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Prediction of Payload Internal Pressure

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

→ An analysis of the internal pressure history of sounding rocket payloads as they ascend through the atmosphere was conducted. The analysis was concerned mainly with compressible flow and included the affects of choking. Computer programs were developed that successfully predict the internal pressure from trajectory data. The programs were based on both the theoretical analysis and mathematical models of the flow rates of various venting components used in relieving the payload internal pressure. The mathematical models were developed from empirical data gathered during

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testing. The payload model can be set up with any combination of relieve valves and air filters, and has provisions for including leaks due to doors and seals. Sample program results for several payloads are included along with the program listings.

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1. INTRODUCTION

Difficulties on several rocket flights in the recent past have been linked to the build-up of the internal pressure of the payload. This increase produced an environment that was adverse to the operation of components of the payload, resulting in their malfunction or failure. To determine the affects of these unfavorable conditions, it was necessary to calculate the internal pressure as a function of time. The analysis contained herein was performed to accomplish this task. It consisted of the mathematical development of the differential equations that represent the modelled pressure functions and the subsequent utilization of a digital computer to determine their solution. The computer programs and their results have been verified by comparison to empirical data. These supplementary programs can be used in after-the-fact calculations of the pressure the payload experienced for a particular rocket flight. A more useful approach would be to use them analytically to predict the internal pressure of a payload under design. In this manner, possible pressure problems can be found and corrected in advance of the actual flight.

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2. SINGLE VOLUME MATHEMATICAL ANALYSIS

The problems from pressure build-up arise from the fact that the internal gas cannot vent fast enough to lower the payload pressure. A pressure differential is formed which results in loads to sensitive items such as doors, compartments and components, causing damage, malfunction, or inoperation of these devices.

On the launch pad, the payload is usually pressurized to insure that the "clean" area is at a slightly higher pressure than the surrounding environment. In this manner, dust particles can be kept from contaminating the important payload areas. As the rocket ascends through the atmosphere the external pressure drops faster than the payload pressure can follow, creating a differential between the internal and external pressures.

The payload is modelled as a simple box of volume equal to the volume of gas to be vented. To this box is attached the venting apparatus of the payload, as shown in Figure 1. The configuration consists of any combination of valves, filters and orifices used in relieving the internal pressure of the payload. The only way for the internal pressure of the payload to be released is through the venting apparatus and any leaks. With the proper design configuration, the internal pressure can be made to approximately track the external pressure.

The valves are closed until the pressure differential across them is equal to or greater than their cracking pressure. The filters are open and operating at all times. Provision is included for any leaks due to doors or seals, which are modelled as orifices with an effective exit area. More will be presented on the operating characteristics of these devices later in this report.

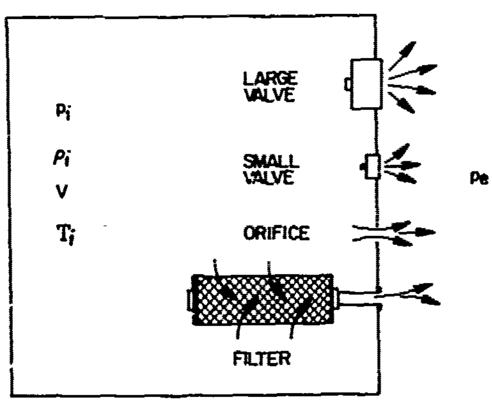

Figure 1. Payload Model for Venting Analysis

The mathematical analysis is begun by writing the perfect gas law for the fluid in the box:

$$p_i = \rho_i R T_i = m_i R T_i / V \; . \tag{1}$$

Differentiating with respect to time, we obtain

$$\frac{dp_i}{dt} = \frac{d}{dt}\left[\frac{m_i R T_i}{V}\right] = \frac{R}{V}\left[T_i \frac{dm_i}{dt} + m_i \frac{dT_i}{dt}\right] \tag{2}$$

For simplicity, the internal temperature will be assumed to be constant throughout the flight. The average ascent through the atmospher lasts 80 sec; this does not allow enough heat to be transferred to or from the gas to significantly change its temperature. Then Eq. (2) becomes

$$\frac{dp_i}{dt} = \frac{RT_i}{V} \frac{dm_i}{dt} = \frac{RT_i}{V} \dot{m}_i \tag{3}$$

where dp_i/dt is negative for $p_i > p_e$. To calculate the internal pressure from Eq. (3), we need to determine the rate of change of the mass in the box. The fluid mass is decreased by the flow through the venting apparatus, which is governed by the flow characteristics of the valves, filters and orifices. These characteristics have been measured experimentally from actual hardware and are presented in detail in Appendix A.

The mass flow rate is a function of the density of the gas and the pressure differential across the device, which is defined as:

$$\Delta p = p_{int} - p_{ext} \; . \tag{4}$$

The external pressure is taken as the atmospheric pressure (at altitude) that the payload experiences, which can be determined from the rocket's trajectory. Aerodynamic affects producing a pressure coefficient and a subsequent change in the "external" pressure are ignored for the following reasons:

(1) In all cases analyzed so far, the valves and filters have been mounted on the cylindrical sections of the payloads, for which c_p is negligible or zero;

(2) The effects of angle of attack and boundary layers are considered to be negligible.

The total mass flow rate is the sum of the contributions of the individual venting components:

$$\dot{m}_T = \dot{m}_v \text{ (\# of valves)} + \dot{m}_f \text{ (\# of filters)} + \dot{m}_o . \tag{5}$$

From the considerations of continuity, we find that the rate of change of the internal gas mass is equal to the rate at which the gas leaves the volume:

$$\dot{m}_i = -\dot{m}_T . \tag{6}$$

Using this substitution, the differential equation which models the payload internal pressure becomes

$$\frac{dp_i}{dt} = -\frac{RT_i}{V}\dot{m}_T . \tag{7}$$

With the external pressure as a function of time and the equation for the mass flow rate, the above differential equation can be integrated to give the internal pressure as a function of time.

