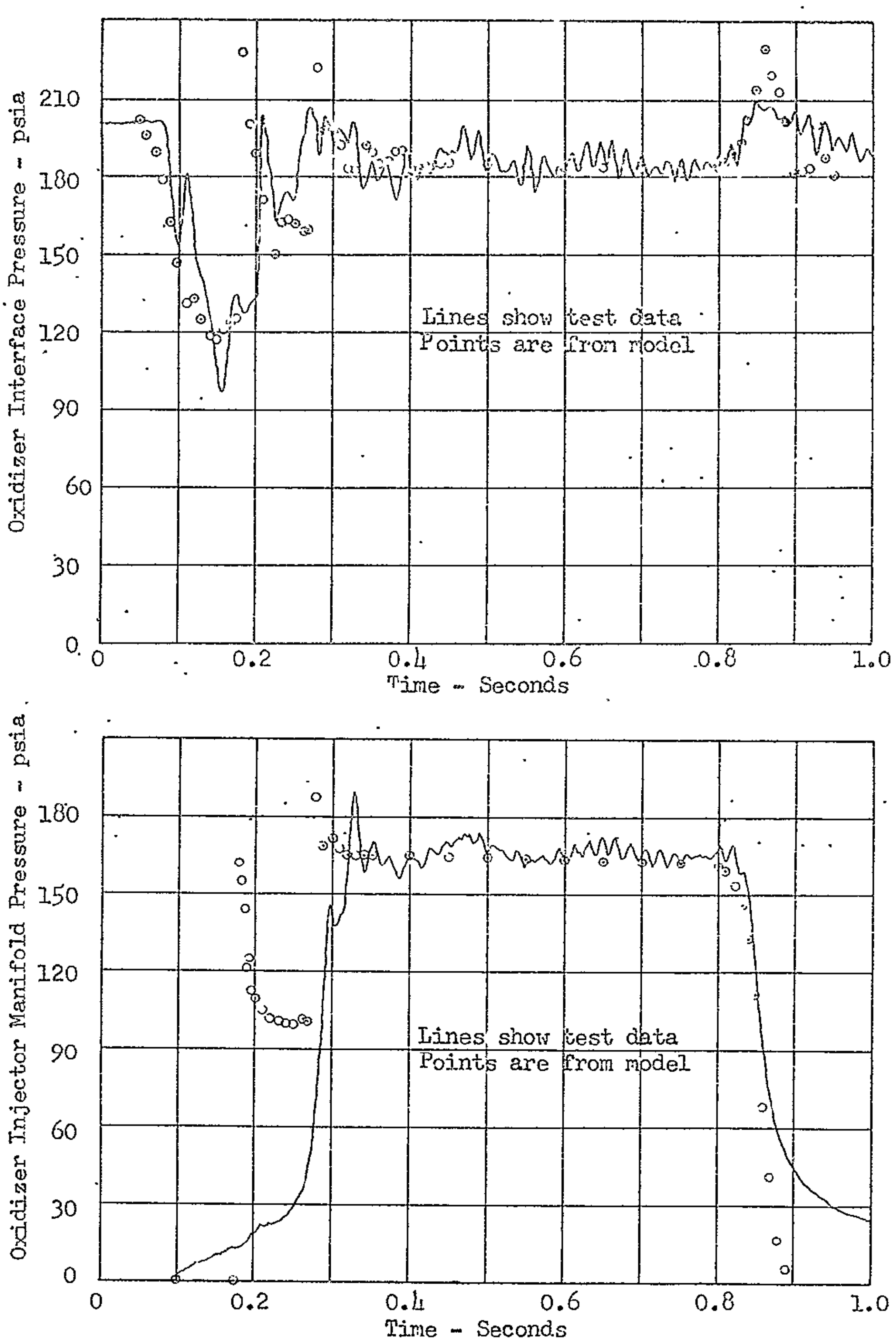


Figure 7 - Apollo Ascent Engine Data Correlation - Oxidizer System Pressures Subsystem PA-1, Series 7B, Test 006, Run 1

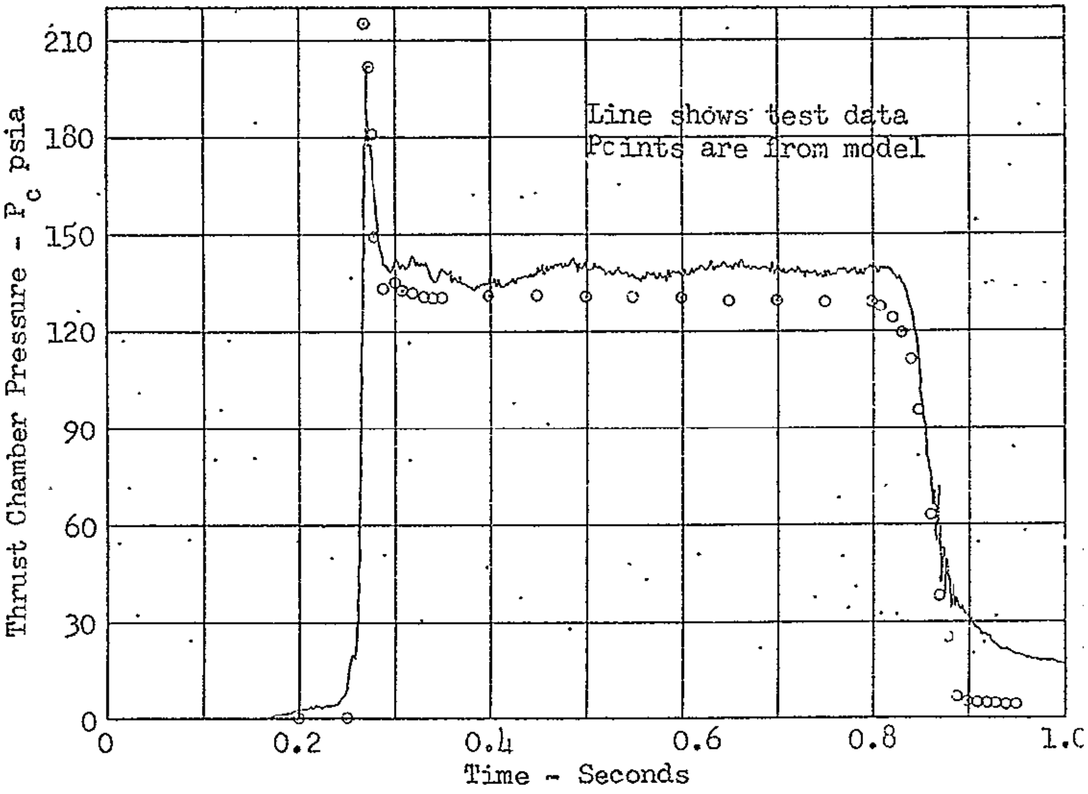


Figure 8 - Apollo Ascent Engine Data Correlation - Thrust Chamber Pressure Subsystem PA-1, Series 7B, Test 006, Run 1

(1) the oxidizer injector primes at 0.2 seconds as evidenced by the rise in the interface pressure measurement and (2) the pressure rise in the model. The injector pressure is increasing slowly at this time and does not reach its correct valve until after engine ignition. This behavior is characteristic of a line priming, and since the model did not simulate the instrumentation lines the model would not show this phenomenon. The differences at cutoff can be considered to be caused by two things; first, the propellant temperature in the injector was assumed to be ambient and second, there was no pressurant gas dissolved in the propellant. Thermal analysis of the Ascent Engine shows that the temperature of the liquid rises an appreciable amount only in the baffles and the run was short enough that steady state temperatures were not reached. However, local heating of the propellant will raise the vapor pressure in the injector and hence raise the chamber pressure after valve closure by forcing out more propellant. The propellants were not saturated with pressurant gas for this run; however, if there was a small amount of dissolved gas present it would start to come out of solution when the injector pressure falls below the saturation level. This phenomenon could also account for the disagreement between test data and model results.

APOLLO DESCENT ENGINE SIMULATION

The second demonstration of the model's use was a simulation of an Apollo Descent Engine start transient using helium saturated propellants. The data needed to model this system is given in Appendix B, and the results are shown in Fig. 9, 10, and 11. The correlation is not as good as that seen in the Ascent Engine simulation, although the two cases shown tend to bracket the data. The difference between the two model runs is the value of the time constant which controls the rate at which the pressurant gas in solution changes its concentration. The two values used were 0.1 and 1.0 second, and from the data it would appear that an intermediate value would give better simulation. Also, the time required for the model to prime appears to be too long. This discrepancy would appear to be caused by the resistance in the system --probably propellant valve--being too high. This would also account for the fact that the low values of steady state injector and thrust chamber pressure.

Lines show test data - LTA-5, Series 11, Test 2, Run 2
Points are from model

○ TAUPRG = 0.1 seconds

△ TAUPRG = 1.0 seconds

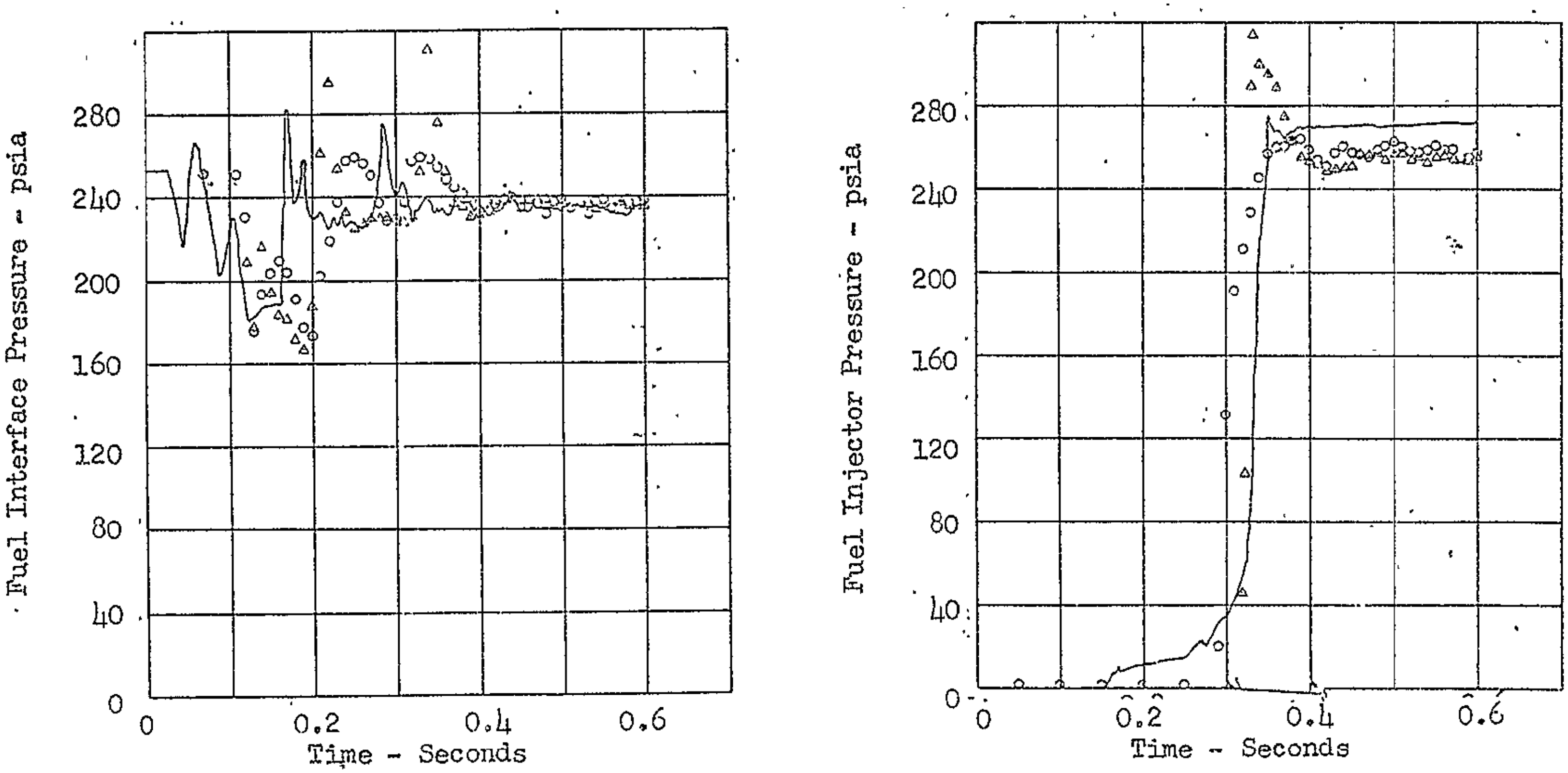
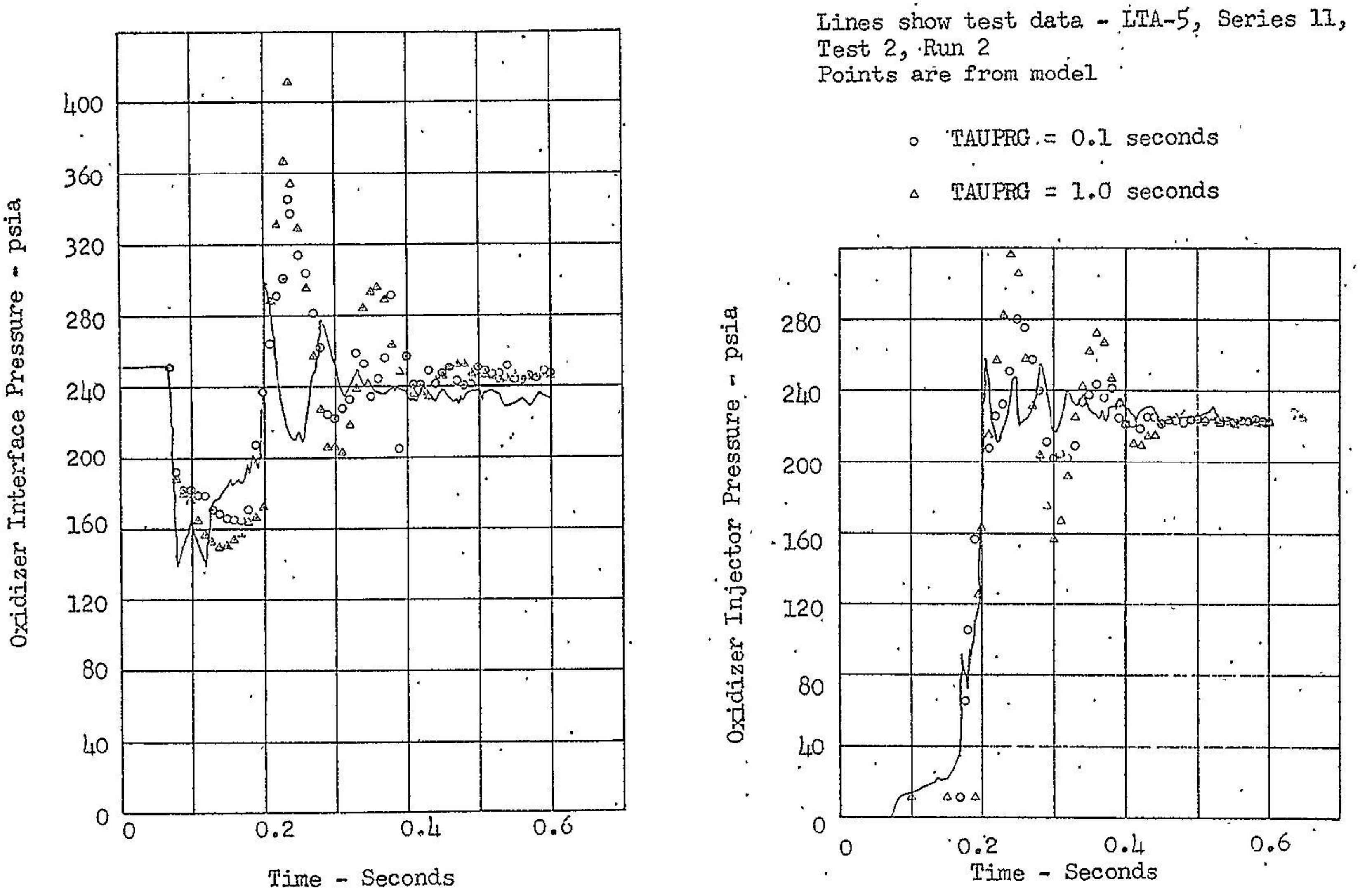


Figure 9 - Apollo Descent Engine Data Correlation Showing Effect of Gas Evolution Rate - Fuel System Pressures

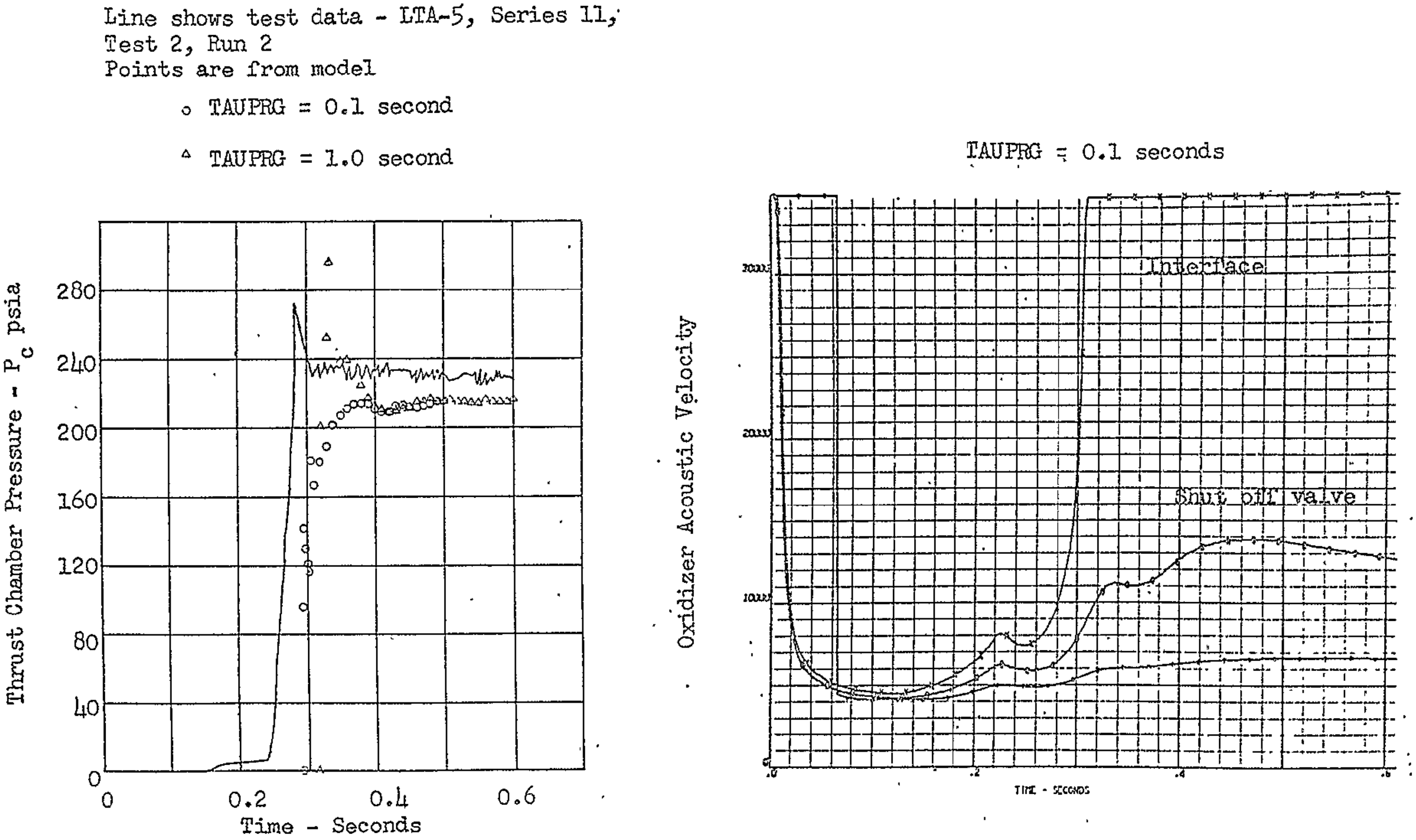


Lines show test data - LTA-5, Series 11, Test 2, Run 2
Points are from model

○ TAUPRG = 0.1 seconds

△ TAUPRG = 1.0 seconds

Figure 10 - Apollo Descent Engine Data Correlation Showing Effect of Gas Evolution Rate - Oxidizer System Pressures



Line shows test data - LTA-5, Series 11,
Test 2, Run 2
Points are from model

○ TAUPRG = 0.1 second

△ TAUPRG = 1.0 second

TAUPRG = 0.1 seconds

Figure 11 - Apollo Descent Engine Data Correlation Showing Effect of Gas Evolution Rate

While trying to run the Descent Engine simulation an instability occurred in which pressures would fluctuate with increasing amplitude. After much documentation it was determined that this was caused by the variable acoustic velocity. In the model the acoustic velocity is computed using the equation

$$a = \left[\frac{1}{\left(\dfrac{\rho_m}{1 + \phi \dfrac{\rho_\ell}{\rho}}\right)\left(\dfrac{1}{\rho_\ell a_\ell^2} + \dfrac{\phi \rho_\ell}{\rho_g a_g^2} + \dfrac{1 + \phi \dfrac{\rho_\ell}{\rho_g}}{g} \dfrac{Dc}{Ec}\right)} \right]^{1/2}$$

where $$\rho_g = \frac{P_{pg}}{R_{pg} T} + \frac{P_{\ell vp}}{R_{\ell vp} T}$$

During a start transient the pressures downstream of the main propellant valve approach vapor pressure. This low pressure causes dissolved pressurant gas in the propellant to come out of solution, and because the pressure is low, the gas density ρ_g is small. This gives rise to acoustic velocities in the order of 2500 inches per second.

When the engine manifolding primes, there is a rise in pressure which increases ρ_g and hence the acoustic velocity increases. As the pressure increases the pressurant gas starts to go back into solution, and the acoustic velocity increases further. In the original analysis for the model it was recognized that the wave equations used to calculate the transient flow and pressures in the system assume that the acoustic velocity is constant; however, initial evaluation showed that a slowly varying acoustic velocity would not cause trouble. The changes in acoustic velocity were expected to be slow in the program as the fluid properties were calculated using an average pressure, and the pressurant gas dissolved or evolved from the liquid at a slow rate. The data showed that when the injector primed, the acoustic velocity increase was much greater than had been expected - Fig. 11.

A method to decrease the rate of increase in acoustic velocity was looked for and as an aid to understanding the problem a five segment version of the model was programmed on a time sharing computer. This program calculated flow and pressure as in the large model and used a change in resistance at the injector end of a five segment feed line to produce a transient. Variation of acoustic velocity was controlled by use of an equation

$$a = f(\bar{P}) \qquad a_1 \quad a \quad a_2$$

where the acoustic velocity, a, was allowed to vary between the limits a_1 and a_2, and $\bar{P}$ is a running average of the last 50 values of pressure in a segment. The results for a few of the cases run are shown in Fig. 12. Generally, changing acoustic velocity tends to sustain the pressure oscillations, and large changes can cause instability. The data generated using this model led to the scheme which allowed the model to run stably. This scheme was to use a constant value for gas density, g in the model, and let the acoustic velocity change as a function of free gas concentration, ϕ, only.

DESCENT ENGINE LM-3 ANOMALY SIMULATION

The purpose of modeling this transient was to demonstrate the model's ability to simulate a throttling transient and also schemes of modifying it so that the simulation of the passage of a discrete bubble through the feed system could be simulated. On the Apollo 9 flight the astronauts reported engine roughness during the second burn of the Descent Propulsion Engine, approximately 6 seconds after engine start. Analysis of this event--Ref. (e), showed that a gas bubble had been trapped in the propellant feed lines and the roughness resulted when the bubble passed through the engine.

In order to run this case it was necessary to reprogram subroutines ROCKET and CAVENT, and add two new routines, VENTR 2 and GASFLO. The analytical basis of this version of the model is given in Appendix C. Basically, the model assumes that the system is operating normally at time = 0, which corresponds to 93:47:39.250 flight ground elapsed time. At 1 ms (model time) the bubble in the oxidizer feed system starts to pass throuth the cavitating venturi; the bubble in the fuel line starts through the fuel cavitating venturi at 0.41 seconds. Fig. 13 and 14 compare the model results with the flight data. The general trend of the model results agree with the data. When the bubble starts through the cavitating venturi the downstream pressure rises; after passage of the bubble completely through the venturi we see a surge in the interface pressure, the downstream pressure falls off while there is an increase in P_c. These events occur because

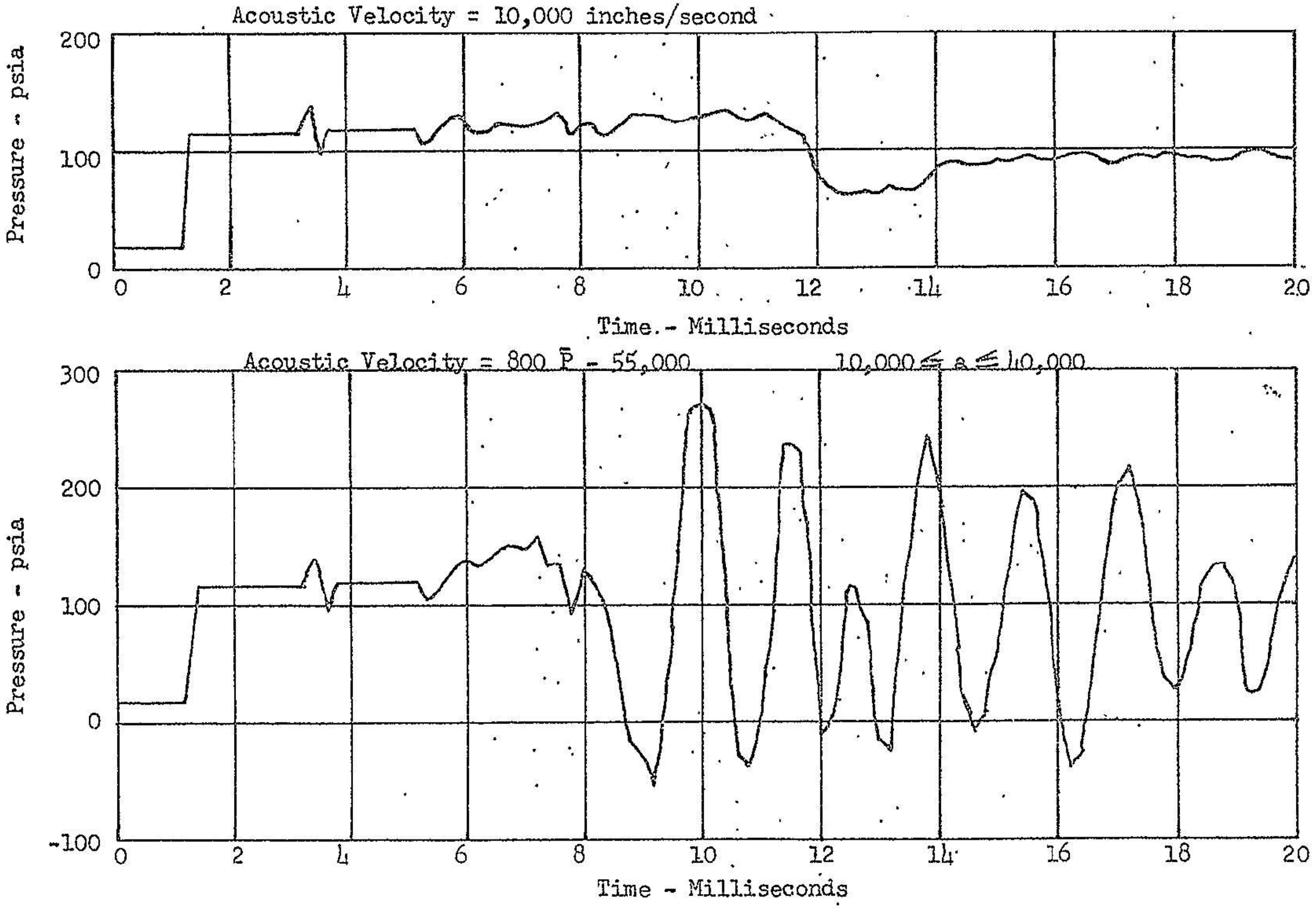
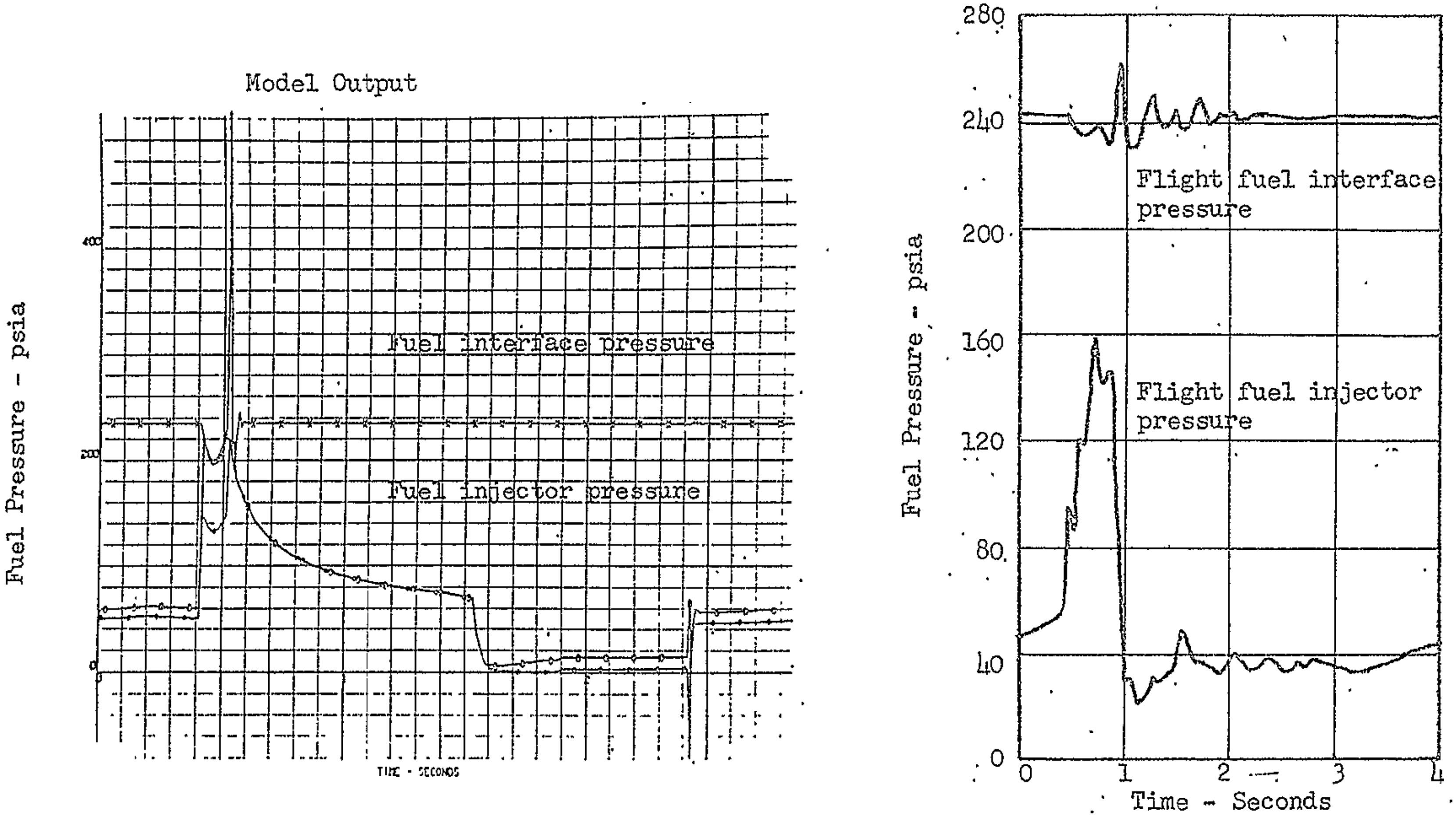
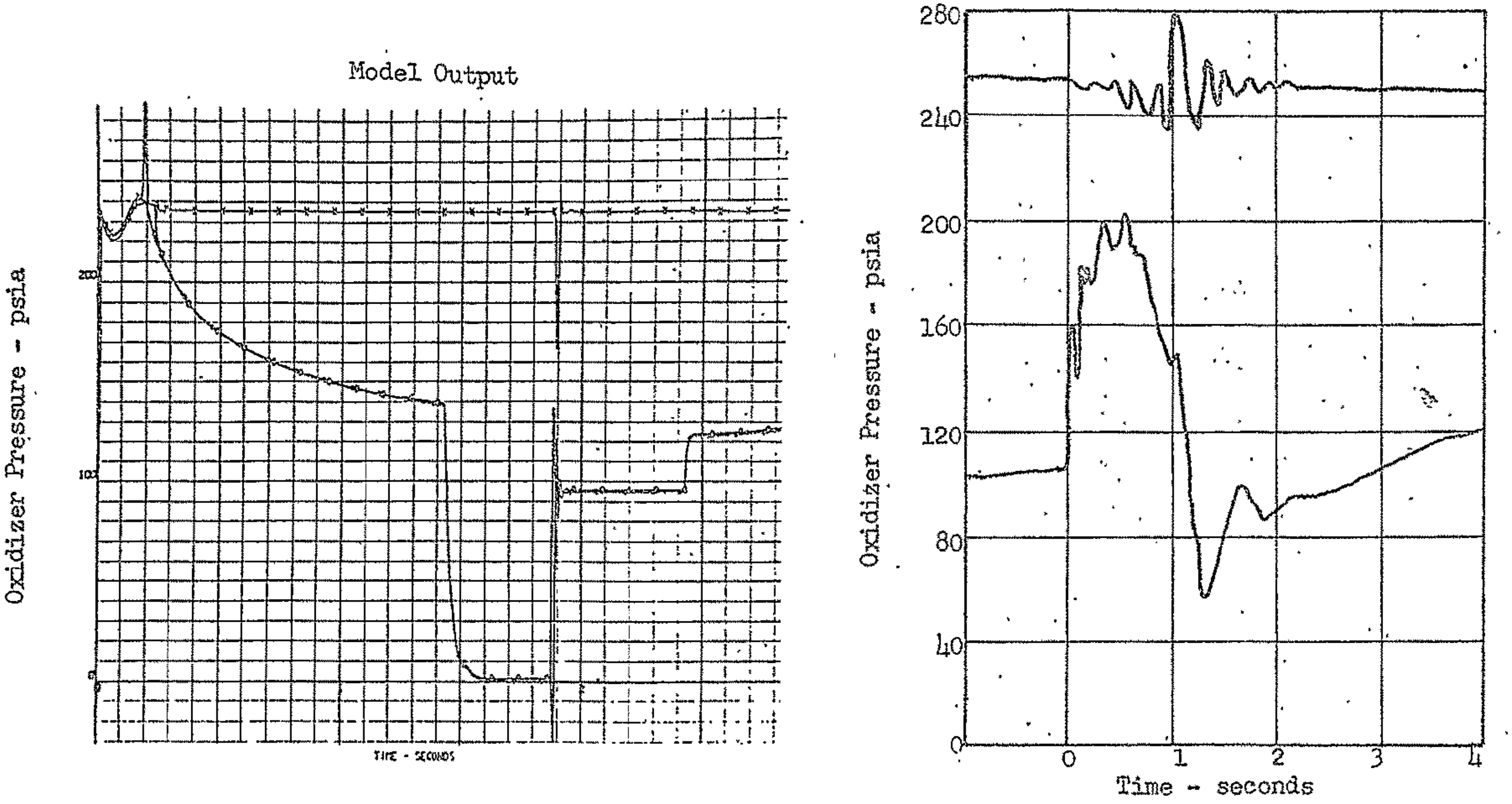


Figure 12 - Effect of Variable Acoustic Velocity on the Response of a Simple Feed System



Time 0.0 is Equivalent to 93:47:39.25 Hours
Elapsed Time

Figure 13 - Apollo Descent Engine Data Correlation - LM-3 Flight Anomaly



Time 0.0 is equivalent to 93:47:39.25 hours
Ground Elapsed Time

Figure 14 - Apollo Descent Engine Data Correlation - LM-3 Flight Anomaly

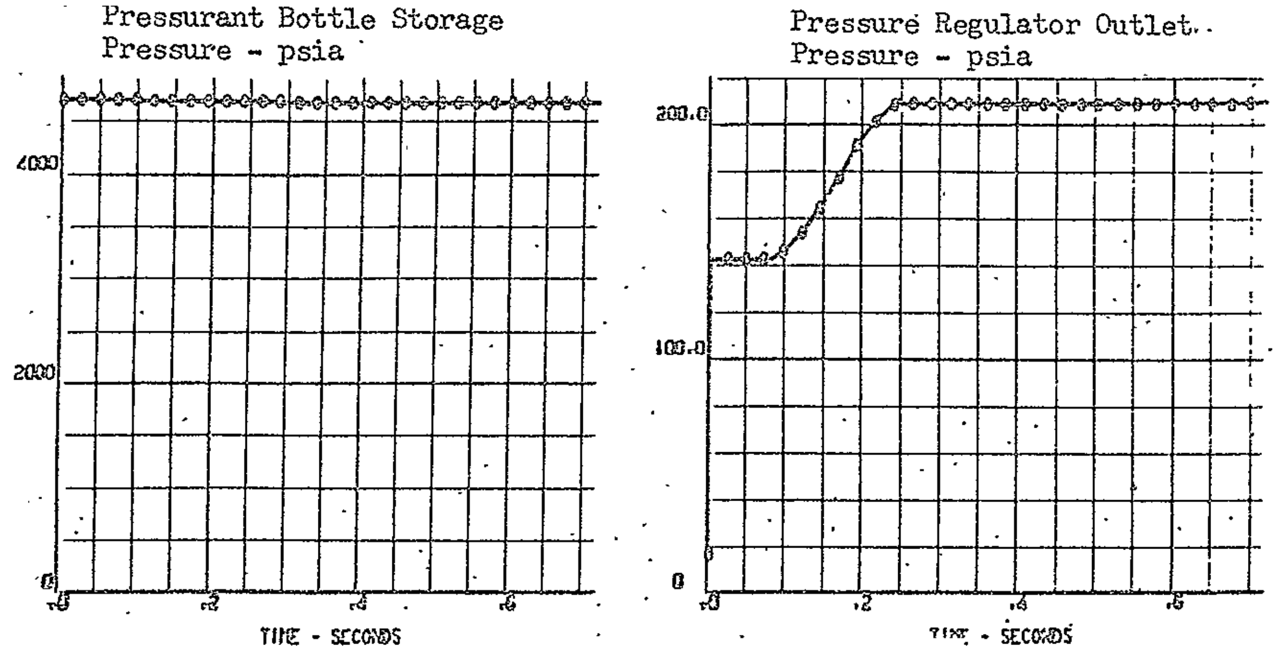
the volumetric flow of the gas through the venturi is much greater than for liquid flow after the bubble passes the venturi. When the bubble has passed through the venturi we see it expand (decrease in pressure) and force propellant out of the injector. When the bubble starts to pass through the injector the manifold pressure drops to a level which is close to the combustion chamber pressure. Chamber pressure of course drops off because of the lack of propellant. After all gas has passed through the system it returns to normal.

The lack of correlation seen in this case is probably caused by two factors: (1) The bubble size selected was 30 cubic inches in both fuel and oxidizer sides--Ref. (c), and (2) The actual bubble was probably not a single bubble as assumed for the model. A series of bubbles separated by discrete amounts of fuel could cause the stepwise rise seen in the fuel and oxidizer injector pressures. Each rise would correspond to the passage of a bubble and each drop would correspond to expansion of the bubble downstream of the venturi while the propellant separating the bubbles passes through the cavitating venturi.

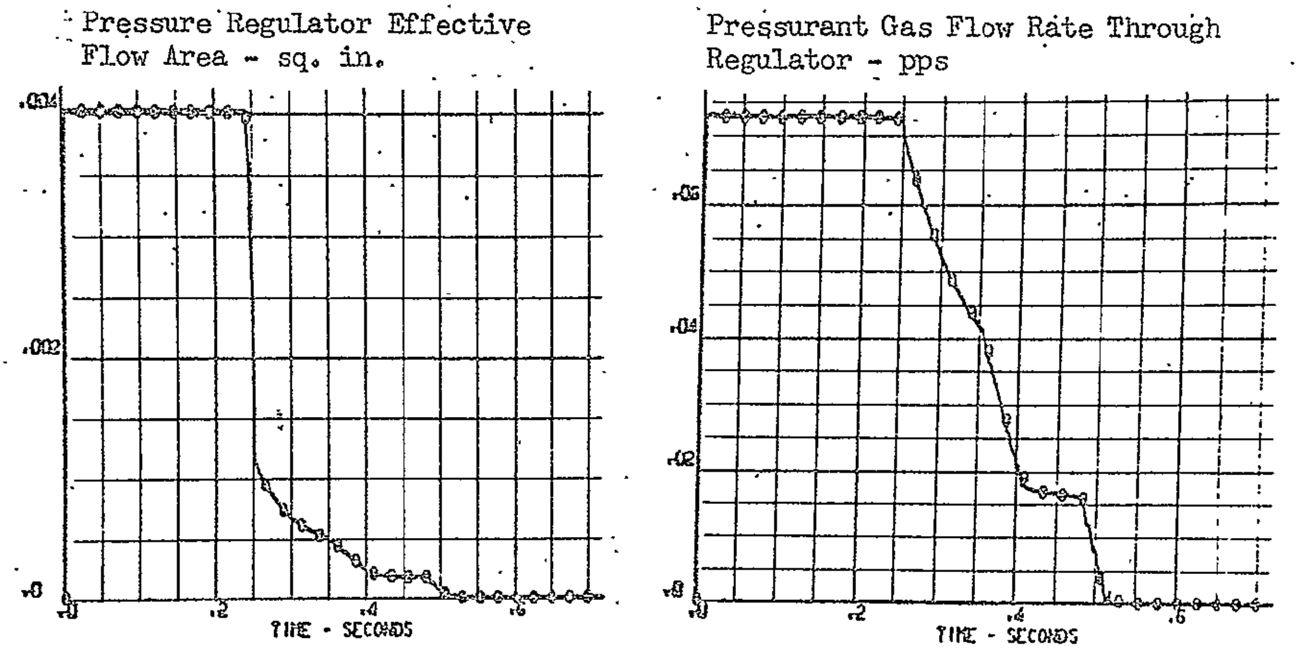
The rapid falloff in the flight fuel injector pressure would indicate that the size of the fuel bubble in the model is probably much too large; also, the passage of the fuel bubble through the engine, based on the fuel velocity and fuel line lengths would suggest that the fuel bubbles did not start to pass into the combustion chamber until a G.E.T. of 41 seconds. The small perturbations in chamber pressure seen at this time would also suggest that at the low injector pressure the bubbles are quite small.

SE5-5 TANK PRESSURIZATION MODEL

To demonstrate operation of the simplified pressurization feature of the model the feed system of Rocketdyne's SE5-5 engine system was modeled. This system consists of a pressurant storage bottle, a pressure regulator, two propellant tanks, and two engines. Details of the system are shown in Appendix D. Fig. 15 and 16 show the results obtained. At time zero the pressurization transient starts. Initially, the propellant tanks are at a pressure of 16 psia and the regulator is wide open. The pressure in the propellant tank starts to increase; when it reaches 160 psia the propellant burst diaphragms break and the


Pressurant Bottle Storage Pressure - psia

Pressure Regulator Outlet Pressure - psia


Pressure Regulator Effective Flow Area - sq. in.

Pressurant Gas Flow Rate Through Regulator - pps

Figure 15 - SE5-5 Engine System Predicted Pressurization Transient Performance

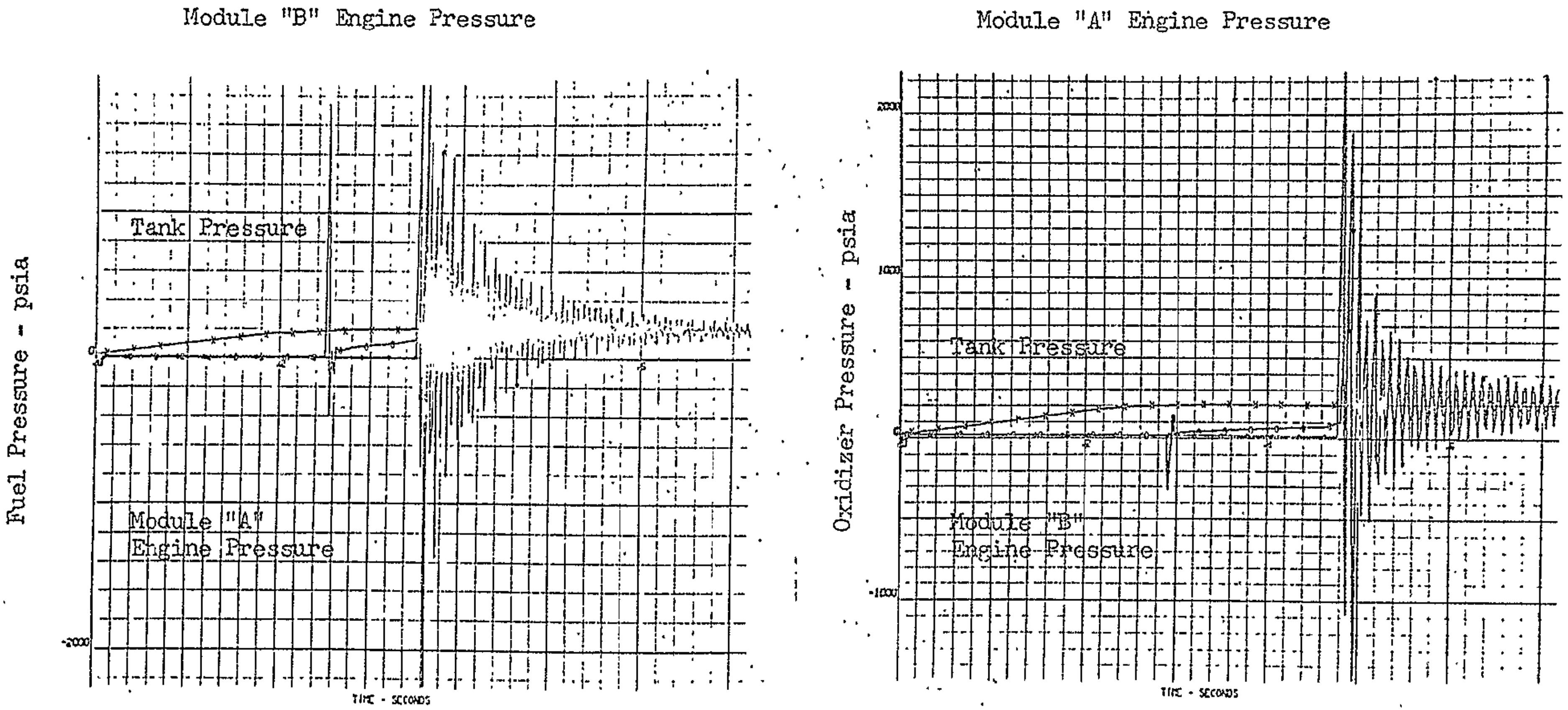


Figure 16 - SE5-5 Engine System Predicted Pressurization System Performance

and the feed lines between the tank and engine start to prime.

When the feed lines prime a surge of approximately 2000 psi is produced. In the model the pressure than oscillates about the mean pressure level until the water hammer phenomena damps out. Since the surge pressure is several times the normal operating level, the pressures go below zero. This happens because the equations work for negative as well as positive pressures. In a real system, the fluid will vaporize then the pressure decreases below its vapor pressure, and the resultant gas will change the shape of the oscillation wave form.

DEFINITION OF SYMBOLS

A	area	square inches
C*	characteristic velocity	in/sec
CP, C_v	heat capacity	BTU/pound
D	diameter	inches
E	Young's Modulus	psi
G	ratio of disolved gas weight to fluid weight	---
G_s	equilibrium value of G	---
H	heat of vaporization	BTU/lb
K	constant	---
M	molecular weight	---
P	pressure	psia
R	resistance	$psi/(pps)^2$
R_o	universal gas constant	psia in^3
T	temperature	degrees R
U	internal energy	BTU/pound
V	volume	cubic inches
W	total mass	pounds
Z	compressibility factor	---
c	pipe end restraint factor	---
e	pipe wall thickness	inches
e	base of natural logarithms	---
g	gravitational constant	386 in/sec/sec
k	ratio of specific heats	---
ℓ	length	inches
t	time	seconds
v	velocity	inches/second
x	distance	inches
$\dot{w}$	flowrate	pounds/second
β	fluid compressibility	psi

DEFINITION OF SYMBOLS (CONTINUED)

α	ratio of volume of gas to volume of liquid	
γ	time constant	seconds^{-1}
ξ	heat exchanger effectiveness	---
ρ	density	pounds/cubic inch
τ	time delay constant	seconds
η_{c^*}	combustion efficiency	

SUBSCRIPTS

c	combustion chamber
g	gas
i	sequence number
ℓ	liquid
ℓv	liquid vapor
m	mixture
k	piston
S	spring
t	throat
v	vapor

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(c) Compact Heat Exchangers, Kays, M., and A. L. London, The National Press, Palo Alto, California, 1955.

(d) Oscillatory Flame Front Flowrate Amplification through Propellant Injection Ballistics (The Klystron Effect), J. R. Fenwick and G. J. Bugler - Presented at Third ICRPG Combustion Symposium, Cape Kennedy, Florida, 17-21 October 1966.

(e) Apollo 9 Flight LM-3 Anomaly No. 4 DPS-2 Roughness, LED-271-94 Grumman Aerospace Corporation.

APPENDIX A

APOLLO ASCENT ENGINE MODELING

Feed Line Modeling

The system geometry and certain system parameters must be defined prior to the computer model operation. A major portion of this information relates to the propellant feed lines. In order to use this data, the feed lines must be broken into segments having some logical order with the length, internal cross-sectional area, fluid resistance, and line compliance factor specified.

Criteria for the sizing of segments is based on changes in line size, branching of lines, location of concentrated fluid resistance elements such as valves and orifices, model frequency response, and the time period to be simulated. The Apollo Ascent Engine transient which is to be modeled is approximately 0.8 seconds long, and the program will produce 300 data points for this transient. Thus, the spacing of the data points will be 2.7 ms, and if 10 data points are assumed necessary to define a sine wave cycle then the model would have a frequency response of 37.5 cps. If one wants a model with 600 cps frequency response then the time interval between points should be 0.167 ms. For this model a calculation interval of 0.170 ms will be selected so that the capability of 600 cps frequency response may be retained.

Having picked an integration interval the minimum and maximum line lengths that can exist in the model will be selected. The minimum line length is related to the maximum fluid acoustic velocity by the relation

$$\ell \text{ min} \geqslant a_{max} \Delta t$$

For the fuel, a_{max} = 60,000 in/sec, and thus the line segments must be at least 10.2 inches long. For the oxidizer, a_{max} = 40,500 in/sec, and ℓ_{min} = 6.89 inches. The maximum line length can be found from the relation

$$\ell \text{ max} \geqslant 25 \quad a_{min} \Delta t$$

If the propellants are saturated with pressurant gas it is possible for their acoustic velocity to go as low as 2500 inches/second, and thus ℓ_{max} = 10.6 inches. However, it should be pointed out that low values of acoustic velocity will occur only when the average pressure in a segment is very low. This condition will usually only occur downstream of the propellant valves or, in the case of the Apollo Descent Engine, downstream of the cavitating venturi. Thus, as one approaches the propellant tanks, longer line lengths can be used.

Figure A-1 shows a schematic of the Apollo Ascent Engine feed system which is to be modeled. Starting with the fuel system, the plumbing schematic will be modified to fit the techniques used for modeling. In order to achieve flexibility and the correct frequency response, the length of the line segment at the engine inlet should lie between 10.2 and 10.6 inches. The line between the fuel prime delay volume and the injector is only 3 inches long, and it is reasonable to ignore it in the model. Thus, the fuel prime delay volume, injector volume, and the feed line volume will be combined and the total will be injector volume. Thus, the injector volume will be 38.58 cubic inches.

Next, the propellant valve will be considered. The minimum length of the lines between the balls and the injector is 2.05 inches. Since each of the lines are short, it would seem reasonable to combine them. Thus, the parallel series combination of the main propellant valve will be lumped into a single line with a single valve. The total distance between the upstream ball valve and the engine is 22.8 inches, and this length will be divided into 2 segments. The one nearest the engine will be 10.2 inches long, and the upstream one will be 12.6 inches long. The total volume downstream of the upstream ball is 65.12 cu. in.; the injector contains 38.58 cu. in. so the two line segments need a volume of 26.54 cubic inches. The first segment has an internal diameter of 1.37" so its volume is 15.02 cubic inches. The area of the second segment will have to be 11.52/12.6 = 0.916 square inches. These numbers assume that the feed system is primed down to the upstream ball valve. If the engine has propellant to the downstream valve there are 2.9 cubic inches less volume to prime and the area would be 0.648 square inches.

Upstream of the ball valve there is the engine interface, trim orifice and line branch to consider. Experience has shown that the location of an orifice in a primed line is not critical, and since the engine-feed system interface is only important because of a pressure measurement located close to it, this line section will be considered as one length and segmented as necessary. The total distance is 52.10 inches. Experience also has shown that a series of identical line lengths tends to cause computational instabilities, and that the segment upstream of a valve should be short. Thus, this line will be broken into 4 segments which are 10.2, 13, 15, and 13.9 inches long. The orifice will be

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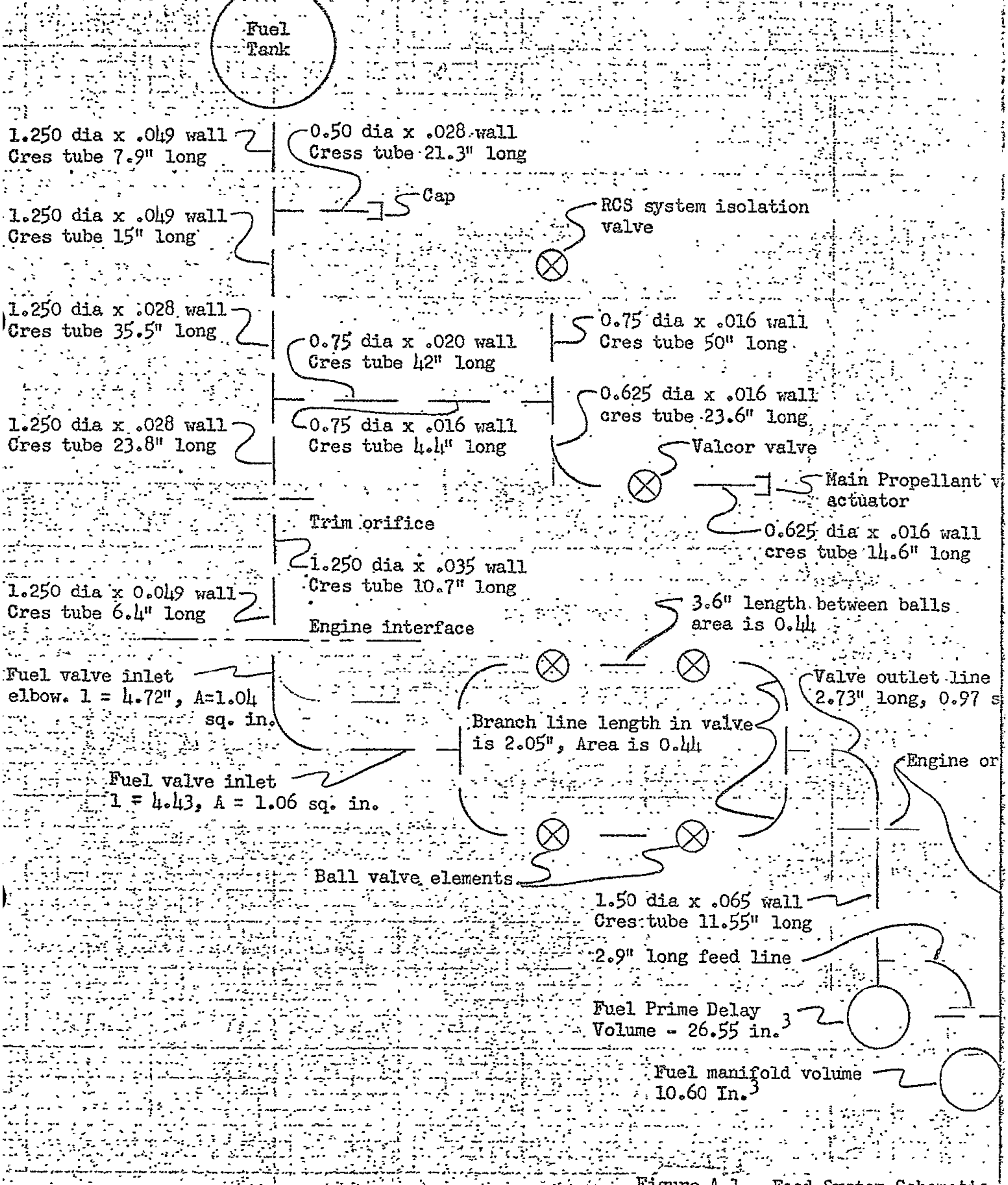
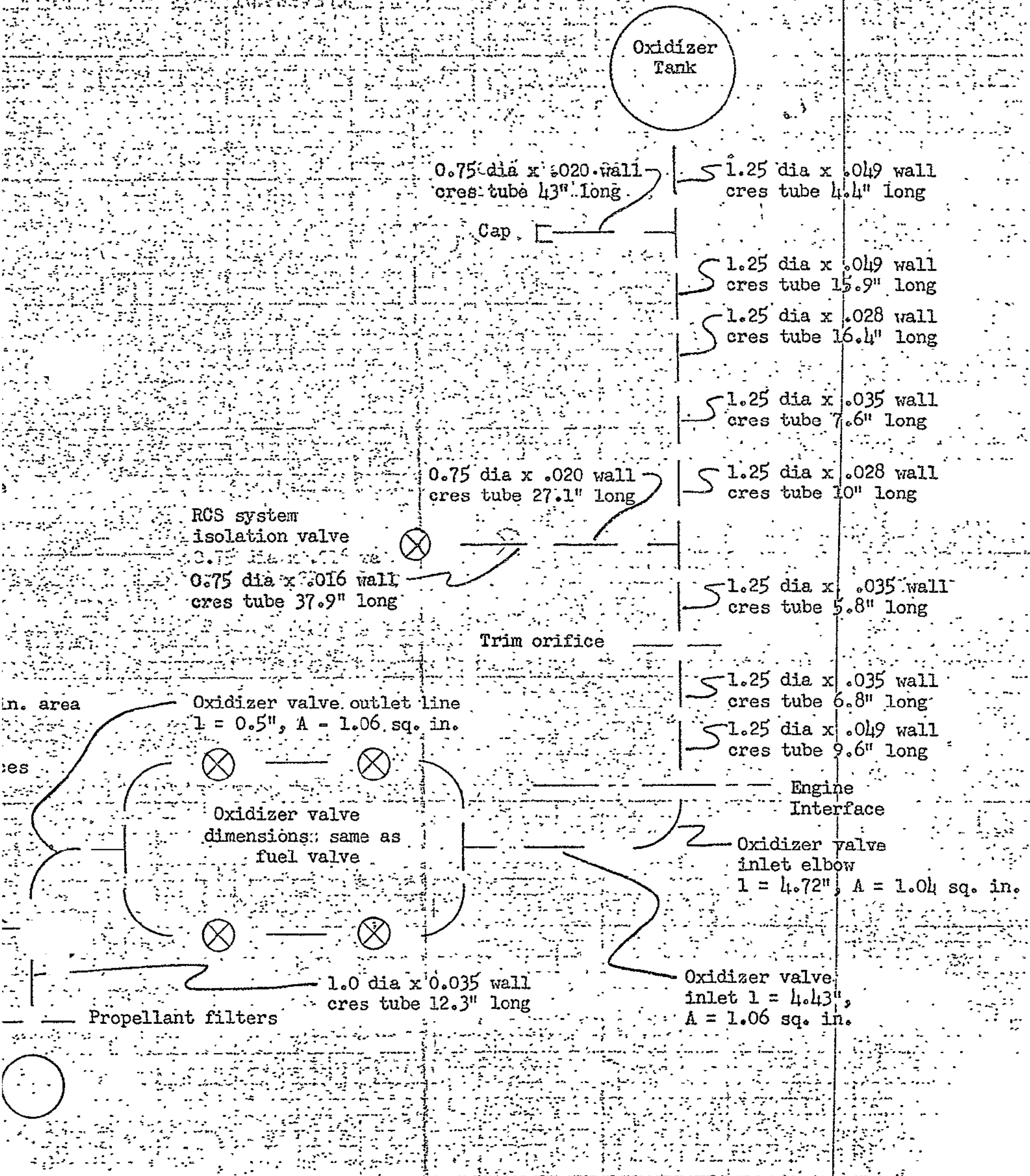


Figure A-1 - Feed System Schematic

FOLDOUT FRAME 2



llo Ascent Engine

placed between the 13 and 15 inch segment and is actually only 5 inches from its true location. The engine interface pressure will be between the 10.2 and 13 inch segment and this pressure is only about 1 inch from its true location. The rest of the system is split up in a similar fashion. The resulting model is shown in Figure A-2 with segment numbers assigned to each segment.

To use the model, the line segments which have been generated must be described by their physical properties - length, area, compliance and resistance. These values are shown in Table A-I and A-II. The compliance is calculated using the formula shown in the Engineer and Programmers Manual, pp. 4.1.2. The resistance values are based on actual values shown below, and distributed in accordance with system geometry.

FEED SYSTEM RESISTANCE - SEC^2/IN^5

	Fuel	Oxidizer
Tank Bottom to Interface	.017912	.011458
Interface to Injector Manifold	.023413	.017361
Injector Manifold to Combustion Chamber	.054856	.030382

For example, the oxidizer trim orifice has an area of 0.8784 square inches. Its resistance, assuming an orifice coefficient of 0.65 is,

$$R = \frac{1}{(27.807 \times 0.65 \times 0.8784)^2} = 0.003967 \text{ sec}^2/\text{in}^5$$

The remaining resistance (0.011458 - 0.003967 = 0.007491) will be distributed along the 80.7 inches of line between the oxidizer tank and enging interface.

The resistance of the side branch lines can be calculated from the following formula

$$R = 0.001294 \frac{f \ell}{dA^2}$$

where f = friction factor

ℓ = length - inches

d = internal diameter - inches

A = internal area - square inches

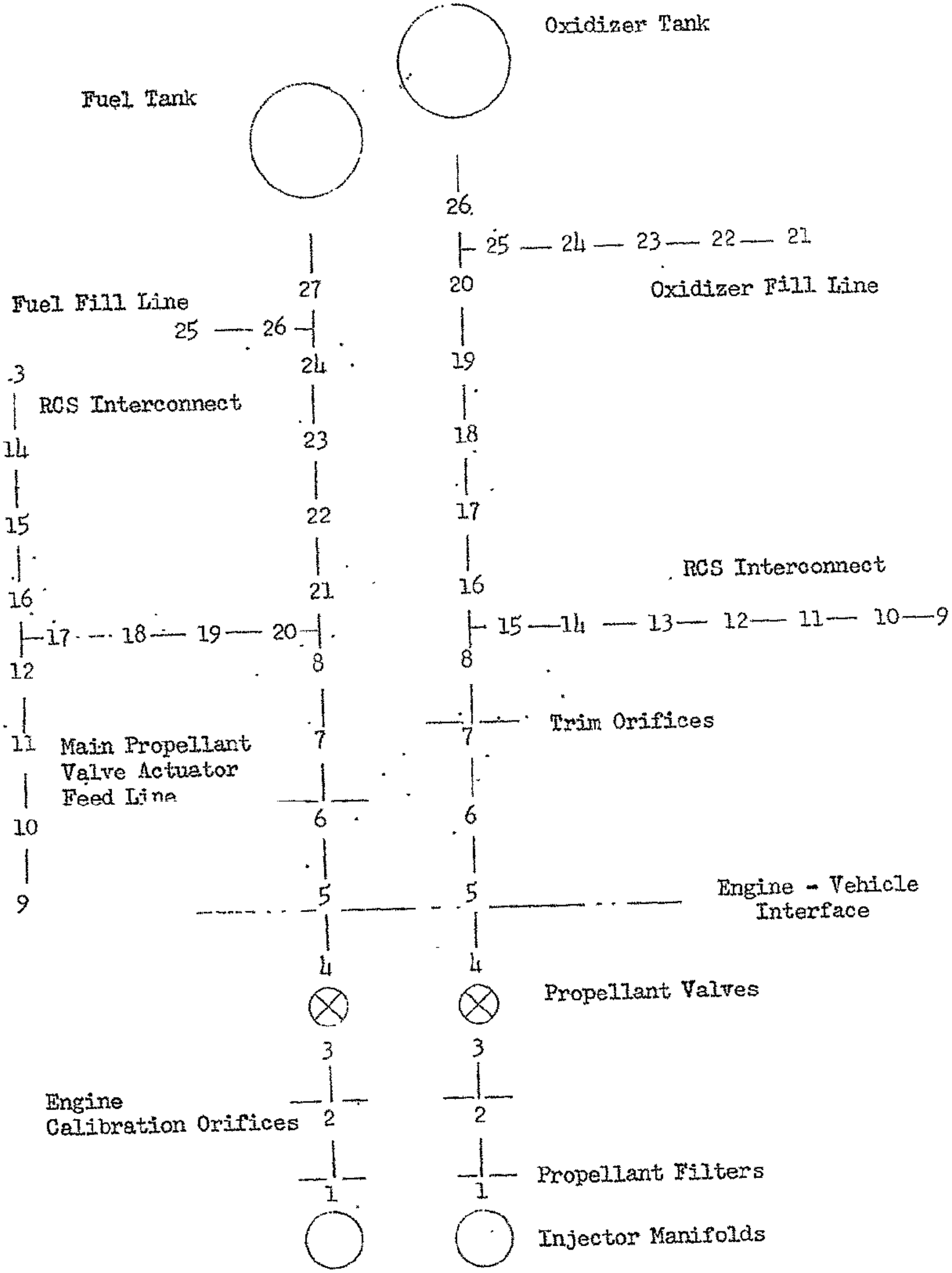


Figure A-2 - Apollo Ascent Engine Feed System Line Segments Used for Modeling

TABLE A-I

FUEL SYSTEM FEED LINE PARAMETERS

SEGMENT NO.	LENGTH IN.	AREA SQ IN	WALL COMPLIANCE SQ IN/LB X 10^7	RESISTANCE SEC^2/IN^5	COMMENTS
1	10.2	1.472	7.52	.003335	
2	12.6	.92	2.91	.003989	When ball valve is wet A=.684 in^2
3	-	-	-	-	Valve
4	10.2	1.04	6.67	.003335	
5	13.0	1.09	9.55	.001603	Interface
6	15.0	1.10	12.1	.001850	
7	13.9	1.10	12.1	.007258	Trim Orifice
8	-	-	-	-	Branch
9	14.2	.276	10.5	.010576	
10	13.	.276	10.5	.009682	
11	11.	.276	10.5	.008193	
12	-	-	-	-	Branch
13	11.	.405	12.7	.00345	
14	16.	.405	12.7	.00502	
15	23.	.405	12.7	.00721	
16	-	-	-	-	Branch
17	20.4	.396	10.1	.00640	
18	15.	.396	10.1	.00471	
19	11.	.396	10.1	.00345	
20	-	-	-	-	Branch
21	11.	1.10	12.1	.001356	
22	15.	1.10	12.1	.001850	
23	19.	1.04	6.67	.002343	
24	-	-	-	-	Branch
25	21.3	0.156	4.49	.066322	
26	-	-	-	-	Branch
27	13.4	1.04	6.67	.001652	

TABLE A-II

OXIDIZER FEED LINE PARAMETERS

SEGMENT NO.	LENGTH IN	AREA SQ IN	WALL COMPLIANCE SQ IN/LB X 10^7	RESISTANCE SEC^2/IN^5	COMMENTS
1	10.0	.679	7.52	.001772	
2	8.9	.912	2.91	.001577	When ball valve is wet A = .542
3	-	-	-	-	Valve
4	6.9	1.04	2.91	.001222	
5	9.0	1.04	2.91	.000835	Interface
6	10.5	1.09	9.55	.000975	
7	6.9	1.09	9.55	.004607	Trim Orifice
8	-	-	-	-	Branch
9	7.	0.405	12.7	.00219	
10	9.	0.405	12.7	.00283	
11	14.	0.405	12.7	.00439	
12	17.	0.396	10.1	.00534	
13	11.	0.396	10.1	.00345	
14	7.	0.396	10.1	.00219	
15	-	-	-	-	Branch
16	7.	1.10	12.1	.000650	
17	13.	1.0	12.1	.001207	
18	15.	1.10	12.1	.001392	
19	12.3	1.04	2.91	.001142	
20	-	-	-	-	Branch
21	7.	0.396	10.1	.00219	
22	13.	0.396	10.1	.00408	
23	15.	0.396	10.1	.00471	
24	8.	0.396	10.1	.00251	
25	-	-	-	-	Branch
26	7.	1.04	2.91	.000650	

which is merely a form of the D'arcy head loss equation. The pressure dro between the engine and injector is made up of that across the propellant valve, engine orifice, and propellant filters in addition to the line resistance.

The effective area of the valve may be calculated and Fig. A-3 shows the results for a single ball and for the parallel series combination. The maximum area is used to calculate the resistance of the valve in the open position. The resistance of the engine filter is based on a pressure drop of 2.7 psi at rated flow, and the resistance of the trim orifice is calculated as before.

Thus the total lumped resistance between the engine interface and the injector is:

	Fuel	Oxidizer
Propellant Valve	.006620	.006620
Engine Trim Orifice	.004279	.005445
Propellant Screen	.001725	.001725
Total Lumped Resistance	.012624	.012790

The difference between the total lumped resistance and the measured resistance will be distributed in the feed lines between the interface and injector. This completes the definition of the feed system.

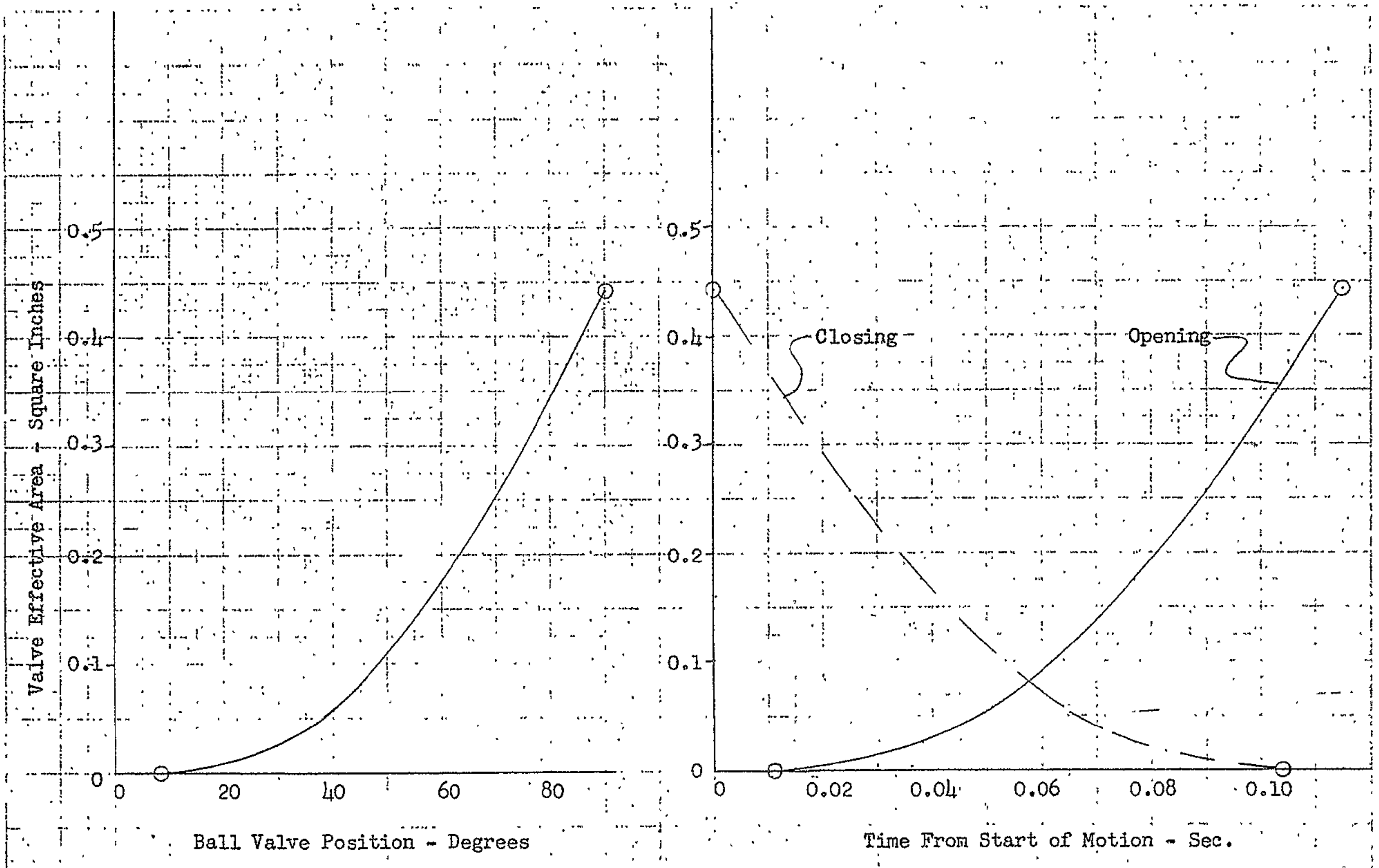


Figure A-3 - Apollo Ascent Engine Bipropellant Valve Data

Combustion Chamber Performance

Combustion performance in the Generalized Propulsion System Model is determined from the lumped parameter equation

$$\frac{d\ P_c}{dt} = \frac{R_c T_c}{V_c} - \frac{R_c T_c}{V_c} \circ \frac{A_t\ P_c}{\eta_{c*} \frac{C*}{g}}$$

The constants $R_c T_c$ and $\frac{C*}{g}$ are functions of the particular propellants being used and vary with mixture ratio and pressure level. These constants can be determined from thermochemical performance using the properties of the propellants. The results of one such analysis for the Apollo propellants over a range of mixture ratios and pressures are shown in Table A-III. To use them in the program it has been found convenient to use the oxidizer fraction rather than mixture ratio. This allows the combustion property data to be extrapolated to fuel only, (MR) = 1.0, or oxidizer only, (MR) = 0.0, operation.

During propellant blowdown after engine cutoff the model assumes that no combustion occurs. To calculate thrust chamber pressure during this period, the oxidizer fraction is set to either 0.0 or 1.0 and equation (1) is used. Thus, the values of $R_c T_c$ and $C*/g$ must be known for each propellant in its vapor phase. This was determined for nitrogen tetroxide and 50-50 UDMH - hydrazine as follows. The value of C_p for the propellants was found at a temperature of 660°R. Assuming that the vapor phase behaved as a perfect gas the ratio of specific heats was found from the relation

$$k = \frac{C_p}{C_p - R}$$

and then C* may be calculated

$$C* = \frac{\sqrt{gkRT}}{\left[k \quad \frac{2}{k+1}\right]^{\frac{k+1}{k+1}}}$$

Values for the constants which apply to the propellant vapor are shown in Table A-IV. A plot of the combustion parameters as a function of oxidizer

TABLE A-III

COMBUSTION DATA FOR NITROGEN TETROXIDE 50/50 HYDRAZINE-UDMH

MIXTURE RATIO	OXIDIZER FRACTION	CHAMBER PRESSURE (PSIA)	$\frac{C^*}{g}$	$\frac{RT_c}{M.W.} \times 10^{-6}$
0.05	0.048	150.0	132.12	3.054
0.10	0.091	150.0	134.08	3.133
0.20	0.167	150.0	137.16	3.219
0.40	0.286	150.0	141.70	3.351
0.50	0.333	150.0	146.42	3.714
0.60	0.375	150.0	153.29	4.055
0.80	0.444	150.0	164.17	4.566
1.00	0.500	150.0	171.38	4.886
1.20	0.546	150.0	175.48	5.023
1.40	0.583	150.0	177.72	5.059
1.60	0.615	150.0	178.22	5.006
2.00	0.667	150.0	175.14	4.768
2.40	0.706	150.0	170.17	4.495
3.00	0.750	150.0	162.83	4.129
3.60	0.783	150.0	156.24	3.826
5.00	0.833	150.0	143.28	3.276
10.00	0.909	150.0	112.70	2.130
20.0	0.952	150.0	85.63	1.264
50.0	0.980	150.0	58.61	0.613
100.0	0.990	150.0	46.40	0.363
1.6	0.615	5.0	173.03	4.632
1.6	0.615	50.0	176.88	4.899
1.6	0.615	170.0	178.37	5.020
1.6	0.615	190.0	178.50	5.031
1.6	0.615	200.0	178.47	5.048

TABLE A-IV

PROPELLANT VAPOR PROPERTIES

		50-50 UDMH-HYDRAZINE	NITROGEN TETROXIDE
C_p	BTU/LB MOLE °R	17.50	124.0
C_p	BTU/LB °R	0.418	1.35
MOLECULAR WT		41.8	92.02
R	PSIA IN^3/LB °R	444.	202.
k		1.165	1.016
C^*	FT/SEC	1333.94	946.19
T	°R	660.	660.
RT	PSIA IN^3/LB	0.293040×10^6	$.133320 \times 10^6$
C^*/g	-	41.478	29.42

fraction is shown in Fig. A-4. Figure A-5 shows a plot of the parameters vs pressure at a mixture ratio of 1.6, and this data is used to find the pressure correction factors.

$$CF_{RT} = \frac{\ln (RT)_{ref} - \ln (RT)_{act}}{\ln \left(\frac{P_{ref}}{P_{act}}\right)}$$

and $$CF_{c*/g} = \frac{\ln (C*/g)_{ref} - \ln (C*/g)_{act}}{\ln \left(\frac{P_{ref}}{P_{act}}\right)}$$

For the Apollo propellant combination the correction factors are:

$$CF_{RT} = 0.02779$$

$$CF_{c*/g} = 0.008453$$

The efficiency curve shown in Fig. A-4 is an arbitrary shape except for the fact that it passes through the value of 97.6% at an oxidizer fraction of 0.615. Its correction factor will be set to zero for the present time.

To complete the description of the thrust chamber, data to describe its size and shape are required from Table A-V. The injector manifold volume was defined previously and is noted in the table for reference.

Orifice length used to calculate injector inertance is obtained from a drawing. Injector effective area can be calculated from its resistance, and the flame front distance may be estimated from knowledge of the distance from injector face to impingement, past experience, or actual injector-engine frequency response data. The combustion chamber data may be obtained from engine prints or model specifications.

Program Input/Output

Table A-VI gives a listing of the input data cards, graphical output is presented in Figs. A-6A through A-6F, and Table A-VII contains the program printed output obtained for this case.

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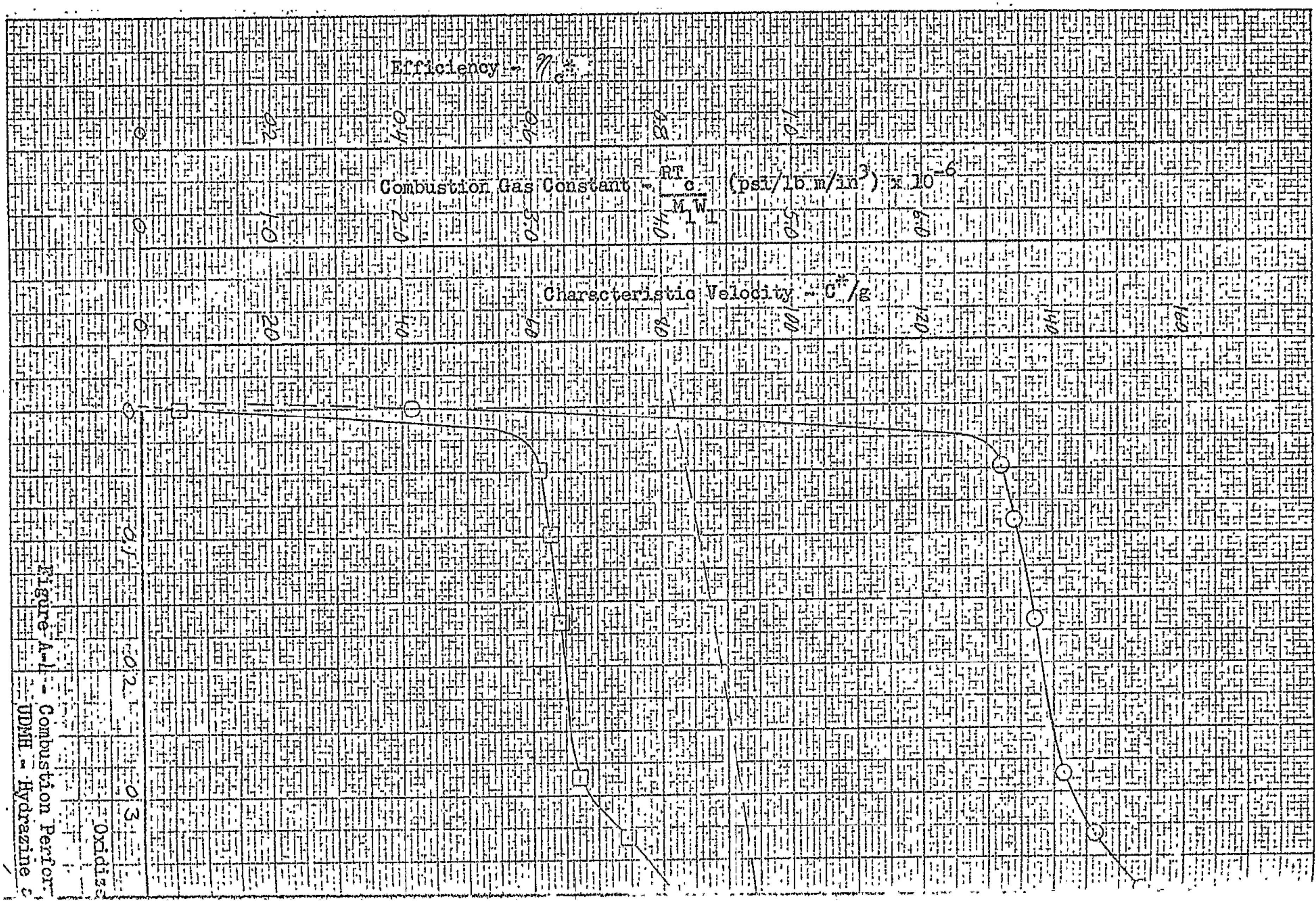
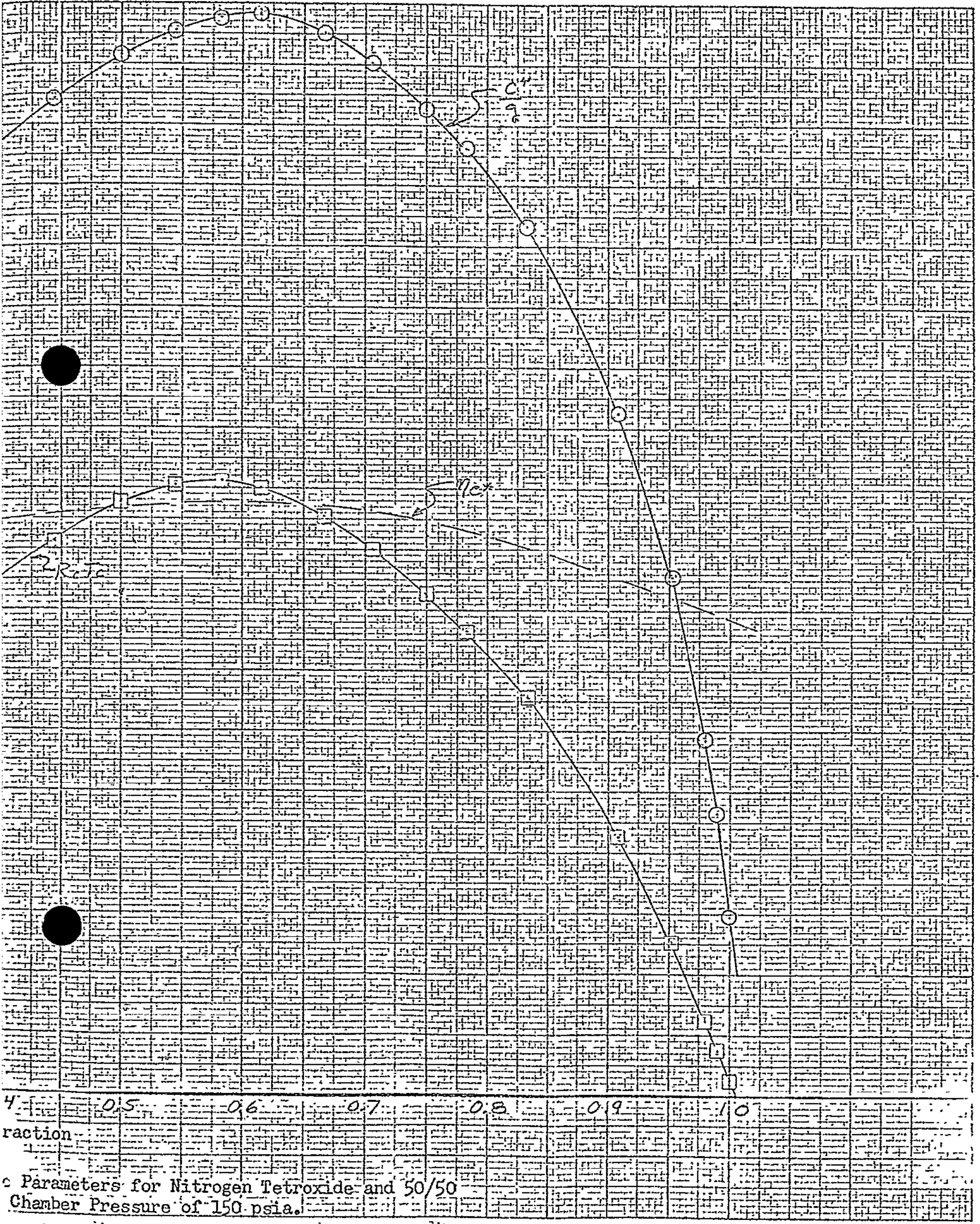


Figure A-1 - Combustion Perfor-
UDMH - Hydrazine c



c Parameters for Nitrogen Tetroxide and 50/50
Chamber Pressure of 150 psia.

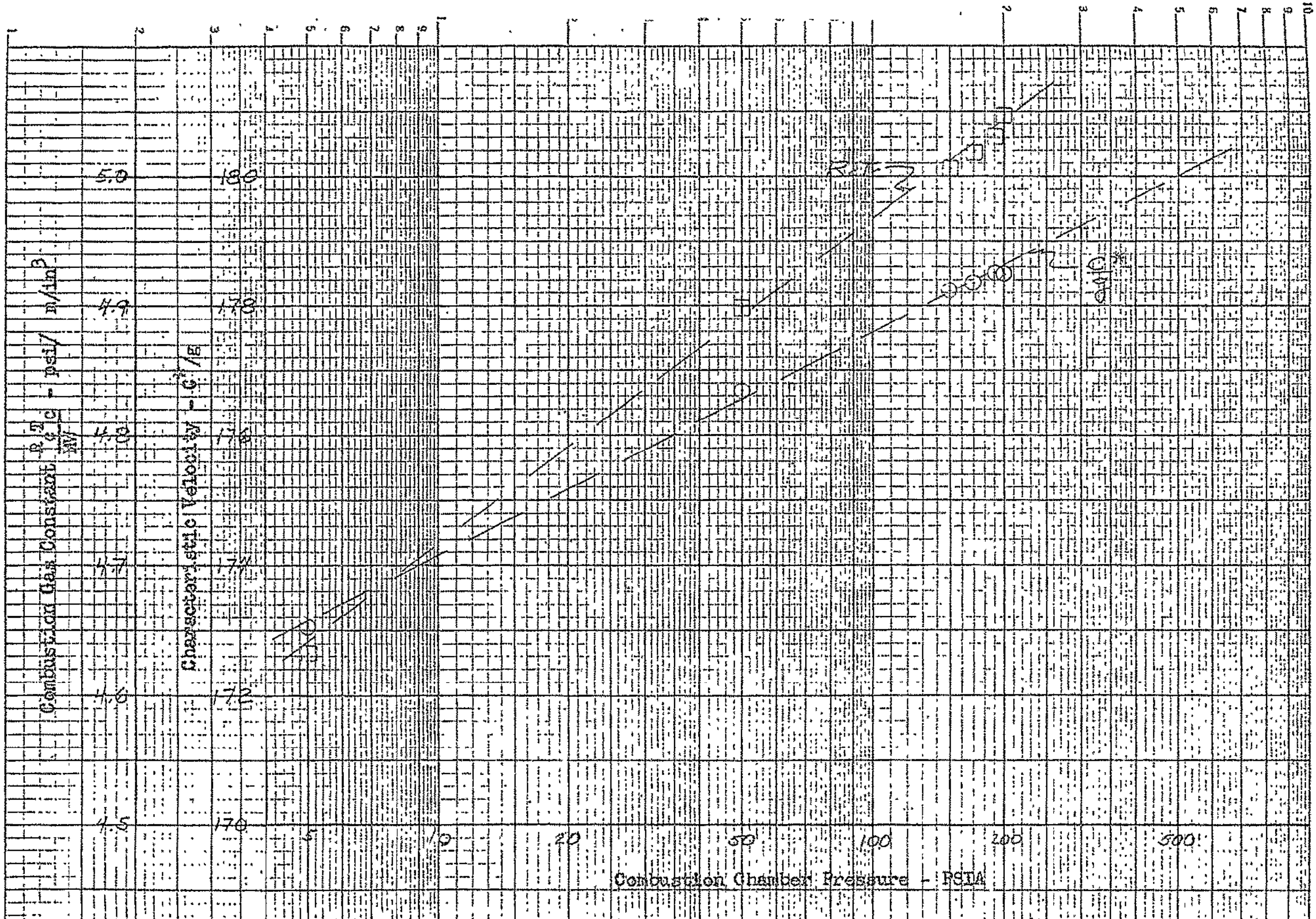


Figure A-5 - Variation of Combustion Performance Parameters with Pressure-
Nitrogen Tetroxide, 50/50 UDMH, Hydrazine

TABLE A-V

COMBUSTION CHAMBER AND INJECTOR DATA

	FUEL	OXIDIZER
MANIFOLD VOLUME - IN^3	38.58	11.38
ORIFICE LENGTH - IN	0.112	0.141
INJECTOR C_pA - IN^2	0.153544	0.206318
FLAME FRONT DISTANCE - IN	0.375	0.375
COMBUSTION CHAMBER THROAT AREA - IN^2	16.4	
COMBUSTER CHAMBER VOLUME - IN^3	453.2	
THRUST CHAMBER NOZZLE EXIT AREA - IN^2	750.0	
THRUST COEFFICIENT	1.784	

TABLE A-VI

APOLLO ASCENT ENGINE COMPUTER PROGRAM INPUT DATA

```
2     1 27   1.472       0.684       0.0         1.04        1.09      0000100,
 1.10        1.10        0.0         0.276       0.276       0.276     0000200,
 0.0         0.405       0.405       0.405       0.0         0.396     0000300,
 0.396       0.396       0.0         1.10        1.10        1.04      0000400,
 0.0         0.156       0.0         1.04                              0000500,
2   121 27  10.2        12.6         0.0        10.2        13.0       0000600,
15.0        13.9         0.0        14.2        13.0        11.0       0000700,
 0.0        11.0        16.0        23.0         0.0        20.4       0000800,
15.0        11.0         0.0        11.0        15.0        19.0       0000900,
 0.0        21.3         0.0        13.4                               0001000,
2   241 27   7.52 E-08   2.91 E-08   0.0         6.67 E-08   9.55 E-080001100,
12.1  E-08  12.1  E-08   0.0        10.5  E-08  10.5  E-08  10.5  E-080001200,
 0.0        12.7  E-08  12.7  E-08  12.7  E-08   0.0        10.1  E-080001300,
10.1  E-08  10.1  E-08   0.0        12.1  E-08  12.1  E-08   6.67 E-080001400,
 0.0         4.49 E-08   0.0         6.67 E-08                         0001500,
2   361 27   0.003335    0.003989    0.0         0.003335    0.001603 0001600,
 0.001850    0.007258    0.0         0.010576    0.009682    0.008193 0001700,
 0.0         0.00345     0.00502     0.00721     0.0         0.00640  0001800,
 0.00471     0.00345     0.0         0.001356    0.001850    0.002343 0001900,
 0.0         0.066322    0.0         0.001652                         0002000,
2    61 26   0.679       0.542       0.0         1.04        1.04      0002100,
 1.09        1.09        0.0         0.405       0.405       0.405     0002200,
 0.396       0.396       0.396       0.0         1.10        1.10      0002300,
 1.10        1.04        0.0         0.396       0.396       0.396     0002400,
 0.396       0.0         1.04                                          0002500,
2   181 26  10.0         8.9         0.0         6.9         9.0       0002600,
10.5         6.9         0.0         7.0         9.0        14.0       0002700,
17.0        11.0         7.0         0.0         7.0        13.0       0002800,
15.0        12.3         0.0         7.0        13.0        15.0       0002900,
 8.0         0.0         7.0                                           0003000,
2   301 26   7.52 E-08   2.91 E-08   0.0         2.91 E-08   2.91 E-080003100,
 9.55 E-08   9.55 E-08   0.0        12.7  E-08  12.7  E-08  12.7  E-080003200,
10.1  E-08  10.1  E-08  10.1  E-08   0.0        12.1  E-08  12.1  E-080003300,
12.1  E-08   2.91 E-08   0.0  E-08  10.1  E-08  10.1  E-08  10.1  E-080003400,
10.1  E-08   0.0  E-08   2.91 E-08                                     0003500,
2   421 26   0.001772    0.001577    0.0         0.001222    0.000835 0003600,
 0.000975    0.004607    0.0         0.00219     0.00283     0.00439  0003700,
 0.00534     0.00345     0.00219     0.0         0.000650    0.001207 0003800,
 0.001392    0.001142    0.0         0.00219     0.00408     0.00471  0003900,
 0.00251     0.0         0.00065                                       0004000,
5     1 26            21 150.0       0.02779     0.008453    0.0       0004100,
-0.005       0.0         0.02        0.04        0.06        0.10      0004200,
```

```
0.20         0.25         0.30         0.35         0.45         0.50         0004300,
0.55         0.60         0.65         0.70         0.80         0.90         0004400,
0.98         1.0          1.005                                              0004500,
5    36 21 -0.2    E+06   0.293 E+06   2.82  E+06   3.04  E+06   3.07  E+060004600,
3.13  E+06   3.24  E+06   3.28  E+06   3.42  E+06   3.87  E+06   4.60  E+060004700,
4.88  E+06   5.03  E+06   5.02  E+06   4.86  E+06   4.55  E+06   3.63  E+060004800,
2.27  E+06   0.37  E+06   0.133 E+06   0.01  E+06                            0004900,
5    66 21   15.0         41.5         115.0        131.5        .32.9        0005000,
134.7        138.0        139.8        142.6        148.8        .65.0         005100,
171.3        175.8        178.1        176.8        171.1        .52.0         005200,
116.6        58.7         29.4         21.0                                   005300,
5    96 21   0.816        0.818        0.826        0.833        ).841        )005400,
0.856        0.889        0.903        0.920        0.933        ).959        )005500,
0.967        0.974        0.978        0.973        0.964        ).922        )005600,
0.859        0.801        0.787        0.781                                  )005700,
3     1 47    3.0          0.0          0.0          0.005        0.01        0005800,
 0.015        0.02         0.028        0.03         0.053        0.04        0005900,
 0.09         0.05         0.137        0.06         0.194        0.07        0006000,
 0.257        0.08         0.328        0.09         0.404        0.10        0006100,
 0.442        0.105        0.442        0.740        0.370        0.750       0006200,
 0.292        0.760        0.225        0.770        0.166        0.780       0006300,
 0.114        0.790        0.072        0.800        0.040        0.810       0006400,
 0.022        0.820        0.010        0.830        0.0          0.844       0006500,
3   101 47    3.0          0.0          0.0          0.005        0.01        0006600,
 0.015        0.02         0.028        0.03         0.053        0.04        0006700,
 0.09         0.05         0.137        0.06         0.194        0.07        0006800,
 0.257        0.08         0.328        0.09         0.404        0.10        0006900,
 0.442        0.105        0.442        0.740        0.370        0.750       0007000,
 0.292        0.760        0.225        0.770        0.166        0.780       0007100,
 0.114        0.790        0.072        0.800        0.040        0.810       0007200;
 0.022        0.820        0.010        0.830        0.0          0.844       0007300,
 3   401  5   1.0         38.58         0.112        0.153544     0.375       0007400,
 3   433  5   1.0         11.38         0.141        0.206318     0.375       0007500,
 3   526  5  16.4        453.2        750.0          1.784        0.0         0007600,
 3   497  6   1.0          0.003335     0.001725     2.0          0.003989 0007700,
 0.004279                                                                    0007800,
 3   509  6   1.0          0.001772     0.001725     2.0          0.001577 0007900,
 0.005445                                                                    0008000,
 3   201  9 328.          203.          0.006       200.0          0.10        0008100,
195.0          0.75       193.0         2.0                                    0008200,
-3   301  9 327.0         202.0         0.006       200.0          0.12        0008300,
194.00         0.82       194.0         2.0                                    0008400,
```

```
$D1 ICMT=3, IPR=3, IST=1, NSEGF=27, NSEGO=26, DELT=170E-06,          ID=1000000,
LFF=3*1,57*0, LFO=3*1,57*0, ICAPFU=9,13,25,2*0, ICAPOX=9,21,3*0,    ID=1000100,
IORF=2,5,6,7,10,11,14,15,18,19,22,23,48*0,                          ID=1000200,
IORO=2,5,6,7,10,11,12,13,14,17,18,19,22,23,24,45*0,                 ID=1000300,
IBRAN(1,1,1)=21, IBRAN(1,2,1)=8, IBRAN(1,3,1)=20,                   ID=1000400,
IBRAN(2,1,1)=17, IBRAN(2,2,1)=12, IBRAN(2,3,1)=16,                  ID=1000500,
IBRAN(3,1,1)=27, IBRAN(3,2,1)=24, IBRAN(3,3,1)=26,                  ID=1000600,
IBRAN(1,1,2)=16, IBRAN(1,2,2)=8, IBRAN(1,3,2)=15,.                  ID=1000700,
IBRAN(2,1,2)=26, IBRAN(2,2,2)=20, IBRAN(2,3,2)=25,                  ID=1000800,
B(3)=0.0325, B(4)=0.052, B(5)=520, B(6)=520,                        ID=1000900,
B(7)=60000, B(8)=40500,                                             ID=1001000,
IWT=5,205,105,305,1,101,403,404,                                    ID=1001100,
IVARIS=2,100,2,200,2,522,2,525,12*0,                                ID=1001200,
ICAP=1, ICUT=1,                                                     ID=1001300,
PF=3*0,25*203,32*0,      PO=3*0,24*202,33*0,                        ID=1001400,
IPI=1,5,28,3*0,101,105,127,3*0,205,220,4*0,305,314,4*0,                1001500,
109,4*0. IPI(25)=9,                                                 ID=1001600,
ENGCUT(1,1,1)=3, ENGCUT(1,1,2)=3,                                   ID=1005200,
ICUTSG=1,2,3,37*0,1,2,3,37*0,                                       ID=1005300,
B(9)=0.0083446, B(10)=-4.1095, B(11)=0.0089489, B(12)=-3.62944      ID=1005400,
B(13)=41.797, B(14)=92.016, B(15)=4, B(16)=4, B(17)=1.67,           ID=1005500,
B(18)=1.67, B(19)=1.05, B(20)=1.10, B(21)=10, B(22)=10,             ID=1005600,
B(23)=8.8889E-06, B(24)=2.0526E-05, B(25)=2760, B(26)=2760,         ID=1005700,
B(31)=0.691, B(32)=0.368, B(33)=0.75, B(34)=0.75,                   ID=1005900,
B(81)=0.3, B(82)=0.3, B(83)=0.01, B(84)=0.01,                       ID=1007000,
B(85)=600, B(86)=600, B(87)=425.8, B(88)=178.2,                     ID=1007100,
INDEX=18,                                                           ID=1008800,
$END                                                                   1008900,
APOLLO ASCENT ENGINE PREDICTED PERFORMANCE                             1009000,
NASA HOUSTON DATA CORELATION                                           1009100,
SIMULATION OF TEST 006 * RUN NO. 1                                     1009200,
```

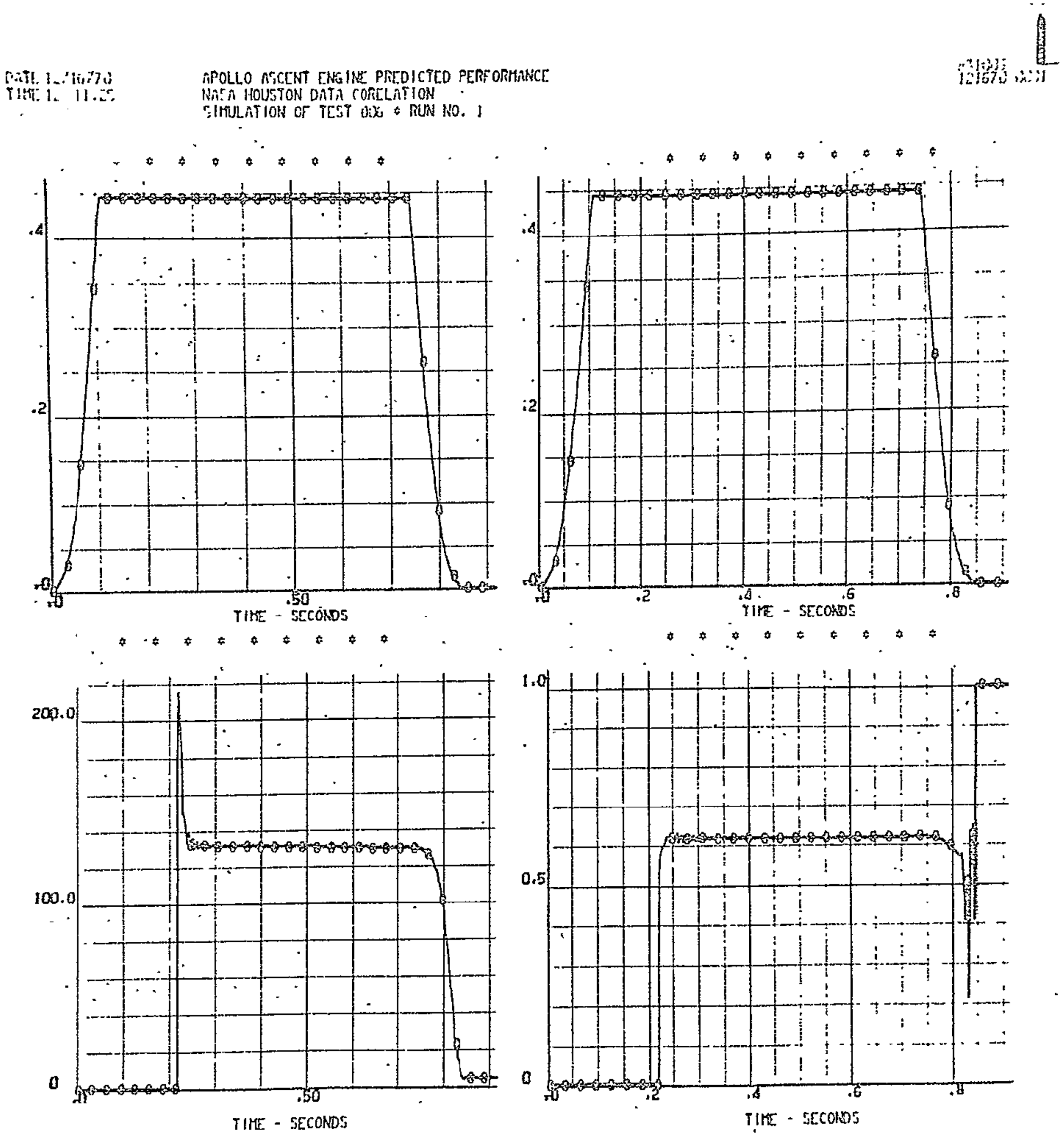


Figure A-6A - Graphical Output of Apollo Ascent Engine Computer Program.

DATE 12/16/70
TIME 12: 11.25

APOLLO ASCENT ENGINE PREDICTED PERFORMANCE
NASA HOUSTON DATA CORELATION
SIMULATION OF TEST 006 * RUN NO. 1

N31003
121670

* FUEL PRESSURE SEGMENT NO. 1.
X FUEL PRESSURE SEGMENT NO. 28.
0 FUEL PRESSURE SEGMENT NO. 5.

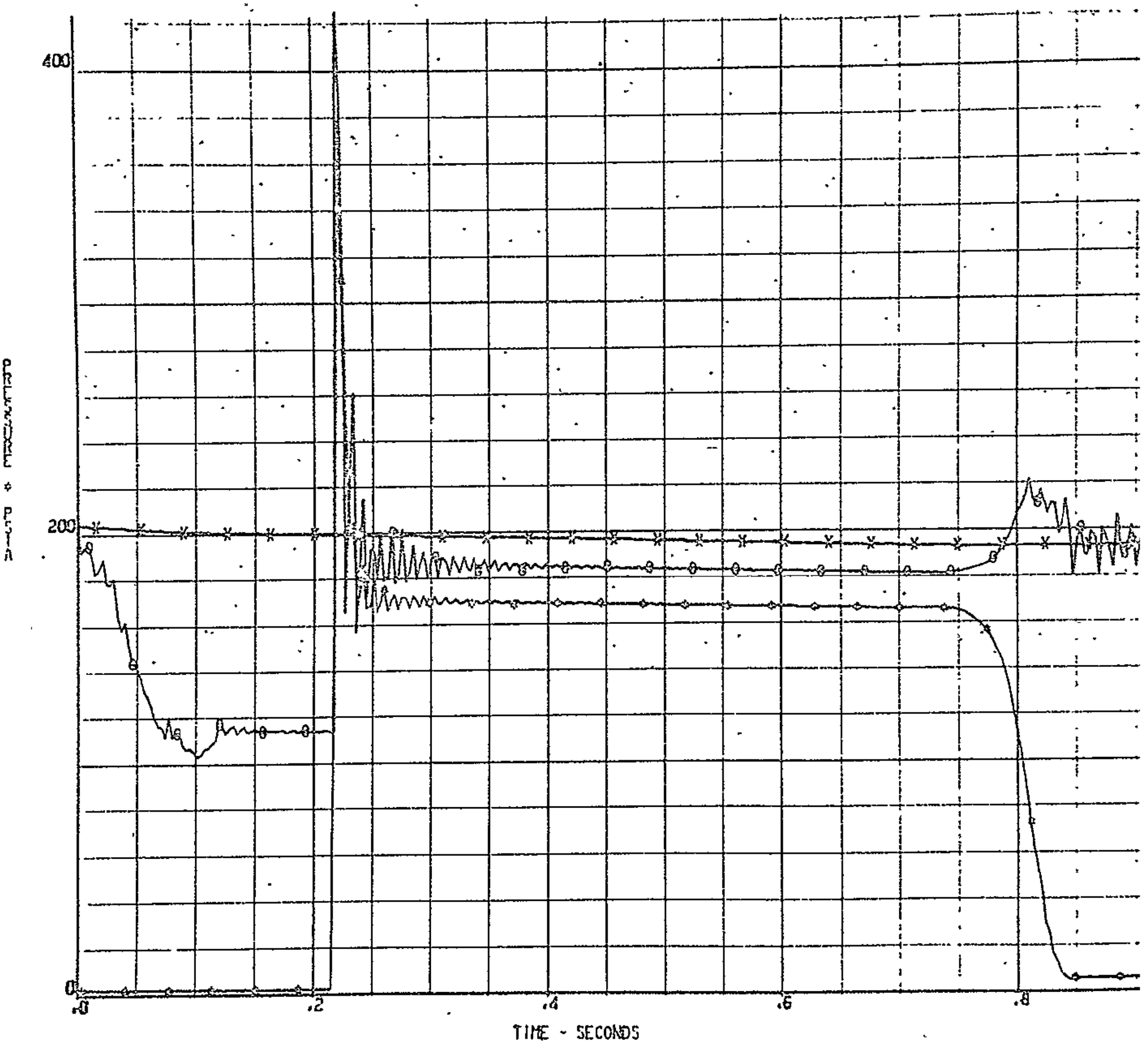


Figure A-6B - Graphical Output of Apollo Ascent Engine Computer Program.

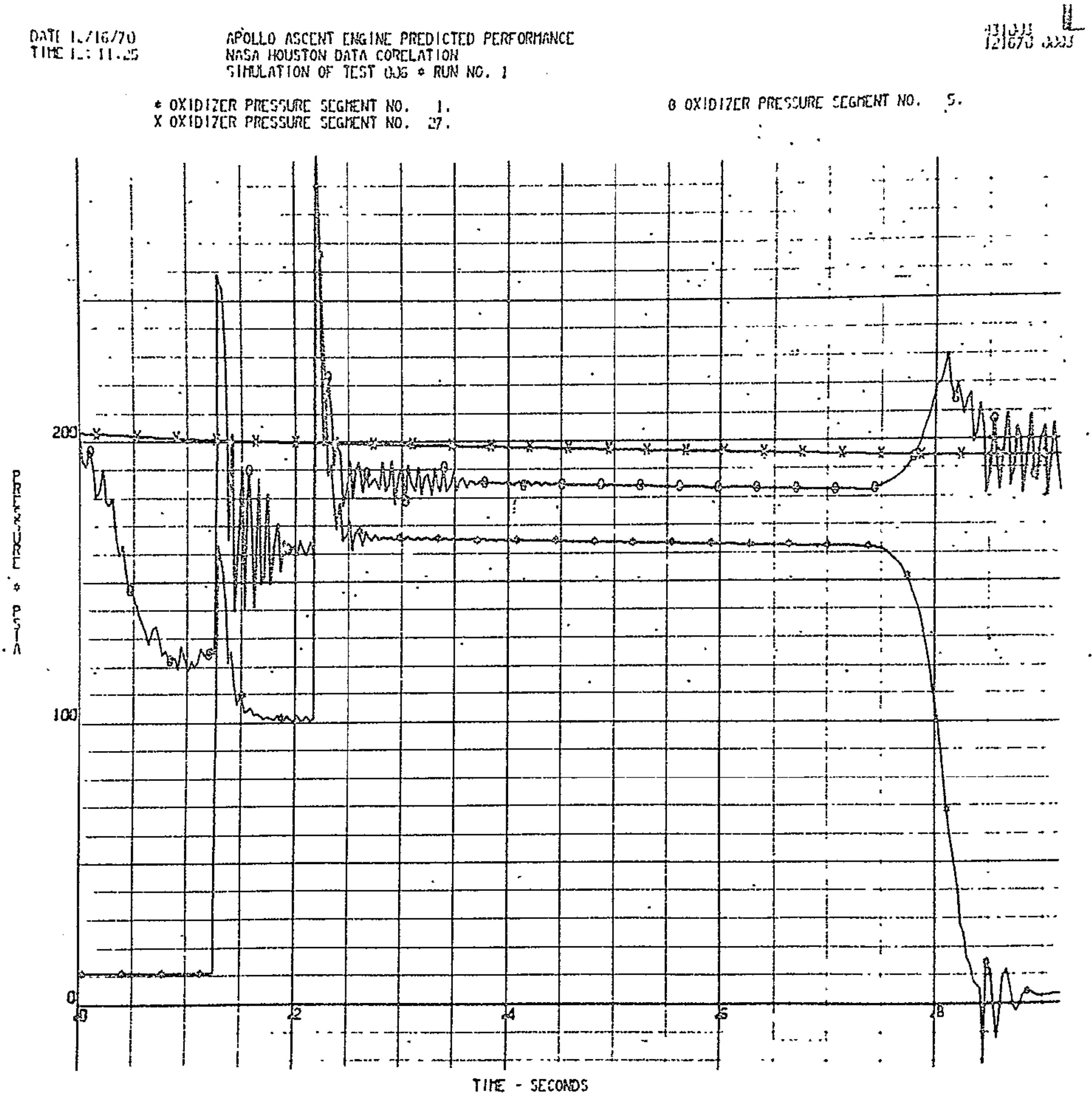


Figure A-6C - Graphical Output of Apollo Ascent Engine Computer Program

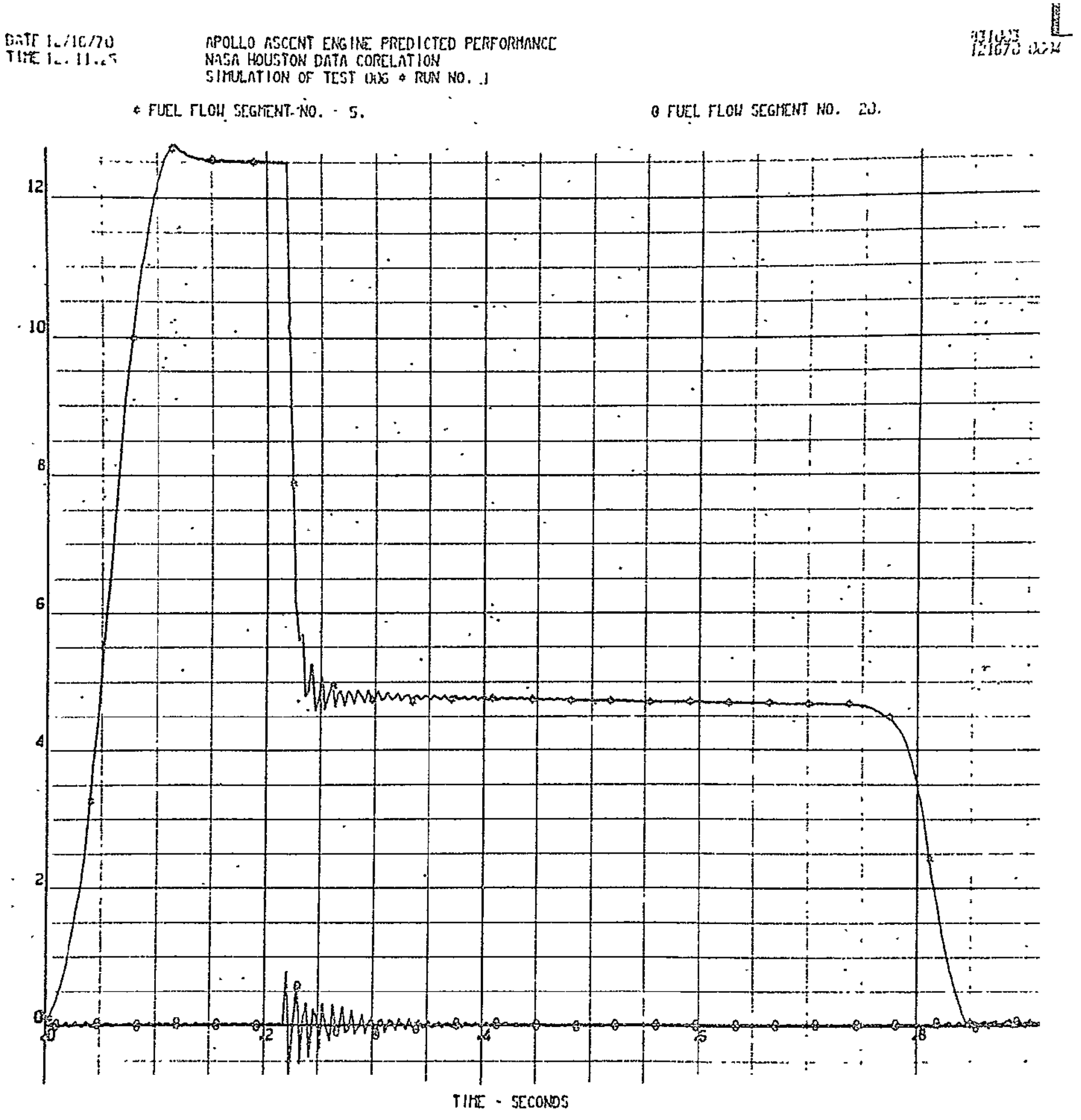


Figure A-6D - Graphical Output of Apollo Ascent Engine Computer Program.

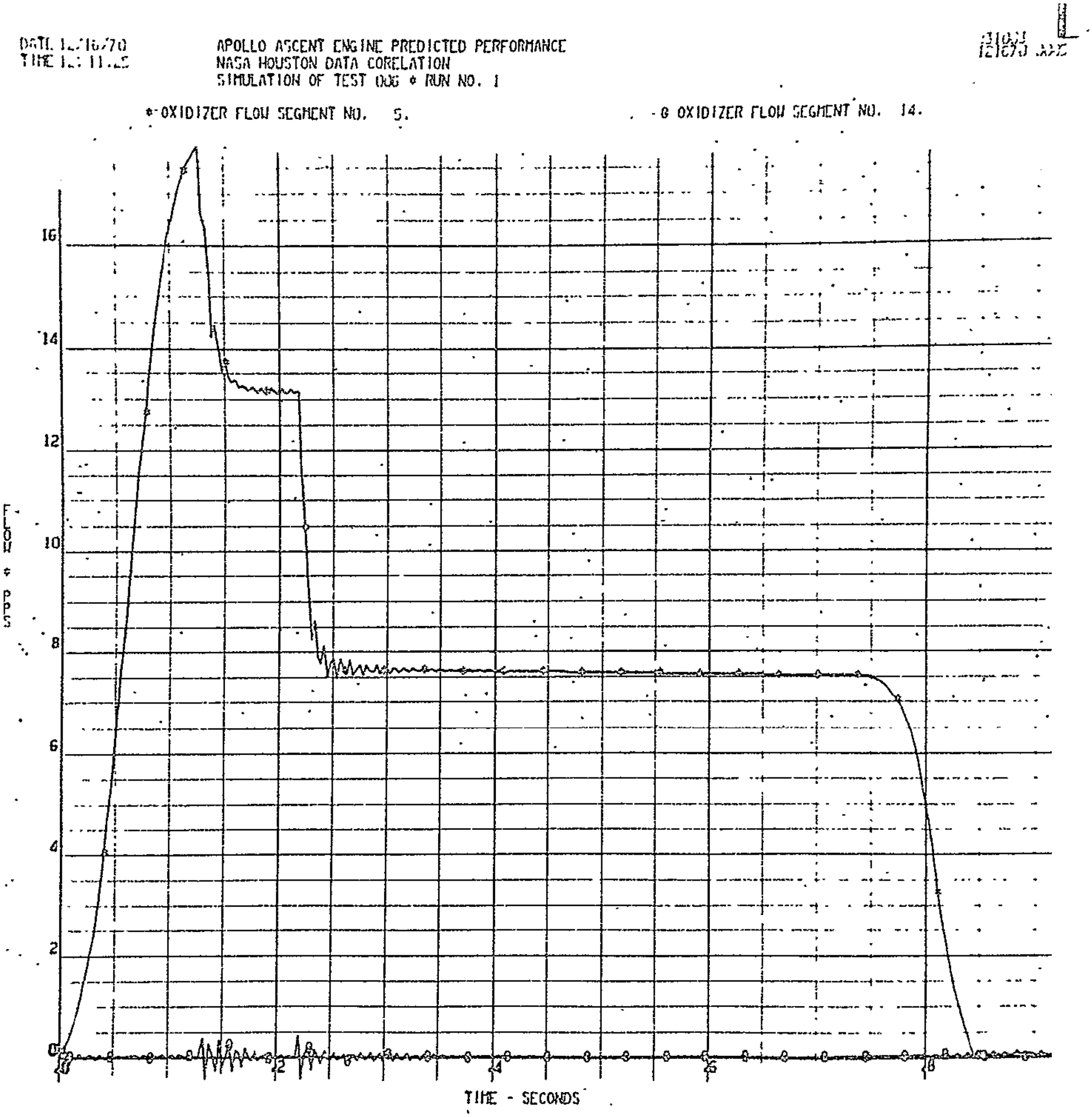


Figure A-6E - Graphical Output of Apollo Ascent Engine Computer Program.