3. COMPUTER PROGRAM PRESS4.FOR

Equation (7) can be integrated numerically to obtain the internal pressure at any time through the use of a digital computer. The general ordinary differential equation of the form $dy/dx = f(x,y)$ with initial condition $y_o = f(x_o)$, is solved using a fourth-order Runge-Kutta integration process. This is a single-step method in which the value of y at $x = x_n$ is used to compute $y_{n+1} = y(x_{n+1})$. The relevant formulas for integration are:

$$y_{n+1} = y_n + \frac{1}{6}(T_1 + 2T_2 + 2T_3 + T_4) \tag{8}$$

where

$$\begin{aligned} T_1 &= hf(x_n, y_n) \\ T_2 &= hf(x_n+h/2, y_n+T_1/2) \\ T_3 &= hf(x_n+h/2, y_n+T_2/2) \\ T_4 &= hf(x_n+h, y_n+T_3) \\ h &= \text{step size} . \end{aligned} \tag{9}$$

A step size of 0.01 sec was selected for this program. The schematic of Figure 2 gives a visual representation of the integration process. The y values defined at intermediate steps are used to calculate the future y values, without using any previous results. The method is a quick and efficient means of integrating a differential equation.

This integration technique and the differential equation have been programmed on the PDP-11/34 computer using the FORTRAN IV language. A listing and flow chart of program PRESS4.FOR are presented in Appendix B.

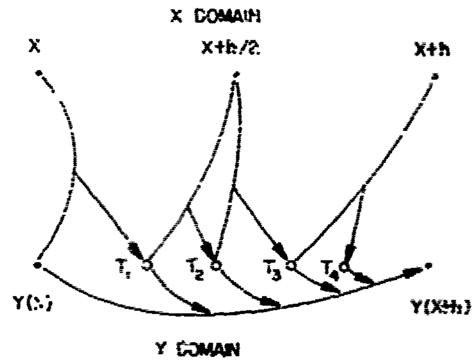

Figure 2. Integration Schematic.

4. MULTIPLE VOLUMES MATHEMATICAL ANALYSIS

A payload can be constructed such that interconnected compartments are involved in the venting process. The model of this case consists of boxes connected by various venting components, as shown in Figure 3 for two volumes. The main volume, box No. 1, is set up in a manner similar to the single volume model: with valves, filters, and orifices exposed to the external environment. The major difference is that it now has fluid input from the secondary volume. The secondary volume, box No. 2, is set up for venting gas to both the main volume (through valves) and the external environment (through filters and orifices).

For volume No. 1, the mass flow rate is

$$\dot{m}_1 = -(\dot{m}_{T_1} - \dot{m}_{T_2}) \tag{10}$$

where $\dot{m}_{T_1}$ is the flow rate output of the main venting apparatus and $\dot{m}_{T_2}$ is the rate input from the second volume. For volume No. 2, the mass flow rate is

$$\dot{m}_i = -\dot{m}_{T_3} . \tag{11}$$

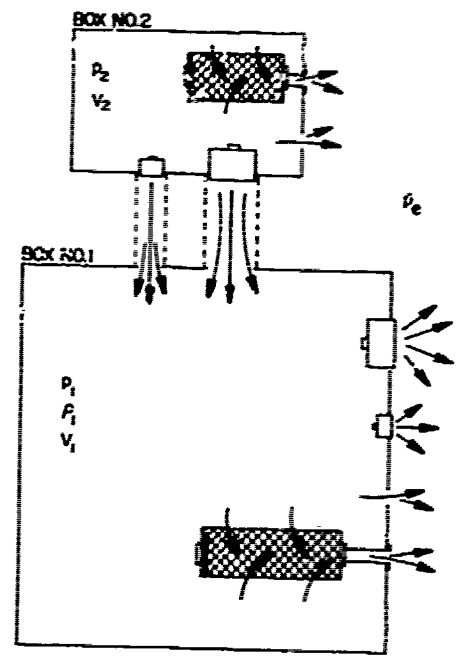

Figure 3. Payload Model for Multiple Volumes Venting Analysis

Proceeding in a manner analogous to the single volume analysis, we obtain two differential equations: one for each volume:

$$\frac{dp_1}{dt} = -\frac{RT_i}{V_1} (\dot{m}_{T_1} - \dot{m}_{T_2}) \tag{12}$$

$$\frac{dp_2}{dt} = -\frac{RT_i}{V_2} (\dot{m}_{T_3}) \tag{13}$$

where

$$\begin{aligned} \dot{m}_{T_1} &= \dot{m}_{v_1} + \dot{m}_{f_1} + \dot{m}_{o_1} \\ \dot{m}_{T_2} &= \dot{m}_{v_2} \\ \dot{m}_{T_3} &= \dot{m}_{T_2} + \dot{m}_{f_2} + \dot{m}_{o_2} . \end{aligned} \tag{14}$$

Thi   alysis can be extended to include an infinite number of volumes, obtaining n differential equations for n volumes interconnected together and venting to the atmosphere.

5. COMPUTER PROGRAM PRESSM.FOR

A two-volume venting calculation has also been programmed on the PDP-11/34 computer. The numerical integration process is similar to that used for the single-volume problem; here it is set up for a system of ordinary differential equations. The method is contained in the FORTRAN IV subroutine RKGS. FOR in the IBM Scientific Subroutines Manual (Reference 4). A lis g and flowchart of program PRESSM. FOR are presented in Appendix C.

6. SAMPLE PROGRAM RESULTS

The two computer programs referenced in this report have been used to analyze payload designs. Presented here are the results for the SPICE, IRBS, and ZIP payloads. Also presented are the results of the test case used to verify program operation and validity.

6.1 SPICE Payload

The SPICE payload was flown on 27 Jan 1979 and experienced failure of the door unlatching mechanism. The cause of this failure was determined to be a buildup of the internal pressure which resulted in increased loading on the door. The SPICE payload was analyzed using an earlier version of the single volume computer program. Figure 4 is a plot of the computer results.

SPICE payload configuration:

Volume:	19.55 cu ft,
Venting apparatus:	2 P7-637 0.50 psi relief valves.