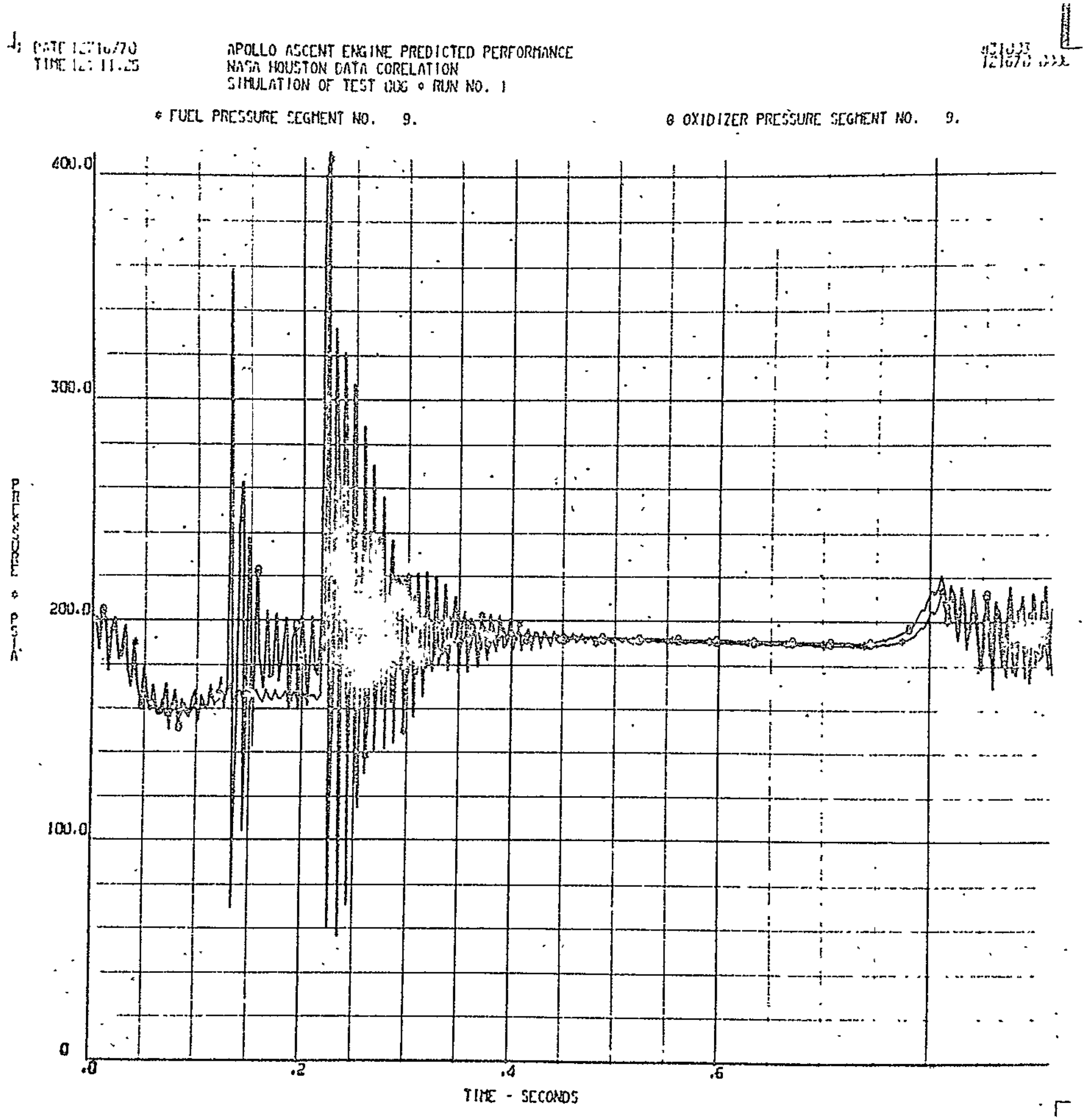


Figure A-6F - Graphical Output of Apollo Ascent Engine Computer Program.

TABLE A-VII

ASCENT ENGINE PROGRAM OUTPUT LISTINGS

```
                              DATE  12/16/70            TIME 12: 4.18
                APOLLO ASCENT ENGINE PREDICTED PERFORMANCE
                NASA HOUSTON DATA CORELATION
                SIMULATION OF TEST 006 * RUN NO. 1
 *        *         *         *        FUEL FEEDSYSTEM PARAMETERS         *          *              *       *
 SEGMENT DATA      PRESSURE     FLOW       ACOUSTIC      AREA      LENGTH     RESISTANCE          DISOLVED GAS
  NO.  STATE        PSIA        PPS        VELOCITY     SQ. IN.    INCHES     SEC**2/IN**5        LBS G / LB L
                                           IN / SEC
   1   EMPTY          1.70      0.0        59327.7      1.4720      10.20     0.3335E-02          0.0
   2   EMPTY          1.70      0.0        59737.2      0.6840      12.60     0.3989E-02          0.0
   3   EMPTY          1.70      0.0        59402.6      0.0          0.0      0.1000E 32          0.0
   4   FULL         203.00      0.0        59402.6      1.0400      10.20     0.3335E-02          0.0
   5   FULL         203.00      0.0        59150.0      1.0900      13.00     0.1603E-02          0.0
   6   FULL         203.00      0.0        58929.1      1.1000      15.00     0.1850E-02          0.0
   7   FULL         203.00      0.0        58929.1      1.1000      13.90     0.7258E-02          0.0
   8   FULL         203.00      0.0        58929.1      0.0          0.0      0.0                 0.0
   9   FULL         203.00      0.0        59067.4      0.2760      14.20     0.1058E-01          0.0
  10   FULL         203.00      0.0        59067.4      0.2760      13.00     0.9682E-02          0.0
  11   FULL         203.00      0.0        59067.4      0.2760      11.00     0.8193E-02          0.0
  12   FULL         203.00      0.0        59102.2      0.0          0.0      0.0                 0.0
  13   FULL         203.00      0.0        58877.5      0.4050      11.00     0.3450E-02          0.0
  14   FULL         203.00      0.0        58877.5      0.4050      16.00     0.5020E-02          0.0
  15   FULL         203.00      0.0        58877.5      0.4050      23.00     0.7210E-02          0.0
  16   FULL         203.00      0.0        59102.2      0.0          0.0      0.0                 0.0
  17   FULL         203.00      0.0        59102.2      0.3960      20.40     0.6400E-02          0.0
  18   FULL         203.00      0.0        59102.2      0.3960      15.00     0.4710E-02          0.0
  19   FULL         203.00      0.0        59102.2      0.3960      11.00     0.3450E-02          0.0
  20   FULL         203.00      0.0        58929.1      0.0          0.0      0.0                 0.0
  21   FULL         203.00      0.0        58929.1      1.1000      11.00     0.1356E-02          0.0
  22   FULL         203.00      0.0        58929.1      1.1000      15.00     0.1850E-02          0.0
  23   FULL         203.00      0.0        59402.6      1.0400      19.00     0.2343E-02          0.0
  24   FULL         203.00      0.0        59402.6      0.0          0.0      0.0                 0.0
  25   FULL         203.00      0.0        59595.9      0.1560      21.30     0.6632E-01          0.0
  26   FULL         203.00      0.0        59402.6      0.0          0.0      0.0                 0.0
  27   FULL         203.00      0.0        59402.6      1.0400      13.40     0.1652E-02          0.0
  28   FULL         203.00      0.0        60000.0      0.0          0.0      0.0                 0.0
```

```
                APOLLO ASCENT ENGINE PREDICTED PERFORMANCE
                NASA HOUSTON DATA CORELATION
                SIMULATION OF TEST 006 * RUN NO. 1
*         *        *          *     OXIDIZER FEEDSYSTEM CONSTANTS      *         *          *           *
 SEGMENT DATA      PRESSURE   FLOW    ACCOUSTIC      AREA      LENGTH    RESISTANCE      DISOLVED GAS
  NO.  STATE        PSIA      PPS     VELOCITY      SQ. IN.    INCHES    SEC**2/IN**5    LBS G / LB L
                                      IN / SEC
   1   EMPTY        10.57     0.0     40167.6       0.6790     10.00      0.1772E-02     0.0
   2   EMPTY        10.57     0.0     40370.4       0.5420      8.90      0.1577E-02     0.0
   3   EMPTY        10.57     0.0     40370.4       0.0         0.0       0.1000E 32     0.0
   4   FULL        202.00     0.0     40370.4       1.0400      6.90      0.1222E-02     0.0
   5   FULL        202.00     0.0     40370.4       1.0400      9.00      0.8350E-03     0.0
   6   FULL        202.00     0.0     40079.3       1.0900     10.50      0.9750E-03     0.0
   7   FULL        202.00     0.0     40079.3       1.0900      6.90      0.4607E-02     0.0
   8   FULL        202.00     0.0     39969.2       0.0         0.0       0.0            0.0
   9   FULL        202.00     0.0     39943.4       0.4050      7.00      0.2190E-02     0.0
  10   FULL        202.00     0.0     39943.4       0.4050      9.00      0.2830E-02     0.0
  11   FULL        202.00     0.0     39943.4       0.4050     14.00      0.4390E-02     0.0
  12   FULL        202.00     0.0     40055.5       0.3960     17.00      0.5340E-02     0.0
  13   FULL        202.00     0.0     40055.5       0.3960     11.00      0.3450E-02     0.0
  14   FULL        202.00     0.0     40055.5       0.3960      7.00      0.2190E-02     0.0
  15   FULL        202.00     0.0     39969.2       0.0         0.0       0.0            0.0
  16   FULL        202.00     0.0     39969.2       1.1000      7.00      0.6500E-03     0.0
  17   FULL        202.00     0.0     39969.2       1.1000     13.00      0.1207E-02     0.0
  18   FULL        202.00     0.0     39969.2       1.1000     15.00      0.1392E-02     0.0
  19   FULL        202.00     0.0     40370.4       1.0400     12.30      0.1142E-02     0.0
  20   FULL        202.00     0.0     40370.4       0.0         0.0       0.0            0.0
  21   FULL        202.00     0.0     40055.5       0.3960      7.00      0.2190E-02     0.0
  22   FULL        202.00     0.0     40055.5       0.3960     13.00      0.4080E-02     0.0
  23   FULL        202.00     0.0     40055.5       0.3960     15.00      0.4710E-02     0.0
  24   FULL        202.00     0.0     40055.5       0.3960      8.00      0.2510E-02     0.0
  25   FULL        202.00     0.0     40370.4       0.0         0.0       0.0            0.0
  26   FULL        202.00     0.0     40370.4       1.0400      7.00      0.6500E-03     0.0
  27   FULL        202.00     0.0     40500.0       0.0         0.0       0.0            0.0
```

```
              APOLLO ASCENT ENGINE PREDICTED PERFORMANCE
              NASA HOUSTON DATA CORELATION
              SIMULATION OF TEST 006 * RUN NO. 1
*       *       *       *       FEEDSYSTEM CONFIGURATION        *       *       *       *
                FUEL                                                    OXIDIZER
                                  SEGMENT BRANCH DATA
NDEX INLET  *       *       *   BRANCHES    *       *       *   INLET   *       *       *   BRANCHES    *       *       *
 1     21        8, 20,                                             16       8, 15,
 2     17       12, 16,                                             26      20, 25,
 3     27       24, 26,

                                     CAPPED SEGMENTS
                         9, 13, 25,  0,  0,                          9, 21,  0,  0,  0,

                         FUEL IORDER ARRAY          *       NSEGF = 27
   2    5    6    7   10   11   14   15   18   19   22   23

                         OXIDIZER IORDER ARRAY      *       NSEGO = 26
   2    5    6    7   10   11   12   13   14   17   18   19   22   23   24

                         CUTOFF SEGMENTS
              FUEL                                              OXIDIZER
HAMBER NO. 1  *   1,  2,  3,  0,  0,  0,  0,  0,  0,  0,  *   1,  2,  3,  0,  0,  0,  0,  0,  0,  0,
```

```
                             FUEL VALVE TABLE
NDEX    SEGMENT    *          *        VALUES
 1        328   203.000000   0.006000 200.000000   0.100000 193.000000   0.750000 193.000000   2.000000

                             OXIDIZER VALVE TABLE
NDEX    SEGMENT    *          *        VALUES
 1        327   202.000000   0.006000 200.000000   0.120000 194.000000   0.820000 194.000000   2.000000

                             FUEL FUNGEN TABLE
 3.000000   0.0         0.0         0.005000   0.010000   0.015000   0.020000   0.028000   0.030000
 0.053000   0.040000    0.090000    0.050000   0.137000   0.060000   0.194000   0.070000   0.257000
 0.080000   0.328000    0.090000    0.404000   0.100000   0.442000   0.105000   0.442000   0.740000
 0.370000   0.750000    0.292000    0.760000   0.225000   0.770000   0.166000   0.780000   0.114000
 0.790000   0.072000    0.800000    0.040000   0.810000   0.022000   0.820000   0.010000   0.830000
 0.0        0.844000

                             OXIDIZER FUNGEN TABLE
 3.000000   0.0         0.0         0.005000   0.010000   0.015000   0.020000   0.028000   0.030000
 0.053000   0.040000    0.090000    0.050000   0.137000   0.060000   0.194000   0.070000   0.257000
 0.080000   0.328000    0.090000    0.404000   0.100000   0.442000   0.105000   0.442000   0.740000
 0.370000   0.750000    0.292000    0.760000   0.225000   0.770000   0.166000   0.780000   0.114000
 0.790000   0.072000    0.800000    0.040000   0.810000   0.022000   0.820000   0.010000   0.830000
 0.0        0.844000

                            CAVITATING VENTURI DATA
                                   FUEL                                   OXIDIZER

                             ORIFICE DATA
NDEX NO.                 1          2          3          4          1          2          3          4
EGMENT NO.               1.         2.         0.         0.         1.         2.         0.         0.
INE RESIS: SEC**2/IN**5  0.003335   0.003989   0.0        0.0        0.001772   0.001577   0.0        0.0
RIFICE RESISTANCE        0.001725   0.004279   0.0        0.0        0.001725   0.005445   0.0        0.0

                             ACCUMULATOR DATA
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                                        INJECTOR MANIFOLD DATA
                                                 FUEL                                          OXIDIZER
INDEX NO.                              1          2           3           4           1          2           3           4
SEGMENT NO.                        1.000000   0.0         0.0         0.0         1.000000   0.0         0.0         0.0
MANIFOLD VOLUME - CU.IN.           38.5800    0.0         0.0         0.0         11.3800    0.0         0.0         0.0
ORIFICE LENGTH - INCHES          0.112000   0.0         0.0         0.0         0.141000   0.0         0.0         0.0
INJECTOR C-SUB-D*A - SQIN        0.153544   0.0         0.0         0.0         0.206318   0.0         0.0         0.0
FLAME FROUNT DISTANCE-IN.        0.375000   0.0         0.0         0.0         0.375000   0.0         0.0         0.0

                                        COMBUSTION CHAMBER DATA
INDEX NO.                                  1                         2                         3                         4
CHAMBER PRESSURE - PSIA                   0.0                       0.0                       0.0                       0.0
OXIDIZER FLOWRATE - PPS                   0.0                       0.0                       0.0                       0.0
FUEL FLOWRATE - PPS                       0.0                       0.0                       0.0                       0.0
OXIDIZER FRACTION                       0.0                       0.0                       0.0                       0.0
THROAT AREA - SQ. IN.                     16.400                     0.0                       0.0                       0.0
CHAMBER VOLUME - CU. IN.                453.200                      0.0                       0.0                       0.0
NOZZLE EXIT AREA - SQ. IN.                750.00                      0.0                       0.0                       0.0
THRUST COEFFICIENT                        1.78400                  0.0                       0.0                       0.0
ENGINE AMBIENT PRESSURE - PSIA             0.0                       0.0                       0.0                       0.0
ENGINE THRUST - POUNDS                      0.0                       0.0                       0.0                       0.0

                                        COMBUSTION DATA
          BASE PRESSURE =  150.0 PSIA                                            GAS CONSTANT  CORRECTION =0.027790
          CSTAR CORRECTION =0.008453                                             EFFICIENCY CORRECTION =0.0
                              OX. FRACTION                GAS CONSTANT              CSTAR / G                EFFICIENCY
                              -0.0050                    -2.0000E 05                15.000                  0.8160
                               0.0                        2.9300E 05                41.500                  0.8180
                               0.0200                     2.8200E 06               115.000                  0.8260
                               0.0400                     3.0400E 06               131.500                  0.8330
                               0.0600                     3.0700E 06               132.900                  0.8410
                               0.1000                     3.1300E 06               134.700                  0.8560
                               0.2000                     3.2400E 06               138.000                  0.8890
                               0.2500                     3.2800E 06               139.800                  0.9030
                               0.3000                     3.4200E 06               142.600                  0.9200
                               0.3500                     3.8700E 06               148.800                  0.9330
                               0.4500                     4.6000E 06               165.000                  0.9590
                               0.5000                     4.8800E 06               171.300                  0.9670
                               0.5500                     5.0300E 06               175.800                  0.9740
                               0.6000                     5.0200E 06               178.100                  0.9780
                               0.6500                     4.8600E 06               176.800                  0.9730
                               0.7000                     4.5500E 06               171.100                  0.9640
                               0.8000                     3.6300E 06               152.000                  0.9220
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                  0.9000          2.2700E 06          116.600            0.8590
                  0.9800          3.7000E 05           58.700            0.8010
                  1.0000          1.3300E 05           29.400            0.7870
                  1.0050          1.0000E 04           21.000            0.7810


          APOLLO ASCENT ENGINE PREDICTED PERFORMANCE
          NASA HOUSTON DATA CORELATION
          SIMULATION OF TEST 006 * RUN NO. 1

           INPUT DATA CONSTANTS          *          *        FUEL              OXIDIZER

    ENTRAINED GAS - LBS GAS / LB LIQUID                    0.0               0.0
    PROPELLANT DENSITY - POUNDS / CUBIC INCH               0.03250           0.05200
    LIQUID TEMPERATURE - DEGREES RANKINE                     520.0             520.0
    PROPELLANT ACOUSTIC VELOCITY - INCHES / SECOND         60000.0           40500.0
    VAPOR PRESSURE CURVE FIT CONSTANTS - CON1              8.3446E-03        8.9489E-03
     ( LOG(PVAP) = CON1 * TEMP + CON2 )
                                     - CON2               -4.1095E 00       -3.6294E 00
    PROPELLANT MOLECULAR WEIGHT                              41.8              92.0
    PRESSURANT GAS MOLECULAR WEIGHT                           4.0               4.0
    RATIO OF SPECIFIC HEATS - PRESSURANT GAS                 1.670             1.670
    RATIO OF SPECIFIC HEATS - PROPELLANT VAPOR               1.050             1.100

    DISSOLVED GAS EVOLUTION TIME CONSTANT - 1/SEC.         1.0000E 01        1.0000E 01
    DISSOLVED GAS CONCENTRATION - LBS GAS / LB LIQ / PSI   8.8889E-06        2.0526E-05
    PROPELLANT TANK ULLAGE - CUBIC INCHES                  2.7600E 03        2.7600E 03
    PROPELLANT TANK INITIAL PRESSURE - PSIA                   0.0               0.0
    PRESSURANT GAS BOTTLE VOLUME - CUBIC INCHES            0.0               0.0

    PROPELLANT LIQUID HEAT CAPACITY - BTU / LB / DEGREE R  6.9100E-01        3.6800E-01
    PRESSURANT - LOW PRESSURE C-SUB-V                      7.5000E-01        7.5000E-01
    PRESSURANT - HIGH PRESSURE C-SUB-V                     0.0               0.0
    PRESSURANT - HIGH PRESSURE C-SUB-P                     0.0               0.0
    PRESSURANT - HIGH PRESSURE GAMMA                        0.0               0.0

    PROPELLANT VAPOR C-SUB-P                              3.0000E-01        3.0000E-01
    HEAT SOAKBACK - BTU / LB SEC DEGREE R                 1.0000E-02        1.0000E-02
    SOAKBACK INJECTOR TEMPERATURE - DEGREES R              600.0             600.0
    PROPELLANT HEAT OF VAPORIZATION - BTU / LB             425.8             178.2
                                                          0.0               0.0
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          APOLLO ASCENT ENGINE PREDICTED PERFORMANCE
          NASA HOUSTON DATA CORELATION
          SIMULATION OF TEST 006 * RUN NO. 1
0.0        203.00000    0.0        202.00000    0.0        1.69703   10.56786    0.0      0.0
0.003060   191.15545    0.10147    192.08261    0.12635    1.69703   10.56786    0.0      0.0
0.006120   193.31161    0.20987    190.18991    0.25843    1.69703   10.56786    0.0      0.0
0.009180   194.04840    0.32298    196.14391    0.39891    1.69703   10.56786    0.0      0.0
0.012240   189.96640    0.48879    190.82126    0.60303    1.69703   10.56786    0.0      0.0
0.015300   181.69374    0.69042    179.37956    0.84400    1.69703   10.56786    0.0      0.0
0.018360   164.54080    0.90149    182.24158    1.10913    1.69703   10.56786    0.0      0.0
0.021420   188.54604    1.14518    189.45116    1.41850    1.69703   10.56786    0.0      0.0
0.024480   177.86151    1.37418    178.07689    1.69451    1.69703   10.56786    0.0      0.0
0.027540   177.33925    1.63561    176.87059    2.01460    1.69703   10.56786    0.0      0.0
0.030600   179.58345    1.94151    179.03133    2.39194    1.69703   10.56786    0.0      0.0
0.033660   152.76955    2.32594    164.79218    2.88205    1.69703   10.56786    0.0      0.0
0.036720   157.95264    2.75668    158.78745    3.40125    1.69703   10.56786    0.0      0.0
0.039780   151.28261    3.25073    162.40424    4.01677    1.69703   10.56786    0.0      0.0
0.042840   151.07196    3.78499    153.23453    4.68780    1.69703   10.56786    0.0      0.0
0.045900   143.48824    4.31915    146.89807    5.36299    1.69703   10.56786    0.0      0.0
0.048960   143.08915    4.91950    146.22942    6.11604    1.69703   10.56786    0.0      0.0
0.052020   137.52262    5.53300    141.33997    6.89634    1.69703   10.56786    0.0      0.0
0.055080   131.30673    6.11623    136.92305    7.66267    1.69703   10.56786    0.0      0.0
0.058140   129.07494    6.73768    134.42174    8.47462    1.69703   10.56786    0.0      0.0
0.061200   125.01807    7.34993    131.48282    9.28189    1.69703   10.56786    0.0      0.0
0.064260   119.73695    7.92012    127.36034   10.07122    1.69703   10.56786    0.0      0.0
0.067320   115.66161    8.51198    132.50085   10.80408    1.69703   10.56786    0.0      0.0
0.070380   115.26114    9.06138    133.49069   11.50770    1.69703   10.56786    0.0      0.0
0.073439   111.06042    9.55692    128.95630   12.16080    1.69703   10.56786    0.0      0.0
0.076499   119.53014    9.97220    123.64055   12.72213    1.69703   10.56786    0.0      0.0
0.079559   110.76282   10.34180    125.12430   13.37469    1.69703   10.56786    0.0      0.0
0.082619   112.76555   10.70223    121.75716   13.92398    1.69703   10.56786    0.0      0.0
0.085679   112.60469   10.98656    122.53926   14.43808    1.69703   10.56786    0.0      0.0
0.088739   107.43861   11.27830    122.57639   14.96511    1.69703   10.56786    0.0      0.0
0.091799   105.34756   11.56177    118.39241   15.40265    1.69703   10.56786    0.0      0.0
0.094859   105.80255   11.79995    126.32312   15.77643    1.69703   10.56786    0.0      0.0
0.097918   105.26172   12.01590    122.48489   16.13605    1.69703   10.56786    0.0      0.0
0.100978   102.64490   12.20252    117.97188   16.44292    1.69703   10.56786    0.0      0.0
0.104038   102.38077   12.37281    121.22929   16.72545    1.69703   10.56786    0.0      0.0
0.107098   105.54418   12.51485    119.10260   17.02659    1.69703   10.56786    0.0      0.0
0.110158   105.96350   12.59731    120.90974   17.22153    1.69703   10.56786    0.0      0.0
0.113218   107.48209   12.69303    125.80169   17.41722    1.69703   10.56786    0.0      0.0
0.116278   109.30546   12.70697    123.05956   17.57660    1.69703   10.56786    0.0      0.0
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0.119337   116.98558    12.65529   123.92807    17.66383     1.69703    10.56786     0.0          0.0
0.122397   115.82516    12.61789   126.11011    17.78780     1.69703    10.56786     0.0          0.0
0.125457   112.49278    12.60432   124.28253    17.86014     1.69703    10.56786     0.0          0.0
0.128517   114.15135    12.56708   258.37427    16.58267     1.69703   152.55981     0.0          0.0
0.131577   115.64735    12.55156   253.34683    16.33722     1.69703   155.10632     0.0          0.0
0.134637   112.24681    12.53622   228.41068    15.55170     1.69703   143.83022     0.0          0.0
0.137697   113.77951    12.52458   164.62885    14.20146     1.69703   120.92560     0.0          0.0
0.140756   115.36130    12.52598   201.76282    14.41042     1.69703   124.84138     0.0          0.0
0.143816   112.91135    12.50608   139.15045    13.96230     1.69703   112.74493     0.0          0.0
0.146876   113.12105    12.50376   159.49695    13.50745     1.69703   105.85847     0.0          0.0
0.149936   114.40480    12.51346   189.52721    13.69931     1.69703   109.33871     0.0          0.0
0.152996   113.26555    12.49424   139.45006    13.40352     1.69703   103.37105     0.0          0.0
0.156056   113.27190    12.49286   189.37213    13.30100     1.69703   103.56548     0.0          0.0
0.159116   113.71346    12.50438   170.71922    13.34439     1.69703   104.69229     0.0          0.0
0.162176   113.43927    12.48824   140.66920    13.19232     1.69703   102.09152     0.0          0.0
0.165235   113.56755    12.48797   186.39926    13.21249     1.69703   102.55080     0.0          0.0
0.168295   113.20981    12.49664   149.13774    13.20780     1.69703   101.82013     0.0          0.0
0.171355   113.32892    12.48452   151.37550    13.13810     1.69703   100.73897     0.0          0.0
0.174415   113.72729    12.43583   180.99710    13.19163     1.69703   101.35437     0.0          0.0
0.177475   113.03285    12.48992   149.20546    13.16830     1.69703   101.01828     0.0          0.0
0.180535   113.19655    12.48092   163.18634    13.10176     1.69703   100.30533     0.0          0.0
0.183595   113.72264    12.48422   170.47678    13.17360     1.69703   101.64529     0.0          0.0
0.186654   113.00829    12.48449   153.91364    13.14085     1.69703   101.01636     0.0          0.0
0.189714   113.11752    12.47753   164.35974    13.08250     1.69703    99.79724     0.0          0.0
0.192774   113.60071    12.48222   161.31302    13.17927     1.69703   101.81238     0.0          0.0
0.195834   113.00095    12.48009   160.19505    13.12231     1.69703   100.49690     0.0          0.0
0.198894   113.13219    12.47448   162.69693    13.08597     1.69703    99.63936     0.0          0.0
0.201954   113.42755    12.47966   159.08246    13.17701     1.69703   101.94029     0.0          0.0
0.205014   112.99911    12.47600   164.37192    13.10054     1.69703   100.12004     0.0          0.0
0.208073   113.15378    12.47191   160.99146    13.10365     1.69703   100.04573     0.0          0.0
0.211133   113.27388    12.47647   159.17740    13.16129     1.69703   101.63736     0.0          0.0
0.214193   112.96074    12.47229   164.03654    13.09127     1.69703    99.92056     0.0          0.0
0.217253   113.18074    12.46946   160.47394    13.12202   161.26497   100.50883     0.0          0.0
0.220313   423.66528     9.90551   299.52197    11.41761   378.20581   290.51245   215.25641     0.53520
0.223373   370.01831     7.85461   254.22887    10.46871   308.70215   255.60889   202.31969     0.57248
0.226433   154.95790     6.12007   198.55469     9.31684   250.60791   233.63129   181.74333     0.59144
0.229493   225.96509     5.56390   222.45074     8.23348   201.54379   187.54999   149.18880     0.59271
0.232552   250.25659     5.63928   212.69870     8.60049   203.41884   191.40900   148.63541     0.60536
0.235612   150.43265     4.76097   191.54123     7.87798   179.99078   178.09819   141.53937     0.61897
0.238672   183.72020     4.81063   198.63438     7.73408   171.40154   168.18175   132.93845     0.61551
0.241732   213.75098     5.22109   195.92717     8.08419   185.37311   177.91347   138.87962     0.61047
0.244792   171.77945     4.56320   176.84978     7.48759   167.04713   164.16771   131.85994     0.61947
0.247852   192.09785     4.69216   183.18048     7.77642   167.64406   166.29318   130.86154     0.62677
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.250912   190.77078   5.03461   192.87085   7.81388   179.08159   171.43370   135.63762   0.60627
.253971   179.35442   4.57260   179.86159   7.45175   165.12105   151.10970   129.45996   0.61601
.257031   198.12433   4.73541   189.92177   7.84081   168.38158   157.37914   131.08235   0.62806
.260091   178.85669   4.91259   192.18532   7.61929   174.82292   157.67525   133.64388   0.60691
.263151   180.25433   4.60685   181.89688   7.54012   165.51392   152.66122   129.64622   0.61988
.266211   199.55400   4.79690   188.45642   7.81206   170.09297   157.68784   131.64299   0.62379
.269271   177.49448   4.83019   183.53227   7.52285   172.26514   163.37361   132.49739   0.60604
.272331   181.08820   4.62433   185.56622   7.64849   166.17938   154.31412   130.12967   0.62333
.275391   197.25603   4.83267   186.48413   7.72110   171.11665   166.59001   131.76613   0.61644
.278450   178.08406   4.78158   182.73041   7.52060   170.64676   164.69341   131.82608   0.60911
.281510   182.79912   4.64349   192.41051   7.71189   166.56061   155.37668   130.37236   0.62513
.284570   193.72128   4.84567   182.30957   7.62620   171.43033   155.54248   131.75218   0.61153
.287630   179.12665   4.75139   184.13551   7.57068   169.77126   155.11343   131.57855   0.61377
.290690   185.26799   4.66620   192.59743   7.71608   167.06097   155.54477   130.53323   0.62432
.293750   190.63752   4.84123   177.77344   7.56788   171.43771   154.85670   131.71286   0.60927
.296810   179.82899   4.72940   188.00414   7.62513   169.12770   155.53731   131.38124   0.61707
.299869   187.15277   4.69135   189.86998   7.68495   167.65123   165.20059   130.63409   0.62168
.302929   188.71271   4.83029   178.61185   7.55557   171.12350   164.69136   131.60284   0.60910
.305989   180.33463   4.71339   191.24306   7.65745   168.65039   165.70949   131.20595   0.61917
.309049   188.36978   4.71576   184.92328   7.64743   168.24817   154.91725   130.79555   0.61913
.312109   186.99811   4.81571   182.10960   7.56902   170.73067   154.82751   131.46599   0.61074
.315169   181.00804   4.70298   190.63031   7.66198   168.37915   165.58775   131.10747   0.61967
.318229   188.89093   4.73460   181.20772   7.62152   168.74234   164.77573   130.93173   0.61734
.321288   185.27519   4.80019   186.89510   7.58961   170.25702   164.92621   131.29402   0.61182
.324348   182.09537   4.69759   187.82057   7.65314   168.27820   155.33911   131.06100   0.61963
.327408   188.77733   4.74871   180.64389   7.60956   169.03481   164.74832   130.97844   0.61634
.330468   183.90395   4.78371   190.00348   7.60396   169.85031   164.99176   131.17018   0.61321
.333528   183.22008   4.69706   184.34929   7.64028   168.26460   155.15332   131.05243   0.61940
.336588   188.25053   4.75852   182.21596   7.60399   169.15692   164.72215   130.94470   0.61575
.339648   183.09575   4.76682   190.39948   7.61268   169.50388   165.01422   131.12320   0.61411
.342708   184.23755   4.70012   182.26613   7.63119   168.29472   154.98817   131.00220   0.61918
.345767   187.56682   4.76424   184.39819   7.60054   169.16753   164.63338   130.87541   0.61493
.348827   182.74423   4.75110   188.91600   7.61838   169.28584   165.07336   131.13940   0.61525
.351887   185.00636   4.70585   182.14145   7.62275   168.24501   154.82820   130.90315   0.61850
.354947   186.83007   4.76628   185.78575   7.59684   169.20204   164.55788   130.83719   0.61470
.358007   182.76059   4.73775   186.99742   7.62319   169.03937   165.14267   131.16277   0.61617
.361067   185.45779   4.71284   183.19400   7.61456   168.25995   154.62206   130.76218   0.61834
.364127   186.14532   4.76506   185.94160   7.59606   169.16988   164.54913   130.86485   0.61419
.367186   182.95732   4.72689   185.59634   7.62597   168.87462   165.14240   131.12170   0.61760
.370246   185.64035   4.72050   184.36578   7.60536   168.19769   154.42793   130.64655   0.61693
.373306   185.53555   4.76035   185.50150   7.59817   169.21915   164.61365   130.91019   0.61480
.376366   183.17365   4.71980   185.08728   7.62449   168.60954   165.05443   131.03061   0.61771
.379426   185.77235   4.72621   185.02072   7.59857   168.28333   154.27719   130.56955   0.61653
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0.382486   184.88231   4.75469   185.07251   7.60273   169.13315   164.70934   130.96707   0.61501
0.385546   183.54649   4.71427   184.91916   7.61881   168.40993   164.85258   130.88701   0.61802
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NOT REPRODUCIBLE

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  0.902663   192.02504     0.00144   180.13454    -0.00380     4.55886     1.59993     4.55886     1.00000
  0.905722   201.67516     0.00473   191.53931     0.00909     4.54492     1.77983     4.54492     1.00000
  0.908782   190.08804    -0.01167   204.97755     0.00591     4.53090     1.90675     4.53090     1.00000
  0.911842   186.98824     0.00716   193.93300    -0.01571     4.51683     1.97992     4.51683     1.00000
  0.914902   196.49907     0.00055   181.70210     0.00866     4.50269     2.02127     4.50269     1.00000

HC900I EXECUTION TERMINATING DUE TO ERROR COUNT FOR ERROR NUMBER  217

HC217I FIOCS - END OF DATA SET ON UNIT    5

RACEBACK ROUTINE  CALLED FROM ISN     REG. 14    REG. 15   REG. 0    REG. 1

         FRDNL#                       0003A304   0004B7F8   0000A414   00039A48

            MAIN                      0000DD1A   010399C8   F0000008   00079FF8

NTRY POINT=  010399C8
```

APPENDIX B

APOLLO DESCENT ENGINE START TRANSIENT MODEL

APOLLO DESCENT ENGINE MODELING

The feed line configuration of the Apollo Descent configuration is shown in Fig. B-1. Since this engine model is to have response requirements similar to the Ascent Engine model, the model will be divided into line segments in the same manner as described in Appendix A. The barrier coolant passage which has a very high resistance will be neglected in the start model and it will be assumed that all fuel goes through the injector. Tables B-I and B-II show the physical data on the line segments for this engine.

The effective area of the engine shutoff valves as a function of time is shown in Fig. B-2. For this particular simulation the flow control valve is in its wide-open position and does not cavitate. Thus, it is treated as a valve with an effective area which gives the correct resistance as noted in Tables B-I and B-II.

Table B-III shows the input data used for the simulation of the start transient and Table B-IV shows the output data, along with the graphical results presented in Figures B-3A through B-3F.

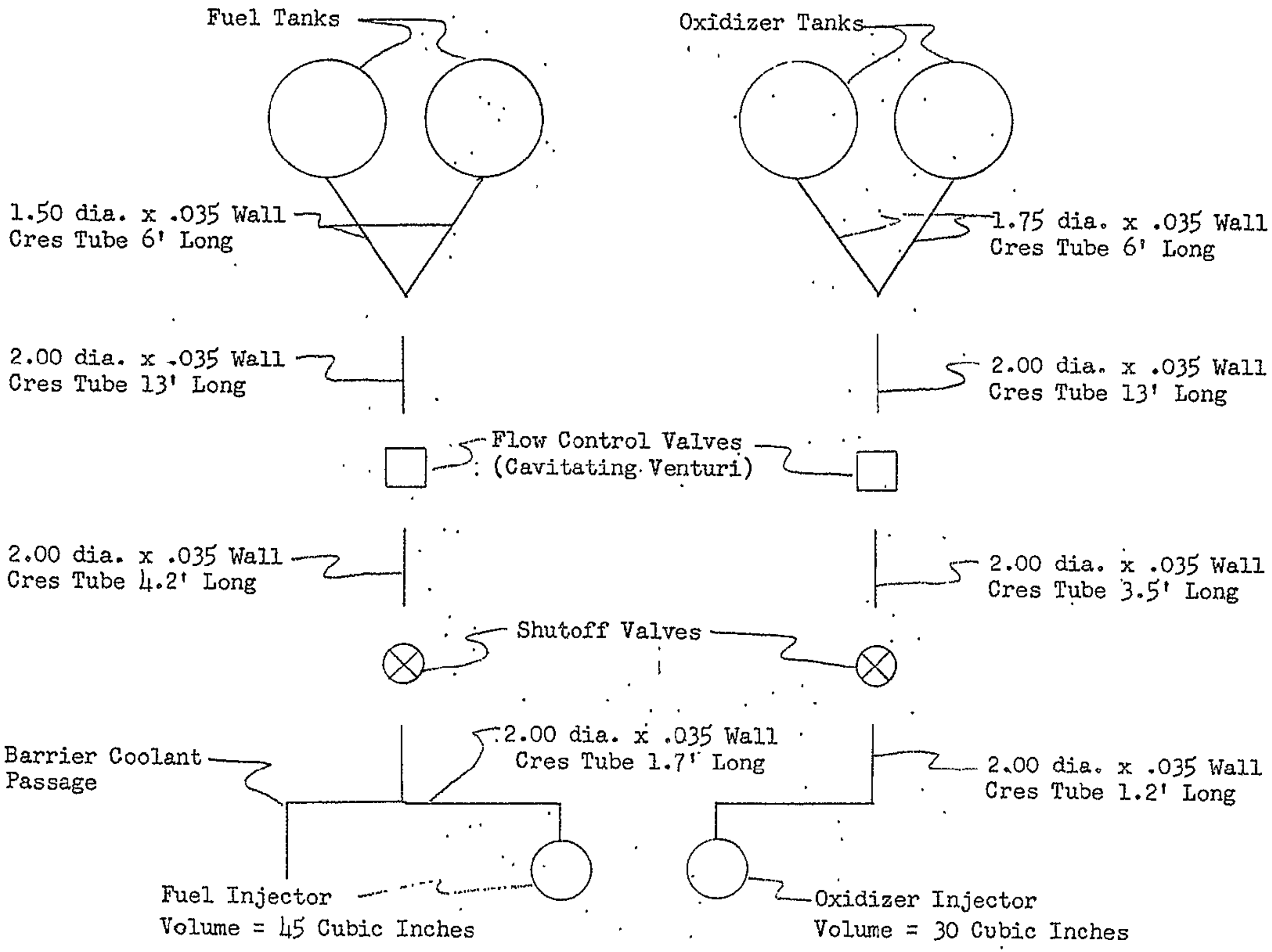

FIGURE B-1 - Apollo Descent Engine Feed System Schematic

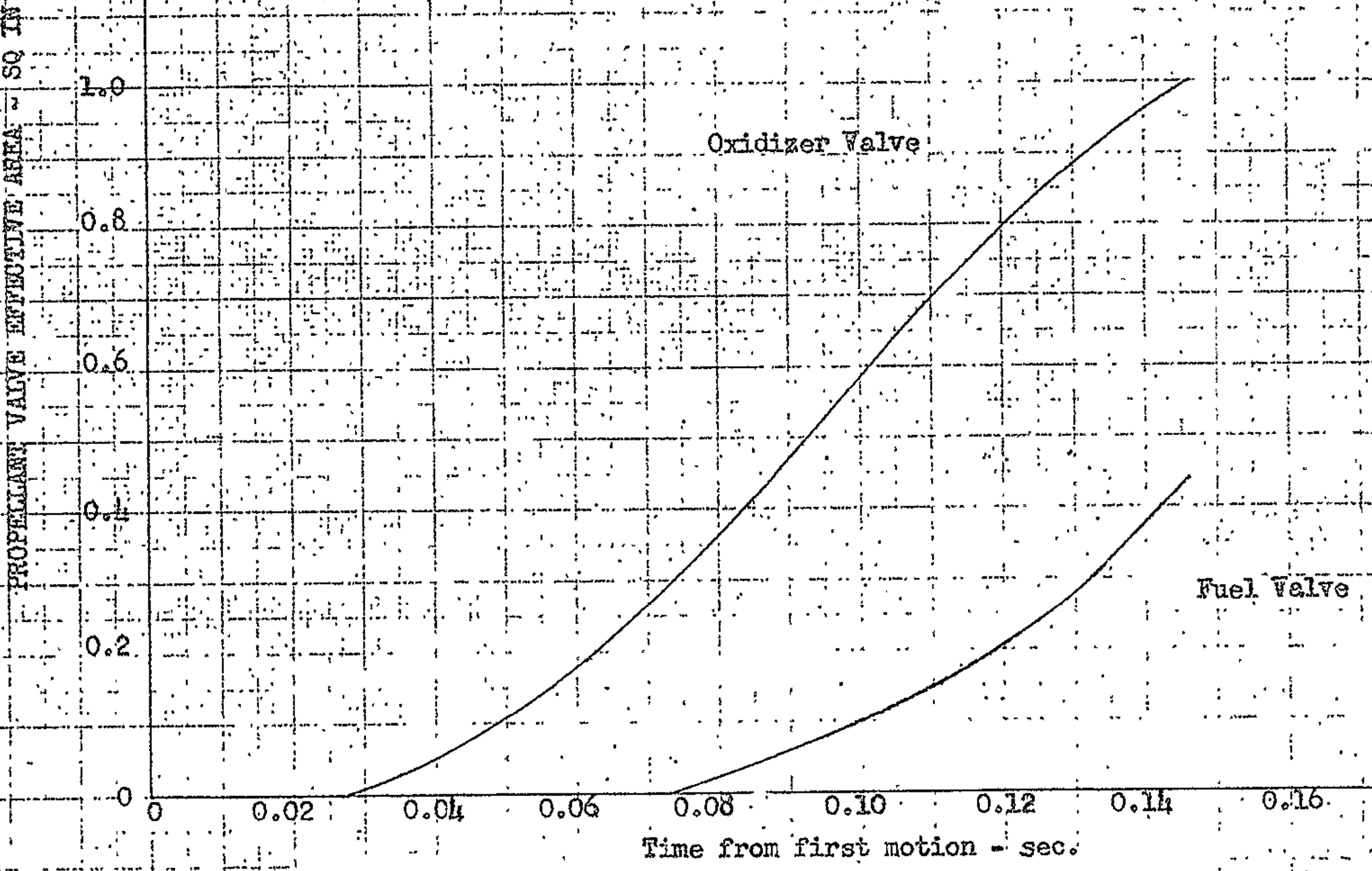

FIGURE B-2 - APOLLO DESCENT ENGINE PROPELLANT VALVE TRANSIENT

TABLE B-I

APOLLO DESCENT ENGINE FUEL FEED LINE PARAMETERS

SEGMENT NO.	LENGTH IN	AREA SQ IN	WALL COMPLIANCE SQ IN/LB X 10^6	RESISTANCE SEC^2/IN^5	COMMENTS
1	10.2	2.92	1.67	.0000800	
2	10.2	2.92	1.67	.0000800	Orifice Resistance = .0080862 Line Resistance = .0000800
3	-	-	-	-	Shutoff Valve Open C_dA = .44 in^2 R = .006680
4	10.2	2.92	1.67	.0000800	
5	12.	2.92	1.67	.0001019	
6	15.	2.92	1.67	.0001176	
7	12.2	2.92	1.67	.0000956	
8	-	-	-	-	Flow Control Valve Simple Resistance at Max Thrust R = 0.004340, C_dA = 0.5459
9	11.	2.92	1.67	0.0000862	Interface
10	13.	2.92	1.67	0.0001019	
11	15.	2.92	1.67	0.0001176	
12	17.	2.92	1.67	0.0001333	
13	19.	2.92	1.67	0.0001489	
14	21.	2.92	1.67	0.0001646	
15	23.	2.92	1.67	0.0001803	
16	20.	2.92	1.67	0.0001568	
17	17.	2.92	1.67	0.0001333	
18	11.	3.22	1.24	0.0000862	
19	15.	3.22	1.24	0.0001176	
20	19.	3.22	1.24	0.0001490	
21	17.	3.22	1.24	0.0001333	
22	10.2	3.22	1.24	0.0000800	

TABLE B-II

APOLLO DESCENT ENGINE OXIDIZER FEED LINE PARAMETERS

SEGMENT NO.	LENGTH IN	AREA SQ IN	WALL COMPLIANCE SQ IN/LB X 10^6	RESISTANCE SEC^2/IN^5	COMMENTS
1	7.0	2.92	1.67	0.0000314	
2	7.4	2.92	1.67	0.0000332	
3	-	-	-	-	Shutoff Valve Open $C_dA=1.0$ in^2 R=.001293
4	7.	2.92	1.67	0.0000314	
5	9.	2.92	1.67	0.0000403	
6	11.	2.92	1.67	0.0000493	
7	15.	2.92	1.67	0.0000672	
8	-	-	-	-	Flow Control Valve Simple Resistance at Max Thrust R=0.001169, $C_dA=1.0518$
9	11.	2.92	1.67	0.0000493	Interface
10	13.	2.92	1.67	0.0000583	
11	15.	2.92	1.67	0.0000672	
12	17.	2.92	1.67	0.0000762	
13	19.	2.92	1.67	0.0000852	
14	21.	2.92	1.67	0.0000942	
15	23.	2.92	1.67	0.0001031	
16	20.	2.92	1.67	0.0000897	
17	17.	2.92	1.67	0.0000762	
18	11.	4.42	1.57	0.0000493	
19	15.	4.42	1.57	0.0000672	
20	19.	4.42	1.57	0.0000852	
21	17.	4.42	1.57	0.0000762	
22	10.	4.42	1.57	0.0000448	

TABLE B-III

APOLLO DESCENT ENGINE START TRANSIENT COMPUTER MODEL INPUT DATA

```
2   121 22  10.2          10.2          0.0          10.2         13.0        0000100,
15.0        12.2          0.0          11.0          13.0         15.0        0000200,
17.0        19.0          21.0         23.0          20.0         17.0        0000300,
11.0        15.0          19.0         17.0          10.2                     0000400,
2   181 22  7.0           7.4           0.0          7.0           9.0        0000500,
11.0        15.0          0.0          11.0          13.0         15.0        0000600,
17.0        19.0          21.0         23.0          20.0         17.0        0000700,
11.0        15.0          19.0         17.0          10.0                     0000800,
2   361 22   0.000112      0.016038     0.0           0.000112     0.000143 0000900,
 0.000165    0.000134      0.0          0.000121      0.000143     0.000165 0001000,
 0.000187    0.000209      0.000231     0.000253      0.000220     0.000187 0001100,
 0.000115    0.000157      0.000199     0.000178      0.000107              0001200,
2   421 22   0.000039      0.000042     0.0           0.000039     0.000051 0001300,
 0.000062    0.000084      0.0          0.000062      0.000073     0.000084 0001400,
 0.000096    0.000107      0.000124     0.000129      0.000112     0.000096 0001500,
 0.000115    0.000156      0.000197     0.000176      0.000104              0001600,
5     1 26            21  150.0        0.02779      0.008453     0.0        0004100,
-0.005      0.0          0.02         0.04         0.06         0.10        0004200,
0.20        0.25         0.30         0.35         0.45         0.50        0004300,
0.55        0.60         0.65         0.70         0.80         0.90        0004400,
0.95        1.0          1.005                                              0004500,
5    36 21 -0.2    E+06  0.293 E+06   2.82   E+06  3.04   E+06  3.07   E+060004600,
3.13   E+06 3.24   E+06  3.28   E+06  3.42   E+06  3.87   E+06  4.60   E+060004700,
4.88   E+06 5.03   E+06  5.02   E+06  4.86   E+06  4.55   E+06  3.63   E+060004800,
2.27   E+06 0.37   E+06  0.133 E+06   0.01   E+06                           0004900,
5    66 21  15.0         41.5         115.0        131.5        132.9       0005000,
134.7       138.0        139.8        142.6        148.8        165.0       0005100,
171.3       175.8        178.1        176.8        171.1        152.0       0005200,
116.6       58.7         29.4         21.0                                  0005300,
5    96 21  0.816        0.818        0.826        0.833        0.841       0005400,
0.856       0.889        0.903        0.920        0.933        0.959       0005500,
0.967       0.974        0.978        0.973        0.964        0.922       0005600,
0.859       0.801        0.787        0.781                                 0005700,
3     1 21   3.0          0.0          0.046        0.06         0.063      0005800,
 0.10        0.073        0.148        0.083        0.205        0.093      0005900,
 0.239       0.098        0.279        0.103        0.326        0.108      0006000,
 0.44        0.119        0.44         1.0                                  0006100,
3   101 31   3.0          0.0          0.0005       0.02         0.005      0006200,
 0.036       0.01         0.06         0.015        0.088        0.02       0006300,
 0.156       0.03         0.238        0.04         0.331        0.05       0006400,
 0.435       0.06         0.662        0.08         0.766        0.09       0006500,
 0.859       0.10         0.938        0.11         1.0          0.119      0006600,
```

```
  1.0          1.0                                                                        0006700,
 3   201  9 323.0        252.0          0.0        245.5          0.5           0006800,
241.0         1.0        240.0          1.25                                            0006900,
 3   211  3   8.0          0.5459       1.0                                             0006920,
 3   301  9  323.0        260.0          0.0        254.5          0.5          0007000,
 251.0          1.0        250.5          1.25                                          0007100,
 3   311  3   8.0          1.0518       1.0                                             0007120,
 3   401  5   1.0         45.0          0.375        0.62065       1.0          0007200,
 3   433  5   1.0         30.0          0.25         0.31727       0.5          0007300,
-3   526  4  54.4       2557.0          0.0          1.7                        0007400,
$D1 IPR=3, IST=1, ICMT=3, NSEGF=22, NSEGO=22, DELT=170.0E-06,           ID=1000000,
AF=2*2.92,0,4*2.92,0,9*2.92,5*3.22,38*0,                                 ID=1000100,
CF=2*1.67E-06,0,4*1.67E-06,0,9*1.67E-06,5*1.24E-06,38*0,                 ID=1000200,
AO=2*2.92,0,4*2.92,0,9*2.92,5*4.42,38*0,                                 ID=1000300,
CO=2*1.67E-06,0,4*1.67E-06,0,9*1.67E-06,5*1.57E-06,38*0,                 ID=1000400,
IORF=2,5,6,7,10,11,12,13,14,15,16,17,18,19,20,21,22,43*0,                ID=1000500,
IORO=2,5,6,7,10,11,12,13,14,15,16,17,18,19,20,21,22,43*0,                ID=1000600,
LFF=3*1,57*0, PF=3*0,20*252,37*0,                                        ID=1000700,
PFAV=3*130,14*230,5*240,38*0,                                            ID=1000720,
LFO=3*1,57*0, PO=3*0,20*252,37*0,                                        ID=1000800,
POAV=3*220,14*230,5*240,38*0,                                            ID=1000820,
IVARIS=2,210,2,310,2,522,6, 64,12*0,                                     ID=1001200,
IWT=9,209,109,309,1,101,403,404,                                         ID=1001300,
IPI=1,9,23,3*0,101,109,123,3*0,209,5*0,309,5*0,3,203,4*0,                ID=1001400,
B(1)=0.0021, B(2)=0.0049,                                                ID=1001700,
GF=3*0,20*0.0021,37*0, GO=3*0,20*0.0049,37*0,                            ID=1001720,
B(3)=0.0325, B(4)=0.052, B(5)=530, B(6)=530,                             ID=1001800,
B(7)=60000, B(8)=40500,                                                  ID=1001900,
B(9)=0.0083446, B(10)=-4.1095, B(11)=0.0089489, B(12)=-3.62944,          ID=1002000,
B(13)=41.797, B(14)=92.016, B(15)=4, B(16)=4,                            ID=1002100,
B(17)=1.67, B(18)=1.67, B(19)=1.05, B(20)=1.1, B(21)=10, B(22)=10,       ID=1002200,
B(23)=8.8869E-06, B(24)=2.0526E-05,                                      ID=1002300,
B(31)=0.691, B(32)=0.368, B(33)=0.75, B(34)=0.75,                        ID=1002400,
INDEX=12,                                                                ID=1008100,
$END                                                                        1100000,
APOLLO DESCENT ENGINE                                                       1200000;
                    DATA CORRELATION                                        1200100,
LTA-5               SERIES 11                  TEST 2              RUN 2 1200200,
```

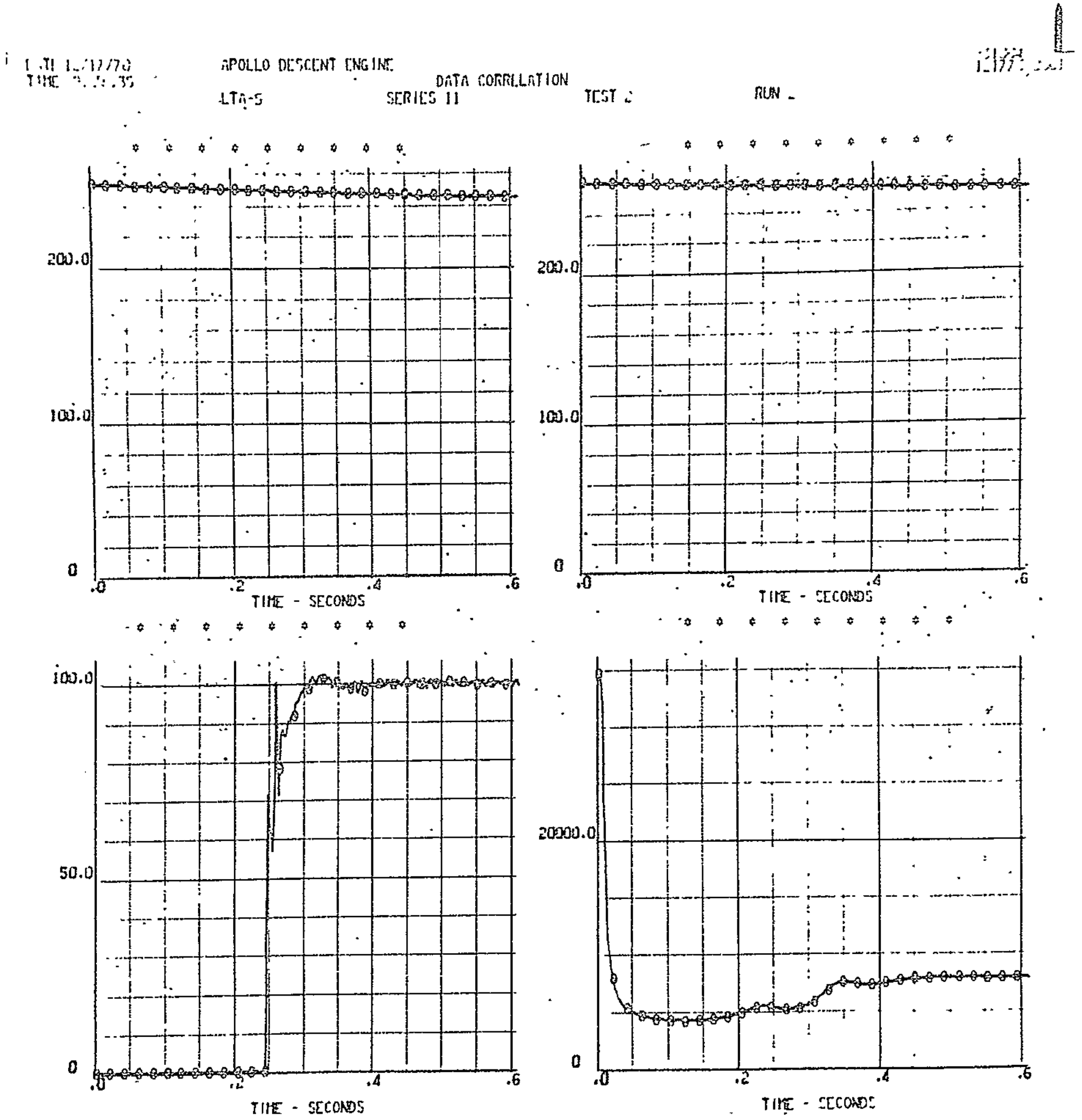

Figure B-3A - Graphical Output of Apollo Descent Engine Start Transient Model.

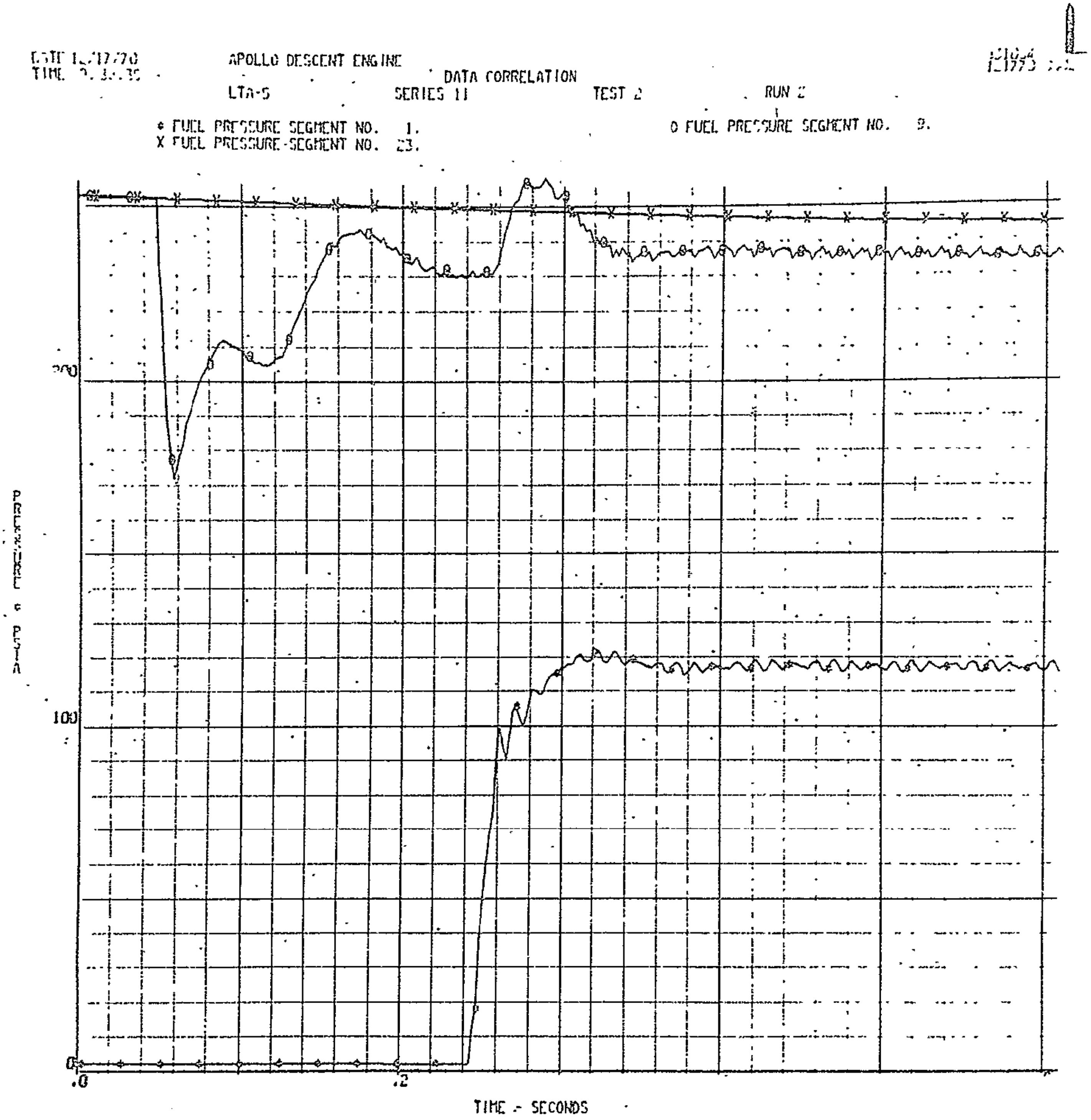

Figure B-3B - Graphical Output of Apollo Descent Engine Start Transient Model.

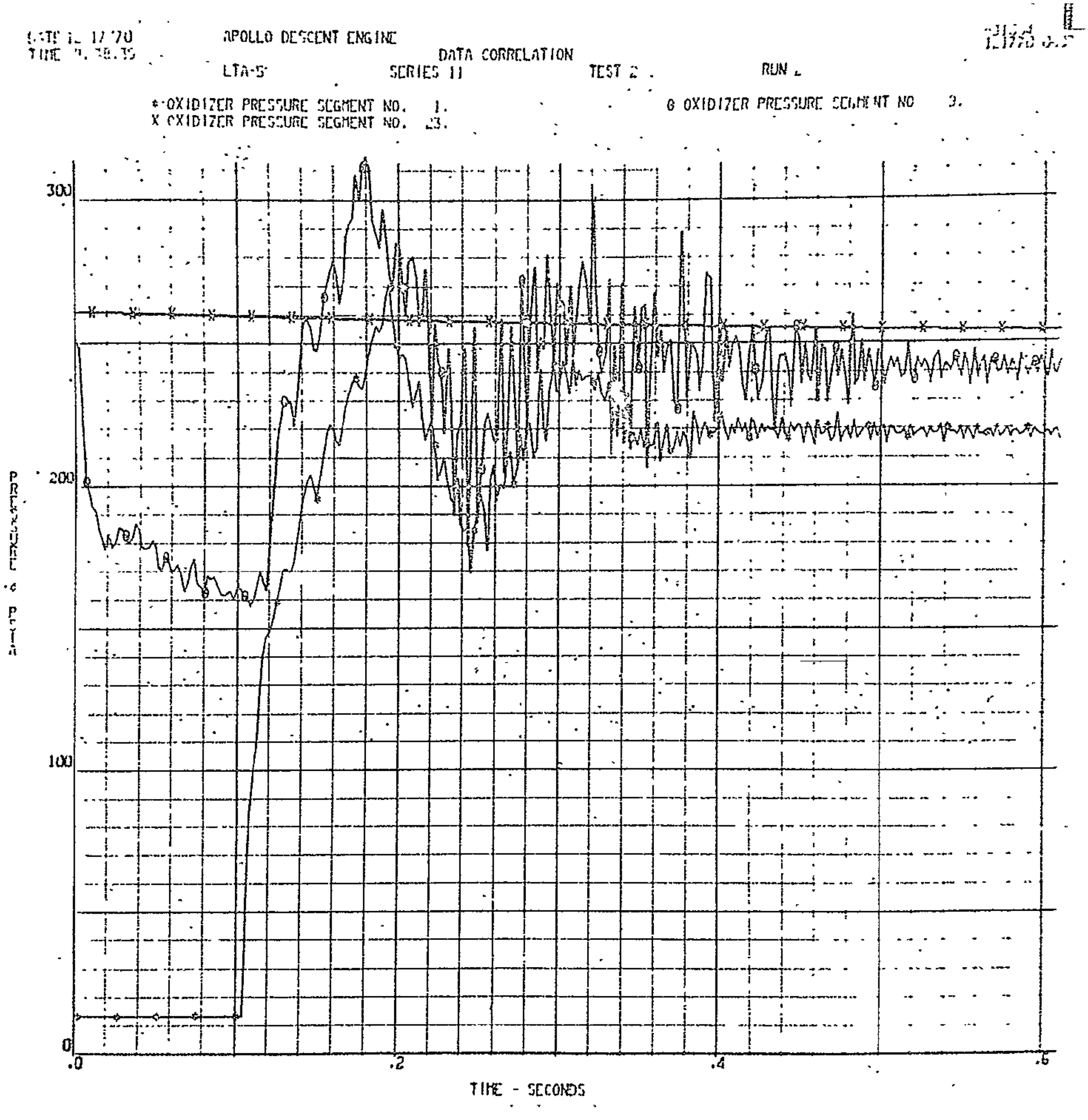

Figure B-3C - Graphical Output of Apollo Descent Engine Start Transient Model.

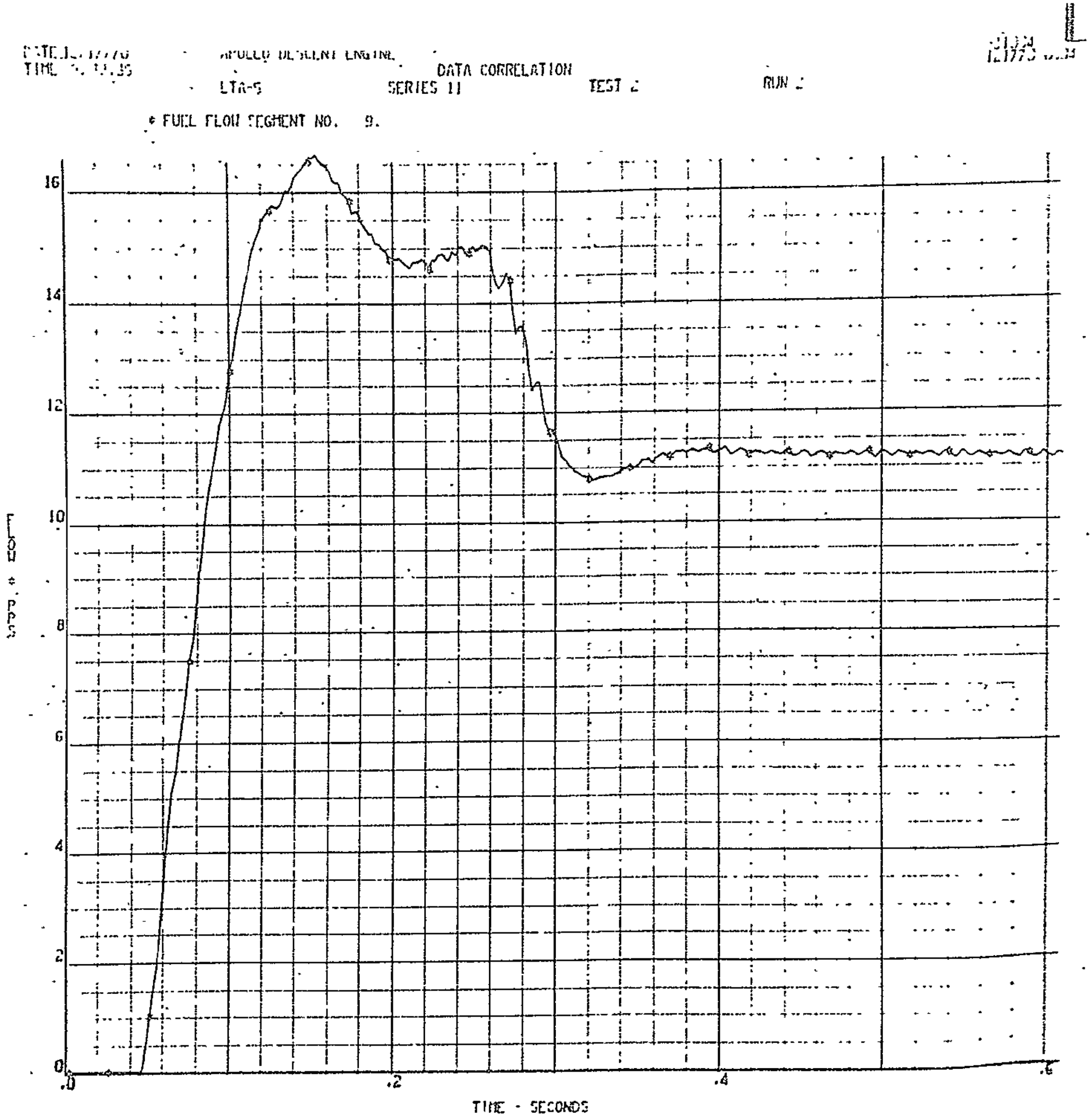

Figure B-3D - Graphical Output of Apollo Descent Engine Start Transient Model.

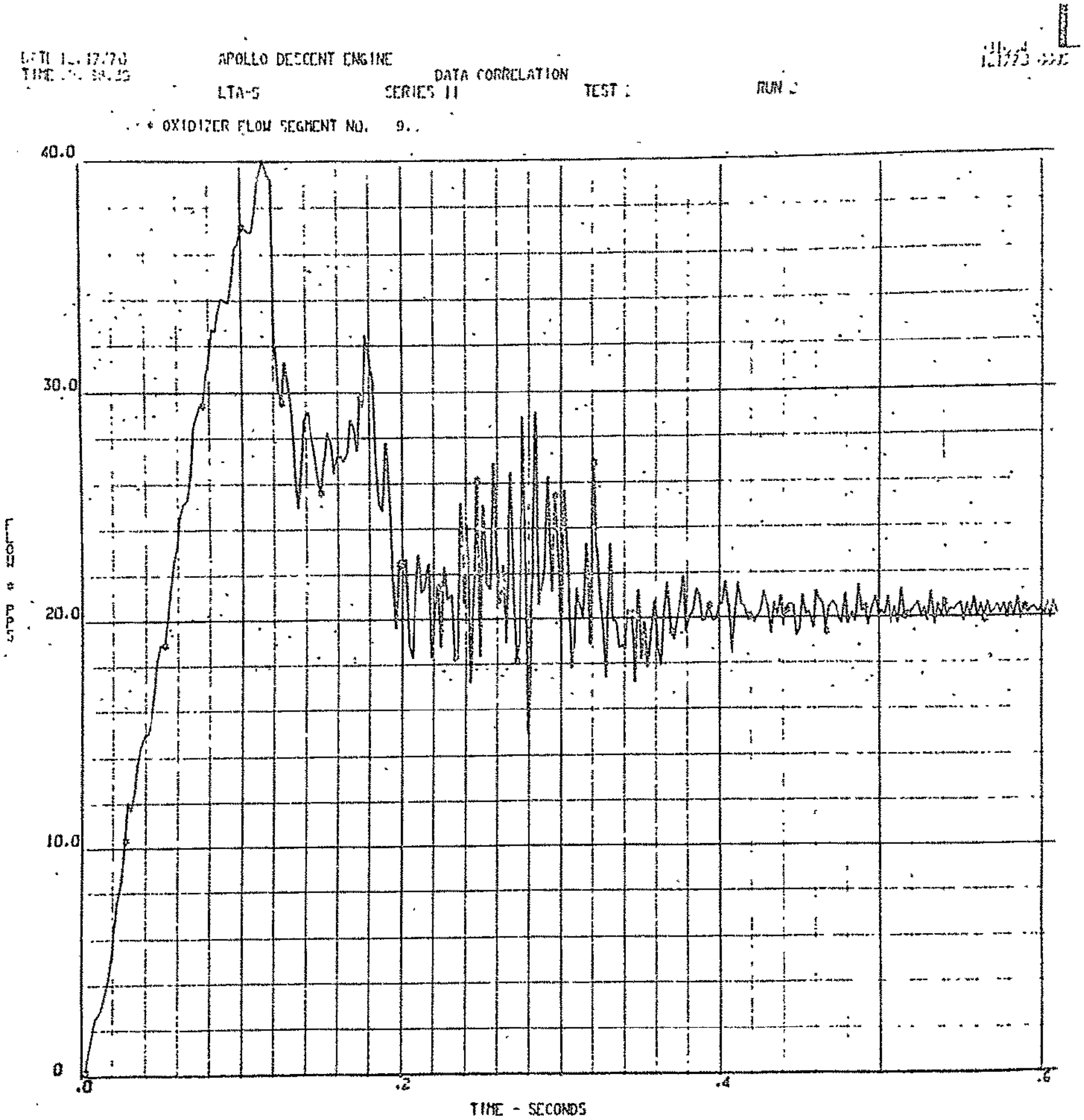

Figure B-3E - Graphical Output of Apollo Descent Engine Start Transient Model.

⊕3

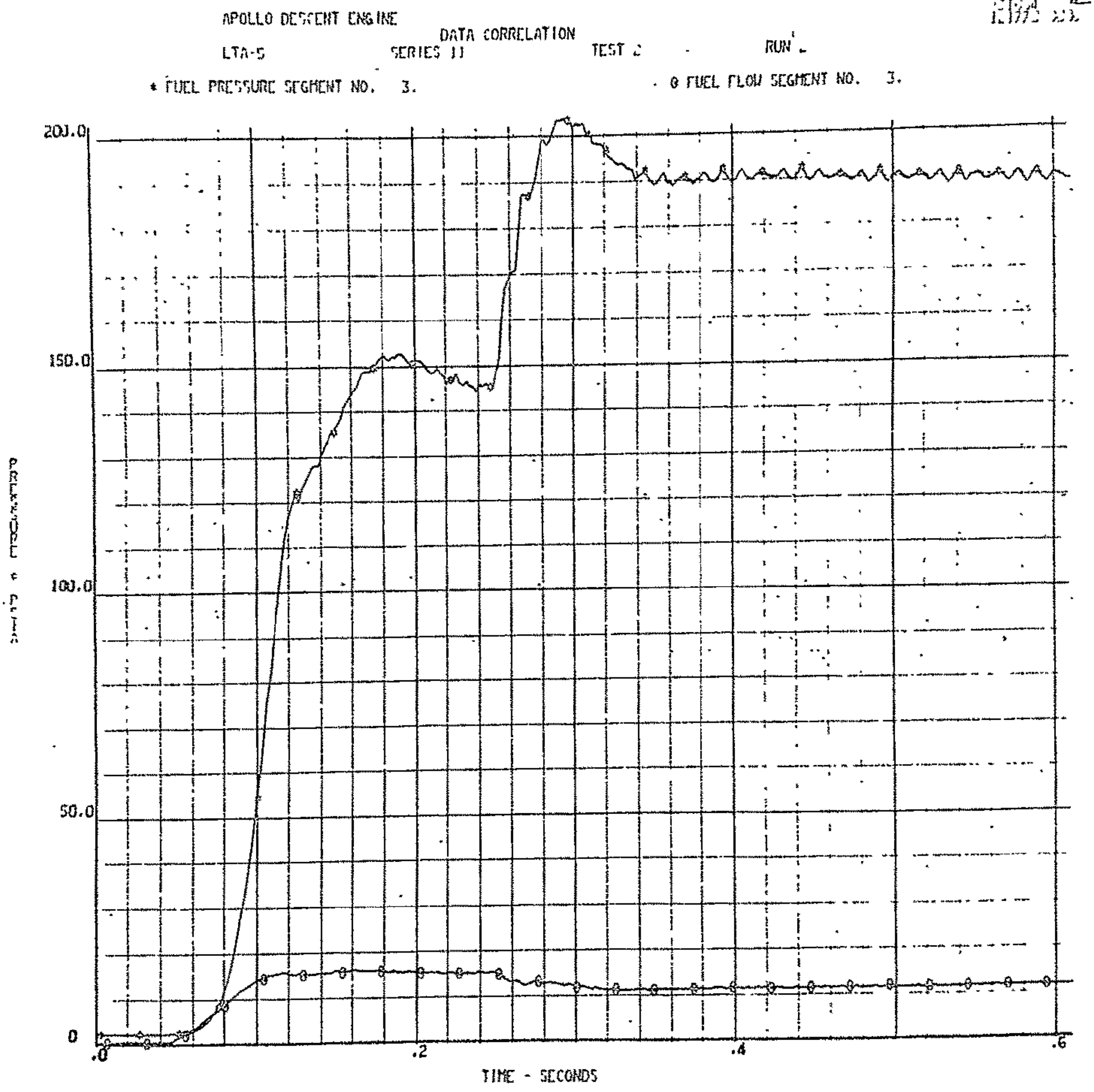

Figure B-3F - Graphical Output of Apollo Descent Engine Start Transient Model.

TABLE B-IV

APOLLO DESCENT ENGINE START TRANSIENT COMPUTER MODEL OUTPUT

NOT REPRODUCIBLE

```
                                     DATE  12/17/70          TIME  9:31.16
                APOLLO DESCENT ENGINE
                                                  DATA CORRELATION
               LTA-5                        SERIES 11                       TEST  2                  RUN  2
*          *            *             *       FUEL FEEDSYSTEM PARAMETERS                *             *              *            *
  SEGMENT DATA      PRESSURE      FLOW       ACOUSTIC        AREA       LENGTH      RESISTANCE       DISOLVED GAS
   NO.  STATE         PSIA        PPS        VELOCITY      SQ. IN.      INCHES      SEC**2/IN**5     LBS G / LB
                                             IN / SEC
     1   EMPTY          2.06      0.0        48889.0        2.9200       10.20      0.1120E-03       0.0
     2   EMPTY          2.06      0.0        48889.0        2.9200       10.20      0.1604E-01       0.0
     3   EMPTY          2.06      0.0        48888.0        0.0           0.0       0.1000E 32       0.2100E-02
     4   FULL         252.00      0.0        48888.0        2.9200       10.20      0.1120E-03       0.2100E-02
     5   FULL         252.00      0.0        48888.0        2.9200       13.00      0.1430E-03       0.2100E-02
     6   FULL         252.00      0.0        48888.0        2.9200       15.00      0.1650E-03       0.2100E-02
     7   FULL         252.00      0.0        48888.0        2.9200       12.20      0.1340E-03       0.2100E-02
     8   FULL         252.00      0.0000     48888.0        0.0           0.0       0.4340E-02       0.2100E-02
     9   FULL         252.00      0.0000     48888.0        2.9200       11.00      0.1210E-03       0.2100E-02
    10   FULL         252.00      0.0        48888.0        2.9200       13.00      0.1430E-03       0.2100E-02
    11   FULL         252.00      0.0        48888.0        2.9200       15.00      0.1650E-03       0.2100E-02
    12   FULL         252.00      0.0        48888.0        2.9200       17.00      0.1870E-03       0.2100E-02
    13   FULL         252.00      0.0        48888.0        2.9200       19.00      0.2090E-03       0.2100E-02
    14   FULL         252.00      0.0        48888.0        2.9200       21.00      0.2310E-03       0.2100E-02
    15   FULL         252.00      0.0        48888.0        2.9200       23.00      0.2530E-03       0.2100E-02
    16   FULL         252.00      0.0        48888.0        2.9200       20.00      0.2200E-03       0.2100E-02
    17   FULL         252.00      0.0        48888.0        2.9200       17.00      0.1870E-03       0.2100E-02
    18   FULL         252.00      0.0        51151.4        3.2200       11.00      0.1150E-03       0.2100E-02
    19   FULL         252.00      0.0        51151.4        3.2200       15.00      0.1570E-03       0.2100E-02
    20   FULL         252.00      0.0        51151.4        3.2200       19.00      0.1990E-03       0.2100E-02
    21   FULL         252.00      0.0        51151.4        3.2200       17.00      0.1780E-03       0.2100E-02
    22   FULL         252.00      0.0        51151.4        3.2200       10.20      0.1070E-03       0.2100E-02
    23   FULL         252.00      0.0        60000.0        0.0           0.0       0.0              0.2100E-02
```

```
APOLLO DESCENT ENGINE
                                    DATA CORRELATION
               LTA-5               SERIES 11                  TEST 2                  RUN 2
*         *         *         *    OXIDIZER FEEDSYSTEM CONSTANTS          *         *         *         *
 SEGMENT DATA       PRESSURE   FLOW      ACOUSTIC      AREA      LENGTH     RESISTANCE       DISOLVED GAS
 NO.  STATE           PSIA      PPS      VELOCITY     SQ. IN.    INCHES     SEC**2/IN**5     LBS G / LB L
                                         IN / SEC
   1  EMPTY          12.99     0.0       34613.9      2.9200      7.00     0.3900E-04       0.0
   2  EMPTY          12.99     0.0       34613.9      2.9200      7.40     0.4200E-04       0.0
   3  EMPTY          12.99     0.0       34613.4      0.0         0.0      0.1000E 32       0.4900E-02
   4  FULL          252.00     0.0       34613.4      2.9200      7.00     0.3900E-04       0.4900E-02
   5  FULL          252.00     0.0       34613.4      2.9200      9.00     0.5100E-04       0.4900E-02
   6  FULL          252.00     0.0       34613.4      2.9200     11.00     0.6200E-04       0.4900E-02
   7  FULL          252.00     0.0       34613.4      2.9200     15.00     0.8400E-04       0.4900E-02
   8  FULL          252.00     0.0000    34613.4      0.0         0.0      0.1169E-02       0.4900E-02
   9  FULL          252.00     0.0000    34613.4      2.9200     11.00     0.6200E-04       0.4900E-02
  10  FULL          252.00     0.0       34613.4      2.9200     13.00     0.7300E-04       0.4900E-02
  11  FULL          252.00     0.0       34613.4      2.9200     15.00     0.8400E-04       0.4900E-02
  12  FULL          252.00     0.0       34613.4      2.9200     17.00     0.9600E-04       0.4900E-02
  13  FULL          252.00     0.0       34613.4      2.9200     19.00     0.1070E-03       0.4900E-02
  14  FULL          252.00     0.0       34613.4      2.9200     21.00     0.1240E-03       0.4900E-02
  15  FULL          252.00     0.0       34613.4      2.9200     23.00     0.1290E-03       0.4900E-02
  16  FULL          252.00     0.0       34613.4      2.9200     20.00     0.1120E-03       0.4900E-02
  17  FULL          252.00     0.0       34613.4      2.9200     17.00     0.9600E-04       0.4900E-02
  18  FULL          252.00     0.0       34896.2      4.4200     11.00     0.1150E-03       0.4900E-02
  19  FULL          252.00     0.0       34896.2      4.4200     15.00     0.1560E-03       0.4900E-02
  20  FULL          252.00     0.0       34896.2      4.4200     19.00     0.1970E-03       0.4900E-02
  21  FULL          252.00     0.0       34896.2      4.4200     17.00     0.1760E-03       0.4900E-02
  22  FULL          252.00     0.0       34896.2      4.4200     13.00     0.1040E-03       0.4900E-02
  23  FULL          26[illegible]     0.0       40500.0      0.0         0.0      0.0              0.4900E-02
```

```
              APOLLO DESCENT ENGINE
                                          DATA CORRELATION
              LTA-5                 SERIES 11                   TEST  2                RUN 2
 *        *        *        *        FEEDSYSTEM CONFIGURATION        *          *            *
                 FUEL                                                OXIDIZER
                                         SEGMENT BRANCH DATA
INDEX INLET  *     *     *  BRANCHES  *     *     *  INLET  *     *     *  BRANCHES  *

                                            CAPPED SEGMENTS
                          0,  0,  0,  0,  0,                       0,  0,  0,  0,  0,

                             FUEL IORDER ARRAY          *     NSEGF = 22
     2    5    6    7   10   11   12   13   14   15   16   17   18   19   20   21   22

                             OXIDIZER IORDER ARRAY      *     NSEGO = 22
     2    5    6    7   10   11   12   13   14   15   16   17   18   19   20   21   22

                             CUTOFF SEGMENTS
              FUEL                                         OXIDIZER
```

```
                                FUEL VALVE TABLE
NDEX    SEGMENT    *          *          VALUES
  1        323   252.000000  0.0        245.500000  0.500000 241.000000   1.000000 240.000000  1.250000
  2          8     0.545900  1.000000   0.0         0.0         0.0        0.0        0.0        0.0

                                OXIDIZER VALVE TABLE
NDEX    SEGMENT    *          *          VALUES
  1        323   260.000000  0.0        254.500000  0.500000 251.000000   1.000000 250.500000  1.250000
  2          8     1.051800  1.000000   0.0         0.0         0.0        0.0        0.0        0.0

                                FUEL FUNGEN TABLE
 3.000000    0.0        0.046000   0.060000   0.063000   0.100000   0.073000   0.148000   0.083000
 0.205000    0.093000   0.239000   0.098000   0.279000   0.103000   0.326000   0.108000   0.440000
 0.119000    0.440000   1.000000

                                OXIDIZER FUNGEN TABLE
 3.000000    0.0        0.000500   0.020000   0.005000   0.036000   0.010000   0.060000   0.015000
 0.088000    0.020000   0.156000   0.030000   0.238000   0.040000   0.331000   0.050000   0.435000
 0.060000    0.662000   0.080000   0.766000   0.090000   0.859000   0.100000   0.938000   0.110000
 1.000000    0.119000   1.000000   1.000000
```

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CAVITATING VENTURI DATA
       FUEL                                          OXIDIZER

ORIFICE DATA

ACCUMULATOR DATA
```

```
                                 INJECTOR MANIFOLD DATA
                                        FUEL                                                  OXIDIZER
INDEX NO.                          1          2           3           4                   2              3             4
SEGMENT NO.                    1.000000   0.0         0.0         0.0          1.000000   0.0          0.0           0.0
MANIFOLD VOLUME - CU.IN.       45.0000     0.0         0.0         0.0          30.0000     0.0          0.0           0.0
ORIFICE LENGTH - INCHES      0.375000   0.0        0.0         0.0          0.250000   0.0          0.0           0.0
INJECTOR C-SUB-D*A - SQIN    0.620650   0.0        0.0         0.0          0.317270   0.0          0.0           0.0
FLAME FROUNT DISTANCE-IN.    1.000000   0.0        0.0         0.0          0.500000   0.0          0.0           0.0

                                 COMBUSTION CHAMBER DATA,
INDEX NO.                           1                     2                        3                    4
CHAMBER PRESSURE - PSIA            0.0                   0.0                      0.0                  0.0
OXIDIZER FLOWRATE - PPS            0.0                   0.0                      0.0                  0.0
FUEL FLOWRATE - PPS                0.0                   0.0                      0.0                  0.0
OXIDIZER FRACTION                  0.0                  0.0                     0.0                  0.0
THROAT AREA - SQ. IN.             54.400                 0.0                      0.0                  0.0
CHAMBER VOLUME - CU. IN.        2557.000                 0.0                      0.0                  0.0
NOZZLE EXIT AREA - SQ. IN.         0.0                    0.0                      0.0                  0.0
THRUST COEFFICIENT               1.70000                0.0                     0.0                  0.0
ENGINE AMBIENT PRESSURE - PSIA     0.0                   0.0                      0.0                  0.0
ENGINE THRUST - POUNDS             0.0                    0.0                      0.0                  0.0

                                 COMBUSTION DATA
          BASE PRESSURE =  150.0 PSIA                                    GAS CONSTANT CORRECTION =0.027790
          CSTAR CORRECTION =0.008453                                     EFFICIENCY CORRECTION =0.0
                        OX. FRACTION                GAS CONSTANT          CSTAR / G              EFFICIENCY
                         -0.0050                    -2.0000E 05            15.000                 0.8160
                          0.0                        2.9300E 05            41.500                 0.8180
                          0.0200                     2.8200E 06           115.000                 0.8260
                          0.0400                     3.0400E 06           131.500                 0.8330
                          0.0600                     3.0700E 06           132.900                 0.8410
                          0.1000                     3.1300E 06           134.700                 0.8560
                          0.2000                     3.2400E 06           138.000                 0.8890
                          0.2500                     3.2800E 06           139.800                 0.9030
                          0.3000                     3.4200E 06           142.600                 0.9200
                          0.3500                     3.8700E 06           148.800                 0.9330
                          0.4500                     4.6000E 06           165.000                 0.9590
                          0.5000                     4.8800E 06           171.300                 0.9670
                          0.5500                     5.0300E 06           175.800                 0.9740
                          0.6000                     5.0200E 06           178.100                 0.9780
                          0.6500                     4.8600E 06           176.800                 0.9730
                          0.7000                     4.5500E 06           171.100                 0.9640
                          0.8000                     3.6300E 06           152.000                 0.9220
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0.9000          2.2700E 06          116.600          0.8590
0.9800          3.7000E 05           58.700          0.8010
1.0000          1.3300E 05           29.400          0.7870
1.0050          1.0000E 04           21.000          0.7810
```

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                         DATE  12/17/70        TIME  9:31.16
          APOLLO DESCENT ENGINE
                                  DATA CORRELATION
          LTA-5              SERIES 11               TEST 2               RUN 2

           INPUT DATA CONSTANTS        *        *            FUEL             OXIDIZER

     ENTRAINED GAS - LBS GAS / LB LIQUID                     2.1000E-03        4.9000E-03
     PROPELLANT DENSITY - POUNDS / CUBIC INCH                0.03250           0.05200
     LIQUID TEMPERATURE - DEGREES RANKINE                     530.0             530.0
     PROPELLANT ACOUSTIC VELOCITY - INCHES / SECOND          60000.0           40500.0
     VAPOR PRESSURE CURVE FIT CONSTANTS - CON1               8.3446E-03        8.9489E-03
      ( LOG(PVAP) = CON1 * TEMP + CON2 )
                                       - CON2               -4.1095E 00       -3.6294E 00
     PROPELLANT MOLECULAR WEIGHT                              41.8              92.0
     PRESSURANT GAS MOLECULAR WEIGHT                           4.0               4.0
     RATIO OF SPECIFIC HEATS - PRESSURANT GAS                 1.670             1.670
     RATIO OF SPECIFIC HEATS - PROPELLANT VAPOR               1.050             1.100

     DISSOLVED GAS EVOLUTION TIME CONSTANT - 1/SEC.          1.0000E 01        1.0000E 01
     DISSOLVED GAS CONCENTRATION - LBS GAS / LB LIQ / PSI    8.8889E-06        2.0526E-05
     PROPELLANT TANK ULLAGE - CUBIC INCHES                   0.0               0.0
     PROPELLANT TANK INITIAL PRESSURE - PSIA                   0.0               0.0
     PRESSURANT GAS BOTTLE VOLUME - CUBIC INCHES             0.0               0.0

     PROPELLANT LIQUID HEAT CAPACITY - BTU / LB / DEGREE R   6.9100E-01        3.6800E-01
     PRESSURANT - LOW PRESSURE C-SUB-V                       7.5000E-01        7.5000E-01
     PRESSURANT - HIGH PRESSURE C-SUB-V                      0.0               0.0
     PRESSURANT - HIGH PRESSURE C-SUB-P                      0.0               0.0
     PRESSURANT - HIGH PRESSURE GAMMA                         0.0               0.0
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NOT REPRODUCIBLE

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              APOLLO DESCENT ENGINE
                                        DATA CORRELATION
              LTA-5                     SERIES 11                     TEST 2                        RUN 2
 0.0          251.99998     0.00000     251.99998      0.00000        2.05654      12.98603       0.0       34613.35938
 0.002040     251.99998     0.00000     247.79466      0.13638        2.05654      12.98603       0.0       34613.35938
 0.004080     251.99998     0.00000     222.29463      0.96245        2.05654      12.98603       0.0       34613.35938
 0.006120     251.97852    -0.00049     200.74428      1.71430        2.05654      12.98603       0.0       32070.95313
 0.008160     251.92996    -0.00063     197.26343      2.47837        2.05654      12.98603       0.0       23302.40234
 0.010200     251.87631    -0.00061     192.11464      2.64688        2.05654      12.98603       0.0       16960.52734
 0.012240     251.82307    -0.00063     190.47972      2.81990        2.05654      12.98603       0.0       13296.42188
 0.014280     251.77000    -0.00061     184.19046      3.51208        2.05654      12.98603       0.0       11097.27734
 0.016320     251.72569    -0.00044     180.86087      4.09324        2.05654      12.98603       0.0        9677.69922
 0.018360     251.70821     0.00005     177.08289      5.02773        2.05654      12.98603       0.0        8677.12891
 0.020400     251.71056     0.00001     182.56113      6.31398        2.05654      12.98603       0.0        7924.18750
 0.022440     251.71031    -0.00000     177.61127      7.62139        2.05654      12.98603       0.0        7344.20313
 0.024480     251.71106     0.00002     179.74863      8.26297        2.05654      12.98603       0.0        6886.50391
 0.026520     251.70840    -0.00007     184.46115     10.26412        2.05654      12.98603       0.0        6523.87500
 0.028560     251.68495    -0.00047     184.37283     11.96219        2.05654      12.98603       0.0        6234.62109
 0.030600     251.63681    -0.00065     181.93489     11.61106        2.05654      12.98603       0.0        5997.86719
 0.032640     251.58138    -0.00062     179.06618     12.32423        2.05654      12.98603       0.0        5804.50000
 0.034680     251.52896    -0.00060     180.85898     13.63357        2.05654      12.98603       0.0        5646.11719
 0.036720     251.47647    -0.00061     185.97922     14.40375        2.05654      12.98603       0.0        5514.00000
 0.038760     251.43408    -0.00037     184.23528     14.86636        2.05654      12.98603       0.0        5400.85938
 0.040800     251.41914     0.00002     178.08624     14.94370        2.05654      12.98603       0.0        5301.15625
 0.042840     251.42101     0.00004     177.36975     15.46395        2.05654      12.98603       0.0        5210.71484
 0.044880     251.42154    -0.00002     177.70978     16.59673        2.05654      12.98603       0.0        5127.51953

          ITERATION ERROR IN BRANCH. TIME = 0.046070, SEGMENT  3  PG =  126.738        PANS =-0.135997E 12
 0.046920     251.32021     0.00235     180.29716     18.17114        2.05654      12.98603       0.0        5051.88672
 0.048960     229.06276     0.51548     178.52560     18.81091        2.05654      12.98603       0.0        4983.43359
 0.051000     207.85471     1.00188     170.76404     18.85364        2.05654      12.98603       0.0        4919.82813
 0.053040     189.23865     1.43059     169.80843     19.75922        2.05654      12.98603       0.0        4859.25000
 0.055080     176.87076     1.79566     174.59639     21.28186        2.05654      12.98603       0.0        4802.08594
 0.057120     171.17711     2.24112     173.84555     22.50418        2.05654      12.98603       0.0        4749.52344
 0.059160     175.06183     3.09958     169.54160     23.19884        2.05654      12.98603       0.0        4701.58984
 0.061200     178.26009     3.94470     169.88136     24.51541        2.05654      12.98603       0.0        4657.23438
 0.063240     181.88177     4.54407     171.49376     24.99030        2.05654      12.98603       0.0        4615.66406
 0.065280     187.43063     5.07593     168.75372     25.20300        2.05654      12.98603       0.0        4576.62109
 0.067320     190.50494     5.42060     162.17818     26.26967        2.05654      12.98603       0.0        4540.38281
 0.069360     193.63876     5.95655     165.05658     28.41769        2.05654      12.98603       0.0        4507.49219
 0.071400     196.05711     6.30292     171.15375     28.83673        2.05654      12.98603       0.0        4477.91797
 0.073440     198.66837     6.86840     172.73654     29.28029        2.05654      12.98603       0.0        4450.73047
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0.075479   200.75729    7.46199   165.19151   29.33351   2.05654    12.98603   0.0   4425.15625
0.077519   203.00189    7.86937   163.48634   30.70485   2.05654    12.98603   0.0   4401.07422
0.079559   204.48126    8.52184   161.78757   31.37794   2.05654    12.98603   0.0   4378.70313
0.081599   206.80084    9.11435   167.54610   32.67938   2.05654    12.98603   0.0   4358.30859
0.083639   208.59979    9.65889   166.38203   32.58719   2.05654    12.98603   0.0   4340.03125
0.085679   210.16672   10.22205   167.22591   33.45799   2.05654    12.98603   0.0   4323.58594
0.087719   211.11708   10.69761   163.65562   34.00713   2.05654    12.98603   0.0   4308.41016
0.089759   210.87666   11.02129   161.06641   33.90813   2.05654    12.98603   0.0   4294.05859
0.091799   210.13162   11.38417   160.87833   33.79723   2.05654    12.98603   0.0   4280.47656
0.093839   209.78459   11.78434   161.43024   34.78352   2.05654    12.98603   0.0   4267.89844
0.095878   209.49984   12.02444   162.14725   36.18880   2.05654    12.98603   0.0   4256.55078
0.097918   208.71263   12.28778   159.32265   36.35318   2.05654    12.98603   0.0   4246.42578
0.099958   208.53171   12.76054   163.63708   37.13531   2.05654    12.98603   0.0   4237.22656
0.101998   206.41710   12.95890   162.83067   37.03690   2.05654    12.98603   0.0   4228.59766
0.104038   206.59761   13.35766   160.63806   36.87155   2.05654    12.98603   0.0   4220.42969
0.106078   205.44394   13.73610   159.74663   36.90016   2.05654    54.23944   0.0   4212.83594
0.108118   204.70956   14.02775   157.45140   37.71587   2.05654    85.55806   0.0   4205.97656
0.110158   204.81546   14.36182   159.71263   38.98872   2.05654   100.09439   0.0   4199.98047
0.112198   204.13953   14.56211   164.33189   39.44740   2.05654   107.18739   0.0   4195.09375
0.114238   204.08954   14.85685   169.52913   39.98555   2.05654   125.94559   0.0   4191.41016
0.116278   203.91818   15.09625   165.50807   39.37622   2.05654   139.82463   0.0   4188.80078
0.118317   204.61102   15.24265   162.53154   39.15363   2.05654   146.39293   0.0   4187.12500
0.120357   205.85536   15.43385   185.48335   31.98744   2.05654   148.41270   0.0   4186.15234
0.122397   206.37602   15.52773   198.90211   30.02068   2.05654   152.75510   0.0   4185.66406
0.124437   206.50125   15.62387   214.54256   29.48955   2.05654   158.45596   0.0   4185.64844
0.126477   208.75073   15.72555   221.79430   31.24358   2.05654   163.83276   0.0   4186.10938
0.128517   211.74173   15.68399   229.15239   30.05247   2.05654   169.75931   0.0   4186.94141
0.130557   213.11687   15.67687   229.03705   28.96053   2.05654   170.34703   0.0   4188.02344
0.132597   216.06409   15.75536   228.23611   26.24142   2.05654   168.98244   0.0   4189.36328
0.134637   218.00203   15.90547   220.44914   24.88695   2.05654   171.96080   0.0   4191.06641
0.136677   219.94896   15.96922   229.55278   26.72188   2.05654   179.93805   0.0   4193.41406
0.138717   222.05353   16.08240   242.81921   28.75142   2.05654   188.00015   0.0   4196.60156
0.140756   224.69949   16.22327   256.66650   29.05974   2.05654   194.60664   0.0   4200.61328
0.142796   227.14101   16.30635   257.57813   28.01913   2.05654   201.33647   0.0   4205.19141
0.144836   228.34204   16.37933   255.22263   27.18654   2.05654   203.31924   0.0   4210.01563
0.146876   231.29544   16.47725   247.69063   26.24855   2.05654   198.59163   0.0   4215.00000
0.148916   233.11818   16.53346   246.83620   25.54750   2.05654   194.84657   0.0   4220.41016
0.150956   234.82506   16.57101   252.20605   26.71220   2.05654   201.94365   0.0   4226.77344
0.152996   237.55627   16.61519   265.63623   28.15176   2.05654   211.17270   0.0   4234.57813
0.155036   239.05888   16.53491   270.27856   27.72462   2.05654   217.84019   0.0   4243.81641
0.157076   238.25515   16.47044   274.60352   26.41409   2.05654   220.76202   0.0   4253.98828
0.159116   238.76030   16.44476   278.21021   27.07486   2.05654   219.79272   0.0   4264.55859
0.161156   240.73622   16.38651   273.57861   27.13011   2.05654   215.21637   0.0   4275.44531
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0.163195   241.38989   16.17416   263.54541   26.89011    2.05654   214.10417    0.0        4287.25391
0.165235   241.70372   16.14270   271.20972   27.23322    2.05654   221.23441    0.0        4300.85938
0.167275   242.06847   16.13321   287.00342   28.71548    2.05654   227.83055    0.0        4316.79297
0.169315   242.10838   15.98092   291.12500   28.43620    2.05654   231.98604    0.0        4334.26563
0.171355   242.37579   15.91591   292.90112   27.37531    2.05654   235.71384    0.0        4352.91797
0.173395   243.25290   15.80783   308.11328   29.68025    2.05654   237.43477    0.0        4372.69922
0.175435   241.80194   15.56429   299.70947   29.29558    2.05654   234.48987    0.0        4393.60547
0.177475   242.06880   15.60215   310.79614   32.45024    2.05654   233.86172    0.0        4415.65234
0.179515   241.94611   15.59896   314.29346   31.33229    2.05654   238.76204    0.0        4438.90625
0.181555   241.42657   15.39102   310.75610   30.38557    2.05654   245.75018    0.0        4463.51172
0.183595   240.91995   15.30583   292.43018   26.53726    2.05654   250.61066    0.0        4489.56250
0.185634   239.83162   15.21688   287.30469   24.99893    2.05654   255.60329    0.0        4517.07813
0.187674   240.71959   15.20808   283.10962   24.74403    2.05654   253.79828    0.0        4546.09375
0.189714   238.54404   15.05641   296.48730   27.71657    2.05654   255.74805    0.0        4576.66016
0.191754   238.23112   15.01937   286.58960   25.15993    2.05654   265.67529    0.0        4608.78125
0.193794   237.56567   14.93726   274.61133   21.58141    2.05654   270.18726    0.0        4642.40234
0.195834   238.22446   14.92203   268.35913   19.60283    2.05654   259.75610    0.0        4677.47266
0.197874   236.11623   14.76244   284.35645   22.37302    2.05654   248.85889    0.0        4713.87891
0.199914   236.46162   14.78140   282.50586   22.27667    2.05654   244.54652    0.0        4751.64063
0.201954   234.84949   14.76578   269.33228   22.58505    2.05654   245.92027    0.0        4790.94922
0.203994   233.60498   14.77898   259.92261   18.79436    2.05654   244.72968    0.0        4831.91406
0.206034   233.42720   14.73606   277.81641   18.23396    2.05654   237.21414    0.0        4874.66797
0.208073   235.18250   14.67309   279.78564   21.17767    2.05654   227.40088    0.0        4919.48828
0.210113   233.14171   14.62234   273.68311   22.74504    2.05654   231.91496    0.0        4966.32422
0.212153   232.00703   14.70532   255.79492   21.17242    2.05654   236.20592    0.0        5015.19531
0.214193   231.21950   14.71452   260.01782   21.31367    2.05654   223.49841    0.0        5066.27734
0.216233   231.77098   14.72583   275.32910   22.32280    2.05654   215.70793    0.0        5117.74609
0.218273   232.43449   14.77410   240.52916   18.27138    2.05654   220.54314    0.0        5167.56641
0.220313   230.98637   14.69913   222.45592   20.28683    2.05654   222.35394    0.0        5214.33594
0.222353   230.02458   14.60345   256.13477   21.30484    2.05654   213.96283    0.0        5255.31250
0.224393   230.51929   14.75643   243.74460   18.75804    2.05654   201.73671    0.0        5291.99219
0.226433   231.67355   14.74468   239.49571   22.25148    2.05654   205.17491    0.0        5321.83203
0.228473   229.95023   14.83585   218.44841   20.84805    2.05654   209.35236    0.0        5344.24219
0.230512   230.08858   14.85256   248.00453   21.04053    2.05654   199.70499    0.0        5362.83594
0.232552   229.60300   14.78697   221.74376   18.14240    2.05654   194.79391    0.0        5376.71484
0.234592   229.79391   14.74846   189.23442   18.23160    2.05654   193.73590    0.0        5384.25000
0.236632   230.22592   14.90341   217.90245   25.07097    2.05654   202.43213    0.0        5384.08203
0.238672   229.52080   14.83275   221.32895   20.68040    2.05654   185.91562    0.0        5378.41016
0.240712   230.12883   14.96610   247.95801   24.10693    2.05654   183.95773    0.0        5365.30469
0.242752   231.21703   14.98748   178.69882   17.20702    2.05654   184.70396    0.0        5341.65234
0.244792   229.67621   14.87538   210.09151   21.17795   11.60011   169.19429    0.0        5315.07422
0.246832   229.90611   14.88746   255.28052   26.03624   18.03334   183.93675   57.61061    5285.58984
0.248872   230.41244   14.91328   186.63316   18.30528   38.07881   188.21385   71.20961    5259.66016
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NOT REPRODUCIBLE

0.250912	231.02260	14.92520	205.55037	24.95918	50.66214	196.20341	64.76981	5231.82422
0.252952	230.66458	14.96106	221.15913	21.57518	60.04472	191.22067	60.18648	5200.45313
0.254991	230.05023	15.01758	225.21835	21.30885	68.15117	176.91858	56.78569	5179.49609
0.257031	231.46149	14.99453	220.12450	26.80899	73.85385	202.16940	70.39720	5160.40234
0.259071	233.07657	14.90766	215.66171	22.60568	89.38498	206.97401	100.03549	5146.00781
0.261111	236.90314	14.54199	215.59595	20.65085	99.60506	194.44467	86.04308	5139.24609
0.263151	242.53551	14.33242	257.90967	22.30730	93.10954	199.99625	71.18285	5129.00781
0.265191	245.32808	14.24853	204.39227	18.90009	90.22661	198.67033	77.89638	5124.55469
0.267231	249.01595	14.36838	219.84648	26.40868	96.76389	208.93604	86.49959	5125.61328
0.269271	251.00328	14.53006	255.52518	20.93556	104.15161	211.79132	87.80904	5127.22266
0.271311	251.44901	14.38951	233.69965	18.04257	105.35242	200.27884	86.29333	5134.02344
0.273351	255.43864	13.78038	205.64226	18.88153	101.83366	206.73740	86.31918	5139.37500
0.275391	256.30396	13.40940	271.90601	28.85582	99.85023	217.37782	87.77295	5145.00000
0.277430	256.71533	13.55268	245.21124	22.47585	102.68370	208.90636	90.10722	5158.92969
0.279470	255.12198	13.54044	219.13876	14.95407	107.21181	219.04732	89.60724	5175.86719
0.281510	255.02892	13.32045	258.36841	21.77034	110.47644	222.01706	91.16553	5190.87109
0.283550	255.05765	12.73078	276.29321	29.02548	109.87163	210.00851	91.56120	5209.44922
0.285590	255.97597	12.37352	240.09439	20.57707	108.87584	212.38623	91.46216	5234.26953
0.287630	257.53198	12.51913	252.00464	21.34363	109.13651	240.72734	94.06645	5259.71875
0.289670	256.16895	12.54078	247.95667	22.23749	111.75467	220.47418	94.91533	5290.49609
0.291710	255.27773	12.19911	280.43921	26.21255	113.58188	215.64771	94.90170	5328.16797
0.293750	252.30722	11.79123	262.05737	21.20107	114.53793	233.21794	95.97346	5368.66406
0.295790	252.09357	11.62376	242.41232	25.36292	114.96219	242.26764	97.35693	5418.84375
0.297830	253.35980	11.66044	271.03589	23.02994	115.60869	232.78473	97.20850	5476.43750
0.299869	252.73021	11.55968	262.86230	19.48453	116.37357	236.01334	98.57727	5540.97656
0.301909	248.86467	11.36192	263.93628	25.64294	116.90079	243.70697	99.08604	5607.86328
0.303949	247.29114	11.18876	242.39386	22.98457	117.38763	239.92007	99.43834	5676.25000
0.305989	247.26811	11.12318	269.76855	17.78247	117.60236	232.17230	98.45766	5753.30469
0.308029	247.84657	11.03113	244.93102	18.71822	118.90140	244.01472	100.12315	5833.82422
0.310069	244.26283	10.98180	256.78784	21.30942	119.96776	235.42223	100.48090	5918.17578
0.312109	245.01154	10.90658	270.34839	20.57790	120.57449	240.39273	101.47725	6006.63281
0.314149	242.87894	10.87715	278.47998	20.02235	118.99213	236.93443	100.33893	6099.39063
0.316189	243.02936	10.82047	270.62280	23.28877	118.38400	238.00781	99.99121	6196.95313
0.318229	239.97238	10.80432	256.70996	18.85759	118.60356	238.70325	100.07159	6297.91406
0.320269	241.05334	10.75907	299.36719	26.80351	120.98103	236.19984	101.37869	6403.68750
0.322308	239.16376	10.75156	267.52881	23.09731	121.71605	233.14429	101.72896	6512.54297
0.324348	239.72011	10.75305	247.00046	21.21356	121.03346	239.63875	101.79660	6623.34766
0.326388	238.68811	10.79325	239.16476	19.77435	118.81905	232.46779	101.05806	6728.79297
0.328428	238.85289	10.77978	245.61198	17.43741	118.17346	229.63158	99.85312	6842.10547
0.330468	235.05777	10.79677	272.26123	23.29059	119.19862	236.01129	100.86516	6943.95703
0.332508	237.65297	10.79503	211.07724	19.87706	121.07236	222.53171	100.60123	7035.52734
0.334548	235.75102	10.80725	248.69980	19.88358	120.93044	222.52235	101.15576	7118.89453
0.336588	239.09601	10.83922	217.22832	18.66815	119.47211	224.15508	101.08455	7194.87891

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0.342708   234.03928   10.93926   232.08852   20.28812   118.67142   221.71503    99.68816   7353.75391
0.344747   235.17534   10.98273   212.82782   20.12891   119.09334   216.16484    99.18219   7385.75391
0.346787   235.83980   10.94718   262.23584   17.20671   118.78336   218.37546   100.16707   7405.81641
0.348827   236.95619   10.96425   240.92413   21.20471   118.03125   213.85144    99.56184   7414.6093
0.350867   235.85971   11.01007   261.98291   18.13994   117.76631   219.68137    99.69978   7418.1640
0.352907   237.01376   11.10275   263.28784   19.76099   117.15132   213.34393    98.40590   7413.2578
0.354947   234.40726   11.10151   206.45702   17.83279   116.93042   218.28377    98.78630   7398.9648
0.356987   234.94814   11.11619   241.85358   19.49681   116.72815   213.78128    98.11505   7379.5312
0.359027   236.34169   11.05468   267.53613   20.73322   117.57256   214.29355    98.92462   7364.3789
0.361067   236.6[illegible]220   11.12802   245.32733   18.68646   117.91106   221.92444    99.51370   7337.5039
0.363107   236.88129   11.18354   254.10785   17.90041   117.68959   208.58501    98.53754   7316.2656
0.365147   236.95462   11.22506   240.03032   20.13541   115.76225   215.41162    98.20383   7297.2617
0.367186   235.71579   11.20208   248.06441   21.53278   115.23077   221.30244    98.50116   7275.1484
0.369226   235.40044   11.17584   250.86382   19.35022   115.89211   212.12619    97.37976   7250.5625
0.371266   236.53719   11.19007   229.39862   19.04976   117.93362   212.76714    98.54057   7237.4453
0.373306   237.21820   11.25431   226.52826   19.86763   118.08269   218.65288   100.02403   7218.0820
0.375346   237.07234   11.25807   288.45605   20.64085   116.78561   213.63652    99.37682   7201.4570
0.377386   237.33504   11.26945   257.41479   21.79521   114.64021   218.47147    97.57996   7195.3203
0.379426   237.28079   11.23740   230.82037   19.41339   115.13402   216.33211    97.12074   7183.9726
0.381466   235.20076   11.26517   249.45366   20.09918   116.71935   209.65179    98.33675   7176.3906
0.383506   236.97711   11.28638   248.69026   20.27701   118.20483   225.55278   100.27557   7178.3945
0.385546   237.20029   11.27119   245.91609   21.26714   117.31158   221.94263    99.53940   7177.1992
0.387586   237.46024   11.25764   232.98453   20.98846   116.14993   214.32884    97.78368   7179.2656
0.389625   238.29253   11.27691   241.25752   19.84708   115.19566   218.75404    98.14101   7186.1718
0.391665   237.62172   11.29078   274.33862   19.91747   116.19348   221.73909    99.35785   7195.5078
0.393705   234.93181   11.32353   272.52905   20.48944   116.99326   217.61238    99.26825   7204.2460
0.395745   237.06583   11.26276   239.51088   19.87222   117.55463   218.39351    98.86775   7218.3359
0.397785   237.27087   11.23309   223.84735   19.88368   116.98114   218.47154    99.03688   7232.8593
0.399825   238.60469   11.25573   258.86035   20.54356   116.99863   220.60332    99.38394   7247.1093
0.401865   238.14626   11.29718   236.59880   20.56721   116.40721   225.39488    99.45584   7269.4101
0.403905   237.29668   11.32136   253.38570   21.57510   116.50336   218.68793    98.78770   7285.6093
0.405945   235.07047   11.27066   241.41747   20.51799   116.28354   216.13916    98.52164   7307.1054
0.407985   237.15198   11.2050[illegible]   249.21806   18.47147   117.36011   221.23875    99.72672   7329.6093
0.410025   237.91460   11.23072   252.32454   20.08446   118.05127   217.93245   100.02675   7352.9921
0.412064   238.75699   11.26771   248.51541   21.51610   118.15350   223.25450   100.29158   7375.3476
0.414104   237.34604   11.29475   235.19179   20.56427   116.48895   218.79242    99.02632   7400.8671
0.416144   237.51523   11.26506   229.78236   20.50310   115.77557   221.64680    98.81075   7423.5156
0.418184   235.3[illegible]122   11.20172   246.69876   19.97774   116.24326   216.36861    99.06274   7444.3398
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0.422264   237.87439   11.24815   240.59219   19.78497   119.00043   221.59970   100.53662   7493.2500
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0.432464	237.01844	11.24851	233.86032	19.31694	119.07858	219.50432	99.55775	7599.35156
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0.436543	237.94455	11.19299	245.29730	20.09215	117.13446	216.06874	99.75970	7628.08594
0.438583	237.48990	11.20265	245.28386	20.92937	116.03288	223.24940	99.71989	7647.27734
0.440623	237.55360	11.23334	245.33728	19.62410	116.89705	218.60144	99.17897	7656.50391
0.442663	234.62332	11.26115	238.87843	20.25110	117.59775	216.57599	98.88297	7669.89453
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0.446743	236.76924	11.15176	255.36319	20.54057	117.67798	218.73685	100.10640	7691.71094
0.448783	238.36865	11.18600	251.42715	19.18484	117.60806	221.12502	99.91350	7702.04297
0.450823	237.04492	11.23363	235.96288	19.43401	116.97974	220.88754	99.63991	7711.68359
0.452863	236.77681	11.26174	250.22577	20.98790	116.82172	214.69354	99.07094	7713.75391
0.454903	234.41225	11.21081	239.06021	20.09219	116.46368	221.66338	99.24361	7724.94531
0.456942	236.24971	11.14066	236.74643	20.23672	117.67404	219.95488	99.64229	7728.69141
0.458982	236.91284	11.17494	254.18944	19.48306	118.44453	214.22958	99.63927	7731.69531
0.461022	238.26262	11.22444	228.97375	21.11174	118.34212	222.50536	100.42371	7742.48438
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0.467142	234.66284	11.16199	229.01482	19.29701	116.31081	220.38576	98.65846	7749.54297
0.469182	236.13020	11.18181	240.53128	20.41203	118.62616	215.54642	99.50562	7747.44141
0.471222	236.73087	11.22639	247.76637	20.66148	118.94504	216.88602	100.52036	7753.16406
0.473262	237.63416	11.20786	238.17450	20.44923	117.61160	225.10352	100.63315	7756.20703
0.475302	235.82806	11.19839	247.11407	19.89612	115.61508	214.86821	98.83981	7753.33594
0.477342	237.21710	11.18781	240.48576	19.69092	115.86429	218.24066	98.21719	7756.79688
0.479381	234.53764	11.20951	228.38693	21.00812	117.30386	219.78310	99.61266	7758.57422
0.481421	235.60497	11.23642	258.95776	19.66895	118.81021	215.96602	100.07141	7757.13672
0.483461	236.37320	11.18937	234.38689	20.17975	117.93456	222.75404	100.40775	7762.80859
0.485501	237.51689	11.15931	236.74092	19.78088	116.90665	216.46431	99.28923	7761.44531
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0.489581	237.10422	11.23517	236.18883	20.23343	116.76299	219.67369	99.47244	7764.75000
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0.493661	235.34032	11.19808	241.19455	19.57368	117.76213	215.38013	99.11281	7764.07422
0.495701	236.50999	11.13246	234.44528	20.46194	117.49263	221.37129	99.77521	7767.04297
0.497741	237.75691	11.18686	247.04535	20.87987	117.68147	216.76508	99.92418	7762.54688
0.499781	236.12149	11.24685	245.71046	19.94638	116.76816	219.20485	99.67029	7767.04297
0.501820	236.31517	11.24253	235.38107	20.27829	116.31482	220.64453	99.34766	7765.85156
0.503860	233.77821	11.19384	240.89270	19.95665	116.16614	214.63684	98.54352	7763.82031
0.505900	235.67000	11.13608	244.75032	20.88902	117.62674	220.42618	99.36295	7767.89063
0.507940	236.57288	11.17430	240.95567	19.69449	118.46423	219.95104	100.32290	7769.16406
0.509980	237.52176	11.23644	244.40646	20.38531	118.16849	218.00931	100.19151	7765.34766
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0.558938   237.18549   11.22084   237.47481   20.80316   117.81004   220.91721   100.32210   7739.55469
0.560978   235.22168   11.20691   242.08406   19.92915   115.64153   217.55525    99.31081   7733.78125
0.563018   235.30942   11.15621   244.62546   20.55328   115.35707   217.90308    98.50838   7729.69922
0.565058   234.57353   11.16859   235.00029   19.80104   116.63643   217.97754    98.73555   7730.69141
0.567098   235.08125   11.17925   243.94763   20.61392   118.70226   219.28160    99.89819   7725.61328
0.569137   235.21193   11.20038   243.43037   20.02380   118.27388   216.58755   100.14595   7724.11719
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0.579337   234.44661   11.17496   243.36449   19.86069   118.10634   216.95061    99.68846   7707.88672
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0.583417   237.52939   11.12604   236.14720   19.89120   116.77393   219.10442    99.41035   7704.51172
0.585457   235.45427   11.19623   245.48166   20.82251   116.23479   217.23024    99.26343   7697.27344
0.587497   235.07138   11.23121   242.13844   19.80937   116.51958   217.82799    99.15784   7696.86328
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0.591576   234.45932   11.12068   241.47215   20.08083   117.29271   215.95610    99.03854   7687.78516
0.593616   235.30566   11.13056   242.42947   20.28020   117.58440   219.51108    99.60840   7688.02734
0.595656   237.46194   11.16997   238.56322   20.37044   117.67996   218.49062    99.90984   7682.56250
0.597696   235.08188   11.23666   244.51258   20.09752   116.26019   217.62341    99.43280   7677.67969
0.599736   234.65131   11.18592   239.68599   20.35094   115.57996   217.44540    98.74675   7674.92188
```

```
  0.601776   233.94162    11.13532   237.53636    20.00294   115.90953   219.12698    98.65652  7671.59766
  0.603816   235.05957    11.12628   246.44232    20.56027   117.94695   216.78947    99.34311  7666.42180
  0.605856   235.09004    11.17568   239.15924    19.79517   118.39977   218.80217    99.96498  7666.66016
  0.607896   236.77808    11.19233   238.94653    20.62619   117.41655   219.50429   100.08771  7661.33594
  0.609936   235.03061    11.18837   243.68048    20.00739   115.26129   215.52226    98.76115  7655.05469

HC900I EXECUTION TERMINATING DUE TO ERROR COUNT FOR ERROR NUMBER  217

HC217I FIOCS - END OF DATA SET ON UNIT   5

RACEBACK  ROUTINE  CALLED FROM ISN   REG. 14   REG. 15   REG.  0   REG.  1

          FRDNL#                     000364A4  00049358  0000A414  00035BE8

            MAIN                     0000DD1A  01035B68  FD000008  00074FF8

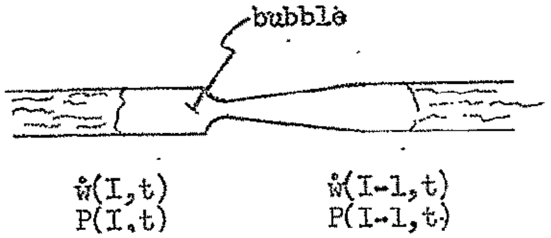
NTRY POINT=  01035B68
```

APPENDIX C

APOLLO DESCENT ENGINE LM-3 FLIGHT ANOMALY

The LM-3 anomaly simulation considers the passage of a gas bubble through both the fuel and oxidizer feed systems of the Apollo Descent Engine. It is assumed that the bubble has no effect on the system until it starts to pass through the cavitating venturi. This model will use the same segmentation and physical characteristics as the start transient demonstration - Appendix B. The equations and procedures used to calculate the performance of the system are presented as well as the calculations of parameters needed for the input data shown in Table C-I. Table C-II contains a listing of the modified program subroutines. The program pictorial output is shown in Figs. C-1A through C-1F and a listing of the output data is presented in Table C-III.

I. Gas Flow Through the Cavitating Venturi



The upstream fluid flow and pressure are:

$$P(I,t) = C4(I) - C3(I) \cdot \mathring{w}(I,t) - R(I) \cdot \mathring{w}(I,t) \cdot \lvert w(I,t)\rvert \tag{C-1}$$

Downstream

$$P(I-1,t) = C3(I-2) \cdot \mathring{w}(I-1,t) - C2(I-1) \tag{C-2}$$

The gas flow through the cavitating venturi will be calculated using the compressible flow equation .

$$\mathring{w}_g = f(P(I,t),\ P(I-1,t),\ A_t,\ \ldots) \tag{C-3}$$

The upstream gas pressure can be found from the perfect gas law.

$$P(I,t) = \frac{M_{gu}(t)\ RT}{V_{gu}(t)} \quad \text{when:} \quad \begin{aligned} M_{gu}(t) &= M_{gu}(t-1) - \mathring{w}_g \Delta t \\ V_{gu}(t) &= V_{gu}(t-1) - \mathring{w}(I,t)\,\frac{\Delta t}{\rho_\ell} \end{aligned} \tag{C-4}$$

The downstream gas pressure is found in a similar fashion

$$P(I-1,t) = \frac{M_{gd}(t) RT}{V_{gd}(t)} \quad \text{when:} \quad \begin{aligned} M_{gd}(t) &= M_{gd}(t-1) + \mathring{w}_g \Delta t \\ V_{gd}(t) &= V_{gd}(t-1) - w(I,t)\frac{\Delta t}{\rho_\ell} \end{aligned} \tag{C-5}$$

These equations will be programmed as follows:

1. Estimate P_{Gu} and P_{Gd}
2. Calculate $\mathring{w}_g$ - Eq. (C-3)
3. Calculate $\mathring{w}\ (I-1,t)$ - Eq. (C-2)

4. Calculate $M_{gd}(t), V_{gd}(t)$ - Eq. (C-5)

5. Calculate $P(I-1,t)$ - Eq. (C-5)

6. Reiterate if necessary

7. Calculate $\dot{w}(I,t)$ - Eq. (C-1)

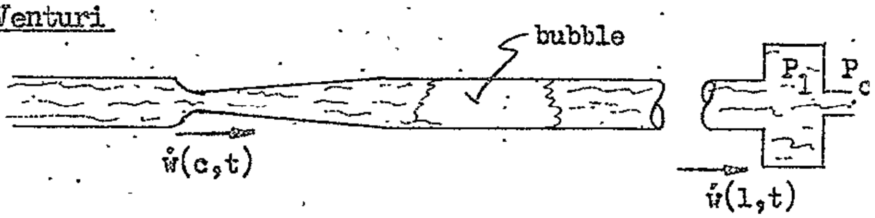
8. Calculate $M_{gu}(t), V_{gu}(t)$ - Eq. (C-4)

9. Calculate $P(I,t)$ - Eq. (C-4)

10. Reiterate if necessary

II. Gas Bubble Downstream of Venturi

We have the following relations:



Upstream flow determined by cavitating venturi flow, downstream pressure will be bubble pressure.