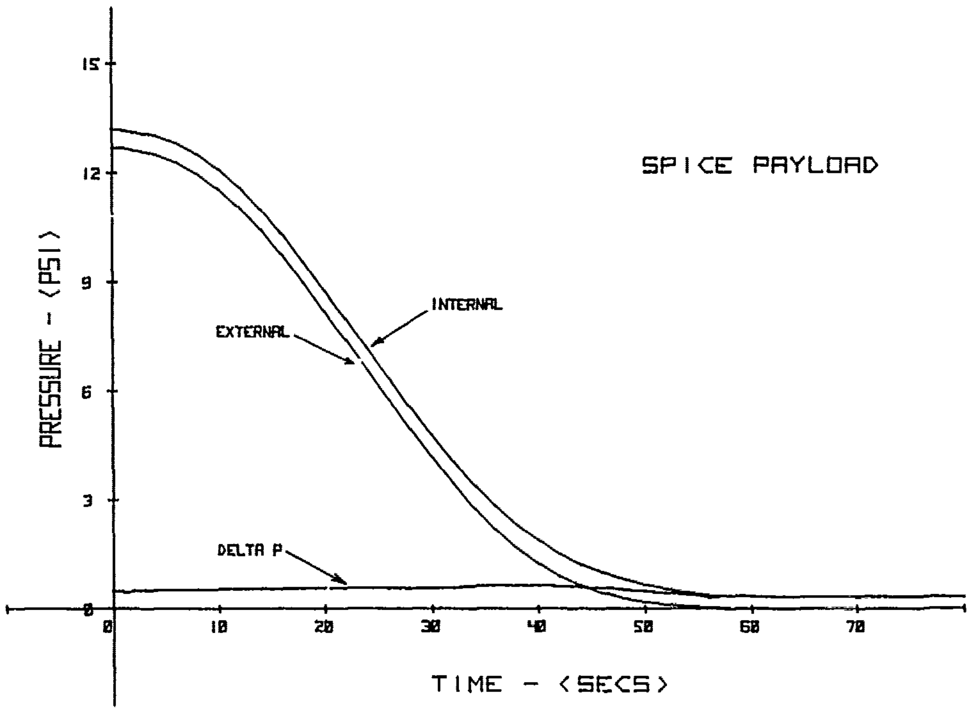

Figure 4. Program Results for SPICE Payload

6.2 IRBS Payload

The IRBS payload was analyzed during the testing phase. It consists of a small chamber venting into the larger main volume of the payload. The intent here was to determine the maximum internal pressure that the payload would experience in order to generate proper testing levels. Figure 5 is a plot of the program results for Volume No. 1; Figure 6 shows those for volume No. 2. Notice that the valves on the secondary volume do not operate at all; this is shown by the secondary volume internal pressure being lower than the main volume pressure in Figure 6. The leak takes care of any pressure build-up in volume No. 2.

IRBS configuration:

Volume No. 1:	46.80 cu ft,
Venting apparatus:	3 P7-637 0.50 psi relief valves venting to the atmosphere,
Volume No. 2:	0.18 cu ft,
Venting apparatus:	2 P-249 0.10 psi relief valves venting to the main volume; 1 leak (orifice) with effective area of 0.000042 sq ft venting to the atmosphere.