The injector flow will be calculated by

$$P(1,t) - P_c(t) = R_i\dot{w}(1,t) \cdot |\dot{w}(1,t)| + \frac{\ell i}{A_i g} \cdot \frac{\dot{w}(1,t) - \dot{w}(1,t-1)}{\Delta t} \qquad \text{(C-6}$$

and the flow in the line is:

$$P(B,t) - P(1,t) = R_\ell\dot{w}(1,t) \cdot |\dot{w}(1,t)| + \frac{L}{Ag} \cdot \frac{\dot{w}(1,t) - \dot{w}(1,t-1)}{\Delta t} \qquad \text{(C-7}$$

Solving these equations to eliminate $P(1,t)$ we have:

$$P(B,t) - P_c(t) - R_\ell\dot{w}(1,t) \cdot \dot{w}(1,t) - \frac{L}{Ag\Delta t}\ \dot{w}(1,t)$$

$$+ \frac{L}{Ag\Delta t}\dot{w}(1,t-1) - R_i\ \dot{w}(1,t) \cdot |\dot{w}(1,t)| - \frac{\ell i}{Ag\Delta t}\dot{w}(1,t) + \frac{\ell i}{Ag\Delta t}\dot{w}(1,t-1) = 0$$

(C-8

or

$$(R_\ell + R_i)\mathring{w}(1,t)\,|w(1,t)| + \left(\frac{\ell i}{Ag\Delta I} + \frac{L}{Ag\Delta I}\right)\mathring{w}(1,t)$$

$$-\left[P(B,t) - P_c(t) + \left(\frac{\ell i}{Ag\Delta t} + \frac{L}{Ag\Delta t}\right)\mathring{w}(1,t-1)\right] = 0$$

$$+ \frac{\ell i}{\Delta t A_i g}\,(P(1,t-1) - P(B,t)) - 1 - \left[\frac{\ell i}{\Delta t\, A_i g}\right]\left(\frac{L}{Ag\Delta t}\right)(P(B,t) - P(B,t-1)) \qquad \text{(C-9)}$$

The pressure in the bubble is:

$$P(B,t) - \frac{M_R RT}{V_B}, \quad V_B = V_T - \frac{(M_c + \Delta t\mathring{w}(c,t))}{\rho} - \frac{(M_1 \Delta t\ \mathring{w}(1,t))}{\rho} \qquad \text{(C-10)}$$

The flows and pressures will be calculated as follows:

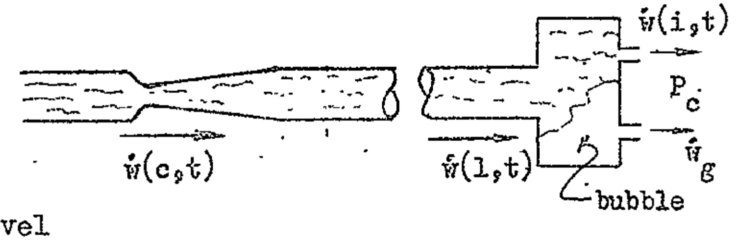
1. Estimate P_B
2. Calculate $\mathring{w}(c,t)$ - Subroutine Cavent
3. Calculate $\mathring{w}(1,t)$ - Eq. (C-9)
4. Calculate V_B, $P(B,t)$ - Eq. (C-10)
5. Reiterate if necessary
6. Calculate $P(I,t)$ - Eq. (C-7)

The length of the fluid column L will be calculated from $M_1(t-1)$ as follows:

$$L = \left(\frac{M_1(t-1)}{\rho} - V_i\right) \cdot \frac{1}{A} \qquad \text{(C-11)}$$

The minimum value of L will be set to 1 inch to prevent computational difficulties.

III. Gas Bubble Passing Through Injector



It will be assumed that the bubble starts to flow into the combustion chamber when $M_l(t)/\rho$ falls below some level (set by data). The gas will flow through a fixed proportion of the injector area. Thus:

$$A_i = A_g + A_\ell \qquad \text{(C-12)}$$

$$\dot{w}_g = f\,(P_B, P_c, A_g) \qquad \text{(C-13)}$$

$$\dot{w}(i,t) = 27{,}807\ A_\ell \sqrt{(P_B - P_c)} \qquad \text{(C-14)}$$

$$\dot{w}(c,t) = f\ (\text{cavitating venturi}) \qquad \text{(C-15)}$$

$$P_B = \frac{M_g(t)\ RT}{V_g(t)}, \qquad M_g(t) = M_g(t-1) - \dot{w}_g \Delta t \qquad \text{(C-16)}$$

$$V_g(t) = V_T - \frac{M_c + \Delta\ \dot{w}(c,t)}{\rho} + \frac{\Delta\ \dot{w}(i,t)}{\rho}$$

The calculation will proceed as follows:

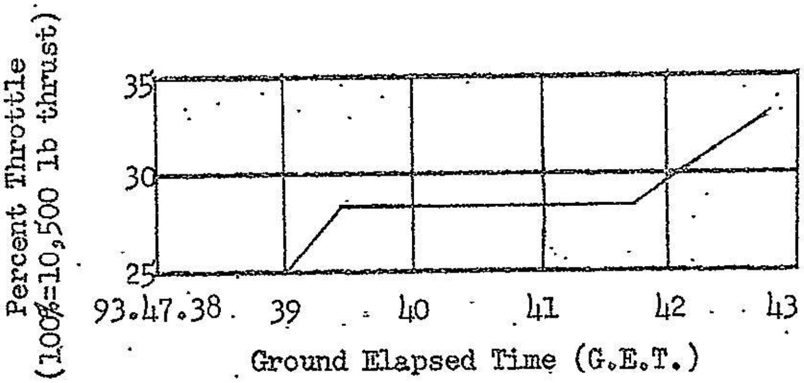
1. Estimate P_B
2. Calculate $\dot{w}_g$, $\dot{w}(i,t)$ - Eq. (C-13), (C-10)
3. Calculate $\dot{w}(c,t)$ - Eq. (C-15)
4. Calculate P_B - Eq. (C-16)
5. Reiterate if necessary

IV. Distribution of Resistance

The resistance of the line between the cavitating venturi and the injector will be initially lumped at the injector end. All pressures and flows will be set equal. As the line downstream of the venturi starts to fill with liquid the lumped resistance will be reduced and resistance added to the upstream element.

Data Package

The anomaly started at a G.E.T. of 40:47:39.25, and is noted by a rise in oxidizer injector pressure. The period to be simulated in the model will be from 39.25 sec through 42.80 sec, the throttling transient during this period. The throttle position is related to command voltage by the relation



VDC = 0.116X + 1.12 where: X = Percent Throttle

VDC = Volts

Using TRW data, the area time relations can be obtained for the injector:

G.E.T.	Model Time (sec)	Throttle (%)	V.D.C.	Fuel Res.	Area	Oxidizer Res.	Area
39.25	0	26.6	4.205	0.03384	0.195489	0.14904	0.092893
39.50	.250	28.3	4.403	0.03131	0.203234	0.13341	0.098459
41.80	2.550	28.3	4.403	0.03131	0.203234	0.13341	0.098459
42.80	3.550	33.0	4.948	0.02579	0.223938	0.10213	0.112530

Units -

Res - $lb_F\ sec^2/lb_m\ in^5$

Area - sq. in.

The throat area of the cavitating venturi will be determined from the equation:

$$P_1 - P_2 = \frac{\dot{w}^2}{2g\rho}\left(\frac{1}{A_2^{\,2}} - \frac{1}{A_1^{\,2}}\right)$$

$A_1 = 2.92 \ \text{in}^2$

$g = 386 \ \frac{LB_m \ in}{LB_F \ sec^2}$

$\dot{w}$ = Flowrate PPS

ρ = Density lb_m/in^3

P_1 = Upstream pres. 235 psia

P_2 = Vapor Pressure - psia

A_2 = Throat Area - in^2

Solving for A_2 we obtain:

$$A_2 = \left[\frac{\dot{w}^2 A_1^{\,2}}{2g\rho A_1^{\,2}(P_1 - P_2) + \dot{w}^2}\right]^{1/2}$$

The flowrates at various throttle settings will be determined as follows:

$$\dot{w}_I = \frac{10,500}{300}\,\frac{X}{100} = .35X$$

$$\dot{w}_o + \dot{w}_f = \dot{w}_t, \text{ and } \frac{\dot{w}_o}{\dot{w}_f} = 1.6$$

Model Time	X	$\dot{w}_t$	$\dot{w}_o$	$\dot{w}_f$	A_f	A_o
0	26.6	9.30	5.73	3.57	0.046646	0.059659
0.250	28.3	9.90	6.09	3.81	0.049781	0.063405
2.550	28.3	9.90	6.09	3.81	0.049781	0.063405
3.550	33.0	11.55	7.11	4.44	0.058009	0.074018

	Fuel	Oxidizer
ρ	0.0325	0.052
P_r	1.60	5.30

The size of the bubble is given in cubic inches and the model uses weight. The perfect gas law will be used to relate the two.

$$W_t = \frac{PV}{RT} = \frac{235\ V}{\frac{1544}{4} \times 525}$$

$$= 9.6552 \times 10^{-5}\ V$$

Input Data

Time bubble starts through venturi

E (161)	0.410	Fuel
E (162)	0.001	Oxidizer

Initial bubble weight = $9.6552 \times 10^{-5} \times 30$

E (163)	0.00290	Fuel
E (164)	0.00290	Oxidizer

Ratio of liquid flow area to total injector flow area when bubble goes through injector

E (165)	0.1	Fuel
E (166)	0.1	Oxidizer

TABLE C-I

APOLLO DESCENT ENGINE COMPUTER MODEL

INPUT DATA - LM-3 FLIGHT ANOMALY

```
2   121 22  10.2        10.2        0.0         10.2        13.0        0000100,
15.0        12.2        0.0         11.0        13.0        15.0        0000200,
17.0        19.0        21.0        23.0        20.0        17.0        0000300,
11.0        15.0        19.0        17.0        10.2                    0000400,
2   181 22  7.0         7.4         0.0         7.0         9.0         0000500,
11.0        15.0        0.0         11.0        13.0        15.0        0000600,
17.0        19.0        -21.0       23.0        20.0        17.0        0000700,
11.0        15.0        19.0        17.0        10.0                    0000800,
2   361 22  0.000112    0.016038    0.0         0.000112    0.000143    0000900,
 0.000165   0.000134    0.0         0.000121    0.000143    0.000165    0001000,
 0.000187   0.000209    0.000231    0.000253    0.000220    0.000187    0001100,
 0.000115   0.000157    0.000199    0.000178    0.000107                0001200,
2   421 22  0.000039    0.000042    0.0         0.000039    0.000051    0001300,
 0.000062   0.000084    0.0         0.000062    0.000073    0.000084    0001400,
 0.000096   0.000107    0.000124    0.000129    0.000112    0.000096    0001500,
 0.000115   0.000156    0.000197    0.000176    0.000104                0001600,
5     1 26            21  150.0     0.02779     0.008453    0.0         0004100,
-0.005      0.0         0.02        0.04        0.06        0.10        0004200,
0.20        0.25        0.30        0.35        0.45        0.50        0004300,
0.55        0.60        0.65        0.70        0.80        0.90        0004400,
0.98        1.0         1.005                                           0004500,
5    36 21 -0.2   E+06  0.293 E+06  2.82  E+06  3.04  E+06  3.07  E+060004600,
3.13  E+06  3.24  E+06  3.28  E+06  3.42  E+06  3.87  E+06  4.60  E+060004700,
4.88  E+06  5.03  E+06  5.02  E+06  4.86  E+06  4.55  E+06  3.63  E+060004800,
2.27  E+06  0.37  E+06  0.133 E+06  0.01  E+06                          0004900,
5    66 21  15.0        41.5        115.0       131.5       132.9       0005000,
134.7       138.0       139.8       142.6       148.8       165.0       0005100,
171.3       175.8       178.1       176.8       171.1       152.0       0005200,
116.6       58.7        29.4        21.0                                0005300,
5    96 21  0.816       0.818       0.826       0.833       0.841       0005400,
0.856       0.889       0.903       0.920       0.933       0.959       0005500,
0.967       0.974       0.978       0.973       0.964       0.922       0005600,
0.859       0.801       0.787       0.781                               0005700,
3    201  5 323.0       235.0       0.0         235.0       10.0        0006800,
3    211  3   3.0         0.44      10.0                                0006820,
3    221  9 108.0         0.046646  0.0           0.049781  0.250       0006840,
  0.049781    2.550       0.058009  3.550                               0006860;
3    231  9 201.0         0.195489  0.0           0.203234  0.250       0006880,
  0.203234    2.550       0.223938  3.550                               0006900,
3    301  5 323.0       236.0       0.0         236.0       10.0        0007000,
3    311  3   3.0         1.0       10.0                                0007020,
3    321  9 108.0         0.059659  0.0           0.063405  0.250       0007040,
```

```
 0.063405    2.550        0.074018   3.550                                         0007060,
 3   331  9 201.0         0.092893   0.0         0.098459     0.250               0007080,
 0.098459    2.550        0.112530   3.550                                         0007100,
 3   401  5   1.0        45.0        0.375       0.62065      1.0                 0007200,
 3   433  5   1.0        30.0        0.25        0.31727      0.5                 0007300,
-3   526  4  54.4      2557.0        0.0         1.7                              0007400,
$D1 IPR=3, IST=1, ICMT=3, NSEGF=22, NSEGO=22, DELT=170.0E-06,              ID=1000000,
AF=2*2.92,0,4*2.92,0,9*2.92,5*3.22,38*0,                                   ID=1000100,
CF=2*1.67E-06,0,4*1.67E-06,0,9*1.67E-06,5*1.24E-06,38*0,                   ID=1000200,
AO=2*2.92,0,4*2.92,0,9*2.92,5*4.42,38*0,                                   ID=1000300,
CO=2*1.67E-06,0,4*1.67E-06,0,9*1.67E-06,5*1.57E-06,38*0,                   ID=1000400,
IORF=2,5,6,7,10,11,12,13,14,15,16,17,18,19,20,21,22,43*0,                  ID=1000500,
IORO=2,5,6,7,10,11,12,13,14,15,16,17,18,19,20,21,22,43*0,                  ID=1000600,
PF=8*45,15*235,37*0,   WF=23*3.57,37*0,                                    ID=1000700,
PO=8*105,15*236,37*0,  WO=23*5.73,37*0,                                    ID=1000800,
IVARIS=5,171,5,172,2,522,2,525,12*0,                                       ID=1001200,
IWT=1,201,101,301,401,402,403,404,                                         ID=1001300,
IPI=1,8,9,3*0,101,108,109,3*0,201,209,4*0,301,309,4*0,207,307,4*0,         ID=1001400,
B(3)=0.0325, B(4)=0.052, B(5)=530, B(6)=530,                               ID=1001800,
B(7)=60000, B(8)=40500,                                                    ID=1001900,
B(9)=0.0083446, B(10)=-4.1095, B(11)=0.0089489, B(12)=-3.62944,            ID=1002000,
B(13)=41.797, B(14)=92.016, B(15)=4, B(16)=4,                              ID=1002100,
B(17)=1.67, B(18)=1.67, B(19)=1.05, B(20)=1.1, B(21)=10, B(22)=10,         ID=1002200,
B(23)=8.8889E-06, B(24)=2.0526E-05,                                        ID=1002300,
B(31)=0.691, B(32)=0.368, B(33)=0.75, B(34)=0.75,                          ID=1002400,
E(161)=0.41, E(162)=0.001, E(163)=0.00290, E(164)=0.00290,                 ID=1003000,
E(165)=0.1, E(166)=0.1,                                                    ID=1003100,
CAVTAT(1,1,1)=8, CAVTAT(2,1,1)=2.92, CAVTAT(4,1,1)=0.1,                    ID=1003200,
CAVTAT(1,1,2)=8, CAVTAT(2,1,2)=2.92, CAVTAT(4,1,2)=0.1,                    ID=1003300,
AF(1)=2.5, AF(2)=2.5, AF(4)=2.5, AF(5)=2.5, AF(6)=2.5, AF(7)=2.5,          ID=1006000,
CRT1=0.0,                                                                  ID=1008000,
INDEX=56,                                                                  ID=1009000,
$END                                                                          1100000,
APOLLO DESCENT ENGINE                                                         1200000,
                      DATA CORRELATION                                        1200100,
LM-3 FLIGHT ANOMALY                                                           1200200,
*                                                                             2000000,
```

TABLE C-II

APOLLO DESCENT ENGINE MODIFIED COMPUTER SUBPROGRAM LISTINGS, LM-3 FLIGHT ANOMALY

```
@FOR  ROCKET,ROCKET
UNIVAC 1108 FORTRAN V LEVEL   2206 0018 FS010H
THIS COMPILATION WAS DONE ON 11 FEB 71 AT 15:15:47

   SUBROUTINE ROCKET     ENTRY POINT 002601

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    002740
         0000    *DATA    000254
         0002    *BLANK   000000
         0003    DATUM1   043120
         0004    DATUM2   000740
         0005    DATUM3   001344
         0006    DATUM4   000144
         0007    CAL2     000740
         0010    CAL3     000062
         0011    CAL4     001441
         0012    CAL5     000310
         0013    CAL6     000360
         0014    DIRECT   001214


   EXTERNAL REFERENCES (BLOCK, NAME)

         0015    COMBUS
         0016    GETFLO
         0017    SOLVE
         0020    CAVENT
         0021    GASFLO
         0022    VENTR2
         0023    NERR2$
         0024    NWDU$
         0025    NIO1$
         0026    NIO2$
         0027    SQRT
         0030    NERR3$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000131 100L        0001     002536 1000L       0001     000160 120L        0001     000106 137G        0001     000272 140L
    0000     000137 150F        0001     000323 160L        0001     000341 180L        0001     000044 20L         0001     000370 200L
    0001     000410 220L        0001     000437 240L        0001     000455 260L        0001     000574 280L        0001     000600 300L
    0001     001041 311G        0001     000700 320L        0001     000765 340L        0001     001016 360L        0001     000066 40L
    0001     001070 440L        0001     001767 444G        0001     001173 460L        0001     001314 500L        0001     002154 506G
    0001     001356 520L        0001     001367 540L        0001     001417 560L        0001     001610 620L        0001     001642 640L
    0001     001657 660L        0001     002002 700L        0001     002064 720L        0001     002113 740L        0001     002143 760L
    0001     002157 800L        0001     002174 900L        0001     002305 920L        0001     002316 940L        0001     002410 960L
    0001     002413 980L        0004 R 000000 A            0000 R 000113 AGAS         0012 R 000244 AGRAT        0000 R 000112 ALIQ
    0013 R 000000 AVFL          0000 D 000004 A1           0000 D 000006 B1           0005 R 000720 CAVTAT       0005 R 001010 CCDATA
    0012 R 000006 CDUM1         0012 R 000272 CDUM2        0000 D 000010 C1           0007 R 000000 C2CON        0007 R 000170 C3CON
    0007 R 000360 C4CON         0007 R 000550 D            0012 R 000256 DENSTY       0000 R 000102 DLTWTB       0000 R 000127 DT
    0004 R 000360 DUM1          0005 R 000000 DUM2         0005 R 000760 DUM3         0005 R 001004 DUM4         0006 R 000000 DUM5
    0006 R 000006 DUM6          0006 R 000022 DUM7         0005 R 000620 ENGMAN       0000 R 000110 FLINER       0021 R 000000 GASFLO
    0012 R 000004 GCONPG        0016 R 000000 GETFLO       0000 I 000104 I            0014 I 000000 IDUM1        0014 I 000612 IDUM2
    0000 I 000065 IGO           0000 I 000063 II           0000 I 000074 IJD          0000 I 000067 IJK          0000 I 000072 IJU
    0000 I 000060 ISAVE         0000 I 000002 ISTEP        0000 I 000002 IS           0000 I 000064 J            0000 I 000117 K
    0011 I 000000 KCC           0000 I 000131 KL           0014 I 000502 LFILL        0000 I 000070 N            0014 I 000500 NSPD
    0003 R 000000 P             0000 R 000073 PD           0000 R 000111 PDUM         0000 R 000066 PG           0012 R 000002 PHICON
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0012 R 000000 PLVAP      0000 D 000012 PS         0000 D 000016 PT         0006 R 000020 PTGAM      0000 R 000071 PI
0004 R 000550 R          0012 R 000264 RDN        0000 R 000115 RDUM       0000 R 000106 RINJ       0000 R 000105 RTOT
0012 R 000262 RUP        0010 R 000000 T          0012 R 000240 TBUBLE     0000 R 000112 TDUM       0000 R 000125 THI
0006 R 000004 TLIQ       0000 R 000123 TLO        0000 R 000133 TMAX       0000 R 000134 TMIN       0000 R 000121 TI
0000 R 000122 T2         0003 R 027140 V          0013 R 000170 VBAR       0000 R 000114 VDUM       0000 R 000116 VLIQ
0000 R 000103 VOLBUB     0000 R 000100 VOLDN      0012 R 000260 VOLTOT     0000 R 000101 VOLUP      0012 R 000246 VOL1BL
0012 R 000250 VOL2BL     0000 R 000120 VSFG       0003 R 013560 W          0000 R 000075 WDOT       0012 R 000254 WDOTGV
0000 R 000126 WHI        0000 R 000124 WLO        0000 R 000136 WMAX       0000 R 000135 WMIN       0011 R 000001 WSTORE
0012 R 000242 WTBUBL     0000 R 000077 WTGDN      0000 R 000076 WTGUP      0012 R 000270 WTPCAV     0012 R 000266 WTPINJ
0012 R 000252 WT1BUB     0004 R 000170 X          0000 R 000107 XDUM       0000 R 000110 XN


00090  *DIAGNOSTIC*  THE NAME IMAN APPEARS IN A DIMENSION OR TYPE STATEMENT BUT IS NEVER REFERENCED
00100       1*    C      J. ROEHNLEIN * D596-112 * EX 2721                                           03600000
00101       2*           SUBROUTINE ROCKET (KA, KAM1, KAM2, DELT)                                    03600100
00101       3*    C                                                                                  03600200
00103       4*           COMMON /DATUM1/   P(60,50,2)    ,  W(60,50,2)    ,  V(60,50,2)              03600300
00103       5*          1        /DATUM2/  A(60,2)       ,  X(60,2)       ,  DUM1(120)      ,        03600400
00103       6*          2                  R(60,2)                                                   03600500
00103       7*          3        /DATUM3/  DUM2(400)     ,  ENGMAN(6,4,2), CAVTAT(4,4,2),            03600600
00103       8*          4                  DUM3(24)      ,  CCDATA(11,4)  ,  DUM4(176)               03600700
00103       9*          5        /DATUM4/  DUM5(4)       ,  TLIQ(2)       ,  DUM6(10)       ,        03600800
00103      10*          6                  PTGAM(2)      ,  DUM7(82)                                 03600900
00103      11*    C                                                                                  03601000
00104      12*           COMMON /CAL2/     C2CON(60,2)   ,  C3CON(60,2)   ,  C4CON(60,2)    ,        03601100
00104      13*          1                  D(60,2)                                                   03601200
00104      14*          2        /CAL3/    T(50)                                                     03601300
00104      15*          3        /CAL4/    KCC           ,  WSTORE(100,4,2)                          03601400
00104      16*          4        /CAL5/    PLVAP(2)      ,  PHICON(2)     ,  GCONPG(2)      ,        03601500
00104      17*          5  CDUM1(154)   ,  TBUBLE(2)     ,  WTBUBL(2)     ,  AGRAT(2)       ,        03601600
00104      18*          6  VOL1BL(2)    ,  VOL2BL(2)     ,  WT1BUB(2)     ,  WDOTGV(2)      ,        03601700
00104      19*          7  DENSTY(2)    ,  VOLTOT(2)     ,  RUP(2)        ,  RDN(2)         ,        03601800
00104      20*          8  WTPINJ(2)    ,  WTPCAV(2)     ,  CDUM2(14)                                03601900
00104      21*          9        /CAL6/    AVEL(60,2)    ,  VBAR(60,2)                               03602000
00104      22*    C                                                                                  03602100
00105      23*           COMMON /DIRECT/   IDUM1(120)    ,  NSEG(2)       ,  LFILL(60,2)    ,        03602200
00105      24*          1                  IDUM2(210)                                                03602300
00105      25*    C                                                                                  03602400
00106      26*           DIMENSION         IMAN(2)       ,  ISAVE(2)      ,  ISTEP(2)                03602500
00106      27*    C                                                                                  03602600
00107      28*           DOUBLE PRECISION  A1            ,  B1            ,  C1             ,        03602700
00107      29*          1                  PS(10)        ,  PT(10)                                   03602800
00107      30*    C                                                                                  03602900
00110      31*           DATA   ISTEP, ISAVE / 1, 1, 7, 7 /                                          03603000
00113      32*           DATA   II / 1 /                                                             03603100
00113      33*    C                                                                                  03603200
00115      34*           KCC           = KCC + 1                                                     03603300
00116      35*           IF (KCC .GT. 100)                KCC  =  1                                  03603400
00116      36*    C                                                                                  03603500
00116      37*    C      CALCULATE COMBUSTION CHAMBER PRESSURE.                                      03603600
00116      38*    C                                                                                  03603700
00120      39*           CCDATA(4,1)       = WSTORE(KCC,1,1) / DELT                                  03603800
00121      40*           WSTORE(KCC,1,1) = 0.0                                                       03603900
00122      41*           CCDATA(3,1)       = WSTORE(KCC,1,2) / DELT                                  03604000
00123      42*           WSTORE(KCC,1,2) = 0.0                                                       03604100
00124      43*           IF (CCDATA(4,1) .GT. 1.0E-10)                                  GO TO 20     03604200
00126      44*           CCDATA(5,1)       = 1.0                                                     03604300
00127      45*                                                                          GO TO 40     03604400
00130      46*        20 CCDATA(5,1)       = CCDATA(3,1) / CCDATA(4,1)                               03604500
00130      47*          1                  / (1.0 + CCDATA(3,1) / CCDATA(4,1))                       03604600
00131      48*           IF (CCDATA(5,1) .LT. 0.0)        CCDATA(5,1)  =  0.0                        03604700
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00133    49*          IF (CCDATA(5,1) .GT. 1.0)        CCDATA(5,1)  =  1.0              03604800
00135    50*       40 CALL COMBUS (KA, KAM1, 1, DELT)                                   03604900
00135    51*    C                                                                       03605000
00135    52*    C     CALCULATE FLOW AND PRESSURES.                                     03605100
00135    53*    C                                                                       03605200
00136    54*          DO 1000                    J = 1, 2                               03605300
00141    55*          ENGMAN(7,1,J) = ENGMAN(8,1,J)                                     03605400
00142    56*          IGO         = ISTEP(J)                                            03605500
00143    57*          GO TO (100, 200, 220, 380, 440, 540, 760, 800), IGO               03605600
00143    58*    C                                                                       03605700
00143    59*    C     CALCULATE FLOW FOR NORMAL OPERATION.                              03605800
00143    60*    C                                                                       03605900
00144    61*      100 PG          = 2.0 * P(1,KAM1,J) - P(1,KAM2,J)                     03606000
00145    62*          IJK         = 0                                                   03606100
00146    63*          A1          = R(1,J) / D(1,J)                                     03606200
00147    64*          B1          = C3CON(1,J)                                          03606300
00150    65*      120 C1          = C4CON(1,J) - PG                                     03606400
00151    66*          W(1,KA,J) = GETFLO (A1, B1, C1)                                   03606500
00152    67*          ENGMAN(8,1,J) = W(1,KA,J) - 386.0 * ENGMAN(2,1,J) * (PG           03606600
00152    68*         1                  - P(1,KAM1,J)) / (DELT * AVEL(1,J) ** 2)        03606700
00153    69*          P(1,KA,J) = CCDATA(2,1) + ENGMAN(8,1,J) * ABS(ENGMAN(8,1,J))      03606800
00153    70*         1            / (D(1,J) * (27.807 * ENGMAN(4,1,J)) ** 2)            03606900
00153    71*         2            + ENGMAN(3,1,J) * (ENGMAN(8,1,J) - ENGMAN(7,1,J))     03607000
00153    72*         3            / (386.0 * ENGMAN(4,1,J) * DELT)                      03607100
00154    73*      135 IF (IJK .GT. 30)                                   GO TO 140      03607200
00156    74*          CALL SOLVE (PG, P(1,KA,J), PS, IJK, 0.0001, 0.0005)               03607300
00157    75*          IF (IJK - 100)                       120, 120, 160                03607400
00162    76*      140 N           = 140.                                                03607500
00163    77*          WRITE (6,150) N, T(KA), J, PG, P(1,KA,J)                          03607600
00172    78*      150 FORMAT (1H0 10X'ITERATION ERROR IN ROCKET * * STATEMENT NO.' I5,  03607700
00172    79*         1        2X'TIME =' F8.6, 2X'J =' I2 / 11X'PG =' G13.6,            03607800
00172    80*         2        5X'PANS =' G13.6  )                                       03607900
00173    81*      160 GO TO (180, 180, 900, 900, 900, 900, 900, 180), IGO               03608000
00174    82*      180 CALL CAVENT (KA, KAM1, KAM2, DELT, J)                             03608100
00175    83*          IF (IGO .GT. 1)                                    GO TO 900      03608200
00177    84*          IF (T(KA) .GT. TBUBLE(J))        ISTEP(J)  =  2                   03608300
00201    85*                                                             GO TO 900      03608400
00201    86*    C                                                                       03608500
00201    87*    C     *   INITIALIZE PARAMETERS FOR GAS IN CAVITATING VENTURI.          03608600
00201    88*    C                                                                       03608700
00202    89*      200 VOL1BL(J) = WTBUBL(J) * GCONPG(J) * TLIQ(J) / P(9,KAM1,J)         03608800
00203    90*          VOL2BL(J) = 0.0                                                   03608900
00204    91*          WT1BUB(J) = WTBUBL(J)                                             03609000
00205    92*          WDOTGV(J) = 0.0                                                   03609100
00206    93*          ISTEP(J)  = 3                                                     03609200
00206    94*    C                                                                       03609300
00206    95*    C     *    CALCULATE GAS FLOW THROUGH CAVITATING VENTURI.               03609400
00206    96*    C                                                                       03609500
00207    97*      220 PU          = 2.0 * P(9,KAM1,J) - P(9,KAM2,J)                     03609600
00210    98*          IJU         = 0                                                   03609700
00211    99*          A1          = R(9,J) / D(9,J)                                     03609800
00212   100*          B1          = C3CON(9,J)                                          03609900
00213   101*      240 PD          = 2.0 * P(8,KAM1,J) - P(8,KAM2,J)                     03610000
00214   102*          IJD         = 0                                                   03610100
00215   103*      260 WDOT        = GASFLO (CAVTAT(3,1,J), PU, PD, GCONPG(J), TLIQ(J),  03610200
00215   104*         1              PTOAM(J))                                           03610300
00216   105*          WTGUP       = WT1BUB(J) - 0.5 * (WDOT + WDOTGV(J)) * DELT         03610400
00217   106*          IF (WTGUP .LT. 1.0E-10)           WTGUP  =  1.0E-10               03610500
00221   107*          WTGDN       = WTBUBL(J) - WTGUP                                   03610600
00222   108*          W(8,KA,J) = C2CON(7,J) + PD / C3CON(7,J)                          03610700
00223   109*          VOLDN       = VOL2BL(J) + 0.5 * (W(8,KA,J) + W(8,KAM1,J))         03610800
00223   110*         1              * DELT / D(7,J)                                     03610900
00224   111*          P(8,KA,J) = WTGDN * GCONPG(J) * TLIQ(J) / VOLDN                   03611000
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00225    112*          IF (IJD .GT. 30)                                           GO TO 280   03611100
00227    113*          CALL SOLVE (PD, P(8,KA,J), PT, IJD, 0.0001, 0.0005)                    03611200
00230    114*          IF (IJD - 100)                       260, 200, 300                    03611300
00233    115*      200 IJD         = - 1                                                      03611400
00234    116*          N           = 280                                                      03611500
00235    117*      300 C1          = C4CON(9,J) - PU                                          03611500
00236    118*          W(9,KA,J) = GETFLO (A1, B1, C1)                                        03611600
00237    119*          VOLUP       = VOL1BL(J) - 0.5 * (W(9,KA,J) + W(9,KAM1,J))              03611700
00237    120*     1                 * DELT / D(8,J)                                           03611800
00240    121*          IF (VOLUP .LT. 1.0E-10)              VOLUP  =  1.0E-10                 03611900
00242    122*          P(9,KA,J) = WTGUP * GCONPG(J) * TLIO(J) / VOLUP                        03612000
00243    123*          IF (IJU .GT. 30)                                                       03612100
00245    124*          CALL SOLVE (PU, P(9,KA,J), PS, IJU, 0.0001, 0.0005)        GO TO 320   03612200
00246    125*          IF (IJU .LT. 100)                                                      03612300
00250    126*      320 IF (IJD .LT. 0)                                            GO TO 240   03612400
00250    127*     1                                  WRITE (6,150) N, T(KA), J, PG,           03612500
00260    128*          IF (IJU .GT. 100)                    P(8,KA,J)                         03612600
00262    129*          N           = 320                                          GO TO 340   03612700
00263    130*          WRITE (6,150) N, T(KA), J, PG, P(9,KA,J)                               03612800
00272    131*      340 DLTWTB      = WT1BUB(J) - WTGU                                         03612900
00273    132*          WT1BUB(J) = WTGUP                                                      03613000
00274    133*          WDOTOV(J) = WDOT                                                       03613100
00275    134*          VOL1BL(J) = VOLUP                                                      03613200
00276    135*          VOL2BL(J) = VOLDN                                                      03613300
00277    136*          IF (WT1BUB(J) .LT. 2.0 * DLTWTB) ISTEP(J)  =  4                        03613400
00301    137*                                                                                 03613500
00301    138*  C                                                                  GO TO 100   03613600
00301    139*  C     *     INITIALIZE CONDITIONS WHEN THE GAS BUBBLE IS THROUGH VENTURI.          03613700
00301    140*  C                                                                              03613800
00302    141*      380 ISTEP(J)    = 5                                                        03613900
00303    142*          DENSTY(J) = D(1,J)                                                     03614000
00304    143*          VOLBUB      = WTBUBL(J) * GCONPG(J) * TLIO(J) / P(8,KAM1,J)            03614100
00305    144*          VOLTOT(J) = ENGMAN(2,1,J)                                              03614200
00306    145*          RUP(J)      = 0.0                                                      03614300
00307    146*          RDN(J)      = 0.0                                                      03614400
00310    147*          DO 400                         I = 1, 7                                03614500
00313    148*          LFILL(I,J)= - 1                                                        03614600
00314    149*          VOLTOT(J) = VOLTOT(J) + A(I,J) * X(I,J)                                03614700
00315    150*      400 RDN(J)      = RDN(J) + R(I,J) / DENSTY(J)                              03614800
00317    151*          RTOT        = RDN(J)                                                   03614900
00320    152*          WTPINJ(J) = (VOLTOT(J) - VOLBUB) * DENSTY(J)                           03615000
00321    153*          WTPCAV(J) = 0.0                                                        03615100
00322    154*          WT1BUB(J) = WTBUBL(J)                                                  03615200
00323    155*          ISAVE(J)    = 7                                                        03615300
00323    156*  C                                                                              03615400
00323    157*  C     *     PERFORMANCE AFTER BUBBLE HAS GONE THROUGH VENTURI.                     03615500
00323    158*  C                                                                              03615600
00324    159*      440 I           = ISAVE(J)                                                 03615700
00325    160*          RINJ        = 1.0 / (27.007 * ENGMAN(4,1,J)) ** 2 / DENSTY(J)          03615800
00326    161*          XDUM        = (WTPINJ(J) / DENSTY(J) - ENGMAN(2,1,J)) / A(1,J)         03615900
00327    162*          IF (XDUM .LT. 1.0)                   XDUM  =  1.0                      03616000
00331    163*          FLINER      = (XDUM / A(1,J) + ENGMAN(3,1,J) / ENGMAN(4,1,J))          03616100
00331    164*     1                 / (386.0 * DELT)                                          03616200
00332    165*          A1          = RINJ + RDN(J)                                            03616300
00333    166*          B1          = FLINER                                                   03616400
00334    167*          PDUM        = FLINER * W(1,KAM1,J) - CCDATA(2,1)                       03616500
00335    168*          PG          = 2.0 * P(1,KAM1,J) - P(1,KAM2,J)                          03616600
00336    169*          IJK         = 0                                                        03616700
00337    170*      480 CALL VENTR2 (KA, KAM1, KAM2, RUP(J), PG, DELT, J)                      03616800
00340    171*          C1          = PG + PDUM                                                03616900
00341    172*          W(1,KA,J) = GETFLO (A1, B1, C1)                                        03617000
00342    173*      400 VOLBUB      = VOLTOT(J) - (WTPCAV(J) + 0.5 * DELT * (W(8,KA,J)         03617100
00342    174*     1                 + W(8,KAM1,J))) / DENSTY(J) - (WTPINJ(J) - 0.5 * DELT     03617200
                                                                                              03617300
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00342    175*       2                * (W(1,KA,J) + W(1,KAM1,J))) / DENSTY(J)                03617400
00343    176*         P(I,KA,J) = WTBUBL(J) * GCONPG(J) * TLIQ(J) / VOLBUB                   03617500
00344    177*         IF (IJK .GT. 30)                                          GO TO 500    03617600
00346    178*         CALL SOLVE (PG, P(I,KA,J), PS, IJK, 0.0001, 0.0005)                    03617700
00347    179*         IF (IJK - 100)                    460, 460, 660                        03617800
00352    180*     500 N          = 500                                                       03617900
00353    181*         IF (PG .LT. 0.1)                                          GO TO 520    03618000
00355    182*         WRITE (6,150) N, T(KA), J, PG, P(I,KA,J)                               03618100
00364    183*                                                                   GO TO 660    03618200
00365    184*     520 P(I,KA,J) = 0.1                                                        03618300
00366    185*                                                                   GO TO 660    03618400
00366    186*   C                                                                            03618500
00366    187*   C     * CALCULATION WHEN BUBBLE PASSES THROUGH INJECTOR.                     03618600
00366    188*   C                                                                            03618700
00367    189*     540 IJK        = 0                                                         03618800
00370    190*         I          = ISAVE(J)                                                  03618900
00371    191*         PG         = 2.0 * P(1,KAM1,J) - P(1,KAM2,J)                           03619000
00372    192*         ALIQ       = AGRAT(J) * ENGMAN(4,1,J)                                  03619100
00373    193*         AGAS       = ENGMAN(4,1,J) - ALIQ                                      03619200
00374    194*     560 WDOT       = GASFLO (AGAS, PG, CCDATA(2,1), GCONPG(J), TLIQ(J),        03619300
00374    195*       1                PTGAM(J)).                                              03619400
00375    196*         W(1,KA,J) = 27.807 * ALIQ * SQRT(DENSTY(J)                             03619500
00375    197*       1                * ABS(PG - CCDATA(2,1)))                                03619600
00376    198*         IF (PG .LT. CCDATA(2,1))           W(1,KA,J)  =  0.0                   03619700
00400    199*     580 CALL VENTR2 (KA, KAM1, KAM2, RUP(J), PG, DELT, J)                      03619800
00401    200*         VOLBUB     = VOLTOT(J) - (WTPCAV(J) + 0.5 * DELT * (W(8,KA,J)          03619900
00401    201*       1              + W(8,KA,J) - W(1,KA,J) - ENGMAN(7,1,J))) / DENSTY(J)     03620000
00402    202*         WTGUP      = WTIBUB(J) - 0.5 * (WDOT + WDOTGV(J)) * DELT               03620100
00403    203*         IF (VOLBUB .LT. 1.0E-04)           VOLBUB  =  1.0E-04                  03620200
00405    204*         IF (WTGUP .LT. 1.0E-12)            WTGUP  =  1.0E-12                   03620300
00407    205*     600 P(I,KA,J) = WTGUP * GCONPG(J) * TLIQ(J) / VOLBUB                       03620400
00410    206*         IF (IJK .GT. 30)                                          GO TO 620    03620500
00412    207*         CALL SOLVE (PG, P(I,KA,J), PS, IJK, 0.0001, 0.0005)                    03620600
00413    208*         IF (IJK - 100)                     580, 580, 640                       03620700
00416    209*     620 N          = 620                                                       03620800
00417    210*         WRITE (6,150) N, T(KA), J, PG, P(I,KA,J)                               03620900
00417    211*   C                                                                            03621000
00417    212*   C     *   FINALIZE CONDITIONS DOWNSTREAM OF VENTURI.                         03621100
00417    213*   C                                                                            03621200
00420    214*     640 WTIBUB(J) = WTGUP                                                      03621300
00427    215*         WDOTGV(J) = WDOT                                                       03621400
00430    216*         IF (VOLBUB .LT. 0.1)               ISTEP(J)  =  7                      03621500
00432    217*     660 WTPCAV(J) = WTPCAV(J) + 0.5 * DELT * (W(8,KA,J) + W(8,KAM1,J))         0362160
00433    218*         WTPINJ(J) = WTPINJ(J) - 0.5 * DELT * (W(1,KA,J) + W(1,KAM1,J))         0362170
00434    219*         IF (ISTEP(J) .LT. 6 .AND. WTPINJ(J) .LT. 1.0E-06)                      0362180
00434    220*       1                                    ISTEP(J)  =  6                      0362190
00436    221*         ENGMAN(6,1,J) = W(1,KA,J)                                              03622000
00437    222*         VDUM       = 0.0                                                       03622100
00440    223*         RDUM       = 0.0                                                       03622200
00441    224*         RTOT       = 0.0                                                       03622300
00442    225*         VLIQ       = WTPCAV(J) / DENSTY(J)                                     03622400
00443    226*         DO 680                   K = 1, 7                                      03622500
00446    227*         RTOT       = RTOT + R(K,J) / DENSTY(J)                                 03622600
00447    228*         P(K,KA,J) = P(1,KA,J)                                                  03622700
00450    229*     680 W(K,KA,J) = W(1,KA,J)                                                  03622800
00452    230*         K          = 7                                                         03622900
00453    231*     700 VSEG       = A(K,J) * X(K,J)                                           03623000
00454    232*         W(K,KA,J) = W(8,KA,J)                                                  03623100
00455    233*         IF (VDUM + VSEG .GT. VLIQ)                                GO TO 720    03623200
00457    234*         P(K,KA,J) = P(K+1,KA,J) - R(K,J) * W(8,KA,J) * ABS(W(8,KA,J))          03623300
00460    235*         VDUM       = VDUM + VSEG                                               03623400
00461    236*         RDUM       = RDUM + R(K,J) / DENSTY(J)                                 03623500
00462    237*         IF (K .EQ. 2)                                             GO TO 740    03623600
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00464   238*        K           = K - 1                                          03623700
00465   239*                                                          GO TO 700  03623800
00466   240*     720 RUP(J)     = RDUM + (VLIQ - VDUM) * R(K,J) / (VSEG * DENSTY(J))  03623900
00467   241*        RDN(J)      = RTOT - RUP(J)                                  03624000
00470   242*        IF (RDN(J) .LT. 0.0)            RDN(J)  =  0.0               03624100
00472   243*        ISAVE(J)    = K                                              03624200
00473   244*                                                          GO TO 900  03624300
00474   245*     740 K          = 1                                              03624400
00475   246*        VSEG        = A(1,J) * X(1,J)                                03624500
00476   247*        IF (VDUM + VSEG .LT. VLIQ)                        GO TO 720  03624600
00500   248*        RDN(J)      = 0.0                                            03624700
00501   249*        RUP(J)      = RTOT                                           03624800
00502   250*        W(1,KA,J) = W(8,KA,J)                                        03624900
00503   251*                                                          GO TO 900  03625000
00503   252*   C                                                                 03625100
00503   253*   C    *    CALCULATE CONDITIONS WITH NO BUBBLE IN SYSTEM.          03625200
00503   254*   C                                                                 03625300
00504   255*     760 ISTEP(J)   = 8                                              03625400
00505   256*        DO 780            I = 1, 7                                   03625500
00510   257*     780 LFILL(I,J)= 0                                               03625600
00512   258*                                                          GO TO 100  03625700
00513   259*     800 IF (T(KA) .LT. 2.0 * DELT)       ISTEP(J)  =  1             03625800
00515   260*                                                          GO TO 100  03625900
00515   261*   C                                                                 03626000
00515   262*   C    PUT INJECTOR FLOW INTO WSTORE ARRAY.                         03626100
00515   263*   C                                                                 03626200
00516   264*     900 PDUM       = P(1,KAM1,J) - CCDATA(1,II)                     03626300
00517   265*        IF (PDUM .LT. 1.0E-20)          PDUM  =  1.0E-20             03626400
00521   266*        T1          = ENGMAN(5,II,J) / (27.807 * SQRT(PDUM / D(1,J)))  03626500
00521   267*       1            + T(KAM1)                                        03626600
00522   268*        PDUM        = P(1,KA,J) - CCDATA(2,II)                       03626700
00523   269*        IF (PDUM .LT. 1.0E-20)          PDUM  =  1.0E-20             03626800
00525   270*        T2          = ENGMAN(5,II,J) / (27.807 * SQRT(PDUM / D(1,J)))  03626900
00525   271*       1            + T(KA)                                          03627000
00526   272*        IF (T2 .LT. T1)                                   GO TO 920  03627100
00530   273*        TLO         = T1                                             03627200
00531   274*        WLO         = ENGMAN(7,II,J)                                 03627300
00532   275*        THI         = T2                                             03627400
00533   276*        WHI         = ENGMAN(8,II,J)                                 03627500
00534   277*                                                          GO TO 940  03627600
00535   278*     920 TLO        = T2                                             03627700
00536   279*        WLO         = ENGMAN(8,II,J)                                 03627800
00537   280*        THI         = T1                                             03627900
00540   281*        WHI         = ENGMAN(7,II,J)                                 03628000
00541   282*     940 DT         = THI - TLO                                      03628100
00542   283*        XN          = (TLO - T(KA)) / DELT + 1.0                     03628200
00543   284*        IF (XN .GE. 100.0 .OR. XN .LT. 1.0)               GO TO 1000 03628300
00545   285*        N           = XN                                             03628400
00546   286*        KL          = KCC + N                                        03628500
00547   287*        IF (KL .GT. 100)                KL  =  KL - 100              03628600
00551   288*        IF (DT .GT. 0.1 * DELT)                           GO TO 960  03628700
00553   289*        WSTORE(KL,II,J) = WSTORE(KL,II,J) + 0.5 * (WHI + WLO) * DELT  03628800
00554   290*                                                          GO TO 1000 03628900
00555   291*     960 TDUM       = DELT / DT                                      03629000
00556   292*     980 TMAX       = T(KA) + N * DELT                               03629100
00557   293*        IF (TMAX .GT. THI)              TMAX  =  THI                 03629200
00561   294*        TMIN        = T(KAM1) + N * DELT                             03629300
00562   295*        IF (TMIN .LT. TLO)              TMIN  =  TLO                 03629400
00564   296*        WMIN        = ((TMIN - TLO) * (WHI - WLO) / DT + WLO) * TDUM  03629500
00565   297*        WMAX        = ((TMAX - TLO) * (WHI - WLO) / DT + WLO) * TDUM  03629600
00566   298*        WSTORE(KL,II,J) = 0.5 * (WMIN + WMAX) * (TMAX - TMIN)        03629700
00566   299*       1                       + WSTORE(KL,II,J)                     03629800
00567   300*        IF (TMAX .GE. THI)                                GO TO 1000 03629900
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00571   301*          IF (N .GT. 98)                                     GO TO 1000 03630000
00573   302*          N          = N + 1                                            03630100
00574   303*          KL         = KL + 1                                           03630200
00575   304*          IF (KL .GT. 100)          KC  =  1 ;                          03630100
00577   305*                                                             GO TO 980  03630400
00600   306*     1000 CONTINUE                                                      03630500
00602   307*          RETURN .                                                      03630600
00603   308*          END                                                           03630700

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      1. *DIAGNOSTIC* MESSAGE(S)
   ROCKET           SYMBOLIC                                  08 JAN 71  14:31:28  -0  01537640   14   146  (DELETED)
   ROCKET   CODE    RELOCATABLE                               08 JAN 71  14:31:28   1  01543634   60     1  (DELETED)
                                                                                    0  01541730   14    74
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@FOR  CAVENT,CAVENT
UNIVAC 1108 FORTRAN V LEVEL   2206 0018-F5018H
THIS COMPILATION WAS DONE ON 11 FEB 71 AT 19:15:54

   SUBROUTINE CAVENT     ENTRY POINT 001151

   STORAGE USED (BLOCK, NAME, LENGTH)

        0001   *CODE    001223
        0000   *DATA    000252
        0002   *BLANK   000000
        0003   DATUM1   043120
        0004   DATUM2   000740
        0005   DATUM3   001344
        0006   DATUM4   000144
        0007   CAL1     000740
        0010   CAL2     000740
        0011   CAL3     000062
        0012   CAL5     000310
        0013   DIRECT   001214


   EXTERNAL REFERENCES (BLOCK, NAME)

        0014   GETFLO
        0015   ERROR
        0016   SOLVE
        0017   BRANCH
        0020   NEXP6$
        0021   NWDU$
        0022   NIO1$
        0023   NIO2$
        0024   SORT
        0025   NERR2$
        0026   NERR3$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   000145 100L      0001   001132 1000L     0001   000246 120L      0001   000251 200L      0001   000363 220L
    0001   000365 300L      0001   000427 320L      0001   000501 340L      0001   000522 360L      0000   000003 370F
    0001   000604 380L      0001   000641 400L      0001   000706 420L      0001   000710 500L      0001   000722 520L
    0001   000746 540L      0001   000075 60L       0001   001011 860L      0001   001026 900L      0001   001047 920L
    0000   000103 930F      0001   001100 940L      0000   000113 950F      0004 R 000000 A         0000 D 000024 A1
    0000 D 000020 A2        0000 D 000030 B1        0000 D 000[illegible] B2        0004 R 000360 C         0005 R 000720 CAVTAT
    0012 R 000006 CDUM1     0000 D 000034 C1        0000 D 000036 C2        0010 R 000000 C2CON     0010 R 000170 C3CON
    0010 R 000360 C4CON     0010 R 000550 D         0006 R 000000 DEQUAL    0000 D 000040 DUM       0000 R 000061 DUMCON
    0005 R 000000 DUM1      0005 R 000760 DUM2      0006 R 000006 DUM3      0006 R 000022 DUM4      0000 R 000053 ER
    0000 R 000054 ERM       0015 R 000000 ERROR     0007 R 000000 G         0012 R 000004 GCONPG    0014 R 000000 GETFLO
    0000 I 000045 I         0013 I 000170 IBRAN     0013 I 000672 IDUM1     0000 I 000046 IERROR    0000 I 000042 IFLAG
    0000 I 000047 IGO       0000 I 000050 IJK       0013 I 000000 IORDER    0000 I 000044 K         0013 I 000502 LFILL
    0013 I 000500 NSEG      0003 R 000000 P         0007 R 000170 PBAR      0000 R 000057 PDUM      0000 R 000051 PG
    0000 R 000060 PHI       0012 R 000002 PHICON    0012 R 000000 PLVAP     0000 D 000000 PS        0006 R 000020 PTGAM
    0006 R 000550 R         0006 R 000002 RHO       0000 R 000055 RHO1      0000 R 000056 RHO2      0011 R 000000 T
    0006 R 000004 TLIQ      0003 R 027340 V         0007 R 000550 VOL       0003 R 013560 W         0007 R 000360 WBAR
    0000 R 000062 WDUM      0004 R 000170 X         0000 R 000052 XDUM
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00100     1*    C      J. BOEHNLEIN * D596-112 * EX 2721                                  03800000
00101     2*           SUBROUTINE CAVENT (KA, KAM1, KAM2, DELT, J)                        03800100
00101     3*    C                                                                         03800200
00103     4*           COMMON /DATUM1/   P(60,50,2)    ,  W(60,50,2)    ,  V(60,50,2)     03800300
00103     5*          1        /DATUM2/   A(60,2)       ,  X(60,2)       ,  C(60,2)      ,  03800400
00103     6*          2                   R(60,2)                                         03800500
00103     7*          3        /DATUM3/   DUM1(464)     ,  CAVTAT(4,4,2),  DUM2(244)      03800600
00103     8*          4        /DATUM4/   DEQUAL(2)     ,  RHO(2)        ,  TLIO(2)      ,  03800700
00103     9*          5  DUM3(10)      ,  PTCAM(2)      ,  DUM4(82)                       03800800
00103    10*    C                                                                         03800900
00104    11*           COMMON /CAL1/     G(60,2)       ,  PBAR(60,2)    ,  WBAR(60,2)    ,  03801000
00104    12*          1                   VOL(60,2)                                       03801100
00104    13*          2        /CAL2/     C2CON(60,2)   ,  C3CON(60,2)   ,  C4CON(60,2)   ,  03801200
00104    14*          3                   D(60,2)                                         03801300
00104    15*          4        /CAL3/     T(50)                                           03801400
00104    16*          5        /CAL5/     PLVAP(2)      ,  PHICON(2)     ,  GCONPG(2)     ,  03801500
00104    17*          6                   CDUM1(194)                                      03801600
00104    18*    C                                                                         03801700
00105    19*           COMMON /DIRECT/   IORDER(60,2)  ,  IBRAN(10,10,2), NSEG(2)       ,  03801800
00105    20*          1                   LFILL(60,2)   ,  IDUM1(210)                     03801900
00105    21*    C                                                                         03802000
00106    22*           DOUBLE PRECISION  PS(10)        ,  A1            ,  A2            ,  03802100
00106    23*          1  B1            ,  B2            ,  C1            ,  C2            ,  03802200
00106    24*          2                   DUM                                             03802300
00107    25*           DIMENSION         IFLAG(2)                                         03802400
00107    26*    C                                                                         03802500
00107    27*    C                                                                         03802600
00110    28*           K            = 1                                                   03802700
00111    29*           I            = 8                                                   03802800
00112    30*           IF (I .LT. 1)                                         GO TO 1000 03802900
00114    31*           IERROR       = 1                                                   03803000
00115    32*           IF (LFILL(I+1,J) .NE. 0)                              GO TO 1000 03803100
00117    33*           IF (LFILL(I-1,J) .EQ. 0)                              GO TO 200  03803200
00117    34*    C                                                                         03803300
00117    35*    C          *     CALCULATE PRIMING WITHOUT CAVITATION.                    03803400
00117    36*    C                                                                         03803500
00121    37*           IGO          = 1                                                   03803600
00122    38*           IJK          = 0                                                   03803700
00123    39*           PG           = 2.0 * P(I,KAM1,J) - P(I,KAM2,J)                     03803800
00124    40*           XDUM         = VOL(I-1,J) / A(I-1,J)                               03803900
00125    41*           IF (XDUM .GT. 0.01)                                   GO TO 80   03804000
00127    42*           XDUM         = 0.01                                                03804100
00130  *DIAGNOSTIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
00130    43*           IF (W(I,KAM1,J) .EQ. 0.0)        W(I,KAM1,J) = W(I+1,KAM1,J)       03804200
00132    44*        80 A1           = R(I-1,J) * XDUM / (X(I-1,J) * D(I+1,J))             03804300
00133    45*           B1           = XDUM / (386.0 * DELT * A(I-1,J))                    03804400
00134    46*           C1           = P(I-1,KA,J) - W(I,KAM1,J) * B1                      03804500
00135    47*       100 DUM          = CAVTAT(4,K,J) * PG - C1                             03804600
00136    48*           W(I-1,KA,J) = GETFLO(A1, B1, DUM)                                  03804700
00137    49*           W(I,KA,J)    = W(I-1,KA,J)                                         03804800
00140    50*           P(I+1,KA,J) = C4CON(I+1,J) - C3CON(I+1,J) * W(I,KA,J)              03804900
00140    51*          1               - R(I+1,J) * W(I,KA,J) * ABS(W(I,KA,J)) / D(I+1,J)  03805000
00141    52*           P(I,KA,J)    = CAVTAT(4,K,J) * P(I+1,KA,J)                         03805100
00142    53*           IF (IJK .GT. 30)                                      GO TO 120  03805200
00144    54*           ER           = ERROR(PG)                                           03805300
00145    55*           ERM          = 5.0 * ER                                            03805400
00146    56*           CALL SOLVE (PG, P(I,KA,J), PS, IJK, ER, ERM)                       03805500
00147    57*           IF (IJK - 100)                      100, 300, 300                  03805600
00152    58*       120 IERROR       = 2                                                   03805700
00153    59*                                                                 GO TO 300  03805800
00153    60*    C                                                                         03805900
00153    61*    C          *     CALCULATE NORMAL FLOW WITHOUT CAVITATION.                03806000
00153    62*    C                                                                         03806100
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NOT REPRODUCIBLE

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00154     63*      200 AZ          = R(I+1,J) / D(I+1,J)                                03806200
00155     64*          BZ          = C3CON(I-1,J) + C1CON(I+1,J) + CAVTAT(4,K,J)        03806300
00156     65*          CZ          = C5CON(I+1,J) + C2CON(I,J) + C1CON(I-1,J)           03806400
00157     66*          W(I,KA,J) = GETFLO(AZ, BZ, CZ)                                   03806500
00160     67*          P(I,KA,J) = C3CON(I-1,J) * (W(I,KA,J) - C2CON(I,J))              03806600
00161     68*          P(I+1,KA,J) = P(I,KA,J) + W(I,KA,J) * CAVTAT(4,K,J)              03806700
00162  *DIAGNOSTIC* THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL
00162     69*          IF (W(I,KAM1,J) .NE. 0.0)                          GO TO 220    03806800
00164     70*          IF (DABS(C1) .GT. 1.0E-06 * ABS(C4CON(I,J)))       GO TO 220    03806900
00166     71*          W(I,KA,J) = 0.0                                                  03807000
00167     72*          P(I,KA,J) = P(I,KAM1,J)                                          03807100
00170     73*      220 IGO         = 2                                                  03807200
00170     74*   C                                                                       03807300
00170     75*   C          *     CHECK TO SEE IF CAVITATION IS OCCURRING                03807400
00170     76*   C                                                                       03807500
00171     77*      300 RHO1        = D(I+1,J)                                           03807600
00172     78*          PG          = 2.0 * P(I+1,KAM1,J) - P(I+1,KAM2,J)                03807700
00173     79*          IF (PG .LT. PLVAP(J))           PG  =  1.0 + PLVAP(J)            03807800
00175     80*          IF (DEQUAL(J) .GT. 1.0E-20)                        GO TO 320    03807900
00177     81*          RHO2        = D(I+1;J)                                           03808000
00200     82*                                                         GO TO 340    03808100
00201     83*      320 PDUM        = 100.0 - PLVAP(J)                                   03808200
00202     84*          PHI         = (DEQUAL(J) - G(I,J)) * (1.0 + PHICON(J) / PDUM)    03808300
00202     85*        1             / (1.0 + G(I,J))                                     03808400
00203     86*          IF (PHI .LT. 0.0)               PHI  =  0.0                      03808500
00205     87*          RHO2        = (1.0 + PHI) / (1.0 / RHO(J) + PHI * GCONPG(J)      03808600
00205     88*        1             * TLIQ(J) * (PLVAP(J) / PDUM) ** ((PTGAM(J) - 1.0)   03808700
00205     89*        2             / PTGAM(J)) / PDUM)                                  03808800
00206     90*      340 DUMCON      = 772.0 / (1.0 / (RHO2 * CAVTAT(3,K,J)) ** 2         03808900
00206     91*        1             - 1.0 / (RHO1 * CAVTAT(2,K,J)) ** 2)                 03809000
00207     92*      360 WDUM        = DUMCON * (PG / RHO1 - PLVAP(J) / RHO2)             03809100
00210     93*          IF (WDUM .LT. 0.0)              WRITE (6,370) T(KA), J, I, IJK,  03809200
00210     94*        1   PG, WDUM                                                       03809300
00221     95*      370 FORMAT (1H0 10X'TIME =' F9.6, 3X'J =' I2, 3X'I =' I3, 3X'IJK ='  03809400
00221     96*        1        I3, 3X'PG =' G15.6, 3X'WDUM =' G15.6 )                    03809500
00222     97*          IF (WDUM .LT. 0.0)              WDUM  =  0.0                     03809600
00224     98*          WDUM        = SQRT(WDUM)                                         03809700
00225     99*          GO TO (380, 380, 400, 400), IGO                                  03809800
00226    100*      380 IF (WDUM .GE. W(I,KA,J))                           GO TO 540    03809900
00230    101*          IGO         = IGO + 2                                            03810000
00231    102*          IERROR      = 1                                                  03810100
00232    103*          IJK         = 0                                                  03810200
00233    104*          PG          = 2.0 * P(I+1,KAM1,J) - P(I+1,KAM2,J)                03810300
00234    105*                                                         GO TO 360    03810400
00234    106*   C                                                                       03810500
00234    107*   C          *     CALCULATE UPSTREAM FLOW AND PRESSURE WITH CAVITATION.  03810600
00234    108*   C                                                                       03810700
00235    109*      400 W(I,KA,J) = WDUM                                                 03810800
00236    110*          P(I+1,KA,J) = C4CON(I+1,J) - C3CON(I+1,J) * WDUM - R(I+1,J)      03810900
00236    111*        1             * WDUM * ABS(WDUM)                                   03811000
00237    112*          IF (IJK .GT. 30)                                   GO TO 420    03811100
00241    113*          CALL SOLVE (PG, P(I+1,KA,J), PS, IJK, 0.0001, 0.0005)            03811200
00242    114*          IF (IJK - 100)                      360, 300, 500                03811300
00245    115*      420 IERROR      = 3                                                  03811400
00246    116*      500 GO TO (380, 380, 520, 880), IGO                                  03811500
00246    117*   C                                                                       03811600
00246    118*   C          *     CALCULATE DOWNSTREAM PRESSURE DURING PRIMING.          03811700
00246    119*   C                                                                       03811800
00247    120*      520 W(I-1,KA,J) = WDUM                                               03811900
00250    121*          W(I,KA,J)   = WDUM                                               03812000
00251    122*          P(I,KA,J)   = A1 * WDUM * ABS(WDUM) + B1 * WDUM + C1             03812100
00252    123*      540 IF (IGO .EQ. 2)                                    GO TO 900    03812200
00254    124*          [illegible]  = I + 1                                             03812300
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00255    125*          IF (J .EQ. 2)                   IFLAG(1)  =  - IFLAG(1)          03R12400
00257    126*          IFLAG(2)  = 100 + I                                              03R12500
00260    127*          CALL BRANCH (KA, KAM1, KAM2, DELT, IFLAG)                        03R12600
00261    128*          IF (LFILL(I-1,J) .EQ. 1)                           GO TO 900     03R12700
00263    129*          LFILL(I-1,J) = 2                                                 03R12800
00264    130*                                                             GO TO 900     03R12900
00264    131*    C                                                                      03R13000
00264    132*    C          *     CALCULATE DOWNSTREAM PRESSURE, AND FINISH THIS CASE   03R13100
00264    133*    C                                                                      03R13200
00265    134*       880 P(I,KA,J) = C1CON(I-1,J) * (WDUM - C2CON(I,J))                  03R13300
00265    135*    C                                                                      03R13400
00266    136*       900 W(I+1,KA,J) = W(I,KA,J)                                         03R13500
00267    137*          GO TO (1000, 920, 940), IERROR                                   03R13600
00270    138*       920 WRITE (6, 930) T(KA), I, J, P(I,KA,J), W(I,KA,J)                03R13700
00277    139*       930 FORMAT (1H0 10X'AN ERROR OCCURRED IN SUBROUTINE CAVENT AT TIME'  03R13800
00277    140*         1       F9.6, ', SEGMENT NO.' I3, ', J =' I2  / 11X'THE CALCULATED'03R13900
00277    141*         2       1X'PRESSURE WAS' G13.6, 5X'THE FLOW WAS' G13.6,          03R14000
00277    142*         3       5X'NO CAVITATION OCCURRED' )                             03R14100
00300    143*                                                             GO TO 1000 03R14200
00301    144*       940 WRITE (6,950) T(KA), I, J, PG, P(I+1,KA,J), W(I,KA,J)           03R14300
00311    145*       950 FORMAT (1H0 10X'AN ERROR OCCURRED IN THE CAVITATION CALCULATION'  03R14400
00311    146*         1       1X'AT TIME' F9.6, ', SEGMENT NO ' I3, ' AND J ='  I2 /    03R14500
00311    147*         2       11X'PG =' G13.6, 5X'PANS =' G13.6, 5X'FLOW =' G13.6 )     03R14600
00312    148*      1000 CONTINUE                                                        03R14700
00313    149*          RETURN                                                           03R14800
00314    150*          END                                                              03R14900

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      2 *DIAGNOSTIC* MESSAGE(S)
   CAVENT          SYMBOLIC                                 06 JAN 71  14:31:04   0  01462426    14    150  (DELETED)
   CAVENT   CODE   RELOCATABLE                              06 JAN 71  14:31:04   1  01466512    60      1  (DELETED)
                                                                                  0  01466606    14     74
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@ FOR  GASFLO,GASFLO                                                                                    11 FEB 71               19 15:57
UNIVAC 1108 FORTRAN V LEVEL   2206 0018 F501MH
THIS COMPILATION WAS DONE ON 11 FEB 71 AT 19:15:57


   FUNCTION GASFLO       ENTRY POINT 000205

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001   *CODE   000235
         0000   *DATA   000023
         0002   *BLANK  000000


   EXTERNAL REFERENCES (BLOCK, NAME)

         0003   NEXP6$
         0004   SQRT
         0005   NERR3$


  STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

   0001   000034 100L        0001   000112 500L        0001   000122 600L        0000 R 000001 CRPR        0000 R 000000 GASFLO
   0000 R 000002 PR


00100     1*   C         THIS FUNCTION SUBPROGRAM WILL CALCULATE THE GAS FLOWRATE       03900000
00100     2*   C      THROUGH AN ORIFICE. THE VALUE OF THE FUNCTION IS THE FLOWRATE IN  03900100
00100     3*   C      POUNDS PER SECOND.                                                03900200
00100     4*   C                                                                        03900300
00100     5*   C        R          SPECIFIC GAS CONSTANT * * LBS-F INCH / LBS-M DEGREES R 03900400
00100     6*   C        T          GAS INLET TEMPERATURE * * DEGREES RANKINE             03900500
00100     7*   C        GAMMA      RATIO OF SPECIFIC HEATS                               03900600
00100     8*   C        PUP        UPSTREAM PRESSURE * * PSIA                            03900700
00100     9*   C        PDOWN      DOWNSTREAM PRESSURE * * PS'^                          03900800
00100    10*   C        CDA        EFFECTIVE AREA OF ORIFICE                  HES        03900900
00100    11*   C                                                                        03901000
00101    12*          FUNCTION GASFLO(CDA, PUP, PDOWN, R, T                             03901100
00101    13*   C                                                                        03901200
00103    14*          CRPR       = (2.0 / (GAMMA + 1.0)) **               A - 1.0))     03901300
00104    15*          IF (PDOWN .GT. PUP)                                   GO TO 500   03901400
00106    16*          IF (PUP .GT. 0.0)                                     GO TO 100   03901500
00110    17*          GASFLO     = 0.0                                                  03901600
00111    18*          RETURN                                                            03901700
00112    19*      100 PR         = PDOWN / PUP                                          03901800
00113    20*          IF (PR .LT. CRPR)                PR =                             03901900
00115    21*          GASFLO     = CDA * SQRT(772.17 * GAMMA                            03902000
00115    22*         1           * (PR ** (2.0 / GAMMA) - PR            1.0) / GAMMA))  03902100
00115    23*         2           / ((GAMMA - 1.0) * R * T))                             03902200
00116    24*          RETURN                                                            03902300
00117    25*      500 IF (PDOWN .GT. 0.0)                               GO TO 600   03902400
00121    26*          GASFLO     = 0.0                                                  03902500
00122    27*          RETURN                                                            03902600
00123    28*      600 PR         = PUP / PDOWN                                          03902700
00124    29*          IF (PR .LT. CRPR)                PR =                             03902800
00126    30*          GASFLO     = - CDA * SQRT(772.17 * GA             2               03902900
00126    31*         1           * (PR ** (2.0 / GAMMA) - PR            1.0) / GAMMA))  03903000
```

```
00126     32*         2                / ((GAMMA - 1.0) * R * T))                                  03903100
00127     33*          RETURN                                                                         03903200
00130     34*          END                                                                            03903300

     END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
@ FOR ,VENTR2,VENTR2                                                                11 FEB 71          19:15:5
UNIVAC 1108 FORTRAN V LEVEL   2206 0018 F501HH
THIS COMPILATION WAS DONE ON 11 FEB 71 AT 19:15:5

  SUBROUTINE VENTR2    ENTRY POINT 000702 .

  STORAGE USED (BLOCK, NAME, LENGTH)

       0001   *CODE   000753
       0000   *DATA   000245
       0002   *BLANK  000000
       0003   DATUM1  043120
       0004   DATUM2  000740
       0005   DATUM3  001344
       0006   DATUM4  000144
       0007   CAL1    000740
       0010   CAL2    000740
       0011   CAL3    000062
       0012   CAL5    000310
       0013   DIRECT  001214


  EXTERNAL REFERENCES (BLOCK, NAME)

       0014   GETFLO
       0015   SOLVE
       0016   BRANCH
       0017   NEXP6$
       0020   NWDU$
       0021   NIO1$
       0022   NIO2$
       0023   SQRT
       0024   NERR2$
       0025   NERR3$


  STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

   0001   000661 1000L     0001   000157 320L      0001   000231 340L      0001   000252 360L      0000   000056 370F
   0001   000334 380L      0001   000371 400L      0001   000438 420L      0001   000440 500L      0001   000452 520L
   0001   000476 540L      0001   000541 880L      0001   000555 900L      0001   000576 920L      0000   000076 930F
   0001   000627 940L      0000   000136 950F      0004 R 000000 A         0000 D 000024 A1        0000 D 000026 A2
   0000 D 000030 B1        0000 D 000032 B2        0004 R 000360 C         0005 R 000720 CAVTAT    0012 R 000006 CDUM1
   0000 D 000034 C1        0000 D 000036 C2        0010 R 000000 C2CON     0010 R 000170 C3CON     0010 R 000360 C4CON
   0010 R 000550 D         0006 R 000000 DEQUAL    0000 R 000054 DUMCON    0005 R 000000 DUM1      0005 R 000760 DUM2
   0006 R 000006 DUM3      0006 R 000022 DUM4      0007 R 000000 G         0012 R 000004 GCONPG    0014 R 000000 GETFLO
   0000 I 000046 I         0013 I 000170 IBRAN     0013 I 000672 IDUM1     0000 I 000043 IERROR    0000 I 000040 IFLAG
   0000 I 000044 IGO       0000 I 000045 IJK       0013 I 000000 IORDER    0000 I 000042 K         0013 I 000502 LFILL
   0013 I 000500 NSEG      0003 R 000000 P         0007 R 000170 PBAR      0000 R 000052 PDUM      0000 R 000050 PG
   0000 R 000053 PHI       0012 R 000002 PHICON    0012 R 000000 PLVAP     0000 D 000000 PS        0006 R 000020 PTGAM
   0004 R 000550 R         0006 R 000002 RHO       0000 R 000047 RHO1      0000 R 000051 RHO2      0011 R 000000 T
   0006 R 000004 TLIQ      0003 R 027340 V         0007 R 000550 VOL       0003 R 013560 W         0007 R 000360 WBAR
   0000 R 000055 WDUM      0004 R 000170 X


00000  *DIAGNOSTIC*  THE VARIABLE, A1, IS REFERENCED IN THIS PROGRAM, BUT IS NOWHERE ASSIGNED A VALUE.
00000  *DIAGNOSTIC*  THE VARIABLE, B1, IS REFERENCED IN THIS PROGRAM, BUT IS NOWHERE ASSIGNED A VALUE.
```

```
00000  *DIAGNOSTIC*  THE VARIABLE, C1, IS REFERENCED IN THIS PROGRAM, BUT IS NOWHERE ASSIGNED A VALUE
00000  *DIAGNOSTIC*  THE NAME DUM APPEARS IN A DIMENSION OR TYPE STATEMENT BUT IS NEVER REFERENCED
00100     1*   C     J. BOERNLEIN * D596-112 * EX 2721                                     03700000
00101     2*         SUBROUTINE VENTR2 (KA, KAM1, KAM2, RES, PDOWN, DELT, J)               03700100
00101     3*   C                                                                           03700200
00103     4*         COMMON /DATUM1/   P(60,50,2)    ,  W(60,50,2)   ,  V(60,50,2)         03700300
00103     5*        1       /DATUM2/   A(60,2)       ,  X(60,2)      ,  C(60,2)       ,  03700400
00103     6*        2                  R(60,2)                                             03700500
00103     7*        3       /DATUM3/   DUM1(484)     ,  CAVTAT(4,4,2),  DUM2(244)          03700600
00103     8*        4       /DATUM4/   DEQUAL(2)     ,  RHO(2)       ,  TLIQ(2)       ,  03700700
00103     9*        5  DUM3(10)      ,  PTGAM(2)     ,  DUM4(82)                           03700800
00103    10*   C                                                                           03700900
00104    11*         COMMON /CAL1/     G(60,2)       ,  PBAR(60,2)   ,  WBAR(60,2)    ,  03701000
00104    12*        1                  VOL(60,2)                                           03701100
00104    13*        2       /CAL2/     C2CON(60,2)   ,  C3CON(60,2)  ,  C4CON(60,2)   ,  03701200
00104    14*        3                  D(60,2)                                             03701300
00104    15*        4       /CAL3/     Y(50)                                          ,  03701400
00104    16*        5       /CAL5/     PLVAP(2)      ,  PHICON(2)    ,  GCONPG(2)     ,  03701500
00104    17*        6                  CDUM1(194)                                          03701600
00104    18*   C                                                                           03701700
00105    19*         COMMON /DIRECT/   IORDER(60,2)  ,  IBRAN(10,10,2), NSEG(2)       ,  03701800
00105    20*        1                  LFILL(60,2)   ,  IDUM1(210)                         03701900
00105    21*   C                                                                           03702000
00106    22*         DOUBLE PRECISION  PS(10)        ,  A1           ,  A2            ,  03702100
00106    23*        1  B1            ,  B2           ,  C1           ,  C2                 03702200
00106    24*        2                  DUM                                                 03702300
00107    25*         DIMENSION         IFLAG(2)                                            03702400
00107    26*   C                                                                           03702500
00107    27*   C                                                                           03702600
00110    28*         K           = 1                                                       03702700
00111    29*         IERROR      = 1                                                       03702800
00112    30*         IGO         = 1                                                       03702900
00113    31*         IJK         = 0                                                       03703000
00114    32*         I           = 0                                                       03703100
00114    33*   C                                                                           03703200
00114    34*   C          *     CALCULATE NORMAL FLOW WITHOUT CAVITATION.                  03703300
00114    35*   C                                                                           03703400
00115    36*     200 A2          = R(9,J) / D(9,J) + RES                                   03703500
00116    37*         B2          = C3CON(9,J) + CAVTAT(4,1,J)                              03703600
00117    38*         C2          = C4CON(9,J) - PDOWN                                      03703700
00120    39*         W(I,KA,J) = GETFLO(A2, B2, C2)                                        03703800
00121    40*         IF (W(I,KA,J) .LT. 0.0)           W(I,KA,J)  =  0.0                   03703900
00123    41*         P(9,KA,J) = C4CON(9,J) - C3CON(9,J) * W(I,KA,J)                       03704000
00123    42*        1            - R(9,J) * W(I,KA,J) * ABS(W(I,KA,J)) / D(9,J)            03704100
00124    43*     220 IGO         = 2                                                       03704200
00124    44*   C                                                                           03704300
00124    45*   C          *     CHECK TO SEE IF CAVITATION IS OCCURRING.                   03704400
00124    46*   C                                                                           03704500
00125    47*     300 RHO1        = D(I+1,J)                                                03704600
00126    48*         PG          = 2.0 * P(I+1,KAM1,J) - P(I+1,KAM2,J)                     03704700
00127    49*         IF (PG .LT. PLVAP(J))             PG  =  1.0 + PLVAP(J)               03704800
00131    50*         IF (DEQUAL(J) .GT. 1.0E-20)                             GO TO 320  03704900
00133    51*         RHO2        = D(I+1,J)                                                03705000
00134    52*                                                                 GO TO 340  03705100
00135    53*     320 PDUM        = 160.0 - PLVAP(J)                                        03705200
00136    54*         PHI         = (DEQUAL(J) - G(I,J)) * (1.0 + PHICON(J) / PDUM)         03705300
00136    55*        1            / (1.0 + G(I,J))                                          03705400
00137    56*         IF (PHI .LT. 0.0)                 PHI  =  0.0                         03705500
00141    57*         RHO2        = (1.0 + PHI) / (1.0 / RHO(J) + PHI * GCONPG(J)           03705600
00141    58*        1            * TLIQ(J) * (PLVAP(J) / PDUM) ** ((PTGAM(J) - 1.0)        03705700
00141    59*        2            / PTGAM(J)) / PDUM)                                       03705800
00142    60*     340 DUMCON      = 772.0 / (1.0 / (RHO2 * CAVTAT(3,K,J)) ** 2              03705900
00142    61*        1            - 1.0 / (RHO1 * CAVTAT(2,K,J)) ** 2)                      03706000
```

```
00141     62*      360 WDUM      = DLMCON * (PG / RHO1 - PLVAP(J) / RHO2)                03706100
00144     63*          IF (WDUM .LT. 0.0)             WRITE (6,370) T(KA), J, I, IJK,    03706200
00144     64*        1    PG, WDUM                                                       03706300
00155     65*      370 FORMAT (1H0 10X'TIME =' F9.6, 3X'J =' I2, 3X'I =' I3, 3X'IJK ='   03706400
00155     66*        1           I3, 3X'PG =' G15.6, 3X'WDUM =' G15.6 )                  03706500
00156     67*          IF (WDUM .LT. 0.0)                 WDUM  =  0.0                   03706600
00160     68*          WDUM        = SQRT(WDUM)                                          03706700
00161     69*          GO TO (380, 380, 400, 400), IGO                                   03706800
00162     70*      380 IF (WDUM .GE. W(I,KA,J))                             GO TO 540    03706900
00164     71*          IGO         = IGO + 2                                             03707000
00165     72*          IERROR      = 1                                                   03707100
00166     73*          IJK         = 0                                                   03707200
00167     74*          PG          = 2.0 * P(I+1,KAM1,J) - P(I+1,KAM2,J)                 03707300
00170     75*                                                               GO TO 360    03707400
00170     76*   C                                                                        03707500
00170     77*   C          *     CALCULATE UPSTREAM FLOW AND PRESSURE WITH CAVITATION.   03707600
00170     78*   C                                                                        03707700
00171     79*      400 W(I,KA,J) = WDUM                                                  03707800
00172     80*          P(I+1,KA,J) = C4CON(I+1,J) - C3CON(I+1,J) * WDUM - R(I+1,J)       03707900
00172     81*        1               * WDUM * ABS(WDUM)                                  03708000
00173     82*          IF (IJK .GT. 30)                                     GO TO 420    03708100
00175     83*          CALL SOLVE (PG, P(I+1,KA,J), PS, IJK, 0.0001, 0.0005)             03708200
00176     84*          IF (IJK - 100)                      360, 360, 500                 03708300
00201     85*      420 IERROR      = 3                                                   03708400
00202     86*      500 GO TO (380, 380, 520, 880), IGO                                   03708500
00202     87*   C                                                                        03708600
00202     88*   C          *     CALCULATE DOWNSTREAM PRESSURE DURING PRIMING.           03708700
00202     89*   C                                                                        03708800
00203     90*      520 W(I-1,KA,J) = WDUM                                                03708900
00204     91*          W(I,KA,J)   = WDUM                                                03709000
00205     92*          P(I,KA,J)   = A1 * WDUM * ABS(WDUM) + B1 * WDUM + C1              03709100
00206     93*      540 IF (IGO .EQ. 2)                                      GO TO 900    03709200
00210     94*          IFLAG(1)  = I + 1                                                 03709300
00211     95*          IF (J .EQ. 2)                   IFLAG(1)  =  - IFLAG(1)           03709400
00213     96*          IFLAG(2)  = 100 + I                                               03709500
00214     97*          CALL BRANCH (KA, KAM1, KAM2, DELT, IFLAG)                         03709600
00215     98*          IF (LFILL(I-1,J) .EQ. 1)                             GO TO 900    03709700
00217     99*          LFILL(I-1,J) = 2                                                  03709800
00220    100*                                                               GO TO 900    03709900
00220    101*   C                                                                        03710000
00220    102*   C          *     CALCULATE DOWNSTREAM PRESSURE, AND FINISH THIS CASE.    03710100
00220    103*   C                                                                        03710200
00221    104*      880 P(I,KA,J) = PDOWN + RES * W(I,KA,J) * ABS(W(I,KA,J))              03710300
00221    105*   C                                                                        03710400
00222    106*      900 W(I+1,KA,J) = W(I,KA,J)                                           03710500
00223    107*          GO TO (1000, 920, 940), IERROR                                    03710600
00224    108*      920 WRITE (6, 930) T(KA), I, J, P(I,KA,J), W(I,KA,J)                  03710700
00233    109*      930 FORMAT (1H0 10X'AN ERROR OCCURRED IN SUBROUTINE CAVENT AT TIME'   03710800
00233    110*        1        F9.6, ', SEGMENT NO.' I3, ', J =' I2  / 11X'THE CALCULATED'03710900
00233    111*        2        1X'PRESSURE WAS' G13.6, 5X'THE FLOW WAS' G13.6,            03711000
00233    112*        3        5X'NO CAVITATION OCCURRED' )                               03711100
00234    113*                                                               GO TO 1000 03711200
00235    114*      940 WRITE (6,950) T(KA), I, J, PG, P(I+1,KA,J), W(I,KA,J)             03711300
00245    115*      950 FORMAT (1H0 10X'AN ERROR OCCURRED IN THE CAVITATION CALCULATION'  03711400
00245    116*        1        1X'AT TIME' F9.6, ', SEGMENT NO.' I3, ' AND J ='  I2 /     03711500
00245    117*        2        11X'PG =' G13.6, 5X'PANS =' G13.6, 5X'FLOW =' G13.6 )      03711600
00246    118*     1000 CONTINUE                                                          03711700
00247    119*          RETURN                                                            03711800
00250    120*          END                                                               03711900

     END OF UNIVAC 1108 FORTRAN V COMPILATION.      4 *DIAGNOSTIC* MESSAGE(S)
```