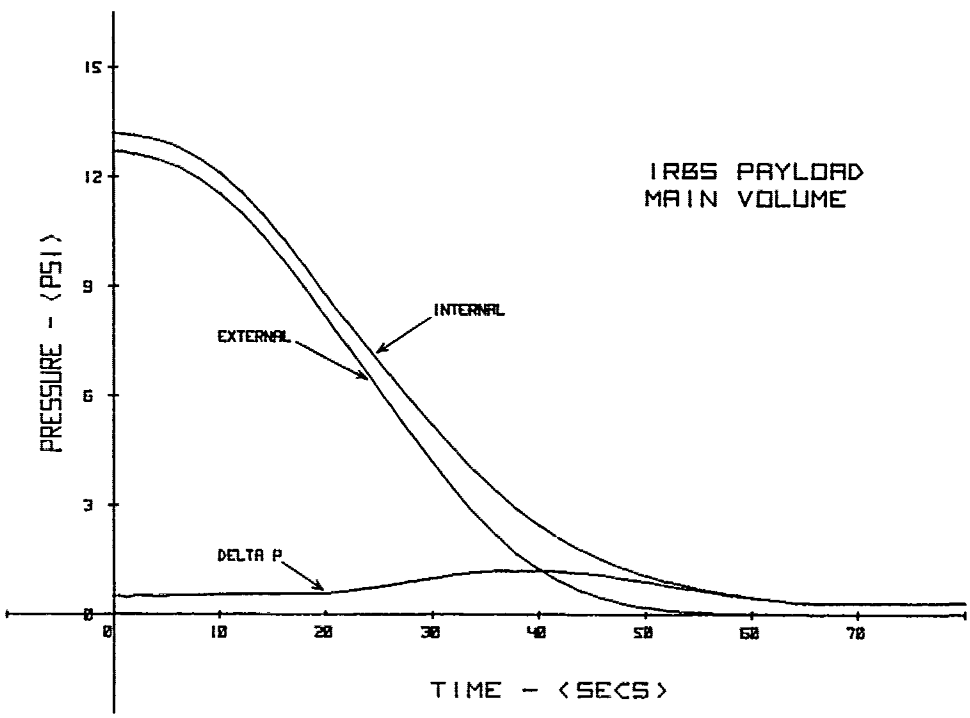

Figure 5. Program Results for IRBS Payload—Main Volume

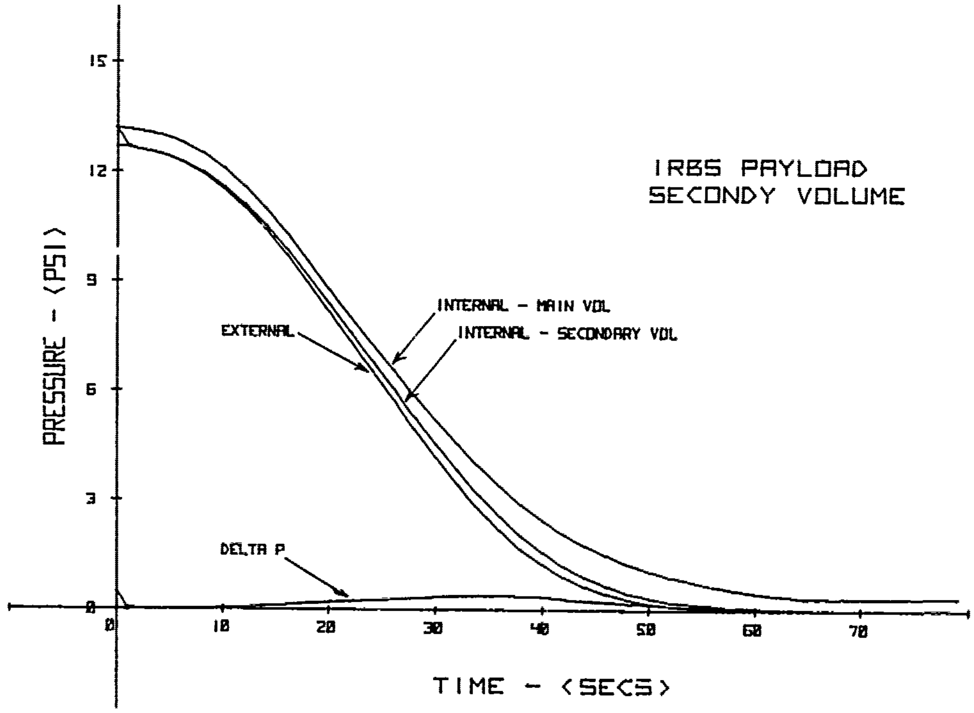

Figure 6. Program Results for IRBS Payload—Secondary Volume

6.3 ZIP Payload

The ZIP payload was analyzed during the design phase. It is a good example of how the programs can be used to pin-point problems in advance. The original analysis of ZIP showed a maximum delta p of over 1.69 psi; it also showed 0.187 psi at the critical time of door unlatching and opening (see Figure 7). The venting configuration was revised to include the larger relief valves. Subsequent reanalysis showed a much improved situation: the maximum delta p was decreased to just over 0.50 psi. Figure 8 presents the revised pressure prediction for the ZIP payload.

ZIP configuration:

Volume:	6.80 cu ft,
Original venting:	6 P-249 0.10 psi relief valves,
	2 RA-2500 filters 0.11045 sq in. in area,
Revised venting:	10 P-249 0.10 psi relief valves,
	4 P7-637 0.50 psi relief valves,
	2 RA-2500 filters 0.11045 sq in. in area.

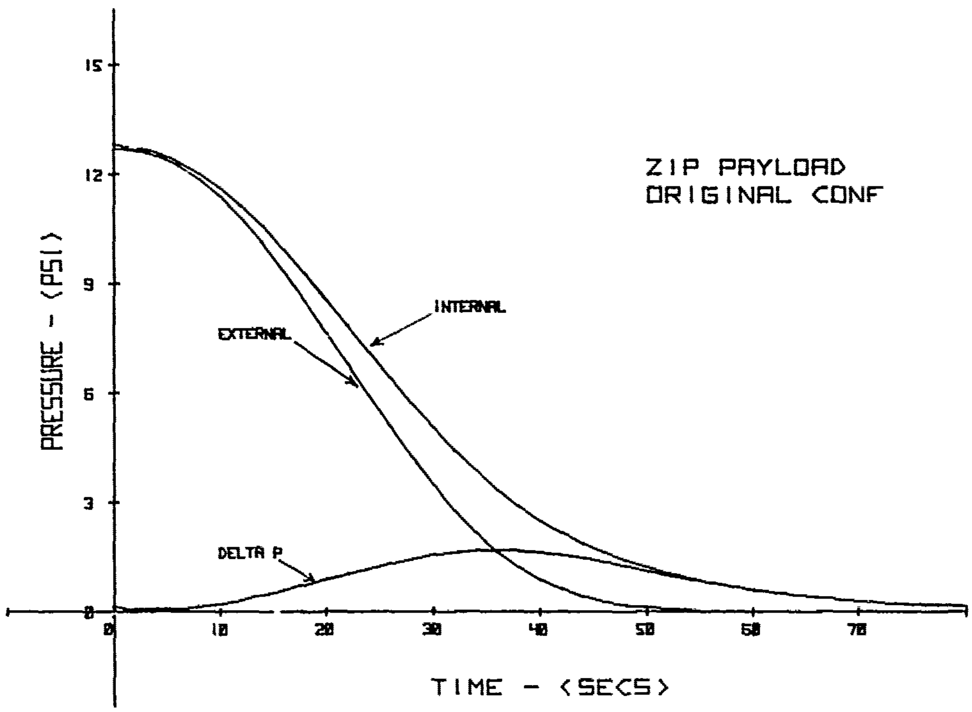

Figure 7. Program Results for ZIP Payload—Original Venting Configuration

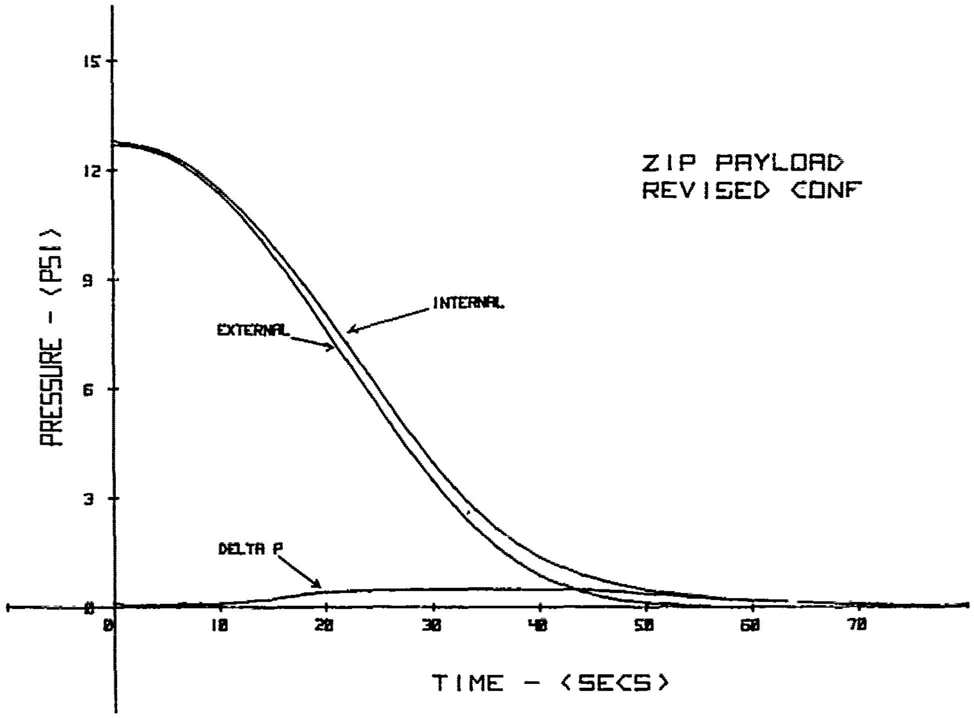

Figure 8. Program Results for ZIP Payload—Revised Venting Configuration

6.4 Program Test Configuration

In order to validate the pressure programs, a test case was developed and evaluated during the ZIP payload analysis. A standard volume with only one relief valve was evacuated using a vacuum pump, such that the external and internal pressures were known to an accuracy of ± 0.1 psi. The test case results were then compared to those predicted by the computer program for the same external pressure variation. This comparison lead to additional refinements in the programs, with subsequent improvement in their prediction capability. A comparison of the results follows in Figure 9. It is evident that the program has sufficient accuracy for design work while remaining slightly conservative.

Test configuration:

Volume:	1.00 cu ft.
Venting apparatus:	1 P-249 0.10 psi relief valve.

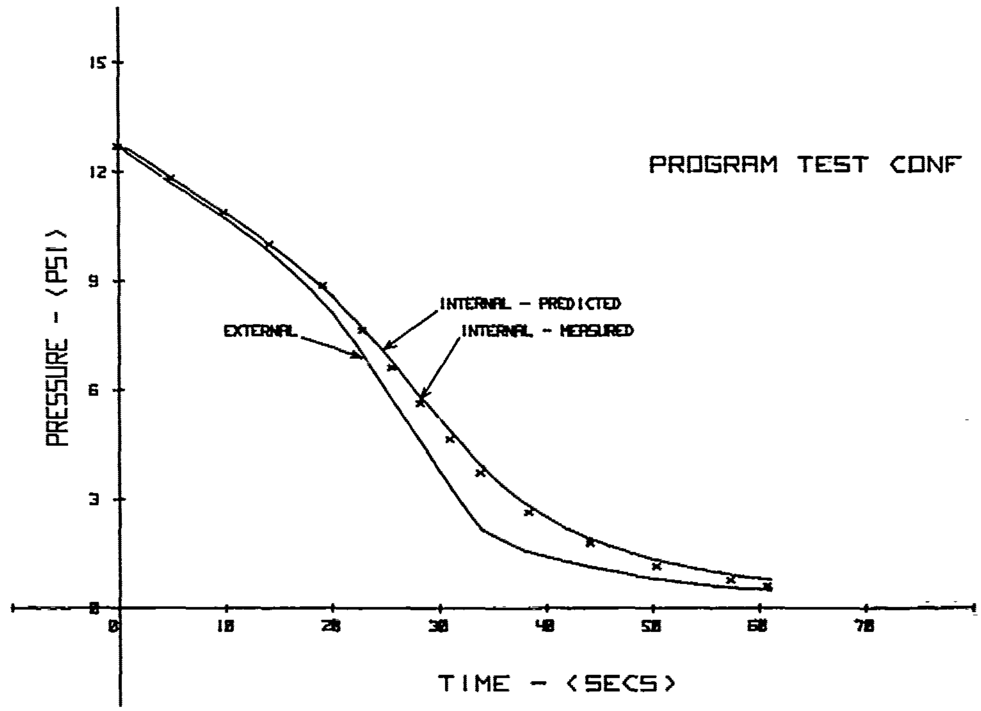

Figure 9. Program Results for Test Configuration

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2. Blackburn, J.F., Reethof, G., and Shearer, J.L. (Editors) (1960) Fluid Power Control, MIT Press, Cambridge, MA, pp 54-55, 63-69, 214-220.
3. Shapiro, A.H. (1953) The Dynamics and Thermodynamics of Compressible Fluid Flow, Ronald Press, New York, pp 83-105.
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5. Lynch, W.P. (1979) SPICE I Failure Analysis, AFGL Technical Memorandum No. 19.

Appendix A

Operating Characteristics of Venting Components

The venting apparatus is analyzed as an opening of a certain area through which the fluid flows. The mass flow rate takes the form of

$$\dot{m} = \rho Q = \rho v A \ . \qquad \text{(A1)}$$

The density of the fluid is a function of the pressure and the temperature and will be determined by inlet and outlet conditions. The volume flow rate depends upon the velocity of the fluid and the area of the opening. Both of these are functions of the fluid pressure. The velocity is related to the pressure ratio across the opening. In the case of the relief valves, the opening area is variable and is dependent upon the pressure differential. The cracking pressure on a valve is controlled by the properties of the helical spring which is part of the valve mechanism (see Figure A1). As the delta p is increased, the valve opens and the area of the opening is dependent upon how the spring is compressed. At some value of the pressure differential, the valve will "bottom out;" that is, the spring will reach maximum compression and the exit area will be at its greatest value.