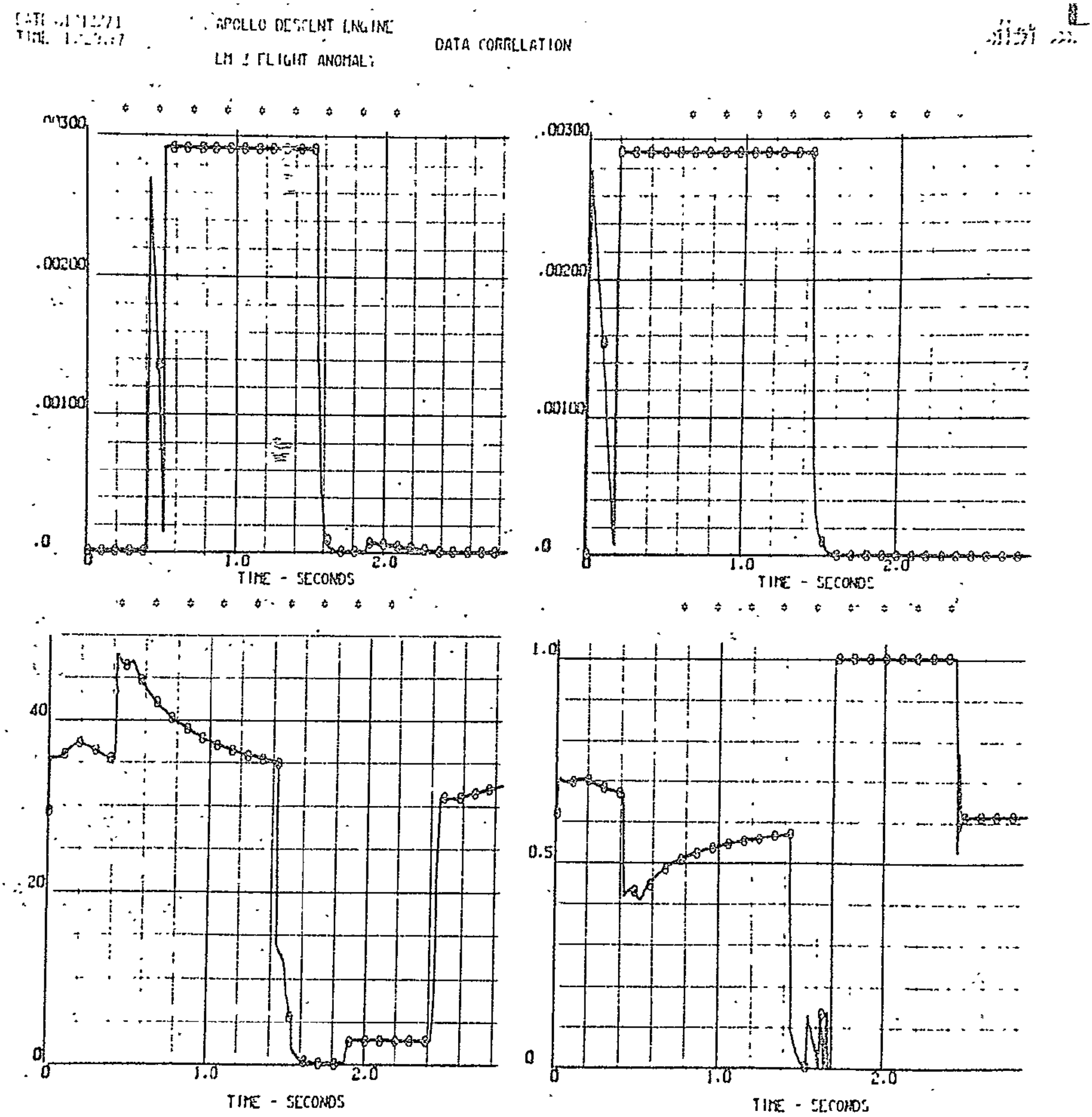

Figure C-1A - Graphical Output of Apollo Descent Engine LM-3 Flight Anomaly.

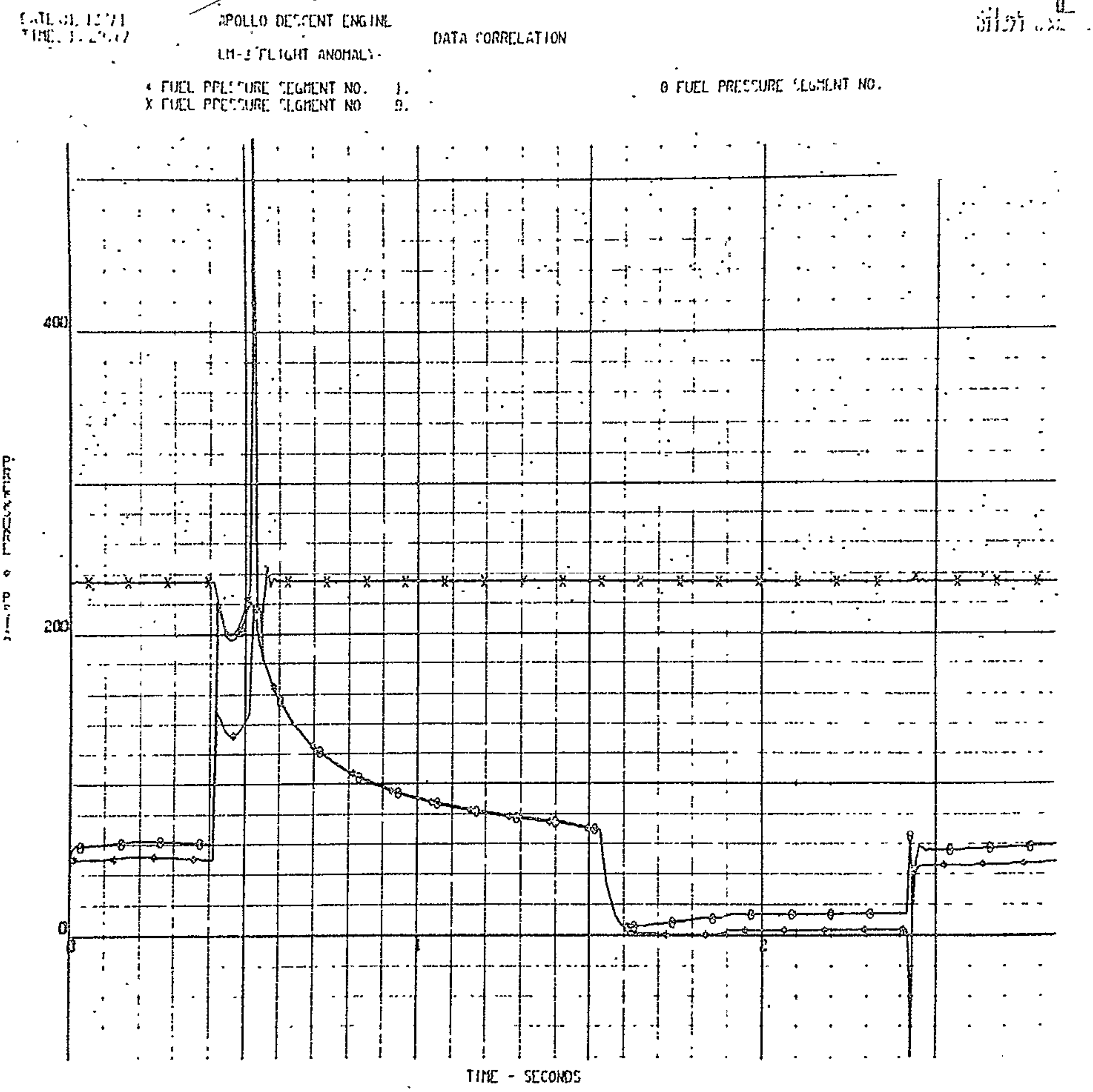

Figure C-1B - Graphical Output of Apollo Descent Engine LM-3 Flight Anomaly.

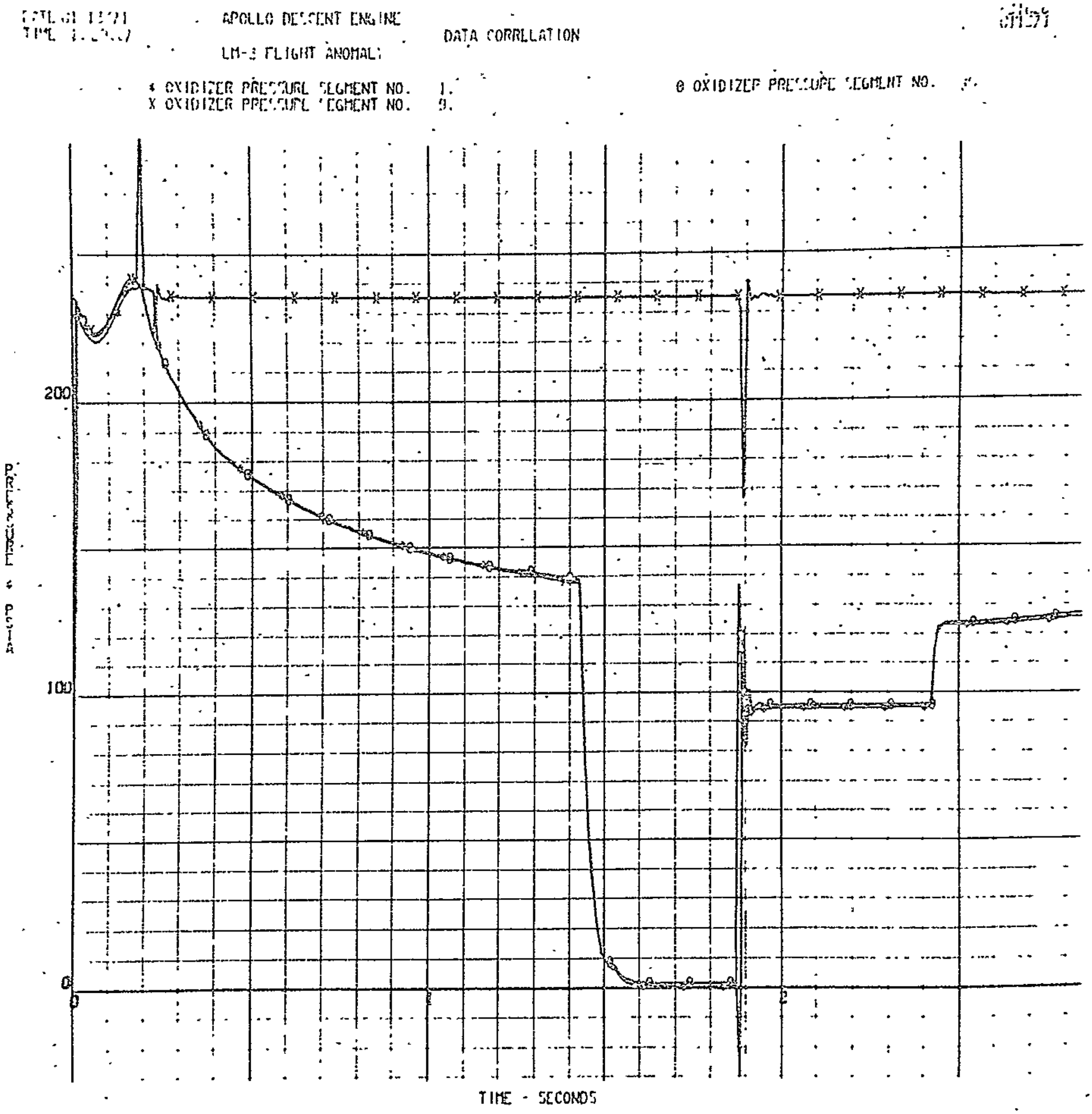

Figure C-1C - Graphical Output of Apollo Descent Engine LM-3 Flight Anomaly.

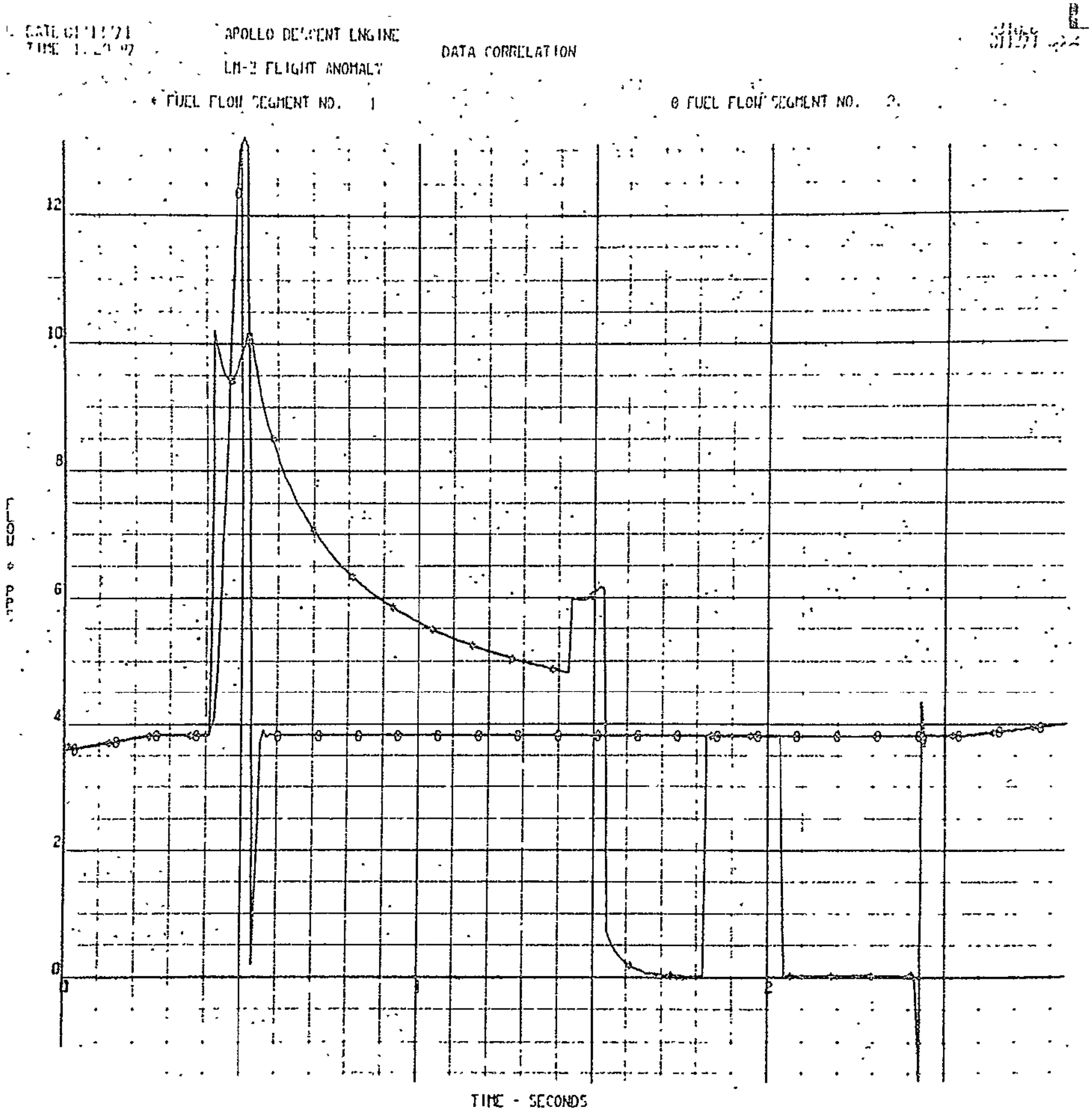

Figure C-1D - Graphical Output of Apollo Descent Engine LM-3 Flight Anomaly.

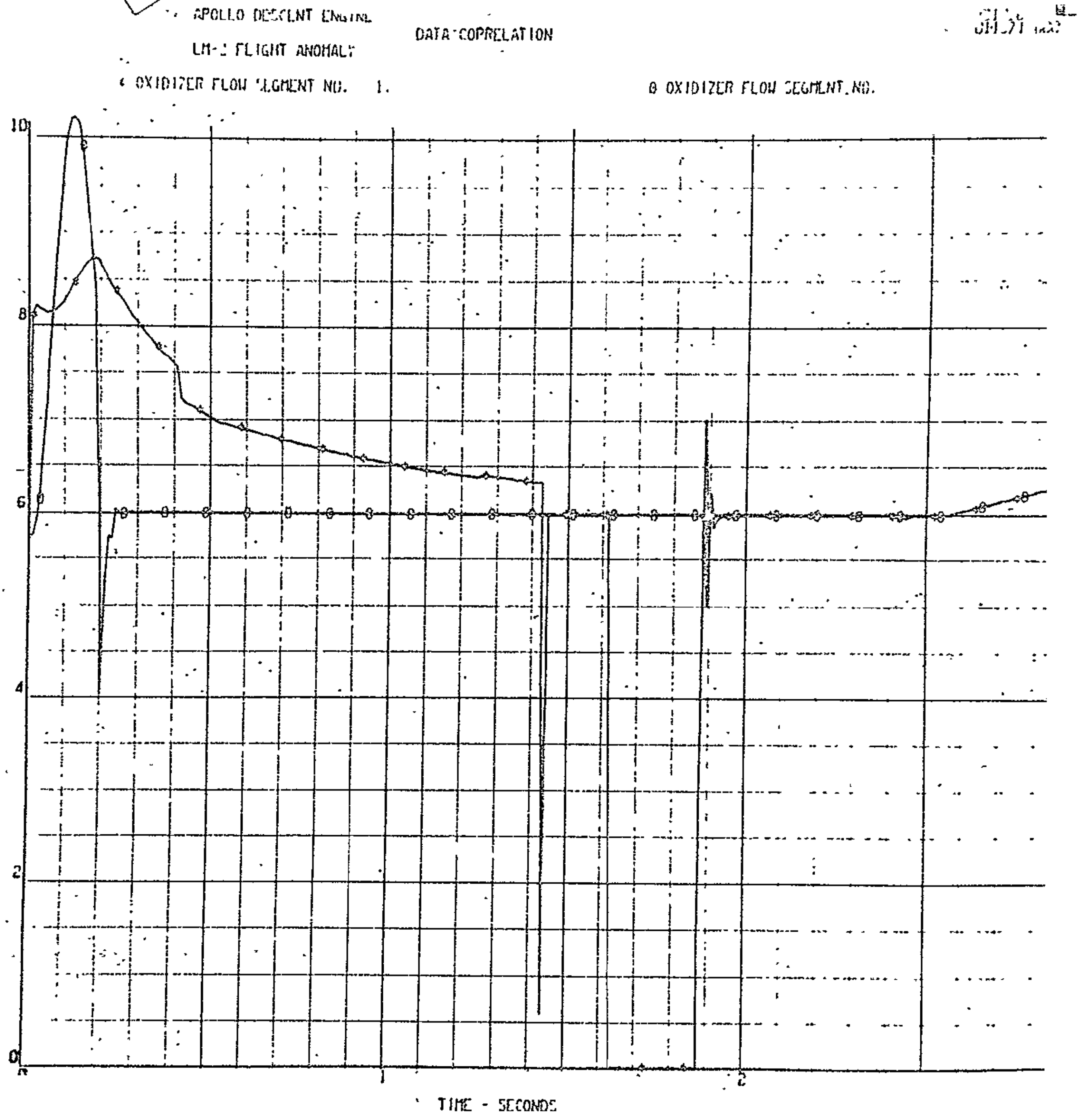

Figure C-1E - Graphical Output of Apollo Descent Engine LM-3 Flight Anomaly.

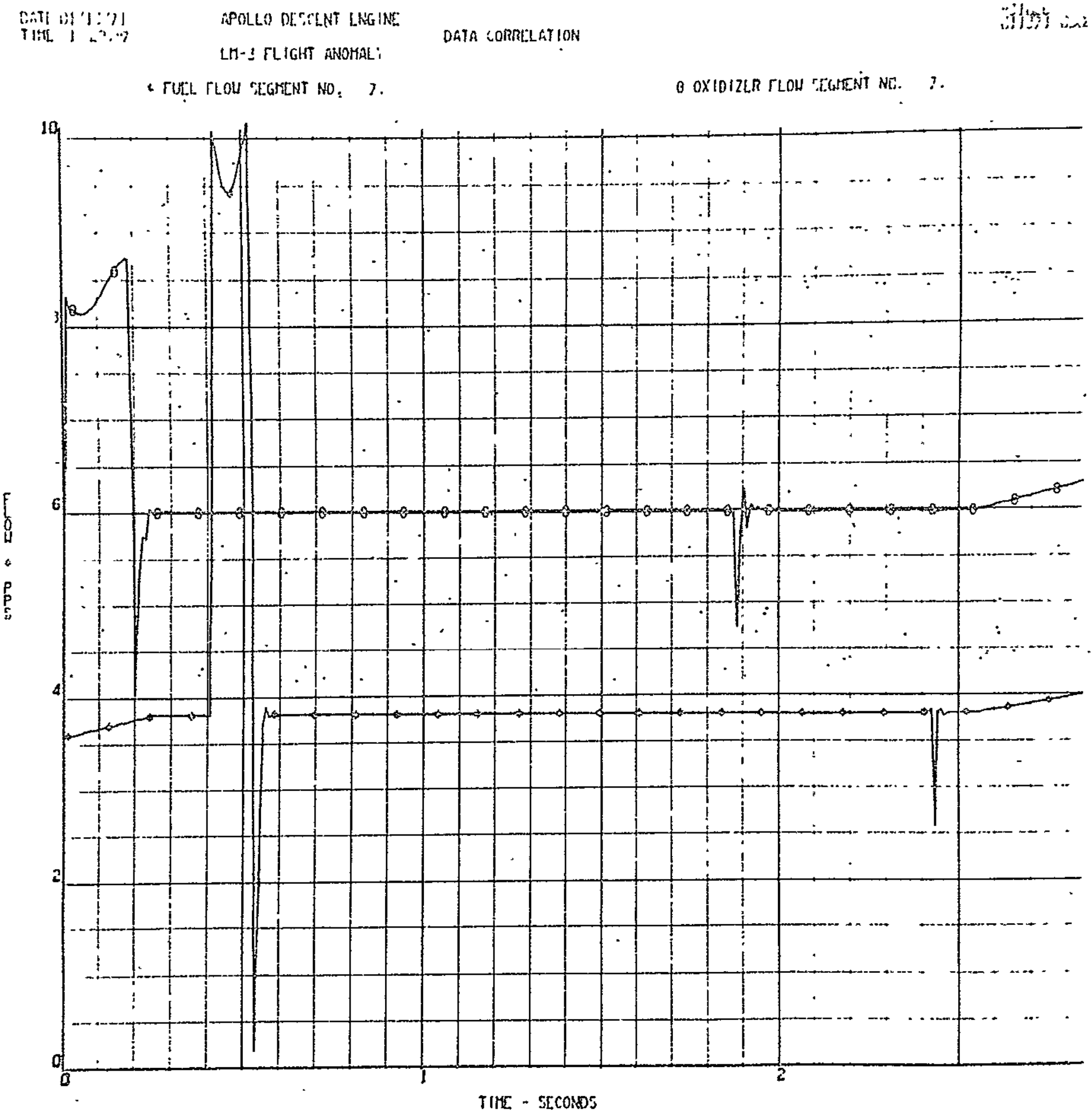

Figure C-1F - Graphical Output of Apollo Descent Engine LM-3 Flight Anomaly.

TABLE C-III

DESCENT ENGINE LM-3 ANOMALY PROGRAM OUTPUT LISTINGS

```
                                        DATE  01/13/71          TIME  1: 9.33
                  APOLLO DESCENT ENGINE
                                                 DATA CORRELATION
                  LM-3 FLIGHT ANOMALY
*          *          *          *         FUEL FEEDSYSTEM PARAMETERS      *           *           *           *
SEGMENT DATA      PRESSURE    FLOW      ACOUSTIC     AREA       LENGTH      RESISTANCE       DISOLVED GAS
  NO.   STATE       PSIA       PPS      VELOCITY     SQ. IN.    INCHES      SEC**2/IN**5     LBS G / LB L
                                        IN / SEC
   1    FULL        45.00     3.5700    48889.0      2.5000     10.20       0.1120E-03       0.0
   2    FULL        45.00     3.5700    48889.0      2.5000     10.20       0.1604E-01       0.0
   3    FULL        43.67     3.5437    48889.0      0.0         0.0        0.6680E-02       0.0
   4    FULL        46.25     3.5437    48889.0      2.5000     10.20       0.1120E-03       0.0
   5    FULL        45.00     3.5700    48889.0      2.5000     13.00       0.1430E-03       0.0
   6    FULL        45.00     3.5700    48889.0      2.5000     15.00       0.1650E-03       0.0
   7    FULL        45.00     3.5700    48889.0      2.5000     12.20       0.1340E-03       0.0
   8    FULL        45.00     3.5700    48889.0      0.0         0.0        0.0              0.0
   9    FULL       235.00     3.5700    48889.0      2.9200     11.00       0.1210E-03       0.0
  10    FULL       235.00     3.5700    48889.0      2.9200     13.00       0.1430E-03       0.0
  11    FULL       235.00     3.5700    48889.0      2.9200     15.00       0.1650E-03       0.0
  12    FULL       235.00     3.5700    48889.0      2.9200     17.00       0.1870E-03       0.0
  13    FULL       235.00     3.5700    48889.0      2.9200     19.00       0.2090E-03       0.0
  14    FULL       235.00     3.5700    48889.0      2.9200     21.00       0.2310E-03       0.0
  15    FULL       235.00     3.5700    48889.0      2.9200     23.00       0.2530E-03       0.0
  16    FULL       235.00     3.5700    48889.0      2.9200     20.00       0.2200E-03       0.0
  17    FULL       235.00     3.5700    48889.0      2.9200     17.00       0.1870E-03       0.0
  18    FULL       235.00     3.5700    51152.3      3.2200     11.00       0.1150E-03       0.0
  19    FULL       235.00     3.5700    51152.3      3.2200     15.00       0.1570E-03       0.0
  20    FULL       235.00     3.5700    51152.3      3.2200     19.00       0.1990E-03       0.0
  21    FULL       235.00     3.5700    51152.3      3.2200     17.00       0.1780E-03       0.0
  22    FULL       235.00     3.5700    51152.3      3.2200     10.20       0.1070E-03       0.0
  23    FULL       235.00     3.5700    60000.0      0.0         0.0        0.0              0.0
```

```
                                    DATE  01/13/71        TIME  1: 9.33
                  APOLLO DESCENT ENGINE
                                              DATA CORRELATION
                  LM-3 FLIGHT ANOMALY
 *         *         *         *      OXICIZER FEEDSYSTEM CONSTANTS       *         *         *         *
   SEGMENT DATA     PRESSURE    FLOW      ACCUSTIC     AREA       LENGTH     RESISTANCE       DISOLVED GAS
    NO.   STATE       PSIA      PPS       VELOCITY    SQ. IN.     INCHES     SEC**2/IN**5     LBS G / LB L
                                          IN / SEC
     1    FULL       105.00    5.7300     34613.9     2.9200       7.00      0.3900E-04       0.0
     2    FULL       105.00    5.7300     34613.9     2.9200       7.40      0.4200E-04       0.0
     3    FULL       104.57    5.7160     34613.9     0.0          0.0       0.1293E-02       0.0
     4    FULL       105.38    5.7160     34613.9     2.9200       7.00      0.3900E-04       0.0
     5    FULL       105.00    5.7300     34613.9     2.9200       9.00      0.5100E-04       0.0
     6    FULL       105.00    5.7300     34613.9     2.9200      11.00      0.6200E-04       0.0
     7    FULL       105.00    5.7300     34613.9     2.9200      15.00      0.8400E-04       0.0
     8    FULL       105.00    5.7300     34613.9     0.0          0.0       0.0              0.0
     9    FULL       236.00    5.7300     34613.9     2.9200      11.00      0.6200E-04       0.0
    10    FULL       236.00    5.7300     34613.9     2.9200      13.00      0.7300E-04       0.0
    11    FULL       236.00    5.7300     34613.9     2.9200      15.00      0.8400E-04       0.0
    12    FULL       236.00    5.7300     34613.9     2.9200      17.00      0.9600E-04       0.0
    13    FULL       236.00    5.7300     34613.9     2.9200      19.00      0.1070E-03       0.0
    14    FULL       236.00    5.7300     34613.9     2.9200      21.00      0.1240E-03       0.0
    15    FULL       236.00    5.7300     34613.9     2.9200      23.00      0.1290E-03       0.0
    16    FULL       236.00    5.7300     34613.9     2.9200      20.00      0.1120E-03       0.0
    17    FULL       236.00    5.7300     34613.9     2.9200      17.00      0.9600E-04       0.0
    18    FULL       236.00    5.7300     34896.7     4.4200      11.00      0.1150E-03       0.0
    19    FULL       236.00    5.7300     34896.7     4.4200      15.00      0.1560E-03       0.0
    20    FULL       236.00    5.7300     34896.7     4.4200      19.00      0.1970E-03       0.0
    21    FULL       236.00    5.7300     34896.7     4.4200      17.00      0.1760E-03       0.0
    22    FULL       236.00    5.7300     34896.7     4.4200      10.00      0.1040E-03       0.0
    23    FULL       236.00    5.7300     40500.0     0.0          0.0       0.0              0.0
```

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                                       DATE  01/13/71          TIME  1: 9.33
                  APOLLO DESCENT ENGINE
                                             DATA CORRELATION
---------------------------------------------------------------------------------------------------------
                  LM-3 FLIGHT ANOMALY
 *         *         *         *         FEEDSYSTEM CONFIGURATION        *         *         *         *
                      FUEL                                                     OXIDIZER
---------------------------------------------------------------------------------------------------------
                                            SEGMENT BRANCH DATA
INDEX INLET  *     *     *    BRANCHES     *     *     *  INLET  *     *     *   BRANCHES    *     *     *
---------------------------------------------------------------------------------------------------------
                                               CAPPED SEGMENTS
                              0,  0,  0,  0,  0,                             0,  0,  0,  0,  0,
---------------------------------------------------------------------------------------------------------
                                 FUEL ICRDER ARRAY           *       NSEGF = 22
      2    5    6    7   10   11   12   13   14   15   16   17   18   19   20   21   22
---------------------------------------------------------------------------------------------------------
                                 OXIDIZER IORDER ARRAY       *       NSEGO = 22
      2    5    6    7   10   11   12   13   14   15   16   17   18   19   20   21   22
---------------------------------------------------------------------------------------------------------
                                 CUTOFF SEGMENTS
                  FUEL                                                   OXIDIZER


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```

```
                              FUEL VALVE TABLE
  INDEX  SEGMENT  *        *        VALUES
    1      323  235.000000  0.0     235.000000 10.000000  0.0       0.0       0.0       0.0
    2        3    0.440000 10.000000  0.0       0.0       0.0       0.0       0.0       0.0
    3      108    0.046646  0.0       0.049781  0.250000  0.049781  2.549999  0.058009  3.549999
    4      201    0.195483  0.0       0.203234  0.250000  0.203234  2.549999  0.223938  3.549999

                              OXIDIZER VALVE TABLE
  INDEX  SEGMENT  *        *        VALUES
    1      323  236.000000  0.0     236.000000 10.000000  0.0       0.0       0.0       0.0
    2        3    1.000000 10.000000  0.0       0.0       0.0       0.0       0.0       0.0
    3      108    0.059659  0.0       0.063405  0.250000  0.063405  2.549999  0.074018  3.549999
    4      201    0.092893  0.0       0.098459  0.250000  0.098459  2.549999  0.112530  3.549999

                              FUEL FUNGEN TABLE

                              CXIDIZER FUNGEN TABLE
```

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                              CAVITATING VENTURI DATA
                                     FUEL                                             OXIDIZER
INDEX NO.                   1         2          3          4           1         2          3          4
SEGMENT NO.                 8.        0.         0.         0.          8.        0.         0.         0.
UPSTREAM AREA - SQ. IN.     2.919999  0.0        0.0        0.0         2.919999  0.0        0.0        0.0
THROAT AREA - SQ. IN.       0.046646  0.0        0.0        0.0         0.059659  0.0        0.0        0.0
PRESSURE RECOVERY RATIO     0.100000  0.0        0.0        0.0         0.100000  0.0        0.0        0.0

                              ORIFICE DATA

                              ACCUMULATOR DATA
```

2 3

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                              INJECTOR MANIFOLD DATA                               OXIDIZER
                                     FUEL
INDEX NO.                          1          2          3          4          1          2          3          4
SEGMENT NO.                   1.000000     0.0        0.0        0.0     1.000000     0.0        0.0        0.0
MANIFOLD VOLUME - CU.IN.       45.0000     0.0        0.0        0.0      30.0000     0.0        0.0        0.0
ORIFICE LENGTH - INCHES       0.375000     0.0        0.0        0.0     0.250000     0.0        0.0        0.0
INJECTOR C-SUB-D*A - SQIN     0.195489     0.0        0.0        0.0     0.092893     0.0        0.0        0.0
FLAME FRONT DISTANCE-IN.      1.000000     0.0        0.0        0.0     0.500000     0.0        0.0        0.0

                              COMBUSTION CHAMBER DATA
INDEX NO.                          1                  2                  3                  4
CHAMBER PRESSURE - PSIA         29.3508              0.0                0.0                0.0
OXIDIZER FLOWRATE - PPS          5.7300              0.0                0.0                0.0
FUEL FLOWRATE - PPS              3.5700              0.0                0.0                0.0
OXIDIZER FRACTION              0.616129              0.0                0.0                0.0
THROAT AREA - SQ. IN.            54.400              0.0                0.0                0.0
CHAMBER VOLUME - CU. IN.       2557.000              0.0                0.0                0.0
NOZZLE EXIT AREA - SQ. IN.          0.0              0.0                0.0                0.0
THRUST COEFFICIENT              1.70000              0.0                0.0                0.0
ENGINE AMBIENT PRESSURE - PSIA      0.0              0.0                0.0                0.0
ENGINE THRUST - POUNDS          2714.36              0.0                0.0                0.0

                              COMBUSTION DATA
        BASE PRESSURE =  150.0 PSIA                                 GAS CONSTANT CORRECTION =0.027790
        CSTAR CORRECTION =0.008453                                  EFFICIENCY CORRECTION =0.0
                       OX. FRACTION              GAS CONSTANT          CSTAR / G            EFFICIENCY
                        -0.0050                  -2.0000E 05             15.000               0.8160
                         0.0                      2.9300E 05             41.500               0.8180
                         0.0200                   2.8200E 06            115.000               0.8260
                         0.0400                   3.0400E 06            131.500               0.8330
                         0.0600                   3.0700E 06            132.900               0.8410
                         0.1000                   3.1300E 06            134.700               0.8560
                         0.2000                   3.2400E 06            138.000               0.8890
                         0.2500                   3.2800E 06            139.800               0.9030
                         0.3000                   3.4200E 06            142.600               0.9200
                         0.3500                   3.8700E 06            148.800               0.9330
                         0.4500                   4.6000E 06            165.000               0.9590
                         0.5000                   4.8800E 06            171.300               0.9670
                         0.5500                   5.0300E 06            175.800               0.9740
                         0.6000                   5.0200E 06            178.100               0.9760
                         0.6500                   4.8600E 06            176.800               0.9730
                         0.7000                   4.5500E 06            171.100               0.9640
                         0.8000                   3.6300E 06            152.000               0.9220
```

NOT REPRODUCIBLE

Zy

0.9000	2.2700E 06	116.600	0.8590
0.9800	3.7000E 05	58.700	0.8010
1.0000	1.3300E 05	29.400	0.7870
1.0050	1.0000E 04	21.000	0.7810

```
                                   DATE  01/13/71        TIME  1: 9.33
          APOLLO DESCENT ENGINE
                                         DATA CORRELATION
          LM-3 FLIGHT ANOMALY

  *          INPUT DATA CONSTANTS            *        *         FUEL                  OXIDIZER

  ENTRAINED GAS - LBS GAS / LB LIQUID                         0.0                   0.0
  PROPELLANT DENSITY - POUNDS / CUBIC INCH                    0.03250               0.05200
  LIQUID TEMPERATURE - DEGREES RANKINE                         530.0                 530.0
  PROPELLANT ACOUSTIC VELOCITY - INCHES / SECOND              60000.0               40500.0
  VAPOR PRESSURE CURVE FIT CONSTANTS - CON1                   8.3446E-03            8.9489E-03
   ( LOG(PVAP) = CON1 * TEMP + CON2 )
                                          - CON2             -4.1095E 00           -3.6294E 00
  PROPELLANT MOLECULAR WEIGHT                                  41.8                  92.0
  PRESSURANT GAS MOLECULAR WEIGHT                              4.0                   4.0
  RATIO OF SPECIFIC HEATS - PRESSURANT GAS                     1.670                 1.670
  RATIO OF SPECIFIC HEATS - PROPELLANT VAPOR                   1.050                 1.100

  DISSOLVED GAS EVOLUTION TIME CONSTANT - 1/SEC.              1.0000E 01            1.0000E 01
  DISSOLVED GAS CONCENTRATION - LBS GAS / LB LIQ / PSI        8.8889E-06            2.0526E-05
  PROPELLANT TANK ULLAGE - CUBIC INCHES                       0.0                   0.0
  PROPELLANT TANK INITIAL PRESSURE - PSIA                        0.0                   0.0
  PRESSURANT GAS BOTTLE VOLUME - CUBIC INCHES                 0.0                   0.0

  PROPELLANT LIQUID HEAT CAPACITY - BTU / LB / DEGREE R       6.9100E-01            3.6800E-01
  PRESSURANT - LOW PRESSURE C-SUB-V                           7.5000E-01            7.5000E-01
  PRESSURANT - HIGH PRESSURE C-SUB-V                          0.0                   0.0
  PRESSURANT - HIGH PRESSURE C-SUB-P                          0.0                   0.0
  PRESSURANT - HIGH PRESSURE GAMMA                             0.0                   0.0
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                                       DATE  01/13/71         TIME  1: 9.33
                APOLLO DESCENT ENGINE
                                            DATA CORRELATION
                LM-3 FLIGHT ANOMALY
 0.0          45.00000      3.57000    105.00000     5.73000      0.0           0.0         29.35081     0.61613
 0.009520     49.31779      3.63240    228.43883     8.09291      0.0           0.00277     35.44040     0.69459
 0.019040     48.62859      3.57788    227.67528     8.18606      0.0           0.00263     35.30196     0.70172
 0.028560     48.58351      3.58324    224.93532     8.16350      0.0           0.00249     35.36827     0.69501
 0.038080     48.65289      3.59402    222.69366     8.13516      0.0           0.00236     35.37247     0.69306
 0.047600     48.68669      3.60218    221.03070     8.11646      0.0           0.00223     35.37219     0.69305
 0.057120     48.75662      3.61199    220.00687     8.11209      0.0           0.00210     35.40588     0.69233
 0.066640     48.84312      3.62094    219.76390     8.12414      0.0           0.00196     35.47252     0.69170
 0.076159     48.97234      3.63001    220.22563     8.15105      0.0           0.00183     35.57130     0.69158
 0.085679     49.11687      3.63891    221.33151     8.19077      0.0           0.00168     35.69341     0.69224
 0.095199     49.29662      3.64792    222.96249     8.24298      0.0           0.00154     35.84180     0.69320
 0.104718     49.49413      3.65698    225.02791     8.30315      0.0           0.00138     36.01118     0.69421
 0.114238     49.69658      3.66600    227.40985     8.36955      0.0           0.00122     36.19298     0.69511
 0.123757     49.91176      3.67498    229.89093     8.43797      0.0           0.00106     36.38097     0.69640
 0.133277     50.12143      3.68412    232.27435     8.50504      0.0           0.00089     36.56490     0.69763
 0.142796     50.32883      3.69312    234.43968     8.56630      0.0           0.00072     36.74274     0.69904
 0.152316     50.51500      3.70230    236.16504     8.61946      0.0           0.00055     36.90083     0.69997
 0.161836     50.67857      3.71146    237.38156     8.66097      0.0           0.00039     37.03899     0.70006
 0.171355     50.81709      3.72058    237.95345     8.68886      0.0           0.00023     37.15358     0.70017
 0.180875     50.93237      3.72970    237.88286     8.70499      0.0           0.00007     37.24138     0.69994
 0.190394     51.00427      3.73923    238.38390     8.68863      0.0           0.00290     37.28096     0.69915
 0.199914     50.97186      3.74827    234.76157     8.63495      0.0           0.00290     37.22531     0.69726
 0.209433     50.87590      3.75750    229.73552     8.54396      0.0           0.00290     37.09698     0.69461
 0.218953     50.77402      3.76646    225.33345     8.46498      0.0           0.00290     36.97643     0.69202
 0.228473     50.72232      3.77562    221.73227     8.40386      0.0           0.00290     36.89278     0.69002
 0.237992     50.68373      3.78452    218.73947     8.35326      0.0           0.00290     36.82809     0.68819
 0.247512     50.65202      3.79352    215.85083     8.30560      0.0           0.00290     36.76985     0.68658
 0.257031     50.59436      3.79820    213.14182     8.25047      0.0           0.00290     36.69038     0.68509
 0.266551     50.46255      3.79781    210.56270     8.19260      0.0           0.00290     36.57112     0.68309
 0.276070     50.34724      3.79797    208.10571     8.13725      0.0           0.00290     36.45024     0.68148
 0.285590     50.23056      3.79774    205.76585     8.08422      0.0           0.00290     36.33270     0.68059
 0.295110     50.11543      3.79783    203.53221     8.03333      0.0           0.00290     36.21519     0.67936
 0.304629     50.00722      3.79789    201.39925     7.98448      0.0           0.00290     36.10760     0.67765
 0.314149     49.89748      3.79776    199.35912     7.93747      0.0           0.00290     36.00258     0.67643
 0.323668     49.79568      3.79780    197.40587     7.89226      0.0           0.00290     35.90224     0.67504
 0.333188     49.70132      3.79788    195.53416     7.84872      0.0           0.00290     35.80085     0.67392
 0.342707     49.60672      3.79781    193.73900     7.80675      0.0           0.00290     35.70547     0.67282
 0.352227     49.50908      3.79775    192.01541     7.76627      0.0           0.00290     35.61232     0.67190
 0.361747     49.41365      3.79785    190.35738     7.72717      0.0           0.00290     35.52309     0.67066
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0.371266    49.33585     3.79778   188.76250   7.68939   0.0       0.00290   35.43817   0.66914
0.380786    49.24661     3.79782   187.22783   7.65289   0.0       0.00290   35.35016   0.66818
0.390305    49.16454     3.79773   185.74931   7.61757   0.0       0.00290   35.26964   0.66730
0.399825    49.08356     3.79763   184.32466   7.58540   0.0       0.00290   35.18906   0.66644
0.409345    49.00835     3.79774   182.95044   7.55031   0.0       0.00290   35.11284   0.66508
0.418864   147.73988    10.17029   181.73790   7.20564   0.00268   0.00290   47.52788   0.41477
0.428384   141.68512     9.89465   180.72684   7.16799   0.00244   0.00290   47.42796   0.42055
0.437903   136.84225     9.65762   179.74239   7.15230   0.00222   0.00290   47.03304   0.42528
0.447423   133.63075     9.49962   178.78270   7.13494   0.00201   0.00290   46.72502   0.42890
0.456942   131.92651     9.41679   177.84750   7.11577   0.00180   0.00290   46.50720   0.43047
0.466462   131.62459     9.40629   176.93852   7.09488   0.00158   0.00290   46.37560   0.43003
0.475982   132.58829     9.46155   176.05577   7.07244   0.00135   0.00290   46.32443   0.42775
0.485501   134.67046     9.57351   175.20033   7.04874   0.00109   0.00290   46.34169   0.42410
0.495021   137.68742     9.73131   174.37204   7.02408   0.00080   0.00290   46.41800   0.41940
0.504540   141.37759     9.91959   173.57115   6.99891   0.00048   0.00290   46.53511   0.41383
0.514060   145.34169    10.11831   172.79709   6.97381   0.00014   0.00290   46.67070   0.40814
0.523579   217.63217    10.11975   172.05228   6.95064   0.00290   0.00290   46.67332   0.40713
0.533099   203.29704     9.76155   171.32133   6.94404   0.00290   0.00290   46.19984   0.41559
0.542619   190.92575     9.36194   170.60013   6.94003   0.00290   0.00290   45.63452   0.42567
0.552138   182.49608     9.08299   169.88960   6.93232   0.00290   0.00290   45.21306   0.43280
0.561658   175.70482     8.86210   169.19110   6.92257   0.00290   0.00290   44.86960   0.43853
0.571177   169.60103     8.66237   168.50581   6.91229   0.00290   0.00290   44.55580   0.44380
0.580697   164.14761     8.47942   167.83400   6.90180   0.00290   0.00290   44.26163   0.44865
0.590217   159.20113     8.31144   167.17500   6.89155   0.00290   0.00290   43.96881   0.45326
0.599736   154.70978     8.15693   166.52847   6.88164   0.00290   0.00290   43.67845   0.45758
0.609256   150.60008     8.01356   165.89398   6.87163   0.00290   0.00290   43.40285   0.46158
0.618775   146.82716     7.88009   165.27116   6.86158   0.00290   0.00290   43.14000   0.46542
0.628295   143.34691     7.75538   164.66055   6.85152   0.00290   0.00290   42.88922   0.46904
0.637814   140.12543     7.63851   164.06071   6.84144   0.00290   0.00290   42.64920   0.47247
0.647334   137.13293     7.52869   163.47244   6.83138   0.00290   0.00290   42.41827   0.47564
0.656854   134.34470     7.42523   162.89525   6.82136   0.00290   0.00290   42.19742   0.47880
0.666373   131.73915     7.32753   162.32922   6.81141   0.00290   0.00290   41.98538   0.48176
0.675893   129.29819     7.23507   161.77373   6.80150   0.00290   0.00290   41.78113   0.48458
0.685412   127.00571     7.14742   161.22849   6.79166   0.00290   0.00290   41.58421   0.48720
0.694932   124.84772     7.06416   160.69327   6.78190   0.00290   0.00290   41.39409   0.48977
0.704451   122.81227     6.98493   160.16829   6.77223   0.00290   0.00290   41.21037   0.49230
0.713971   120.88855     6.90942   159.65262   6.76263   0.00290   0.00290   41.03275   0.49462
0.723491   119.06705     6.83736   159.14629   6.75313   0.00290   0.00290   40.86073   0.49690
0.733010   117.33958     6.76849   158.64902   6.74373   0.00290   0.00290   40.69412   0.49909
0.742530   115.69849     6.70255   158.16167   6.73442   0.00290   0.00290   40.53339   0.50120
0.752049   114.13744     6.53935   157.68298   6.72519   0.00290   0.00290   40.37764   0.50318
0.761569   112.64998     6.57872   157.21329   6.71608   0.00290   0.00290   40.22743   0.50516
0.771088   111.23105     6.520[illegible]   156.75174   6.70709   0.00290   0.00290   40.08006   0.50705
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0.780608	109.87570	6.46458	156.29849	6.69820	0.00290	0.00290	39.93741	0.50887
0.790128	108.57716	6.41074	155.85384	6.68944	0.00290	0.00290	39.79782	0.51064
0.799647	107.33607	6.35881	155.41628	6.68076	0.00290	0.00290	39.66252	0.51235
0.809167	106.14462	6.30875	154.98680	6.67221	0.00290	0.00290	39.53058	0.51401
0.818686	105.00163	6.26047	154.56497	6.66376	0.00290	0.00290	39.40111	0.51555
0.828206	103.90410	6.21385	154.15103	6.65547	0.00290	0.00290	39.27556	0.51709
0.837726	102.84914	6.16881	153.74379	6.64725	0.00290	0.00290	39.15327	0.51855
0.847245	101.83426	6.12527	153.34390	6.63915	0.00290	0.00290	39.03433	0.52008
0.856765	100.85713	6.08314	152.95059	6.63116	0.00290	0.00290	38.91713	0.52156
0.866284	99.91554	6.04236	152.56422	6.62327	0.00290	0.00290	38.80299	0.52296
0.875804	99.00758	6.00285	152.18457	6.61550	0.00290	0.00290	38.69133	0.52424
0.885323	98.13138	5.96456	151.81123	6.60782	0.00290	0.00290	38.58284	0.52561
0.894843	97.28522	5.92741	151.44449	6.60026	0.00290	0.00290	38.47626	0.52674
0.904363	96.46750	5.89137	151.08339	6.59279	0.00290	0.00290	38.37241	0.52805
0.913882	95.67677	5.85637	150.72865	6.58542	0.00290	0.00290	38.27061	0.52934
0.923402	94.91170	5.82237	150.38000	6.57816	0.00290	0.00290	38.17111	0.53051
0.932921	94.17097	5.78932	150.03691	6.57100	0.00290	0.00290	38.07338	0.53152
0.942441	93.45343	5.75719	149.69888	6.56392	0.00290	0.00290	37.97758	0.53271
0.951960	92.75797	5.72594	149.36745	6.55697	0.00290	0.00290	37.88409	0.53381
0.961480	92.08350	5.69551	149.04103	6.55009	0.00290	0.00290	37.79333	0.53486
0.971000	91.42905	5.66590	148.71983	6.54332	0.00290	0.00290	37.70326	0.53592
0.980519	90.79375	5.63705	148.40364	6.53664	0.00290	0.00290	37.61516	0.53692
0.990039	90.17676	5.60892	148.09274	6.53004	0.00290	0.00290	37.52885	0.53785
0.999558	89.57722	5.58152	147.78680	6.52354	0.00290	0.00290	37.44461	0.53888
1.009065	88.99443	5.55476	147.48560	6.51709	0.00290	0.00290	37.36360	0.53975
1.018571	88.42775	5.52895	147.18930	6.51093	0.00290	0.00290	37.27437	0.54113
1.028077	87.87631	5.50325	146.89760	6.50454	0.00290	0.00290	37.20201	0.54159
1.037583	87.33966	5.47835	146.61037	6.49833	0.00290	0.00290	37.12546	0.54247
1.047090	86.81702	5.45419	146.32784	6.49236	0.00290	0.00290	37.04430	0.54335
1.056596	86.30797	5.43048	146.04971	6.48635	0.00290	0.00290	36.97076	0.54420
1.066102	85.81201	5.40747	145.77608	6.46055	0.00290	0.00290	36.89040	0.54408
1.075608	85.32855	5.38466	145.50627	6.47459	0.00290	0.00290	36.82564	0.54585
1.085114	84.85715	5.36251	145.24075	6.46883	0.00290	0.00290	36.75453	0.54665
1.094621	84.39725	5.34102	144.97963	6.46322	0.00290	0.00290	36.68321	0.54743
1.104127	63.94862	5.31973	144.72198	6.45760	0.00290	0.00290	36.61502	0.54821
1.113633	83.51074	5.29904	144.46854	6.45210	0.00290	0.00290	36.54691	0.54897
1.123139	83.08310	5.27881	144.21877	6.44669	0.00290	0.00290	36.47937	0.54971
1.132646	82.66157	5.25878	143.97289	6.44126	0.00290	0.00290	36.41583	0.55045
1.142152	82.25763	5.23919	143.73080	6.43587	0.00290	0.00290	36.35402	0.55168
1.151658	81.85909	5.22015	143.49210	6.43063	0.00290	0.00290	36.29306	0.55186
1.161164	81.46947	5.20153	143.25685	6.42552	0.00290	0.00290	36.22981	0.55255
1.170671	81.08859	5.18310	143.02522	6.42036	0.00290	0.00290	36.17027	0.55366
1.180177	80.71613	5.16526	142.79692	6.41537	0.00290	0.00290	36.11090	0.55389

NOT REPRODUCIBLE

1.189683	80.35176	5.14763	142.57191	6.41042	0.00290	0.00290	36.04843	0.55555
1.199189	79.99525	5.13043	142.35028	6.40552	0.00290	0.00290	35.99474	0.55519
1.208695	79.64629	5.11341	142.13139	6.40062	0.00290	0.00290	35.93980	0.55581
1.218202	79.30476	5.09698	141.91599	6.39596	0.00290	0.00290	35.88069	0.55644
1.227708	78.97034	5.08062	141.70406	6.39121	0.00290	0.00290	35.82811	0.55704
1.237214	78.64276	5.06464	141.49504	6.38657	0.00290	0.00290	35.77422	0.55763
1.246720	78.32188	5.04914	141.28891	6.38209	0.00290	0.00290	35.71751	0.55823
1.256227	78.00774	5.02943	141.08099	6.40594	0.00290	0.00290	35.74405	0.56004
1.265733	77.70097	5.01319	140.80655	6.40046	0.00290	0.00290	35.70915	0.56069
1.275239	77.40025	4.99852	140.65562	6.39566	0.00290	0.00290	35.65733	0.56123
1.284745	77.10550	4.98413	140.44850	6.39096	0.00290	0.00290	35.60606	0.56176
1.294251	76.81636	4.97003	140.24428	6.38634	0.00290	0.00290	35.55481	0.56238
1.303758	76.53281	4.95615	140.04311	6.38177	0.00290	0.00290	35.50499	0.56287
1.313264	76.25453	4.94252	139.84462	6.37726	0.00290	0.00290	35.45581	0.56335
1.322770	75.98157	4.92926	139.64861	6.37287	0.00290	0.00290	35.40585	0.56378
1.332276	75.71367	4.91598	139.45531	6.36842	0.00290	0.00290	35.35922	0.56428
1.341783	75.45064	4.90307	139.26508	6.36411	0.00290	0.00290	35.31148	0.56476
1.351289	75.19252	4.89040	139.07744	6.35987	0.00290	0.00290	35.26413	0.56524
1.360795	74.93953	4.87798	138.89258	6.35570	0.00290	0.00290	35.21719	0.56571
1.370301	74.69110	4.86574	138.71027	6.35158	0.00290	0.00290	35.16946	0.56617
1.379807	74.44710	4.85346	138.53061	6.34737	0.00290	0.00290	35.12978	0.56662
1.389314	74.20737	4.84189	138.35306	6.34346	0.00290	0.00290	35.08202	0.56705
1.398820	73.97185	4.83008	138.17780	6.33942	0.00290	0.00290	35.03914	0.56751
1.408326	73.74040	4.81836	138.00494	6.33535	0.00290	0.00290	34.99976	0.56794
1.417832	73.51294	4.80714	137.83492	6.33153	0.00290	0.00290	34.95631	0.56836
1.427339	73.28934	4.79612	137.66702	6.32777	0.00290	0.00290	34.91075	0.56879
1.436845	72.92488	5.94715	104.49968	0.59439	0.00290	0.00216	13.85638	0.09072
1.446351	72.45435	5.95930	73.39148	5.98556	0.00290	0.00149	13.20605	0.07494
1.455857	71.99005	5.95514	51.13937	5.98573	0.00290	0.00101	12.83199	0.06097
1.465364	71.53313	5.94618	35.34193	5.98567	0.00290	0.00068	12.55883	0.04794
1.474870	71.08311	5.94426	24.21518	5.98563	0.00290	0.00046	12.14790	0.03544
1.484376	70.63719	5.96726	16.62215	5.98561	0.00290	0.00031	11.22489	0.02392
1.493882	70.18860	6.02324	11.90716	5.98575	0.00290	0.00021	9.64833	0.01543
1.503388	69.73370	6.08011	9.06422	5.98573	0.00290	0.00016	8.07006	0.01035
1.512895	69.27528	6.11113	7.32079	5.98557	0.00290	0.00013	7.00963	0.00702
1.522401	68.81763	6.15510	6.18886	5.98575	0.00290	0.00010	5.57320	0.00031
1.531907	68.37039	6.12565	6.45008	5.98569	0.00290	0.00010	5.72206	0.00023
1.541413	49.12423	0.70087	4.25853	5.98561	0.00206	0.00007	1.80195	0.12718
1.550920	33.98061	0.58141	2.67619	5.98562	0.00141	0.00004	1.41206	0.10893
1.560426	23.40826	0.45041	1.68245	5.98563	0.00096	0.00003	1.12596	0.09108
1.569932	16.05890	0.37665	1.10324	5.98575	0.00065	0.00002	0.89947	0.07034
1.579438	10.97062	0.32623	0.79557	5.98562	0.00044	0.00001	0.71680	0.05544
1.588944	7.46279	0.26734	0.61581	5.98562	0.00030	0.00001	0.57652	0.04209

1.598451	5.05361	0.21825	0.49003	5.98557	0.00020	0.00001	0.46408	0.03867
1.607957	3.40702	0.18262	0.31271	5.98575	0.00013	0.00000	0.19399	0.0
1.617463	2.28636	0.14195	0.24719	5.98566	0.00009	0.00000	0.34503	0.12881
1.626969	1.52708	0.11398	0.28586	0.00642	0.00006	0.00000	0.27530	0.09699
1.636476	1.01502	0.09676	0.18226	0.01642	0.00004	0.00000	0.11305	0.0
1.645982	0.67133	0.07935	0.09755	0.01133	0.00002	0.00000	0.06462	0.0
1.655488	0.44177	0.05338	0.16369	0.0	0.00002	0.00000	0.16722	0.13526
1.664994	0.28920	0.04912	0.09607	0.01239	0.00001	0.00000	0.05670	0.0
1.674500	0.18831	0.04000	0.04732	0.00716	0.00001	0.00000	0.03416	0.0
1.684007	0.12195	0.03168	0.02751	0.00297	0.00000	0.00000	0.02524	0.0
1.693513	0.07854	0.02529	0.01948	0.00317	0.00000	0.00000	0.01690	1.00000
1.703019	0.05028	0.02171	0.00899	0.00401	0.00000	0.00000	0.00487	1.00000
1.712525	0.03201	0.01782	0.00364	0.00295	0.00000	0.00000	0.00141	1.00000
1.722032	0.02025	0.01435	0.00139	0.00196	0.00000	0.00000	0.00041	1.00000
1.731538	0.01273	0.01144	0.00050	0.00123	0.00000	0.00000	0.00012	1.00000
1.741044	0.00795	0.00907	0.00017	0.00073	0.00000	0.00000	0.00003	1.00000
1.750550	0.00494	0.00715	0.00005	0.00041	0.00000	0.00000	0.00001	1.00000
1.760056	0.00304	0.00562	0.00002	0.00022	0.00000	0.00000	0.00000	1.00000
1.769563	0.00186	0.00440	0.00000	0.00011	0.00000	0.00000	0.00000	1.00000
1.779069	0.00113	0.00343	0.00000	0.00005	0.00000	0.00000	0.00000	1.00000
1.788575	0.00068	0.00266	0.00000	0.00003	0.00000	0.00000	0.00000	1.00000
1.798081	0.00041	0.00206	0.00000	0.00003	0.00000	0.00000	0.00000	1.00000
1.807588	0.00024	0.00159	0.00000	0.00003	0.00000	0.00000	0.00000	1.00000
1.817094	0.00014	0.00122	0.00000	0.00004	0.00000	0.00000	0.00000	1.00000
1.826600	0.00008	3.79741	0.00000	0.00004	0.00000	0.00000	0.00000	1.00000
1.836106	0.00005	3.79747	0.00000	0.00004	0.00000	0.00000	0.00000	1.00000
1.845613	0.00003	3.79740	0.00000	0.00005	0.00000	0.00000	0.00000	1.00000
1.855119	0.00002	3.79747	0.00000	0.00006	0.00000	0.00000	0.00000	1.00000
1.864625	0.00001	3.79748	0.00000	0.00008	0.00000	0.00000	0.00000	1.00000
1.874131	0.00000	3.79747	0.00001	0.00014	0.00000	0.00000	0.00000	1.00000
1.883637	0.23246	3.79745	136.91151	7.01107	0.00001	0.00000	1.21709	1.00000
1.893144	1.41512	3.79748	83.21832	5.70503	0.00004	0.00000	2.31546	1.00000
1.902650	2.53294	3.79741	101.09247	6.21704	0.00006	0.00000	2.60976	1.00000
1.912156	2.73083	3.79738	92.22765	5.84604	0.00007	0.00000	2.73082	1.00000
1.921662	2.74347	3.79749	92.19870	5.95217	0.00007	0.00000	2.74141	1.00000
1.931169	2.75735	3.79746	94.30188	5.97154	0.00006	0.00000	2.75678	1.00000
1.940675	2.75812	3.79746	94.47144	5.98306	0.00006	0.00000	2.75742	1.00000
1.950181	2.75908	3.79747	94.33897	5.97788	0.00006	0.00000	2.75832	1.00000
1.959687	2.76035	3.79740	94.30124	5.97615	0.00006	0.00000	2.75963	1.00000
1.969193	2.75990	3.79745	94.72241	5.98649	0.00006	0.00000	2.75932	1.00000
1.978700	2.76005	3.79747	94.86380	5.99245	0.00006	0.00000	2.75944	1.00000
1.988206	2.76000	3.79749	94.81567	5.99014	0.00006	0.00000	2.75940	1.00000
1.997712	2.76005	3.79738	94.66464	5.98584	0.00006	0.00000	2.75947	1.00000

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2.007218   2.76005   3.79737   94.66719   5.98538   0.00005   0.00000   2.75949   1.00000
2.016725   2.76002   3.79746   94.66652   5.98518   0.00005   0.00000   2.75948   1.00000
2.026231   2.76000   3.79737   94.65710   5.98421   0.00005   0.00000   2.75949   1.00000
2.035737   2.75995   3.79738   94.71306   5.98627   0.00005   0.00000   2.75945   1.00000
2.045243   2.76007   0.00246   94.67384   5.98528   0.00005   0.00000   2.75948   1.00000
2.054749   2.76005   0.00248   94.70193   5.98650   0.00005   0.00000   2.75946   1.00000
2.064256   2.76007   0.00248   94.66641   5.98555   0.00005   0.00000   2.75948   1.00000
2.073762   2.76007   0.00247   94.67241   5.98551   0.00005   0.00000   2.75948   1.00000
2.083268   2.76005   0.00247   94.68085   5.98584   0.00004   0.00000   2.75946   1.00000
2.092774   2.76006   0.00250   94.68202   5.98550   0.00004   0.00000   2.75947   1.00000
2.102281   2.76002   0.00250   94.69304   5.98609   0.00004   0.00000   2.75945   1.00000
2.111787   2.76015   0.00247   94.67873   5.98571   0.00004   0.00000   2.75947   1.00000
2.121293   2.76007   0.00186   94.67995   5.98580   0.00004   0.00000   2.75947   1.00000
2.130799   2.76013   0.00286   94.67513   5.98558   0.00004   0.00000   2.75947   1.00000
2.140306   2.76002   0.00224   94.68227   5.98581   0.00004   0.00000   2.75947   1.00000
2.149812   2.76009   0.00258   94.68678   5.98580   0.00004   0.00000   2.75947   1.00000
2.159318   2.76010   0.00199   94.67126   5.98542   0.00003   0.00000   2.75947   1.00000
2.168824   2.76012   0.00281   94.68579   5.98584   0.00003   0.00000   2.75947   1.00000
2.178330   2.76003   0.00216   94.67053   5.98550   0.00003   0.00000   2.75947   1.00000
2.187837   2.75998   0.00271   94.68059   5.98592   0.00003   0.00000   2.75947   1.00000
2.197343   2.76016   0.00276   94.67805   5.98575   0.00003   0.00000   2.75947   1.00000
2.206849   2.76017   0.00277   94.68213   5.98582   0.00003   0.00000   2.75947   1.00000
2.216355   2.75991   0.00230   94.68576   5.98596   0.00003   0.00000   2.75947   1.00000
2.225862   2.76015   0.00225   94.68112   5.98571   0.00003   0.00000   2.75947   1.00000
2.235368   2.75997   0.00237   94.68796   5.98590   0.00002   0.00000   2.75947   1.00000
2.244874   2.76018   0.00215   94.68552   5.98575   0.00002   0.00000   2.75947   1.00000
2.254380   2.76008   0.00200   94.68420   5.98571   0.00002   0.00000   2.75947   1.00000
2.263886   2.75988   0.00232   94.67963   5.98579   0.00002   0.00000   2.75947   1.00000
2.273393   2.76002   0.00254   94.68384   5.98570   0.00002   0.00000   2.75947   1.00000
2.282899   2.76015   0.00260   94.68315   5.98576   0.00002   0.00000   2.75947   1.00000
2.292405   2.75991   0.00257   94.68056   5.98556   0.00002   0.00000   2.75947   1.00000
2.301911   2.75993   0.00238   94.68344   5.98590   0.00002   0.00000   2.75947   1.00000
2.311418   2.75997   0.00223   94.68283   5.98587   0.00001   0.00000   2.75947   1.00000
2.320924   2.76009   0.00250   94.68071   5.98567   0.00001   0.00000   2.75947   1.00000
2.330430   2.76005   0.00255   94.67781   5.98580   0.00001   0.00000   2.75947   1.00000
2.339936   2.76015   0.00269   94.68216   5.98597   0.00001   0.00000   2.75947   1.00000
2.349442   2.76004   0.00288   94.68260   5.98591   0.00001   0.00000   2.75947   1.00000
2.358949   2.76006   0.00253   94.68147   5.98590   0.00001   0.00000   2.75947   1.00000
2.368455   2.76005   0.00248   94.68349   5.98584   0.00001   0.00000   2.75947   1.00000
2.377961   2.75997   0.00252   94.68204   5.98576   0.00001   0.00000   2.75947   1.00000
2.387467   2.75996   0.00237   94.67607   5.98562   0.00000   0.00000   2.75947   1.00000
2.396974   2.75998   0.00250   94.68411   5.98600   0.00000   0.00000   2.75947   1.00000
2.406480   2.76005   0.00254   94.68294   5.98584   0.00000   0.00000   2.75947   1.00000
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 2.415986     2.76006     0.00251    94.67673    5.98583    0.00000    0.00000     2.75947    1.00000
 2.425492   -80.66464    -1.63764    96.22690    5.93615    0.00000    0.00000     6.66314    0.99956
 2.434999    44.07652     4.32693   113.36687    6.00126    0.00000    0.00000    21.40753    0.52305
 2.444505    40.78467     3.63535   119.46930    5.95245    0.00000    0.00000    27.66904    0.76751
 2.454011    43.86887     3.81515   121.89024    5.96880    0.00000    0.00000    30.95140    0.57989
 2.463517    44.83527     3.79188   122.68692    5.98791    0.00000    0.00000    30.78554    0.60648
 2.473023    44.82657     3.79997   122.82758    5.98387    0.00000    0.00000    30.96376    0.61001
 2.482530    44.81838     3.79795   122.83914    5.98635    0.00000    0.00000    30.88091    0.61658
 2.492036    44.84357     3.79825   122.84042    5.98555    0.00000    0.00000    30.92923    0.61030
 2.501542    44.83057     3.79883   122.83104    5.98613    0.00000    0.00000    30.90839    0.61188
 2.511048    44.80327     3.79730   122.83876    5.98596    0.00000    0.00000    30.91344    0.61147
 2.520555    44.81662     3.79821   122.83731    5.98582    0.00000    0.00000    30.90816    0.61284
 2.530061    44.80006     3.79751   122.83232    5.98568    0.00000    0.00000    30.90663    0.61184
 2.539567    44.79773     3.79757   122.82333    5.98564    0.00000    0.00000    30.90160    0.61285
 2.549073    44.79648     3.79741   122.83298    5.98575    0.00000    0.00000    30.90616    0.61183
 2.558579    44.82555     3.80136   122.81122    5.99171    0.00000    0.00000    30.92693    0.61189
 2.568086    44.89204     3.80768   122.87373    6.00061    0.00000    0.00000    30.96994    0.61184
 2.577592    44.95564     3.81335   122.98723    6.01068    0.00000    0.00000    31.02087    0.61188
 2.587098    45.02435     3.81949   123.07317    6.01967    0.00000    0.00000    31.07523    0.61080
 2.596604    45.08571     3.82525   123.15143    6.02946    0.00000    0.00000    31.11887    0.61188
 2.606111    45.15004     3.83130   123.24602    6.03860    0.00000    0.00000    31.16641    0.61188
 2.615617    45.21970     3.83732   123.33867    6.04841    0.00000    0.00000    31.21832    0.61076
 2.625123    45.27736     3.84309   123.42419    6.05774    0.00000    0.00000    31.26506    0.61190
 2.634629    45.35005     3.84911   123.50943    6.06703    0.00000    0.00000    31.31270    0.61214
 2.644135    45.41766     3.85508   123.59967    6.07676    0.00000    0.00000    31.36269    0.61300
 2.653642    45.48045     3.86093   123.69771    6.08615    0.00000    0.00000    31.41780    0.61191
 2.663148    45.54631     3.86700   123.79279    6.09571    0.00000    0.00000    31.46449    0.61191
 2.672654    45.60490     3.87276   123.87175    6.10492    0.00000    0.00000    31.50735    0.61302
 2.682160    45.67915     3.87885   123.96664    6.11458    0.00000    0.00000    31.56276    0.61192
 2.691667    45.74190     3.88480   124.04599    6.12394    0.00000    0.00000    31.61058    0.61193
 2.701173    45.80750     3.89068   124.14313    6.13371    0.00000    0.00000    31.66020    0.61193
 2.710679    45.87244     3.89645   124.23012    6.14271    0.00000    0.00000    31.71143    0.61258
 2.720185    45.93668     3.90257   124.31462    6.15234    0.00000    0.00000    31.75731    0.61192
 2.729692    46.00394     3.90856   124.41168    6.16216    0.00000    0.00000    31.80713    0.61194
 2.739198    46.06892     3.91451   124.49950    6.17145    0.00000    0.00000    31.85594    0.61195
 2.748704    46.13039     3.92043   124.58733    6.18086    0.00000    0.00000    31.90442    0.61194
 2.758210    46.19542     3.92625   124.66116    6.19010    0.00000    0.00000    31.95387    0.61195
 2.767716    46.26239     3.93222   124.76077    6.20018    0.00000    0.00000    32.00266    0.61195
 2.777223    46.32802     3.93824   124.85143    6.20974    0.00000    0.00000    32.05219    0.61197
 2.786729    46.39655     3.94471   124.94276    6.21908    0.00000    0.00000    32.10120    0.61197
 2.796235    46.45952     3.94904   125.02733    6.22833    0.00000    0.00000    32.15047    0.61195
 2.805741    46.52184     3.95597   125.11058    6.23765    0.00000    0.00000    32.19925    0.61196
 2.815248    46.59120     3.96204   125.20461    6.24721    0.00000    0.00000    32.24974    0.61197
```

```
   2.824754    46.65633     3.96782   125.28084      6.25660     0.00000     0.00000    32.29793    0.6119
   2.834260    46.71561     3.97383   125.37421      6.26633     0.00000     0.00000    32.34665    0.6119
   2.843766    46.78151     3.97975   125.45218      6.27540     0.00000     0.00000    32.39557    0.6120

IHC900I EXECUTION TERMINATING DUE TO ERROR COUNT FOR ERROR NUMBER  217

IHC217I FIOCS - END OF DATA SET ON UNIT    5

TRACEBACK  ROUTINE  CALLED FROM ISN   REG. 14   REG. 15   REG.  0   REG.  1

          FRDNL#                      0006A1DC  0007D158  0000A414  00069920

            MAIN                      000106CE  010698A0  FFFFFF2E  000AEFF8

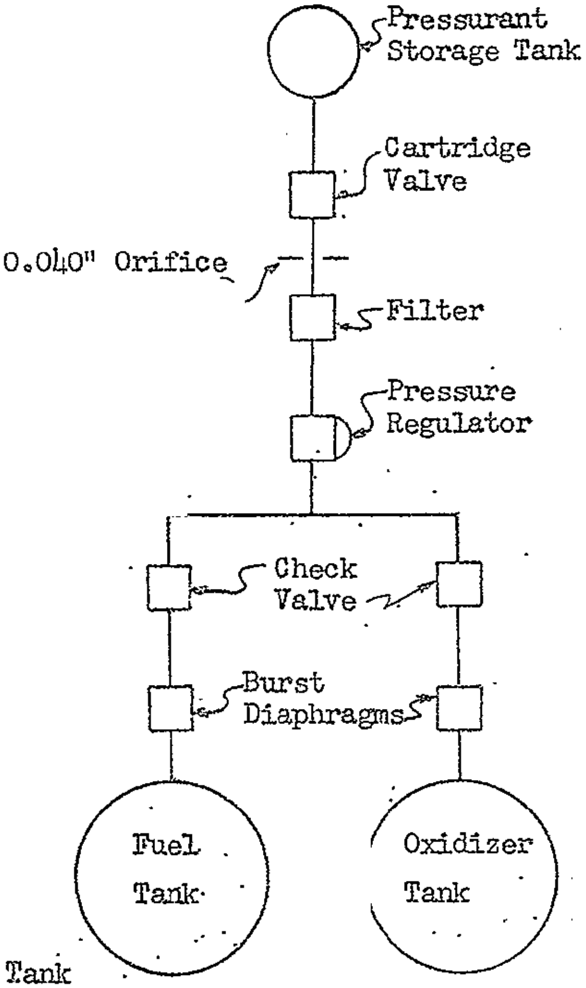
ENTRY POINT=  010698A0
```

APPENDIX D

SE5-5 PRESSURIZATION MODEL

SE-5 PRESSURIZATION MODEL

The SE-5 pressurization system is shown schematically at the right. The necessary input data for simulation of the system is listed below:



B(5), B(6) - Liquid Temp
Assume 70°F - 530°R

B(15), B(16) - Pressurant
Molecular wt. 28 - GN_2

B(17), B(18) - Ratio of Specific
Heat - Propellant Tank Pressure Level
- 1.4

B(30) - Pressurant Bottle
Volume - 886 in^3

B(31) - Fuel Heat Capacity
- 0.7 BTU/lb°F

B(32) - Oxidizer Heat Capacity
- 0.369 BTU/lb°F

B(33), B(34) - Pressurant C_v - Propellant Tank
Pressure - 0.172 BTU/lb°F

B(36) - Pressurant Bottle C_v - 0.185 BTU/lb°F

B(38) - Pressurant Bottle C_p - 0.330 BTU/lb°F

B(40) - Pressurant Bottle γ - 1.781

Regulator Constants

B(42) - Gain = 1.0 in^2/psi

B(44) - Lockup = 209 psia

B(46) - Maximum Flow Area = 0.004 - Estimate

	Fuel	Oxidizer
Propellant Flowrate - PPS	0.2656	0.4258
Density - lbs/in^3	0.0315	0.052
q - in^3/sec	8.43	8.22

$$Q = 16.65 \times 60 = 999.00 \text{ in}^3/\text{min}$$

$$= 999 \times \frac{208}{14.7} \times \frac{1}{1728} = 8.2 \text{ SCFM}$$

$$\dot{m} = \frac{p\,q}{RT} = \frac{208 \times 16.65}{\frac{18544}{28} \times 530} = 0.00985 \text{ pps}$$

Using [illegible] Valve Calculator, $C_DA = 0.0011 \text{ in}^2$

$\dot{m} = 0.00985$, $P_1 = 375$, $P_2 = 208$, $T = 530^\circ R$

B(48) Pressurant Compressibility Factor - 1.15

$$p_r = \frac{4700}{492} = 9.55 \qquad T_r = \frac{530}{277} = 1.91$$

B(50) Heat Input to Pressurant Tank - 0

B(52) Heat Input to Propellant Tank - 0

B(54) Regulator Sense Pressure Flag - 8

B(62) Effective Flow Area - Regulator to Fuel Tank - 0.00546 in^2

$R = 43.2 \text{ sec}^2/\text{in}^5$

$$C_DA = \frac{1}{27.8\sqrt{R}} = 0.00546$$

B(63) Effective Area ΔP 1-2 - 0.00396 in^2

Cartridge Valve ΔP = 30 psi @ 7 SCFM

P_{in} = 100 psia , C_DA = 0.00396

B(64) Effective Area ΔP 6-7 - 0.000815 in^2

Orifice - 0.040 dia,

B(66) Effective Area - Regulator to Oxidizer Tank

$R = 25.8$, C_DA - 0.00710

B(68) Laminar Flow Filter Constant

$$\frac{\dot{w}\sqrt{T}}{\text{psi}} = \frac{0.009 \times \sqrt{530}}{10} = 0.023$$

The gas pressures, temperatures, and flows at time zero must also be provided as input data:

E(13)	P(1,1,1)	,	E(22)	P(1,2,1)	-	
E(14)	P(2,1,1)	,	E(23)	P(2,2,1)	-	
E(15)	P(3,1,1)	,	E(24)	P(3,2,1)	-	
E(16)	P(4,1,1)	,	E(25)	P(4,2,1)	-	
E(17)	P(5,1,1)	,	E(26)	P(5,2,1)	-	
E(18)	P(6,1,1)	,	E(27)	P(6,2,1)	-	
E(19)	P(7,1,1)	,	E(28)	P(7,2,1)	-	
E(20)	P(8,1,1)	,	E(29)	P(8,2,1)	16.0	psia
E(21)	P(9,1,1)	,	E(30)	P(9,2,1)	16.0	psia
E(31)	P(1,1,2)	,	E(40)	P(1,2,2)	4700	psia
E(37)	P(7,1,2)	,	E(46)	P(7,2,2)	4700	psia
E(38)	P(8,1,2)	,	E(47)	P(8,2,2)	16.0	psia
E(39)	P(9,1,2)	,	E(48)	P(9,2,2)	16.0	psia
E(49)	T(1,1,1)	,	E(58)	T(1,2,1)	-	
E(55)	T(7,1,1)	,	E(64)	T(7,2,1)	-	
E(56)	T(8,1,1)	,	E(65)	T(8,1,1)	530	°R
E(57)	T(9,1,1)	,	E(66)	T(9,1,1)	530	°R
E(67)	T(1,1,2)	,	E(76)	T(1,2,2)	530	°R
E(75)	T(9,1,2)	,	E(84)	T(9,2,2)	530	°R

E(85) - E(120) - Flow - 0.0 initially

Figure D-1 shows the configuration of the fluid system. To calculate the priming transient it will be necessary to divide the system into segments. To minimize computer time it will be necessary to increase the length of certain elements. A computer time increment of 0.2 ms. will be used and minimum segment lengths calculated. Effective acoustic velocity is:

$$a_e = \left[\frac{1}{\frac{1}{a_\ell^2} + \frac{\rho}{g} \cdot \frac{Dc}{eE}}\right]^{1/2}$$

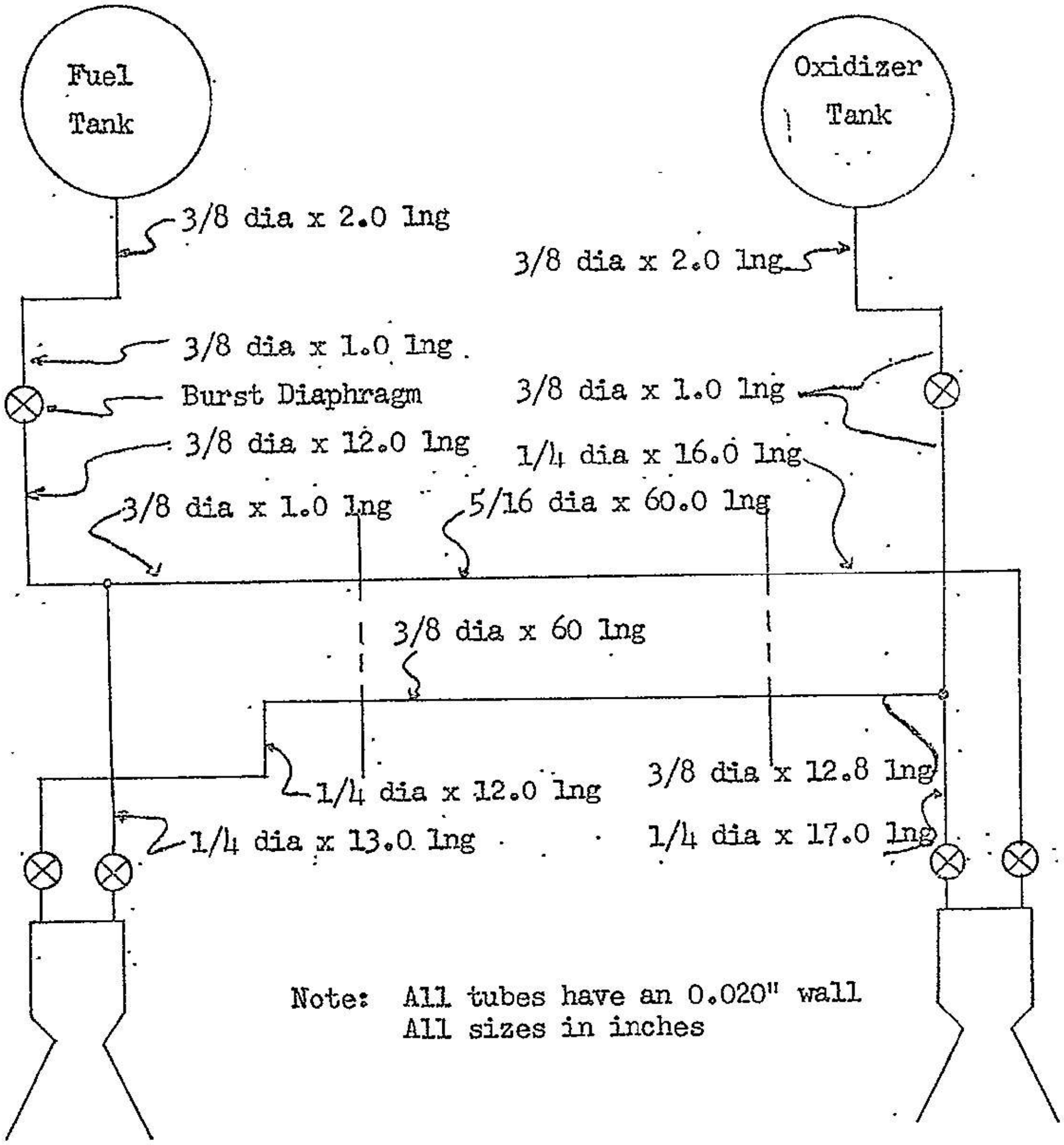


FIGURE D-1 - SE-5 Feed System

The feed system contains three different sizes of tubing each with a 0.020 in. wall

Tube Size	$\bar{D}$	$\frac{Dc}{eE}$
1/4	.230	3.4883×10^{-7}
5/16	.2925	4.4362×10^{-7}
3/8	.355	5.3842×10^{-7}

		Fuel	Oxidizer
Acoustic Velocity - a_ℓ		63,100	39,450
Density - ρ		0.0315	0.052
1/4" Tube	a_ℓ	59,802	38,082
	Min. Length	11.96	7.61
5/16" Tube	a_ℓ	58,991	37,734
	Min. Length	11.80	7.55
3/8" Tube	a_ℓ	58,213	37,396
	Min. Length	11.65	7.48

The segmentation of the feed system is shown on the next page. In the fu side the segment length and sizes are correct except the 1.0 in. length of 3/8" line will be assumed to be 5/16", and the length of line between the tank and burst diaphragm has been increased to 12.0 in. The resistances are those used in the engine balance, except they are distributed in the model.

The oxidizer system is similar to the fuel system modeling except for the segment between the burst diaphragm and tee. To meet model requirements it will be given a length of 8.0 inches. 7.0 inches of the 3/8" and 1/4" lines will be included in this segment so that total system volume is not changed.

$$A = \frac{(8 \times 0.0881 + 7 \times 0.0346)}{8} = 0.1184 \text{ in}^2$$

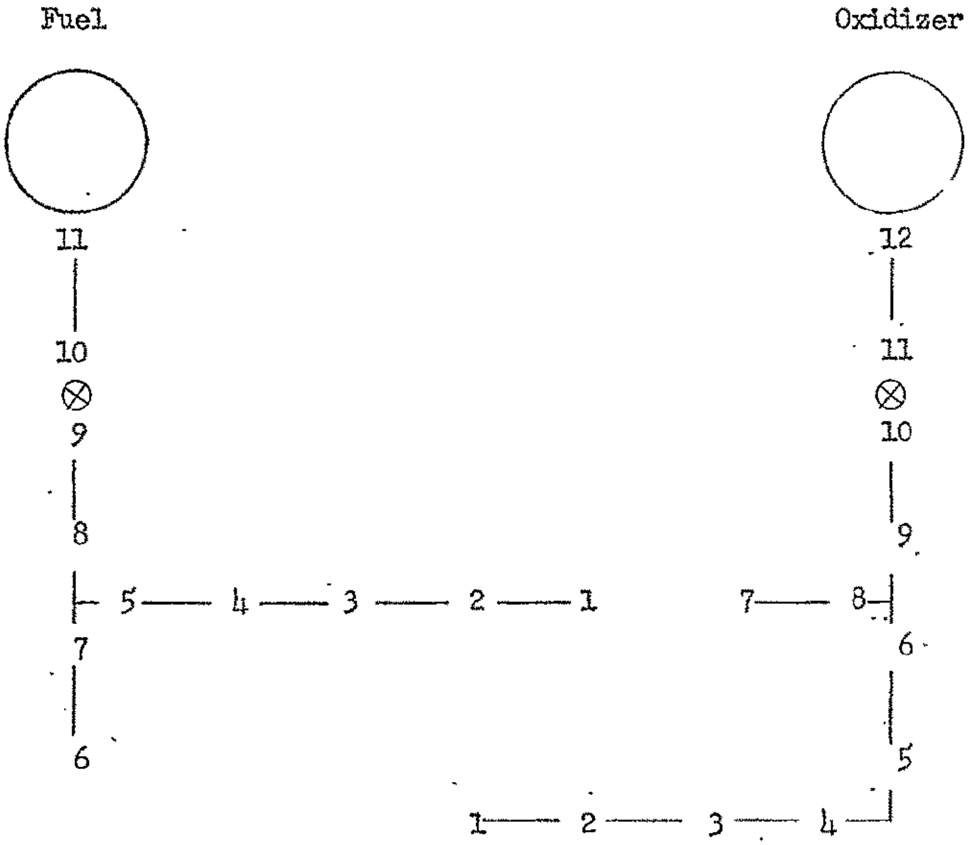
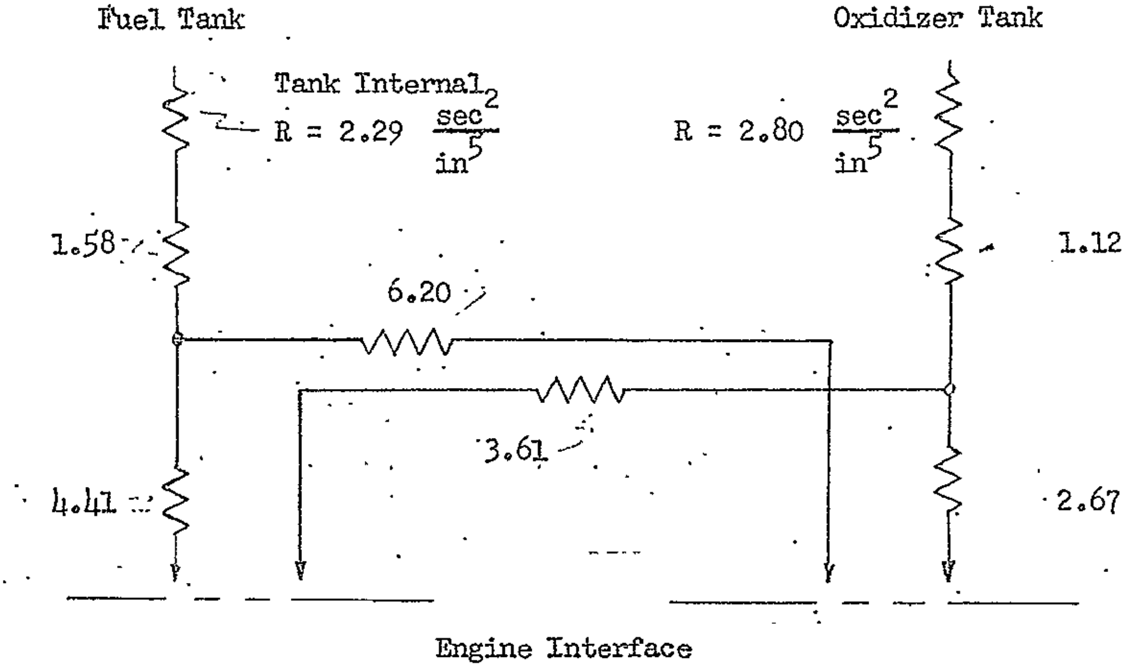


Figure D-2 - SE5-5 Pressurization System Model Segmentation

TABLE D-I - SE-5 MODEL FEED SYSTEM PARAMETERS

Segment No.	Fuel				Oxidizer			
	Length	Area	Compliance	Resistance	Length	Area	Compliance	Resistance
1	16.0	0.0346	3.4883×10^{-7}	2.6464	12.0	0.0346	3.4883×10^{-7}	1.8649
2	15.0	0.0583	4.4362×10^{-7}	0.8739	15.0	0.0881	5.3842×10^{-7}	.3596
3	19.0	0.0583	4.4362×10^{-7}	1.1069	17.0	0.0881	5.3842×10^{-7}	.4075
4	27.0	0.0583	4.4362×10^{-7}	1.5728	19.0	0.0881	5.3842×10^{-7}	.4554
5	-	-	-	-	14.8	0.0881	5.3842×10^{-7}	.3547
6	13.0	0.0346	3.4883×10^{-7}	4.41	-	-	-	-
7	-	-	-	-	10.0	0.0346	3.4883×10^{-7}	1.57063
8	12.0	0.0881	5.3842×10^{-7}	1.435	-	-	-	-
9	Valve	-	-	-	8.0	0.1184	5.3842×10^{-7}	0.145
10	12.0	0.0881	5.3842×10^{-7}	1.435	Valve	-	-	-
11	Tank	-	-	-	8.0	0.0881	5.3842×10^{-7}	2.92
12	-	-	-	-	Tank	-	-	-

Resistance data was obtained from an engine balance. The values shown below will be distributed throughout the system.



The burst diaphragm resistance is 1.0 $\frac{sec^2}{in^5}$; its effective area is:

$$C_D A = \frac{1}{27.807\sqrt{1}} = 0.03596$$

The resistance in the fuel line between tank and tee is:

$$R - 2.29 + 1.58 = 1 = 2.87 \ sec^2/in^5$$

The resistance of the crossover line will be distributed on the basis of length and area

$$6.20 = 61.0 \, R_{5/16} + 16 \, R_{1/4} \ , \quad R_{1/4} = \left(\frac{0.0583}{0.0346}\right)^2 R_{5/16}$$

$$R_{5/16} = \frac{6.20}{61 + 16 \cdot \left(\frac{583}{346}\right)^2} = 0.05826 \ \frac{sec^2}{in^5} / in$$

$$R_{1/4} = 0.05826 \times \left(\frac{583}{346}\right)^2 = 0.1653 \ \frac{sec^2}{in^5} / in$$

The resistance in the oxidizer system will be calculated in a similar fashion.

Between the tank and burst diaphragm

$$R = 2.80 + 1.12 - 1.00 = 2.92$$

Crossover Line

$$3.61 = 72.8\ R_{3/8} + 12.0\ R_{1/4} \qquad R_{1/4} = \left(\frac{0.0881}{0.0346}\right)^2 R_{3/8}$$

$$R_{3/8} = \frac{3.61}{72.8 + 12.0 \times \left(\frac{881}{346}\right)^2} = 0.02397\ \frac{\text{sec}^2}{\text{in}^5} / \text{in}$$

$$R_{1/4} = 0.02397 \times 6.483 = 0.1554\ \frac{\text{sec}^2}{\text{in}^5} / \text{in}$$

The resistance between the "T" and engine is

$$R' = \frac{2.67}{17} = 0.1570\ \frac{\text{sec}^2}{\text{in}^5} / \text{in}$$

The resistance of the composite line is the parallel combination of 0.1679 and 1.0994, or 0.1456.

A listing of the input data deck is shown in Table D-II. Table D-III shows the pictorial output, and Table D-IV presents the output listing.

TABLE D-II

SE5-5 PRESSURIZATION MODEL INPUT DATA

```
2     1 10  0.0346       0.0583       0.0583       0.0583       0.0          0000100,
0.0346      0.0          0.0881       0.0          0.0881                    0000200,
2   121 10 16.0         15.0         19.0         27.0          0.0          0000300,
3.0         0.0         12.0          0.0         12.0                       0000400,
2   241 10  3.4883E-07  4.4362E-07   4.4362E-07   4.4362E-07   0.0          0000500,
3.4883E-07  0.0          5.3842E-07   0.0          5.3842E-07                0000600,
2   361 10  2.6464       0.8739       1.1069       1.5728       0.0          0000700,
4.41        0.0          1.435        0.0          1.435                     0000800,
2    61 11  0.0346       0.0881       0.0881       0.0881       0.0881       0000900,
0.0         0.0346       0.0          0.1184       0.0          0.0881       0001000,
2   181 11 12.0         15.0         17.0         19.0         14.8          0001100,
0.0        10.0          0.0          8.0          0.0          8.0          0001200,
2   301 11  3.4883E-07  5.3842E-07   5.3842E-07   5.3842E-07   5.3842E-070001300,
0.0         3.4883E-07  0.0          5.3842E-07   0.0          5.3842E-070001400,
2   421 11  1.8649       0.3596       0.4075       0.4554       0.3547       0001500,
0.0         1.5706       0.0          0.1456       0.0          2.92         0001600,
3   201  9 409.0          0.0          1.0          0.001        0.001       0001700,
 0.05         0.002        0.05       160.0                                  0001800,
-3   301  9  410.0          0.0          1.0          0.001        0.001     0001900,
  0.05         0.002        0.05       160.0                                 0002000,
$D1 ICMT=3, IPR=3, IST=1, NSEGF=10, NSEGO=11, DELT=0.0002,                 ID=1000000,
LFF=9*1,51*0, LFO=10*1,50*0, ICAPFU=1,6,3*0, ICAPOX=1,7,3*0,               ID=1000100,
IORF=2,3,4,57*0, IORO=2,3,4,5,56*0,                                        ID=1000200,
IBRAN(1,1,1)=8, IBRAN(1,2,1)=5, IBRAN(1,3,1)=7,                            ID=1000300,
IBRAN(1,1,2)=9, IBRAN(1,2,2)=6, IBRAN(1,3,2)=8,                            ID=1000400,
ICAP=1, ITANK=8,                                                           ID=1000500,
B(3)=0.0315, B(4)=0.052, B(5)=530, B(6)=530,                               ID=1000600,
B(7)=63100, B(8)=39450, B(9)=0.0107745, B(10)=-5.81014,                    ID=1000700,
B(11)=0.0089489, B(12)=-3.62944, B(13)=46.075, B(14)=92.016,               ID=1000800,
B(15)=28.0, B(16)=28.0, B(17)=1.4, B(18)=1.4,                              ID=1000900,
B(25)=340, B(26)=340, B(27)=16, B(28)=16, B(30)=886,                       ID=1001000,
B(31)=0.7, B(32)=0.369, B(33)=0.172, B(34)=0.172,                          ID=1001100,
B(36)=0.185, B(38)=0.33, B(39)=1.781, B(40)=1.781, B(42)=0.004,            ID=1001200,
B(44)=209,                                                                 ID=1001220,
B(46)=0.004, B(48)=1.15, B(50)=0, B(52)=0, B(54)=8,                        ID=1001300,
B(62)=0.00546, B(63)=0.00396, B(64)=0.000815, B(65)=0.004,                 ID=1001400,
B(66)=0.0071, B(68)=0.023, B(90)=50,                                       ID=1001500,
E=19*0,2*16,7*0,2*16,7*4700,2*16,7*4700,2*16,7*0,2*530,7*0,20*530,           1001600,
114*0, E(85)=0,                                                            ID=1001700,
PF(10)=16, PF(11)=16, PO(11)=16, PO(12)=16,                                ID=1001800,
IPI=1,6,11,3*0,101,107,112,3*0,211,205,207,3*0,312,308,306,9*0,            ID=1001900,
IWI=11,211,112,312,401,402,403,404,                                        ID=1002000,
```

```
VARIS=5,200,5,112,5,40,5,47,12*0,                                                ID=1002100,
NDEX=12,                                                                         ID=1008800;
(25)=20, B(26)=20, B(62)=0.01092, B(66)=0.0142,                                  ID=1009000,
END                                                                                 1100000,
F5-5 TANK PRESSURIZATION TRANSIENT                                                  1100100,
                                                                                    1100200,
                                                              PROGRAM CHECKOUT 1100300,
```

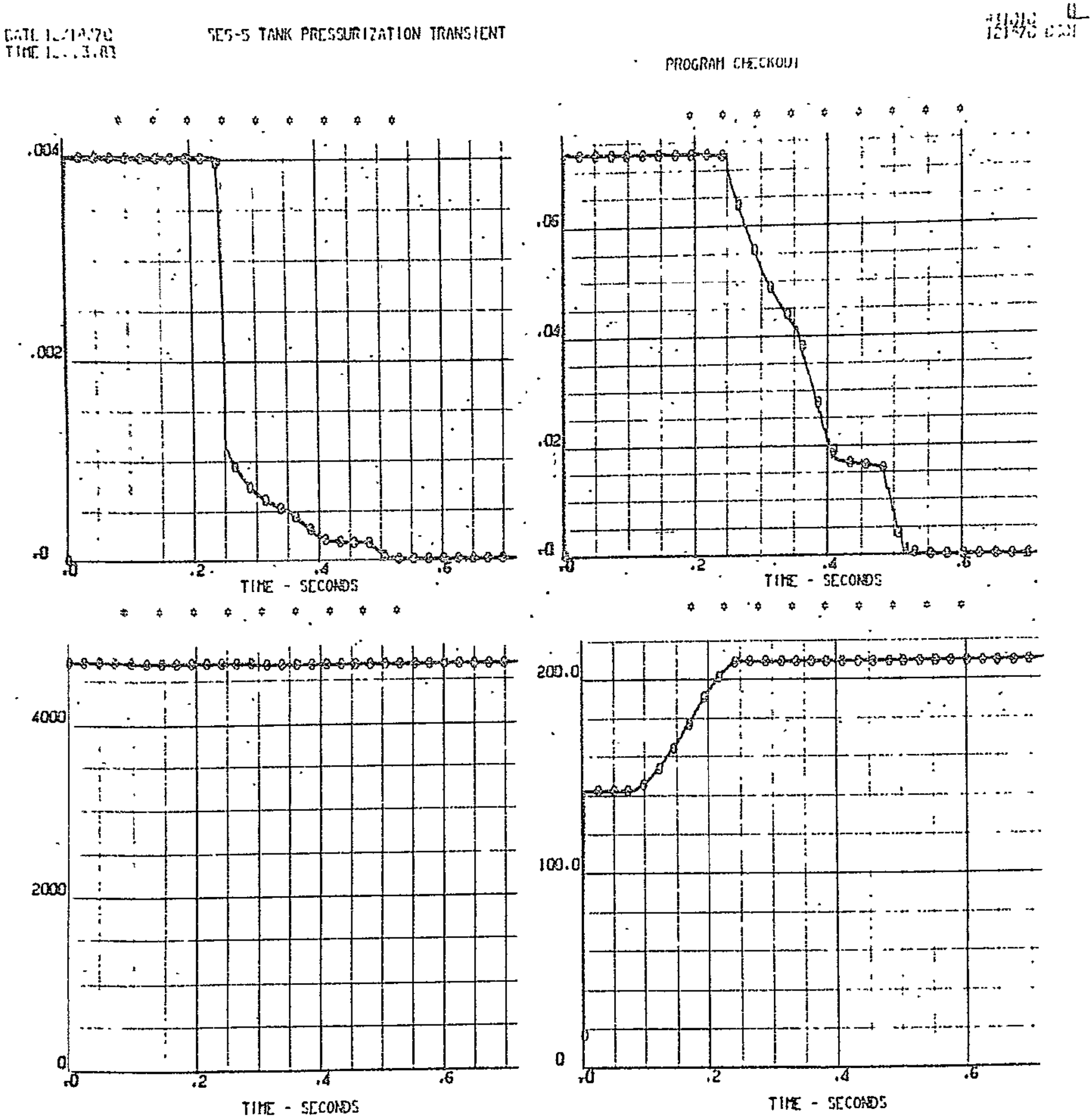


Figure D-3A - Graphical Output of SE5-5 Pressurization System Model.