We must also take into account compressibility affects and the phenomena of choking when analyzing the venting apparatus. The flow through an orifice (or any opening) can increase its velocity only until the Mach number reaches the value of 1. At this point the velocity in the throat (smallest area of the orifice) becomes sonic and the volume flow rate reaches its maximum value. Any attempt to further increase the velocity through an increase in delta p will not be successful in changing the volume flow rate.

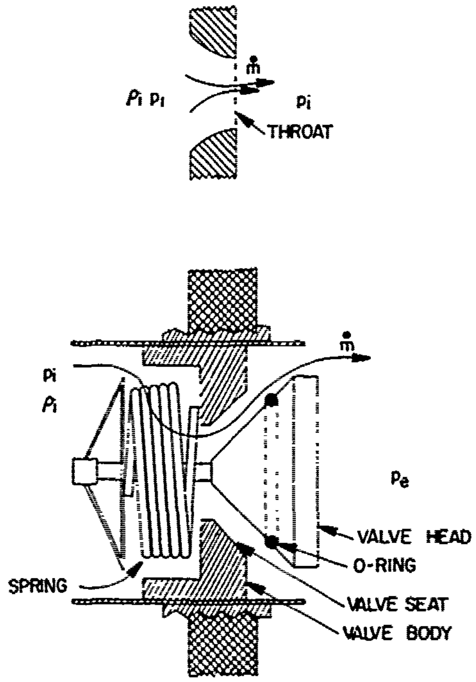


Figure A1. Throat Concept and Valve Mechanism

This is so because an increase in velocity would cause the Mach number at the throat to be greater than 1, which is an impossibility from fluid dynamics. When the velocity in the throat equals the speed of sound, the flow is said to be choked. The volume flow rate will remain constant, no matter how large the pressure differential becomes.

Choking is a function of the pressure ratio across the opening; here p_e/p_i. As the velocity increases and M approaches 1, the pressure ratio decreases. At a certain value of p_e/p_i the flow will reach $M = 1$; this is called the critical pressure ratio and signals the onset of choking. A numerical value for the critical pressure ratio can be determined from fluid dynamics.

Writing Bernoulli's equation for compressible flow, we have

$$\frac{v_i^2}{2} + \int \frac{dp_i}{\rho_i} = \frac{v_e^2}{2} + \int \frac{dp_e}{\rho_e} = \text{constant} . \qquad \text{(A2)}$$

The velocity well away from the opening inside the volume is negligible; thus $v_i = 0$ and

$$\int \frac{dp_i}{\rho_i} = \frac{v_e^2}{2} + \int \frac{dp_e}{\rho_e} \; . \qquad \text{(A3)}$$

Rearranging the above equation, it becomes

$$\frac{v_e^2}{2} = \int \frac{dp_i}{\rho_i} - \int \frac{dp_e}{\rho_e} \; . \qquad \text{(A4)}$$

From the relations of isentropic flow (frictionless, adiabatic flow of a perfect gas) we have the following:

$$p = C\rho^{\gamma} \qquad \rho = (p/C)^{1/\gamma} \qquad C^{1/\gamma} = \frac{p^{1/\gamma}}{\rho} \; . \qquad \text{(A5)}$$

Using this in Eq. (A4), it becomes

$$\frac{v_e^2}{2} = \int (C/p_i)^{1/\gamma}\, dp_i - \int (C/p_e)^{1/\gamma}\, dp_e \qquad \text{(A6)}$$

$$\frac{v_e^2}{2} = C^{1/\gamma} \left(\int dp_i/p_i^{1/\gamma} - \int dp_e/p_e^{1/\gamma} \right) \qquad \text{(A7)}$$

$$\frac{v^2}{2} e = \frac{p_i}{\rho_i}^{1/\gamma} \left(\frac{p_i^{(1-1/\gamma)}}{(1-1/\gamma)} - \frac{p_e^{(1-1/\gamma)}}{(1-1/\gamma)} \right) \qquad \text{(A8)}$$

$$\frac{v_e^2}{2} = \frac{p_i}{\rho_i}^{1/\gamma} (\gamma/\gamma-1) \left(p_i^{(\gamma-1)/\gamma} - p_e^{(\gamma-1)/\gamma} \right) \qquad \text{(A9)}$$

$$\frac{v_e^2}{2} = \gamma/(\gamma-1) \frac{p_i}{\rho_i} \left((1-(p_e/p_i)^{(\gamma-1)/\gamma} \right) . \qquad \text{(A10)}$$

Therefore, the exit velocity of the opening is given by

$$v_e = \sqrt{\frac{2\gamma}{\gamma-1} \frac{p_i}{\rho_i} \left(1-(p_e/p_i)^{(\gamma-1)/\gamma} \right)} \; . \qquad \text{(A11)}$$

At Mach = 1, v_e will equal the speed of sound and $p_e/p_i = (p_e/p_i)_{crit}$; then:

$$v_e = a = \sqrt{\frac{\gamma p_e}{\rho_e}} = \sqrt{\frac{2\gamma}{\gamma-1} \frac{p_i}{\rho_i} \left(1-(p_e/p_i)_{crit}^{(\gamma-1)/\gamma}\right)} \, . \qquad (A12)$$

Rearranging Eq. (A12) gives:

$$1 - (p_e/p_i)_{crit}^{(\gamma-1)/\gamma} = \frac{\gamma-1}{2} \frac{\rho_i}{\rho_e} \frac{p_e}{p_i} \qquad (A13)$$

but

$$\frac{\rho_i}{\rho_e} = (p_i/p_e)^{1/\gamma} \qquad (A14)$$

from the isentropic relations used earlier. Substituting Eq. (A14) into Eq. (A13)

$$1 - (p_e/p_i)_{crit}^{(\gamma-1)/\gamma} = \frac{\gamma-1}{2} \frac{(p_e/p_i)_{crit}}{(p_e/p_i)_{crit}^{1/\gamma}} = \frac{\gamma-1}{2} (p_e/p_i)_{crit}^{(\gamma-1)/\gamma} \qquad (A15)$$

$$(1+(\gamma-1)/2)\, (p_e/p_i)_{crit}^{(\gamma-1)/\gamma} = 1 \qquad (A16)$$

and solving for the pressure ratio, we have

$$(p_e/p_i)_{crit} = (2/(\gamma+1))^{\gamma/(\gamma-1)} \, . \qquad (A17)$$

Equation (A.7) is the expression for the critical pressure ratio. For a $\gamma = 1.40$, the critical pressure ratio is 0.5283. When the pressure ratio is less than $(p_e/p_i)_{crit}$ the flow is choked and the volume flow rate is maximum. Eqs. (A11) and (A17) have been used in the computer programs referenced in this report.

The volume flow rate for the venting apparatus used on our payloads has been measured experimentally. The valves, filters, and orifices are modelled by developing mathematical formulas for their flow characteristics. Originally, this was accomplished from manufacturer's data. However, upon close examination that information was found to be quite dated and it was deemed necessary to experimentally test the apparatus. The numerical information on the valves and filters presented in Table A1 is based upon this empirical data. Leaks are modelled as orifices and are governed by the following equation.

$$m = A_e \sqrt{64.8 \rho \Delta p} \,. \tag{A18}$$

From which we see that $Q \propto \Delta p$, or that $\ln Q \propto 0.5 \ln \Delta p$ for an orifice.

Table A1. Valve and Filter Mathematical Models

CIRCLE SEAL Pressure Relief Valves
James, Pond & Clark, Inc., Pasadena, CA

P-249-0.10

Labeled cracking pressure	0.10	psi
Measured cracking pressure	0.0387	psi
Knee pressure	0.10	psi

Volume flow rate curve:

$\Delta p < 0.10 \quad \ln Q = 10.5789 + 4.7952 \ln \Delta p$

$\Delta p \geq 0.10 \quad \quad = 0.9767 + 0.4956 \ln \Delta p$

P7-637-0.50

Labeled cracking pressure	0.50	psi
Measured cracking pressure	0.3250	psi
Knee pressure	0.59	psi

Volume flow rate curve:

$\Delta p < 0.59 \quad \ln Q = 12.7900 + 17.3978 \ln \Delta p$

$\Delta p \geq 0.59 \quad \quad = 3.8647 + 0.4785 \ln \Delta p$

Valve volume flow rate modelled by:

$$Q = \exp(A + B \ln \Delta p)$$

MILLIPORE Filters
Millipore Corp., Bedford, MA

CW-19 Cartridge Filter

$A = -5.6347$
$B = 114.9396$
$C = -60.0416$
$D = 12.9880$

Filter volume flow rate modelled by:

$$Q = A + B(\Delta p) + C(\Delta p)^2 + D(\Delta p)^3$$

Filter length Q multiplier

31 inch	Q × 1.41
22 inch	Q × 1.00
12 inch	Q × 0.50

RA-2500 Membrane filter 1.2 µm pore size

$A = -0.00702$
$B = 2.0191$
A_e = Exit area in square inches

Filter volume flow rate modelled by:

$$Q = [A + B(\Delta p)] A_e$$

The knee pressure listed in Table A1 is that pressure at which the valve bottoms out and its flow area becomes constant. The valve will then begin to act in a manner similar to an orifice. This is reflected in the values of the slopes of the flow curves approximately equalling 0.5. Any discrepancies are probably due to the effects of discharge coefficients which are not directly taken into account here. They are a function of the fluid pressure and the Reynolds number.

A correction factor must be applied to the above numerical data to correct for the fact that the measurements were taken at atmospheric pressure and are being applied at altitude (lower than atmospheric pressure). From the orifice Eq. (A18) we see that Q is mainly a function of the density:

$$Q = f(\sqrt{\rho \Delta p / \rho}) . \tag{A19}$$

Rearranging we have

$$Q = f(\rho^{1/2}/\rho) = f(1/\rho^{1/2}) = f(1/p^{1/2}) . \tag{A20}$$

Thus, the volume flow rate is inversely proportional to the square root of the pressure:

$$Q_{atm} \propto 1/p_{atm}^{1/2} \quad Q_i \propto 1/p_i^{1/2} . \tag{A21}$$

Then

$$Q_i/Q_{atm} = (p_{atm}/p_i)^{1/2} \tag{A22}$$

and the low pressure correction is

$$Q_i = Q_{atm}(p_{atm}/p_i)^{1/2} \tag{A23}$$

where Q_{atm} is the measured volume flow rate at atmospheric conditions. The low pressure correction was included with the compressible flow equations in the computer programs.

A comparison of the computer prediction and the measured results of the test configuration showed that the program was accurate except at the higher altitudes (lower external pressures). Experimenting with the computer program, it was found that an additional correction factor of the form

$$Q_i = Q_{atm}(p_i/p_{atm})^n \tag{A24}$$

(where n is between 0.20 and 0.30) increases its accuracy. This additional correction factor could possibly incorporate the affects of a discharge coefficient. The total correction factor applied to the measured volume flow rate is:

$$Q_{corr} = (p_{atm}/p_i)^{0.50}\,(p_i/p_{atm})^{0.25} = (p_{atm}/p_i)^{0.25} \,. \tag{A25}$$

The following then, are the operating conditions that are used in the programs developed for the PDP-11/34 computer.

For valves:

$\Delta p < p_c$			$\dot{m}_v \quad 0$
$\Delta p \geq p_c$	$p_e/p_i > (p_e/p_i)_{crit}$	$M < 1$ $Q = f(\Delta p)$	$\dot{m}_v = \rho Q Q_{corr}$
	$p_e/p_i \leq (p_e/p_i)_{crit}$	$M = 1$ $Q =$ constant (choked)	$\dot{m}_v = \rho Q_{previous}$

For filters:

$M < 1$	$Q = f(\Delta p)$	$\dot{m}_f = \rho Q Q_{corr}$
$M = 1$	$Q =$ constant (choked)	$\dot{m}_f = \rho Q_{previous}$

For leaks and orifices:

$M < 1$	$Q = f(\Delta p)$	$\dot{m}_o = \rho Q$
$M = 1$	$Q =$ constant (choked)	$\dot{m}_o = \rho Q_{previous}$

From the above, we can see that even though the venting apparatus becomes choked, the MASS flow rates can increase or decrease because the density of the flow can increase or decrease. Only the VOLUME flow rate is affected by choking.