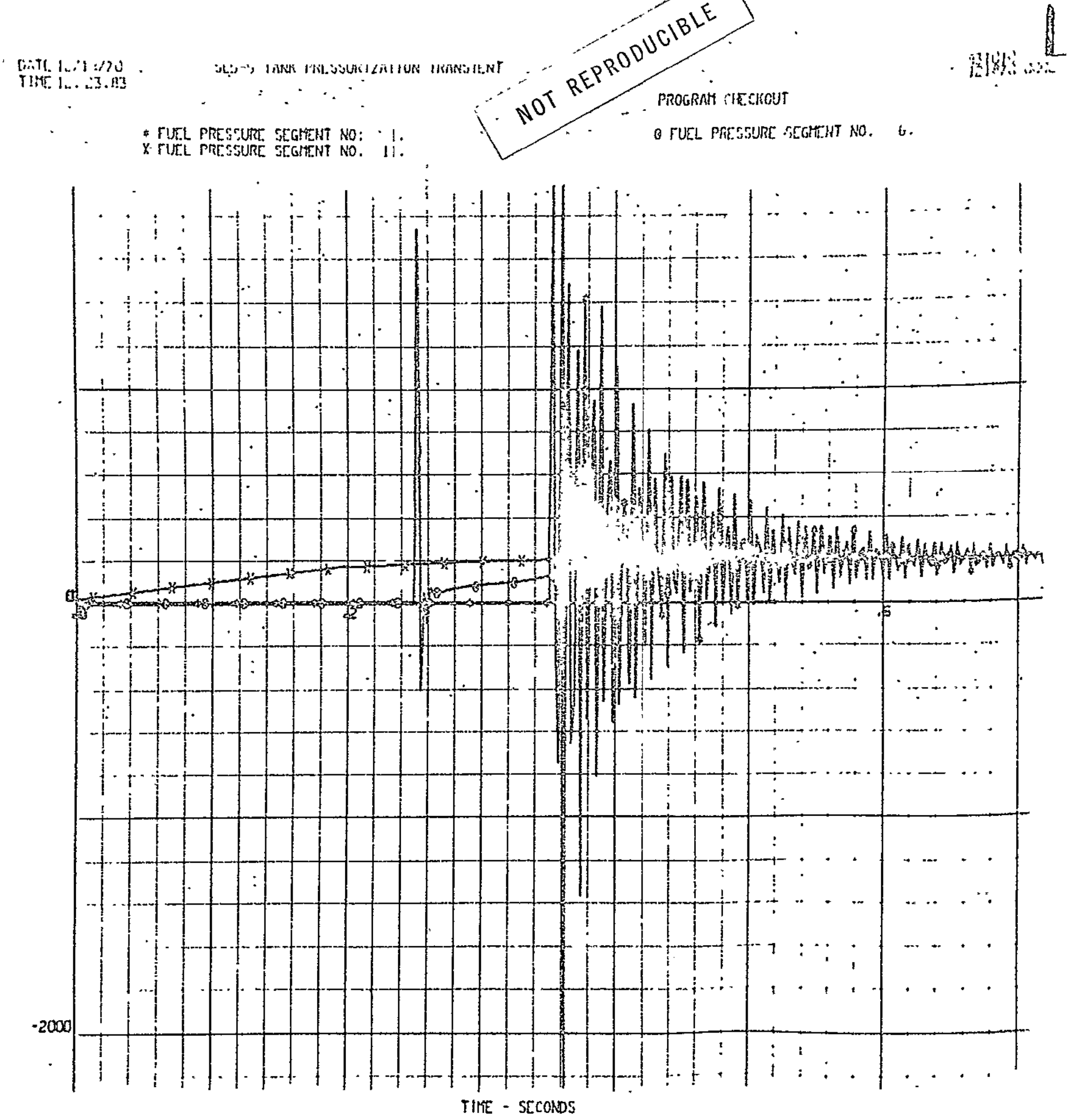


Figure D-3B - Graphical Output of SE5-5 Pressurization System Model.

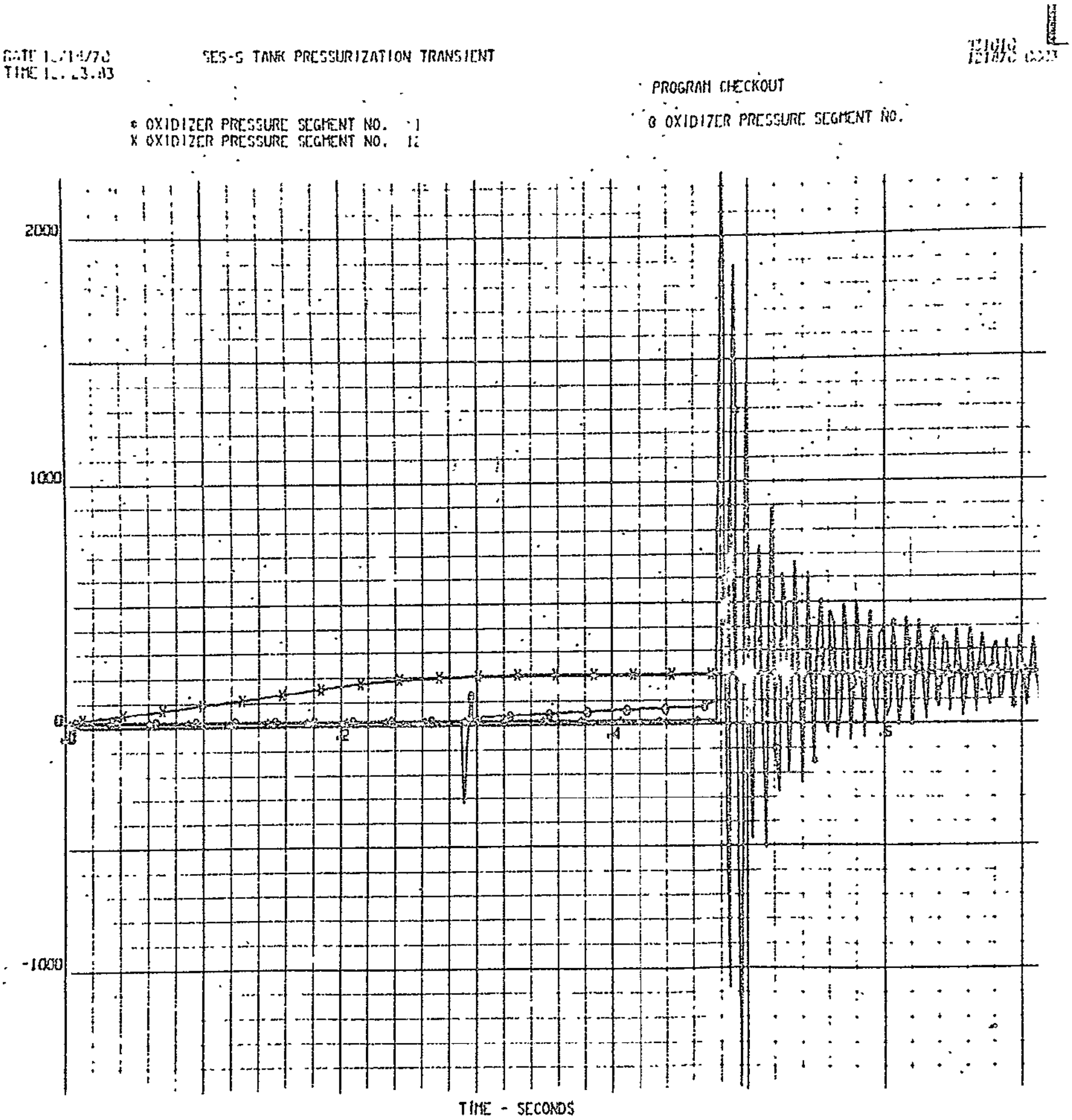


Figure D-3C - Graphical Output of SE5-5 Pressurization System Model.

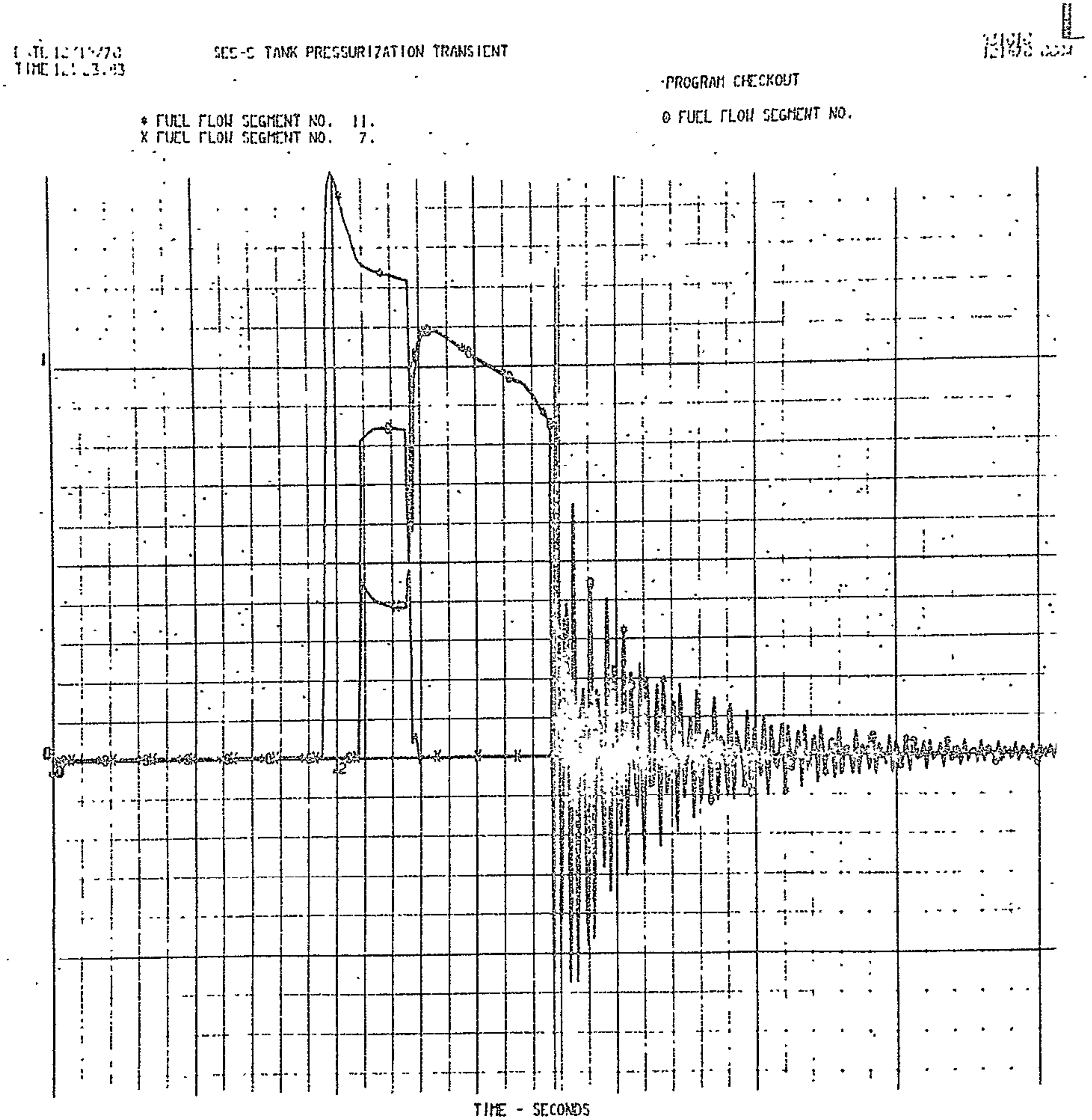


Figure D-3D - Graphical Output of SE5-5 Pressurization System Model.

DATE 1./18/70
TIME 12:23.03

SE5-5 TANK PRESSURIZATION TRANSIENT

— PROGRAM CHECKOUT

+ OXIDIZER FLOW SEGMENT NO. 12.
X OXIDIZER FLOW SEGMENT NO. 6.

0 OXIDIZER FLOW SEGMENT NO. 3.

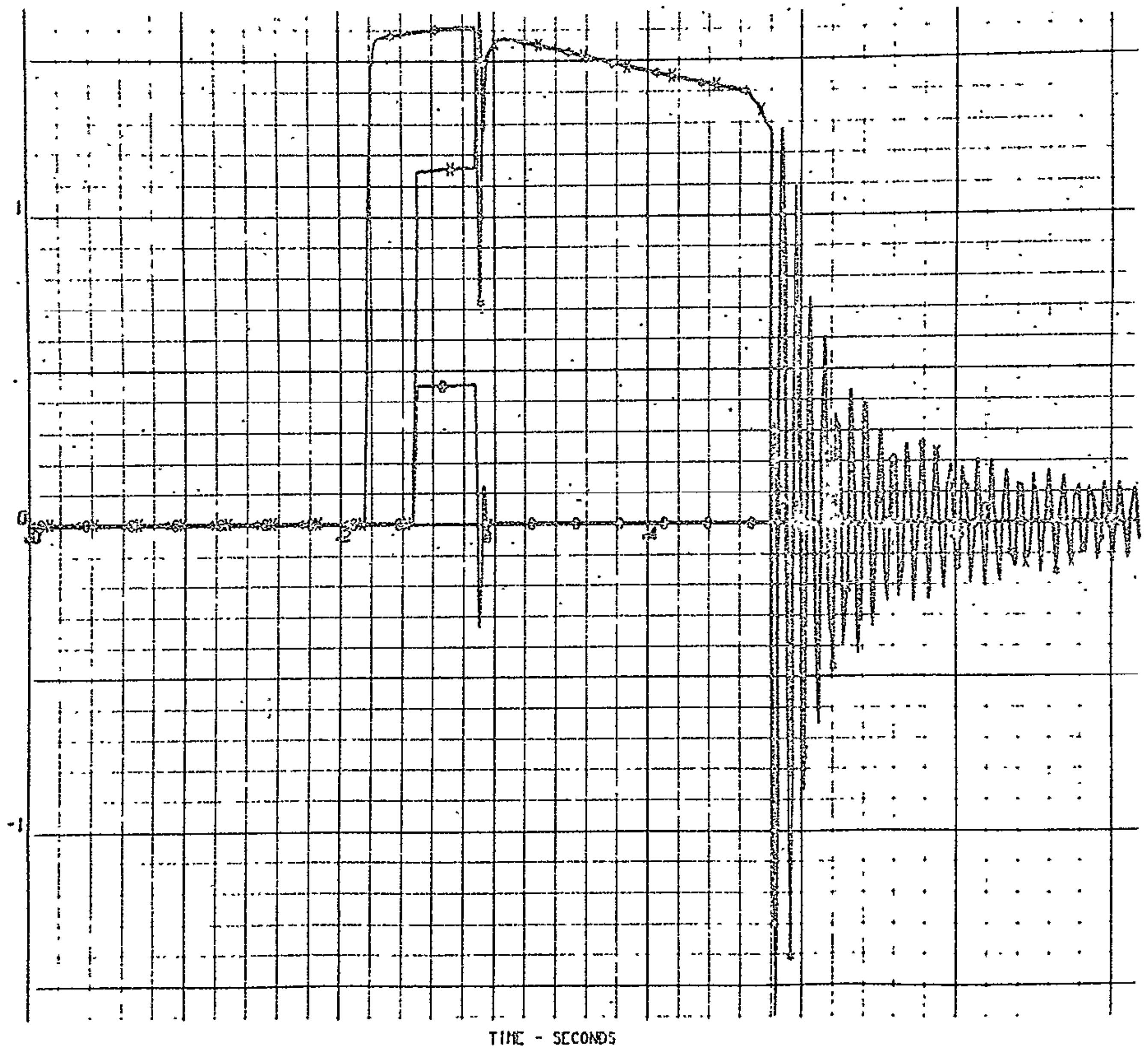


Figure D-3E - Graphical Output of SE5-5 Pressurization System Model.

TABLE D-IV

SE5-5 PRESSURIZATION SYSTEM PROGRAM OUTPUT LISTINGS

```
                                   DATE  12/18/70          TIME 12:21.35
                 SE5-5 TANK PRESSURIZATION TRANSIENT

                                                                  PROGRAM.CHECKOUT
  *        *         *         *         FUEL FEEDSYSTEM PARAMETERS         *         *         *
   SEGMENT DATA     PRESSURE   FLOW     ACOUSTIC      AREA       LENGTH    RESISTANCE      DISOLVED GAS
   NO.  STATE         PSIA      PPS     VELOCITY     SQ. IN.     INCHES    SEC**2/IN**5    LBS G / LB L
                                        IN / SEC
    1   EMPTY         0.79      0.0     59801.9      0.0346      16.00      2.646           0.0
    2   EMPTY         0.79      0.0     58991.5      0.0583      15.00     0.8739           0.0
    3   EMPTY         0.79      0.0     58991.5      0.0583      19.00      1.107           0.0
    4   EMPTY         0.79      0.0     58991.5      0.0583      27.00      1.573           0.0
    5   EMPTY         0.79      0.0     58213.1      0.0          0.0      0.0              0.0
    6   EMPTY         0.79      0.0     59801.9      0.0346      13.00      4.410           0.0
    7   EMPTY         0.79      0.0     58213.1      0.0          0.0      0.0              0.0
    8   EMPTY         0.79      0.0     58213.1      0.0881      12.00      1.435           0.0
    9   EMPTY         0.79      0.0     63100.0      0.0          0.0      0.1000E 32       0.0
   10   FULL         16.00      0.0     58213.1      0.0881      12.00      1.435           0.0
   11   FULL         16.00      0.0     63100.0      0.0          0.0      0.0              0.0
```

```
                                    DATE  12/18/70         TIME 12:21.35
                SE5-5 TANK PRESSURIZATION TRANSIENT

                                                                       ROGRAM CHECKOUT
           *              *           *      OXIDIZER FEEDSYSTEM CONSTANTS       *             *                   *        *
  SEGMENT DATA          PRESSURE     FLOW        ACOUSTIC      AREA        LENGTH     RESISTANCE           DISOLVED GAS
   NO.  STATE             PSIA       PPS         VELOCITY    SQ. IN.      INCHES     SEC**2/IN**5          LBS G / LB L
                                                 IN / SEC
    1   EMPTY            12.99       0.0         38082.0      0.0346      12.00        1.865               0.0
    2   EMPTY            12.99       0.0         37395.7      0.0881      15.00       0.3596               0.0
    3   EMPTY            12.99       0.0         37395.7      0.0881      17.00       0.4075               0.0
    4   EMPTY            12.99       0.0         37395.7      0.0881      19.00       0.4554               0.0
    5   EMPTY            12.99       0.0         37395.7      0.0881      14.80       0.3547               0.0
    6   EMPTY            12.99       0.0         37395.7      0.0          0.0        0.0                  0.0
    7   EMPTY            12.99       0.0         38082.0      0.0346      10.00        1.571               0.0
    8   EMPTY            12.99       0.0         37395.7      0.0          0.0        0.0                  0.0
    9   EMPTY            12.99       0.0         37395.7      0.1184       8.00       0.1456               0.0
   10   EMPTY            12.99       0.0         39450.0      0.0          0.0        0.1000E 32           0.0
   11   FULL             16.00       0.0         37395.7      0.0881       8.00        2.920               0.0
   12   FULL             16.00       0.0         39450.0      0.0          0.0        0.0                  0.0
```

```
                                   DATE  12/18/70         TIME 12:21.35
                     SE5-5 TANK PRESSURIZATICN TRANSIENT

                                                                       PROGRAM CHECKOUT
                                          FEEDSYSTEM CCNFIGURATION       *         *
*          *          *          *                                    OXIDIZER
                      FUEL
                                           SEGMENT BRANCH CATA
INDEX INLET  *      *      *   BRANCHES   *      *      *  INLET  *      *      *  BRANCHES
  1      8        5,  7,                                     9        6,  8,

                                             CAPPED SEGMENTS
                           1,  6,  0,  0,  0,                          1,  7,  0,  0,  0,

                                FUEL ICRDER ARRAY         *      NSEGF = 10

     2    3    4

                                OXIDIZER IORDER ARRAY     *      NSEGO = 11

     2    3    4    5

                                CUTCFF SFGMENTS
                 FUEL                                            OXIDIZER
```

```
                                                FUEL VALVE TABLE
INDEX    SEGMENT    *            *                  VALUES
  1        409     0.0           1.000000   0.001000   0.001000   0.050000   0.002000   0.050000 160.000000

                                                OXIDIZER VALVE TABLE
INDEX    SEGMENT    *            *                  VALUES
  1        410     0.0           1.000000   0.001000   0.001000   0.050000   0.002000   0.050000 160.000000

                                                FUEL FUNGEN TABLE

                                                OXIDIZER FUNGEN TABLE
```

```
CAVITATING VENTURI DATA                                   OXIDIZER
       FUEL

ORIFICE DATA

ACCUMULATOR DATA
```

```
                              INJECTOR MANIFOLD DATA
                                     FUEL                                                      OXIDIZER
NDEX NO.                      1         2         3         4         1         2         3         4
EGMENT NO.                  0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
ANIFOLD VOLUME - CU.IN.      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
RIFICE LENGTH - INCHES    0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
NJECTOR C-SUB-D*A - SQIN  0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
LAME FROUNT DISTANCE-IN.  0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

                              COMBUSTION CHAMBER DATA
NDEX NO.                        1                   2                   3                   4
HAMBER PRESSURE - PSIA          0.0                 0.0                 0.0                 0.0
XIDIZER FLOWRATE - PPS          0.0                 0.0                 0.0                 0.0
UEL FLOWRATE - PPS              0.0                 0.0                 0.0                 0.0
XIDIZER FRACTION              0.0                 0.0                 0.0                 0.0
HROAT AREA - SQ. IN.            0.0                 0.0                 0.0                 0.0
HAMBER VOLUME - CU. IN.         0.0                 0.0                 0.0                 0.0
OZZLE EXIT AREA - SQ. IN.        0.0                 0.0                 0.0                 0.0
HRUST COEFFICIENT              0.0                 0.0                 0.0                 0.0
NGINE AMBIENT PRESSURE - PSIA   0.0                 0.0                 0.0                 0.0
NGINE THRUST - POUNDS            0.0                 0.0                 0.0                 0.0

                              COMBUSTION DATA
       BASE PRESSURE =     0.0 PSIA                            GAS CONSTANT CORRECTION =0.0
       CSTAR CORRECTION =0.0                                   EFFICIENCY CORRECTION =0.0
                      OX. FRACTION          GAS CONSTANT          CSTAR / C          EFFICIENCY
                        0.0                   0.0                   0.0                0.0
```

```
                              DATE  12/18/70        TIME 12:21.35
      SF5-5 TANK PRESSURIZATION TRANSIENT

                                                          PROGRAM CHECKOUT

         INPUT DATA CONSTANTS                          FUEL              OXIDIZER

ENTRAINED GAS - LBS GAS / LB LIQUID                    0.0               0.0
PROPELLANT DENSITY - POUNDS / CUBIC INCH               0.03150           0.05200
LIQUID TEMPERATURE - DEGREES RANKINE                    530.0             530.0
PROPELLANT ACOUSTIC VELOCITY - INCHES / SECOND         63100.0           39450.0
VAPOR PRESSURE CURVE FIT CONSTANTS - CON1              1.0774E-02        8.9489E-03
 ( LOG(PVAP) = CON1 * TEMP + CON2 )
                                     - CON2           -5.8101E 00       -3.6294E 00
PROPELLANT MOLECULAR WEIGHT                             46.1              92.0
PRESSURANT GAS MOLECULAR WEIGHT                         28.0              28.0
RATIO OF SPECIFIC HEATS - PRESSURANT GAS                1.400             1.400
RATIO OF SPECIFIC HEATS - PROPELLANT VAPOR              0.0               0.0

DISSOLVED GAS EVOLUTION TIME CONSTANT - 1/SEC.         0.0               0.0
DISSOLVED GAS CONCENTRATION - LBS GAS / LB LIQ / PSI   0.0               0.0
PROPELLANT TANK ULLAGE - CUBIC INCHES                  2.0000E 01        2.0000E 01
PROPELLANT TANK INITIAL PRESSURE - PSIA                 16.0              16.0
PRESSURANT GAS BOTTLE VOLUME - CUBIC INCHES            0.0               8.8600E 02

PROPELLANT LIQUID HEAT CAPACITY - BTU / LB / DEGREE R  7.0000E-01        3.6900E-01
PRESSURANT - LOW PRESSURE C-SUB-V                      1.7200E-01        1.7200E-01
PRESSURANT - HIGH PRESSURE C-SUB-V                     0.0               1.8500E-01
PRESSURANT - HIGH PRESSURE C-SUB-P                     0.0               3.3000E-01
PRESSURANT - HIGH PRESSURE GAMMA                        1.781             1.781

PRESSURE REGULATOR GAIN - SQ. IN. / PSI                0.0               4.0000E-03
PRESSURE REGULATOR LOCKUP PRESSURE - PSIA                 0.0             209.0
PRESSURE REGULATOR MAXIMUM FLOW AREA - SQ. IN.         0.0               4.0000E-03
PRESSURANT GAS COMPRESSIBILITY FACTOR                   0.0               1.150
PRESSURANT GAS BOTTLE HEAT INPUT - BTU / SEC           0.0               0.0

PROPELLANT TANK HEAT INPUT - BTU / SEC                 0.0               0.0
PRESSURE REGULATOR SENSE PRESSURE INDEX                   0.0               8.0
HEAT EXCHANGER NO. 1 COOLANT SEGMENT NO.                  0.0               0.0
HEAT EXCHANGER NO. 3 COOLANT SEGMENT NO.                  0.0               0.0
EQUIVALENT ORIFICE AREA - DELTA P 1-2 - SQ. IN.        0.0               3.9600E-03
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EQUIVALENT ORIFICE AREA - DELTA P 6-7 - SQ. IN.              0.0                 8.1500E-04
EQUIVALENT ORIFICE AREA - REGULATOR - SQ. IN.                0.0                 4.0000E-03
EQUIVALENT ORIFICE AREA - DELTA P 8-9 - SQ. IN.              1.0920E-02          1.4200E-02
LAMINAR FLOW FILTER CONSTANT - IN**3 / (PSI*SEC)             0.0                 2.3000E-02
HEAT EXCHANGER AREA CAPACITANCE - UNIT NO. 1                 0.0                 0.0
  BTU / DEGREE R / SECOND
                                          UNIT NO. 2         0.0                 0.0
                                          UNIT NO. 3         0.0                 0.0

PROPELLANT VAPOR C-SLB-P                                     0.0                 0.0
HEAT SOAKBACK - BTU / LB SEC DEGREE R                        0.0                 0.0
SOAKBACK INJECTOR TEMPERATURE - DEGREES R                     0.0                 0.0
PROPELLANT HEAT OF VAPORIZATION - BTU / LB                   0.0                50.0000
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                                   DATE  12/18/70          TIME 12:21.35
                    SF5-5 TANK PRESSURIZATION TRANSIENT

                                                                         PROGRAM CHECKOUT
 0.0         16.00000      0.0        16.00000     0.0          0.0          0.0        4700.00000     16.00000
 0.002400    17.77057      0.00009    17.66196     0.00015      0.00400      0.07285    4699.83986    141.58415
 0.004800    19.64098      0.00010    19.39618     0.00016      0.00400      0.07285    4699.67578    141.59151
 0.007200    21.51099      0.00011    21.13037     0.00015      0.00400      0.07285    4699.51563    141.59036
 0.009600    23.38066      0.00011    22.86450     0.00014      0.00400      0.07285    4699.35547    141.58917
 0.012000    25.24954      0.00011    24.59813     0.00014      0.00400      0.07282    4699.19141    141.53503
 0.014400    27.11797      0.00010    26.33150     0.00014      0.00400      0.07282    4699.03125    141.53380
 0.016800    28.98622      0.00010    28.06480     0.00014      0.00400      0.07282    4698.87109    141.53267
 0.019200    30.85428      0.00010    29.79808     0.00014      0.00400      0.07282    4698.71094    141.53143
 0.021600    32.72220      0.00009    31.53127     0.00014      0.00400      0.07282    4698.54688    141.53030
 0.024000    34.59006      0.00009    33.26442     0.00014      0.00400      0.07282    4698.38672    141.52914
 0.026400    36.45775      0.00009    34.99750     0.00014      0.00400      0.07282    4698.22656    141.52798
 0.028800    38.32533      0.00009    36.73053     0.00014      0.00400      0.07282    4698.06641    141.52672
 0.031200    40.19287      0.00009    38.46358     0.00014      0.00400      0.07282    4697.90234    141.53419
 0.033600    42.06035      0.00009    40.19659     0.00014      0.00400      0.07282    4697.74219    141.53302
 0.036000    43.92773      0.00009    41.92955     0.00014      0.00400      0.07282    4697.58203    141.53183
 0.038400    45.79509      0.00009    43.66246     0.00014      0.00400      0.07282    4697.41797    141.53067
 0.040800    47.66231      0.00009    45.39526     0.00014      0.00400      0.07280    4697.25781    141.47876
 0.043200    49.52878      0.00009    47.12746     0.00014      0.00400      0.07280    4697.09766    141.47760
 0.045600    51.39520      0.00009    48.85962     0.00014      0.00400      0.07280    4696.93359    141.47636
 0.048000    53.26160      0.00009    50.59169     0.00014      0.00400      0.07280    4696.77344    141.47516
 0.050400    55.12794      0.00009    52.32372     0.00014      0.00400      0.07280    4696.61328    141.47397
 0.052800    56.99425      0.00009    54.05566     0.00014      0.00400      0.07280    4696.44922    141.47284
 0.055200    58.86057      0.00009    55.78758     0.00014      0.00400      0.07280    4696.28906    141.47166
 0.057600    60.72685      0.00009    57.51945     0.00014      0.00400      0.07280    4696.12500    141.47057
 0.060000    62.59306      0.00009    59.25127     0.00014      0.00400      0.07280    4695.96875    141.47775
 0.062400    64.45929      0.00009    60.98309     0.00014      0.00400      0.07280    4695.80469    141.47665
 0.064800    66.32547      0.00009    62.71487     0.00014      0.00400      0.07280    4695.64453    141.47546
 0.067199    68.19165      0.00009    64.44659     0.00014      0.00400      0.07280    4695.48438    141.47426
 0.069599    70.05782      0.00009    66.17825     0.00014      0.00400      0.07280    4695.32031    141.47310
 0.071999    71.92339      0.00009    67.90942     0.00014      0.00400      0.07278    4695.16016    141.43387
 0.074398    73.78853      0.00009    69.64058     0.00014      0.00400      0.07278    4695.00000    141.49066
 0.076798    75.65245      0.00009    71.37248     0.00014      0.00400      0.07278    4694.83594    141.57794
 0.079198    77.51456      0.00009    73.10542     0.00014      0.00400      0.07278    4694.67578    141.74556
 0.081597    79.37497      0.00009    74.83952     0.00014      0.00400      0.07278    4694.51563    141.98056
 0.083997    81.23354      0.00009    76.57475     0.00014      0.00400      0.07276    4694.35547    142.25378
 0.086397    83.09015      0.00009    78.31107     0.00014      0.00400      0.07277    4694.19141    142.64618
 0.088796    84.94493      0.00009    80.04863     0.00014      0.00400      0.07278    4694.03125    143.09972
 0.091196    86.79776      0.00009    81.78731     0.00014      0.00400      0.07277    4693.87109    143.58134
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0.093596	88.64859	0.00009	83.52747	0.00014	0.00400	0.07277	4693.71094	144.1232
0.095995	90.49727	0.00009	85.26891	0.00014	0.00400	0.07276	4693.54688	144.7208
0.098395	92.34369	0.00009	87.01184	0.00014	0.00400	0.07276	4693.38672	145.3652
0.100795	94.18787	0.00009	88.75612	0.00014	0.00400	0.07276	4693.22656	146.0567
0.103195	96.02982	0.00009	90.50150	0.00014	0.00400	0.07276	4693.06250	146.7917
0.105594	97.86977	0.00009	92.24825	0.00014	0.00400	0.07275	4692.90234	147.5442
0.107994	99.70770	0.00009	93.99664	0.00014	0.00400	0.07276	4692.74219	148.3725
0.110394	101.54355	0.00009	95.74641	0.00014	0.00400	0.07276	4692.58203	149.2238
0.112793	103.37686	0.00009	97.49744	0.00014	0.00400	0.07275	4692.41797	150.0828
0.115193	105.20813	0.00009	99.24985	0.00014	0.00400	0.07273	4692.25781	150.9722
0.117593	107.03743	0.00009	101.00356	0.00014	0.00400	0.07275	4692.09766	151.9336
0.119992	108.86430	0.00009	102.75867	0.00014	0.00400	0.07275	4691.93359	152.9085
0.122392	110.68918	0.00009	104.51520	0.00014	0.00400	0.07273	4691.77734	153.8765
0.124792	112.51164	0.00009	106.27324	0.00014	0.00400	0.07274	4691.61328	154.9135
0.127191	114.33183	0.00009	108.03261	0.00014	0.00400	0.07275	4691.45313	155.9760
0.129591	116.15004	0.00009	109.79327	0.00014	0.00400	0.07273	4691.28906	157.0212
0.131991	117.96603	0.00009	111.55560	0.00014	0.00400	0.07274	4691.12891	158.1283
0.134390	119.78000	0.00009	113.31923	0.00014	0.00400	0.07272	4690.96875	159.2248
0.136790	121.59161	0.00009	115.08424	0.00014	0.00400	0.07274	4690.80469	160.3802
0.139190	123.40114	0.00009	116.85057	0.00014	0.00400	0.07273	4690.64844	161.5316
0.141589	125.20876	0.00009	118.61832	0.00014	0.00400	0.07273	4690.48438	162.6938
0.143989	127.01402	0.00009	120.38727	0.00014	0.00400	0.07271	4690.32422	163.8648
0.146389	128.81757	0.00009	122.15759	0.00014	0.00400	0.07271	4690.16406	165.0801
0.148789	130.61896	0.00009	123.92923	0.00014	0.00400	0.07272	4690.00000	166.3052
0.151188	132.41826	0.00009	125.70212	0.00014	0.00400	0.07273	4689.83984	167.5548
0.153588	134.21559	0.00009	127.47601	0.00014	0.00400	0.07271	4689.67578	168.7980
0.155988	136.01115	0.00009	129.25157	0.00014	0.00400	0.07272	4689.51953	170.0765
0.158387	137.80493	0.00009	131.02832	0.00014	0.00400	0.07272	4689.35547	171.3475
0.160787	139.59674	0.00009	132.80606	0.00014	0.00400	0.07272	4689.19531	172.6465
0.163187	141.38672	0.00009	134.58531	0.00014	0.00400	0.07272	4689.03516	173.9513
0.165586	143.17493	0.00009	136.36542	0.00014	0.00400	0.07271	4688.87109	175.2592
0.167986	144.96135	0.00009	138.14691	0.00014	0.00400	0.07271	4688.71094	176.5901
0.170386	146.74612	0.00009	139.92943	0.00014	0.00400	0.07270	4688.55078	177.9300
0.172785	148.52922	0.00009	141.71309	0.00014	0.00400	0.07270	4688.39063	179.2806
0.175185	150.31058	0.00009	143.49767	0.00014	0.00400	0.07270	4688.22656	180.6415
0.177585	152.09033	0.00009	145.28322	0.00014	0.00400	0.07270	4688.06641	182.0125
0.179984	153.86852	0.00009	147.06949	0.00014	0.00400	0.07270	4687.90625	183.3956
0.182384	155.64503	0.00009	148.85701	0.00014	0.00400	0.07269	4687.74219	184.7852
0.184784	157.42033	0.00009	150.64545	0.00014	0.00400	0.07269	4687.58203	186.1839
0.187183	159.19405	0.00009	152.43469	0.00014	0.00400	0.07269	4687.42188	187.5914
0.189583	160.96643	0.00009	154.22485	0.00014	0.00400	0.07269	4687.26172	189.0072
0.191983	162.61856	0.59272	156.01520	0.00014	0.00400	0.07270	4687.10156	190.3973
0.194387	163.67268	1.25681	157.80199	0.00014	0.00400	0.07267	4686.93750	191.5037

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0.196782   164.21111   1.45992   159.57915   0.00014   0.00400   0.07267   4686.77734   192.48814
0.199182   164.70403   1.48687   161.34431   0.00014   0.00400   0.07267   4686.61719   193.44467
0.201582   165.21213   1.46403   163.09717   0.00014   0.00400   0.07267   4686.45313   194.41002
0.203981   165.75175   1.42990   164.83774   0.00014   0.00400   0.07267   4686.29297   195.39310
0.206381   166.32805   1.39521   166.56624   0.00014   0.00400   0.07266   4686.13281   196.39500
0.208781   166.94005   1.36275   168.28325   0.00014   0.00400   0.07267   4685.97266   197.42305
0.211180   167.58421   1.33304   169.98889   0.00014   0.00400   0.07267   4685.81250   198.45996
0.213580   168.25845   1.30593   171.68349   0.00014   0.00400   0.07267   4685.65234   199.51164
0.215980   168.96031   1.28117   173.36710   0.00014   0.00400   0.07266   4685.48828   200.56560
0.218379   169.68654   1.26378   174.92839   0.95494   0.00400   0.07267   4685.32813   201.59096
0.220779   170.42517   1.25429   176.09386   1.47131   0.00400   0.07266   4685.16797   202.41309
0.223179   171.16685   1.24829   177.13181   1.55586   0.00400   0.07265   4685.00391   203.18089
0.225578   171.90834   1.24445   178.14113   1.56991   0.00400   0.07265   4684.84375   203.93884
0.227978   172.64857   1.24139   179.13597   1.57391   0.00400   0.07265   4684.68359   204.68858
0.230378   173.38708   1.23869   180.11938   1.57632   0.00400   0.07265   4684.52344   205.43332
0.232777   174.12354   1.23617   181.09187   1.57843   0.00400   0.07265   4684.35938   206.17393
0.235177   174.85815   1.23375   182.05330   1.58042   0.00400   0.07265   4684.20313   206.90970
0.237577   175.59050   1.23139   183.00427   1.58233   0.00400   0.07265   4684.03906   207.64104
0.239976   176.32077   1.22908   183.94466   1.58418   0.00396   0.07264   4683.87891   208.36737
0.242376   177.04886   1.22679   184.87492   1.58597   0.00365   0.07264   4683.71484   209.08948
0.244776   177.77451   1.22453   185.79524   1.58769   0.00304   0.07264   4683.55469   209.80699
0.247176   178.49791   1.22228   186.70540   1.58936   0.00218   0.07264   4683.39453   210.52007
0.249575   179.20889   1.22006   187.59407   1.59096   0.00123   0.07005   4683.23438   209.33612
0.251975   179.85262   1.21779   188.39528   1.59250   0.00113   0.06839   4683.07813   208.81329
0.254375   180.74188   0.58087   189.16403   1.59450   0.00108   0.06737   4682.92188   208.82698
0.256774   181.58008   1.04326   189.90193   1.59623   0.00104   0.06636   4682.76953   208.81808
0.259174   182.31180   1.01728   190.61029   1.59785   0.00100   0.06540   4682.62109   208.82156
0.261574   182.99248   1.08975   191.29002   1.59931   0.00097   0.06447   4682.46875   208.82141
0.263973   183.62793   1.07773   191.94080   1.60066   0.00094   0.06357   4682.31641   208.82338
0.266373   184.23465   1.09247   192.56511   1.60189   0.00091   0.06269   4682.16797   208.82617
0.268773   184.81567   1.09019   193.16394   1.60300   0.00089   0.06183   4682.04688   208.82634
0.271172   185.37657   1.09123   193.73604   1.60398   0.00086   0.06098   4681.92969   208.83154
0.273572   185.91975   1.08702   194.28349   1.60486   0.00084   0.06014   4681.80859   208.83092
0.275972   186.44710   1.08267   194.80676   1.60563   0.00082   0.05935   4681.69141   208.84004
0.278371   186.95941   1.07781   195.30696   1.60628   0.00080   0.05856   4681.57031   208.85284
0.280771   187.45799   1.07068   195.78421   1.60683   0.00078   0.05777   4681.44922   208.84573
0.283171   187.94366   1.06479   196.23827   1.60729   0.00077   0.05699   4681.33594   208.84517
0.285570   188.41597   1.05853   196.67101   1.60765   0.00075   0.05624   4681.21875   208.84735
0.287970   188.87607   1.05184   197.08356   1.60791   0.00073   0.05551   4681.10547   208.84970
0.290370   189.32387   1.04596   197.48495   0.72180   0.00072   0.05479   4680.99219   208.85590
0.292769   189.75984   1.03988   198.02055   1.49322   0.00070   0.05391   4680.87500   208.86011
0.295169   190.19425   1.03376   198.42757   1.48348   0.00069   0.05315   4680.76563   208.85976
0.297569   190.53688   1.02811   198.79716   1.52211   0.00067   0.05243   4680.65234   208.85951
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0.299969   190.99843    1.02239   199.13144    1.56399    0.00066    0.05176   4680.53906   208.86090
0.302368   191.38911    1.01672   199.44215    1.56096    0.00065    0.05110   4680.43359   208.86176
0.304768   191.76909    1.01133   199.73471    1.56877    0.00064    0.05048   4680.32422   208.86433
0.307168   192.13849    1.00605   200.01030    1.56818    0.00062    0.04986   4680.21484   208.86624
0.309567   192.49759    1.00075   200.27110    1.56765    0.00061    0.04927   4680.10547   208.86761
0.311967   192.84686    0.99555   200.51877    1.56505    0.00060    0.04869   4680.00000   208.86943
0.314367   193.18610    0.99057   200.75336    1.56354    0.00059    0.04813   4679.88672   208.87100
0.316766   193.51579    0.98555   200.97639    1.56027    0.00059    0.04756   4679.78125   208.86186
0.319166   193.83635    0.98072   201.18777    1.55836    0.00058    0.04706   4679.67969   208.87950
0.321566   194.14725    0.97592   201.38795    1.55500    0.00057    0.04654   4679.57422   208.88078
0.323965   194.44954    0.97122   201.57838    1.55283    0.00056    0.04604   4679.46875   208.88206
0.326365   194.74306    0.96662   201.75842    1.54953    0.00055    0.04554   4679.36719   208.88036
0.328765   195.02802    0.96206   201.92903    1.54718    0.00054    0.04507   4679.26563   208.88200
0.331164   195.30438    0.95760   202.09087    1.54396    0.00054    0.04461   4679.16016   208.88255
0.333564   195.57291    0.95322   202.24445    1.54146    0.00053    0.04417   4679.05469   208.88760
0.335964   195.83440    0.94507   202.38954    1.53833    0.00052    0.04373   4678.95313   208.88547
0.338363   196.09238    0.93401   202.52731    1.53571    0.00052    0.04330   4678.84766   208.88696
0.340763   196.34901    0.92146   202.65813    1.53267    0.00051    0.04288   4678.75000   208.88762
0.343163   196.60526    0.90751   202.78181    1.52995    0.00050    0.04247   4678.64844   208.88724
0.345563   196.86200    0.89313   202.89894    1.52698    0.00050    0.04205   4678.55078   208.88264
0.347962   197.11925    0.87894   203.01012    1.52419    0.00049    0.04166   4678.45313   208.88901
0.350362   197.37701    0.86494   203.11563    1.52129    0.00049    0.04126   4678.35547   208.88910
0.352762   197.63440    0.85124   203.21555    1.51845    0.00048    0.04086   4678.25391   208.88596
0.355161   198.80928   -0.55177   203.31152    1.51560    0.00046    0.03976   4678.15625   208.93616
0.357561   199.86101    1.24221   203.40324    1.51273    0.00045    0.03849   4678.05859   208.90244
0.359961   200.25768   -0.39617   203.48854    1.50993    0.00044    0.03799   4677.96484   208.91922
0.362360   201.62379    0.34897   203.57169    1.50723    0.00042    0.03638   4677.87109   208.92479
0.364760   201.93552    0.35072   203.64915    1.50464    0.00041    0.03584   4677.77734   208.90866
0.367160   202.91301   -0.54554   203.72412    1.50145    0.00039    0.03463   4677.67969   208.94421
0.369559   203.64601    0.64391   203.79497    1.49865    0.00038    0.03346   4677.58984   208.91438
0.371959   204.03487   -0.57238   203.86163    1.49572    0.00037    0.03289   4677.50391   208.93933
0.374359   205.04324    0.12173   203.92780    1.49337    0.00035    0.03128   4677.42969   208.94312
0.376758   205.25328    0.08010   203.98923    1.49034    0.00034    0.03078   4677.36719   208.92674
0.379158   206.01613   -0.47884   204.04898    1.48783    0.00033    0.02948   4677.30859   208.96744
0.381558   206.47769    0.44382   204.10602    1.48455    0.00031    0.02833   4677.25000   208.93137
0.383957   206.76717   -0.46251   204.15938    1.48225    0.00031    0.02776   4677.19141   208.95660
0.386357   207.45169    0.17080   204.21223    1.47910    0.00029    0.02603   4677.13281   208.95833
0.388757   207.51563    0.05521   204.26071    1.47695    0.00028    0.02570   4677.07422   208.93800
0.391156   208.04970   -0.28041   204.30930    1.47372    0.00027    0.02426   4677.01953   208.98903
0.393556   208.24900    0.40079   204.35449    1.47143    0.00025    0.02314   4676.96875   208.92654
0.395956   208.39641   -0.34416   204.39728    1.46826    0.00025    0.02280   4676.91406   208.98061
0.398356   208.78183    0.22973   204.44084    1.46602    0.00022    0.02055   4676.86328   208.97537
0.400755   208.67622    0.02231   204.47858    1.46304    0.00023    0.02094   4676.81250   208.94020
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0.403155	208.98993	-0.17903	204.51888	.46073	0.00021	0.01906	4676.75781	209.04103
0.405555	208.91972	0.32204	204.55684	.45778	0.00019	0.01748	4676.71094	208.92641
0.407954	208.93036	-0.30325	204.58852	.45538	0.00021	0.01911	4676.66406	208.99773
0.410354	209.10094	0.21316	204.62398	.45254	0.00019	0.01735	4676.61719	208.96182
0.412754	208.90656	-0.04011	204.65509	.45018	0.00019	0.01756	4676.57422	208.91562
0.415153	209.09859	-0.12854	204.68613	.44744	0.00018	0.01715	4676.52734	208.92046
0.417553	209.00555	0.23548	204.71550	.44529	0.00018	0.01715	4676.48047	208.95294
0.419953	208.99738	-0.27330	204.74403	.44244	0.00018	0.01718	4676.43359	208.99561
0.422352	209.10460	0.19837	204.77109	.43983	0.00018	0.01705	4676.38672	208.95688
0.424752	208.94583	-0.07924	204.79765	.43742	0.00018	0.01700	4676.33984	208.95216
0.427152	209.10260	-0.07623	204.82318	.43491	0.00018	0.01694	4676.29297	208.95593
0.429551	209.00294	0.18112	204.84778	.43236	0.00018	0.01690	4676.24609	208.95663
0.431951	209.01842	-0.23059	204.87166	.42999	0.00018	0.01685	4676.19922	208.95631
0.434351	209.09024	0.19357	204.89468	.42744	0.00018	0.01680	4676.15234	208.95595
0.436750	208.96330	-0.09459	204.91718	.42502	0.00018	0.01676	4676.10547	208.95776
0.439150	209.10181	-0.02898	204.93890	.42263	0.00018	0.01671	4676.05859	208.95660
0.441550	209.00070	0.13830	204.95979	.42012	0.00018	0.01667	4676.01172	208.95692
0.443950	209.03410	-0.19030	204.98051	.41773	0.00018	0.01663	4675.96484	208.95677
0.446349	209.07733	0.18211	205.00044	.41532	0.00018	0.01659	4675.92188	208.95645
0.448749	208.97787	-0.10670	205.01988	1.41296	0.00018	0.01655	4675.87109	208.95657
0.451149	209.09886	0.00396	205.03900	1.41059	0.00018	0.01651	4675.82422	208.95665
0.453548	209.00055	0.09738	205.05719	1.40827	0.00018	0.01647	4675.77734	208.95734
0.455948	209.04720	-0.15840	205.07552	1.40586	0.00018	0.01643	4675.73047	208.95782
0.458348	209.06747	0.16463	205.09296	1.40357	0.00018	0.01640	4675.68359	208.95685
0.460747	208.99229	-0.11483	205.11018	1.40123	0.00017	0.01636	4675.63672	208.95691
0.463147	209.09645	0.02731	205.12714	1.39897	0.00017	0.01633	4675.58984	208.95729
0.465547	209.00255	0.06266	205.14366	1.39187	0.00017	0.01629	4675.54297	208.95679
0.467946	209.05722	-0.12869	205.16359	1.37599	0.00017	0.01625	4675.50000	208.95715
0.470346	209.05995	0.14674	205.18747	1.35806	0.00017	0.01620	4675.44922	208.95772
0.472746	209.00525	-0.11610	205.21652	1.33649	0.00017	0.01614	4675.40625	208.95851
0.475145	209.09268	0.04599	205.25063	1.31515	0.00017	0.01607	4675.35938	208.95880
0.477545	209.00555	0.03506	205.29005	1.29229	0.00017	0.01599	4675.31250	208.95926
0.479945	209.06511	-0.10050	205.33423	1.27069	0.00017	0.01589	4675.26563	208.95953
0.482344	209.05408	0.12924	205.79091	-1.24251	0.00016	0.01498	4675.21875	209.00668
0.484744	209.01793	-0.11291	206.59143	-0.80593	0.00014	0.01303	4675.17578	209.01353
0.487144	209.08971	0.05937	206.91058	1.25938	0.00013	0.01198	4675.13281	208.95454
0.489543	209.01045	0.01238	206.96361	0.83540	0.00013	0.01187	4675.08984	208.97044
0.491943	209.07202	-0.07555	207.39896	-1.40983	0.00011	0.01071	4675.05078	209.02992
0.494343	209.05052	0.11111	207.95560	-0.59270	0.00009	0.00866	4675.01172	209.01761
0.496743	209.02997	-0.10729	208.08093	1.09084	0.00008	0.00790	4674.97656	208.96564
0.499142	209.08641	0.06755	208.11320	0.21156	0.00008	0.00789	4674.93750	208.99429
0.501542	209.01801	-0.01638	208.48273	-0.87044	0.00007	0.00651	4674.90625	209.01569
0.503942	209.00248	-0.05378	208.80025	0.01819	0.00004	0.00400	4674.87109	209.02637

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 0.506341   209.06294    0.09309   208.74237    0.71149   0.00004    0.00386  4674.83984  208.95267
 0.508741   209.05472   -0.09964   208.75320   -0.13086   0.00004    0.00426  4674.80859  209.00934
 0.511141   209.09886    0.07193   209.03096   -0.65456   0.00002    0.00203  4674.77734  209.08879

        AN ERROR OCCURRED IN THE BRANCH ITERATION IN SUBROUTINE TANK.
        PG( 8,2,1) =  209.089        PG( 8,2,2) =  209.106

        AN ERROR OCCURRED IN THE BRANCH ITERATION IN SUBROUTINE TANK.
        PG( 8,2,1) =  209.077        PG( 8,2,2) =  209.115
 0.513540   209.04453   -0.02110   209.12610    0.19830   0.0        0.0      4674.77344  209.04453
 0.515940   209.10373   -0.03465   208.95190    0.60250   0.00000    0.00045  4674.77344  208.95477
 0.518340   209.06882    0.07603   208.95546   -0.24713   0.00002    0.00210  4674.75391  209.01788

        AN ERROR OCCURRED IN THE BRANCH ITERATION IN SUBROUTINE TANK.
        PG( 8,2,1) =  209.069        PG( 8,2,2) =  209.085

        AN ERROR OCCURRED IN THE BRANCH ITERATION IN SUBROUTINE TANK.
        PG( 8,2,1) =  209.066        PG( 8,2,2) =  209.101
 0.520739   209.08037   -0.09028   209.16132   -0.46577   0.0        0.0      4674.75000  209.08037
 0.523139   209.11295    0.07333   209.18663    0.32781   0.0        0.0      4674.75000  209.11295
 0.525539   209.06075   -0.03214   208.96654    0.31481   0.00000    0.0      4674.75000  208.96654
 0.527938   209.11624   -0.01811   209.03989   -0.39601   0.00000    0.00043  4674.74609  209.04254
 0.530338   209.07852    0.06002   209.23784   -0.19908   0.0        0.0      4674.74609  209.07852
 0.532738   209.08865   -0.07996   209.18077    0.42986   0.0        0.0      4674.74609  209.08865
 0.535137   209.11018    0.07218   208.99608    0.13227   0.0        0.0      4674.74609  208.99608
 0.537537   209.06703   -0.04010   209.09993   -0.42651   0.0        0.0      4674.74609  209.06703
 0.539937   209.11800   -0.00422   209.26099   -0.08507   0.0        0.0      4674.74609  209.11800
 0.542337   209.07874    0.04519   209.15303    0.38840   0.0        0.0      4674.74609  209.07874
 0.544736   209.09564   -0.06923   209.02161    0.01848   0.0        0.0      4674.74609  209.02161
 0.547136   209.10820    0.06900   209.14735   -0.33890   0.0        0.0      4674.74609  209.10820
 0.549536   209.07372   -0.04535   209.24994    0.06924   0.0        0.0      4674.74609  209.07372
 0.551935   209.11891    0.00718   209.11162    0.29163   0.0        0.0      4674.74609  209.11162
 0.554335   209.07999    0.03173   209.03868   -0.15367   0.0        0.0      4674.74609  209.03868
 0.556735   209.10168   -0.05839   209.18541   -0.25292   0.0        0.0      4674.74609  209.10168
 0.559134   209.10605    0.06431   209.23021    0.21364   0.0        0.0      4674.74609  209.10605
 0.561534   209.07994   -0.04822   209.08278    0.21735   0.0        0.0      4674.74609  209.07994
 0.563934   209.12009    0.01631   209.06505   -0.24293   0.0        0.0      4674.74609  209.06505
 0.566333   209.08173    0.01979   209.20880   -0.17587   0.0        0.0      4674.74609  209.08173
 0.568733   209.10638   -0.04774   209.20097    0.25359   0.0        0.0      4674.74609  209.10638
 0.571133   209.10440    0.05853   209.06685    0.12335   0.0        0.0      4674.74609  209.06685
 0.573532   209.08606   -0.04969   209.09866   -0.25640   0.0        0.0      4674.74609  209.08606
 0.575932   209.12035    0.02331   209.22130   -0.06390   0.0        0.0      4674.74609  209.12035
 0.578332   209.08479    0.00938   209.16815    0.25649   0.0        0.0      4674.74609  209.08479
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NOT REPRODUCIBLE

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0.580731   209.11150   -0.03756   209.06110    0.00444   0.0   0.0   4674.74609   209.06110
0.583131   209.10422    0.05200   209.13260   -0.25145   0.0   0.0   4674.74609   209.10422
0.585531   209.09256   -0.04832   209.22382    0.04792   0.0   0.0   4674.74609   209.09256
0.587931   209.12093    0.02836   209.13918    0.23868   0.0   0.0   4674.74609   209.12093
0.590330   209.08839    0.00050   209.06686   -0.09149   0.0   0.0   4674.74609   209.06686
0.592730   209.11592   -0.02803   209.16173   -0.21686   0.0   0.0   4674.74609   209.11592
0.595130   209.10469    0.04505   209.21519    0.12693   0.0   0.0   4674.74609   209.10469
0.597529   209.09897   -0.04622   209.11526    0.18772   0.0   0.0   4674.74609   209.09897
0.599929   209.12134    0.03166   209.08221   -0.15629   0.0   0.0   4674.74609   209.08221
0.602329   209.09216   -0.00685   209.18463   -0.15309   0.0   0.0   4674.74609   209.09216
0.604728   209.11963   -0.01930   209.19893    0.17967   0.0   0.0   4674.74609   209.11963
0.607128   209.10516    0.03794   209.09854    0.11532   0.0   0.0   4674.74609   209.09854
0.609528   209.10448   -0.04309   209.10382   -0.19649   0.0   0.0   4674.74609   209.10382
0.611927   209.12186    0.03343   209.20010   -0.07614   0.0   0.0   4674.74609   209.12186
0.614327   209.09634   -0.01275   209.17810    0.20590   0.0   0.0   4674.74609   209.09634
0.616727   209.12279   -0.01148   209.09015    0.03722   0.0   0.0   4674.74609   209.09015
0.619126   209.10622    0.03091   209.12831   -0.20760   0.0   0.0   4674.74609   209.10622
0.621526   209.10962   -0.03919   209.20750    0.00021   0.0   0.0   4674.74609   209.10962
0.623926   209.12198    0.03390   209.15672    0.20182   0.0   0.0   4674.74609   209.12198
0.626325   209.10037   -0.01726   209.09058   -0.03555   0.0   0.0   4674.74609   209.09058
0.628725   209.12556   -0.00463   209.15237   -0.18898   0.0   0.0   4674.74609   209.12556
0.631125   209.10748    0.02413   209.20621    0.06809   0.0   0.0   4674.74609   209.10748
0.633524   209.11472   -0.03477   209.13728    0.17028   0.0   0.0   4674.74609   209.11472
0.635924   209.12303    0.03326   209.09886   -0.09749   0.0   0.0   4674.74609   209.09886
0.638324   209.10535   -0.02050   209.17332   -0.14694   0.0   0.0   4674.74609   209.10535
0.640724   209.12846    0.00123   209.19792    0.12267   0.0   0.0   4674.74609   209.12846
0.643123   209.11020    0.01775   209.12173    0.12082   0.0   0.0   4674.74609   209.11020
0.645523   209.11989   -0.03004   209.11267   -0.14279   0.0   0.0   4674.74609   209.11267
0.647923   209.12383    0.03173   209.18877   -0.09289   0.0   0.0   4674.74609   209.12383
0.650322   209.10968   -0.02259   209.18446    0.15650   0.0   0.0   4674.74609   209.10968
0.652722   209.13019    0.00608   209.11217    0.06418   0.0   0.0   4674.74609   209.11217
0.655122   209.11191    0.01189   209.13068   -0.16363   0.0   0.0   4674.74609   209.11191
0.657521   209.12357   -0.02518   209.19835   -0.03464   0.0   0.0   4674.74609   209.12357
0.659921   209.12448    0.02950   209.16899    0.16406   0.0   0.0   4674.74609   209.12448
0.662321   209.11401   -0.02365   209.10942    0.00499   0.0   0.0   4674.74609   209.10942
0.664720   209.13220    0.00996   209.15005   -0.15897   0.0   0.0   4674.74609   209.13220
0.667120   209.11453    0.00662   209.20142    0.02442   0.0   0.0   4674.74609   209.11453
0.669520   209.12807   -0.02037   209.15321    0.14897   0.0   0.0   4674.74609   209.12807
0.671919   209.12581    0.02675   209.11320   -0.05186   0.0   0.0   4674.74609   209.11320
0.674319   209.11877   -0.02384   209.16812   -0.13534   0.0   0.0   4674.74609   209.11877
0.676719   209.13419    0.01292   209.19800    0.07640   0.0   0.0   4674.74609   209.13419
0.679118   209.11765    0.00201   209.13916    0.11826   0.0   0.0   4674.74609   209.11765
[illegible]   209.11178   -0.01672   209.12137   -0.09657   0.0   0.0   4674.74609   209.12147
```

```
  0.683918   209.12738    0.02364   209.18256   -0.09860    0.0        0.0     4674.74609   209.12738
  0.686318   209.12350   -0.02327   209.18921    0.11222    0.0        0.0     4674.74609   209.12350
  0.688717   209.13591    0.01501   209.12888    0.07638    0.0        0.0     4674.74609   209.12888
  0.691117   209.12109   -0.00193   209.13397   -0.12278    0.0        0.0     4674.74609   209.12109
  0.693517   209.13531   -0.01135   209.19247   -0.05267    0.0        0.0     4674.74609   209.13531
  0.695916   209.12852    0.02032   209.17702    0.12879    0.0        0.0     4674.74609   209.12852
  0.698316   209.12756   -0.02211   209.12357    0.02784    0.0        0.0     4674.74609   209.12357
  0.700716   209.13760    0.01632   209.14902   -0.13000    0.0        0.0     4674.74609   209.13760
  0.703115   209.12437   -0.00518   209.19734   -0.00325    0.0        0.0     4674.74609   209.12437
  0.705515   209.13824   -0.00733   209.16397    0.12712    0.0        0.0     4674.74609   209.13824
  0.707915   209.13066    0.01693   209.12367   -0.02067    0.0        0.0     4674.74609   209.12367
  0.710314   209.13194   -0.02046   209.16425   -0.11998    0.0        0.0     4674.74609   209.13194
  0.712714   209.13977    0.01694   209.19682    0.04257    0.0        0.0     4674.74609   209.13977
  0.715114   209.12836   -0.00777   209.15173    0.10939    0.0        0.0     4674.74609   209.12836
  0.717513   209.14159   -0.00372   209.12865   -0.06219    0.0        0.0     4674.74609   209.12865

IHC900I EXECUTION TERMINATING DUE TO ERROR COUNT FOR ERROR NUMBER  217

IHC217I FIOCS - END OF DATA SET ON UNIT    5

TRACEBACK  ROUTINE  CALLED FROM ISN   REG. 14   REG. 15   REG.  0   REG.  1

           FRDNL#                     00C3A54C  0004B7F8  0000A414  00039C90

              MAIN                    00000D1A  01039C10  FD000008  00079FF8

ENTRY POINT=  01039C10
```