Appendix B

Listing and Flowchart of PRESS4.FOR

Computer Program PRESS4.FOR

Language:	FORTRAN IV
Computer:	DEC PDP-11/34A
Memory Requirements:	8K Words
Fortran File Size:	21 Blocks
Input File:	FTN30.DAT
Output Files:	FTN31.DAT FTN32.DAT
Major Equations Used:	Equations (7), (A11), (A18), (A25), and those of Table A1.
Integration Technique:	Fourth-order Runge-Kutta process, Eqs. (8) and (9); see also Subroutine RK2 of Reference 4.

```
      PROGRAM PRESS4
C-----PROGRAM PRESS4.FOR
C-----THIS PROGRAM IS AN ATTEMPT TO PREDICT THE INTERNAL PRESSURE OF A
C-----PAYLOAD OF A ROCKET AS ITI ASCENDS THROUGH THE ATMOSPHERE.  THE
C-----PAYLOAD IS SET UP AS A CHAMBER WITH ATTACHED VENTING VALVES,
C-----FILTERS AND ORIFICES.  DOOR LEAKS ARE MODELLED AS ORIFICES.  THE
C-----PROGRAM NUMERICALLY INTEGRATES THE DIFFERENTIAL EQUATION THAT
C-----REPRESENTS THE PRESSURE DERIVATIVE.
C-----AUTHOR: C. F. KREBS
      DIMENSION GAS(5),TITLE(20),PREXT(100),PTIME(100)
      REAL  MASS,MULT
      DATA QRATE1,QRATE2,QRATEF,QRATEL,RATE,RATEF,RATEL,RATEV1,RATEV2,
     *      DCOEFF,INDEX,LINDEX,IMARK/9*0.,0.90,2,0,0/
C-----FORMAT STATEMENTS
 9000 FORMAT(20A4)
 9100 FORMAT(I10,7F10.0)
 9101 FORMAT(8F10.0)
 9200 FORMAT(/10X,'GAS PROPERTIES:'/
     *      15X,'TYPE:                          ',5A4/
     *      15X,'MAIN VOLUME                  = ',F10.2,' CU FT'/
     *      15X,'INITIAL PRESSURE             = ',F10.2,' PSI'/
     *      15X,'TEMPERATURE                  = ',F10.1,' DEGREES R'/
     *      15X,'GAS CONSTANT                 = ',F10.2,' FT-LB/LB-DEG R'
     *      //)
 9201 FORMAT(/10X,'VALVE ONE PROPERTIES:'/
     *      15X,'TYPE:                          ',20A4)
 9202 FORMAT( 15X,'NUMBER OF RELIEF VALVES = ',F10.0/
     *      15X,'CRACKING PRESSURE            = ',F10.2,' PSI'/
     *      15X,'CURVE CHANGE POINT           = ',F10.2,' PSI'/
     *      15X,'COEFFICIENT 1                = ',F10.3/
     *      15X,'COEFFICIENT 2                = ',F10.3/
     *      15X,'COEFFICIENT 3                = ',F10.3/
     *      15X,'COEFFICIENT 4                = ',F10.3/)
 9203 FORMAT(/10X,'VALVE TWO PROPERTIES:'/
     *      15X,'TYPE:                          ',20A4)
 9206 FORMAT(/10X,'FILTER PROPERTIES:'/
     *      15X,'TYPE:                          ',20A4)
 9207 FORMAT( 15X,'NUMBER OF FILTERS            = ',F10.0/
     *      15X,'EXIT AREA                    = ',F10.5,' SQ IN'/
     *      15X,'COEFFICIENT 1                = ',F10.3/
     *      15X,'COEFFICIENT 2                = ',F10.3/
     *      15X,'COEFFICIENT 3                = ',F10.3/
     *      15X,'COEFFICIENT 4                = ',F10.3/)
 9209 FORMAT(/10X,'DOOR LEAK PROPERTIES:'/
     *      15X,'TYPE OF SEAL:                  ',20A4)
 9210 FORMAT( 15X,'EFFECTIVE AREA               = ',F10.8,' SQ FT'/)
 9212 FORMAT(//10X,'CHOKING PROPERTIES:'/
     *        15X,'RATIO OF SPECIFIC HEATS  = ',F10.3/
     *        15X,'CRITICAL PRESSURE RATIO  = ',F10.4/
     *        15X,'SPEED OF SOUND           = ',F10.1,' FPS'///)
 9215 FORMAT(12X,'EXTERNAL  INTERNAL',14X,'INTERNAL',4X,'TOTAL MASS'/
     *      5X,'TIME ',2('  PRESSURE'),3X,'DELTA P',4X,'GAS MASS',
     *      5X,'FLOW RATE'/5X,'SECS',6X,'PSI',2(7X,'PSI'),9X,'LBM',
     *      8X,'LBM/SEC'/)
 9216 FORMAT(F9.1,2F10.2,F10.3,F13.5,F14.7)
 9220 FORMAT(56X,'VALVE ONE',9X,'VALVE TWO',8X,'FILTER ONE',
     *      9X,'LEAK ONE'/13X,'P R E S S U R E',19X,4(9X,'FLOW RATE')/
     *      2X,'TIME   EXT   INT   RATIO  DIFFR',3X,'MACH   DENSITY  ',
     *      4('VOLUME     MASS     ')/2X,'SECS',2(3X,'PSI'),3X,'PE/PI',
     *      '   PSI      NO   LBM/CU FT ',4(' CF/S     LBM/SEC  ')/)
 9221 FORMAT(F6.1,1X,2F6.2,F7.4,F7.3,F8.3,F9.5,4(F8.4,F10.6))
```

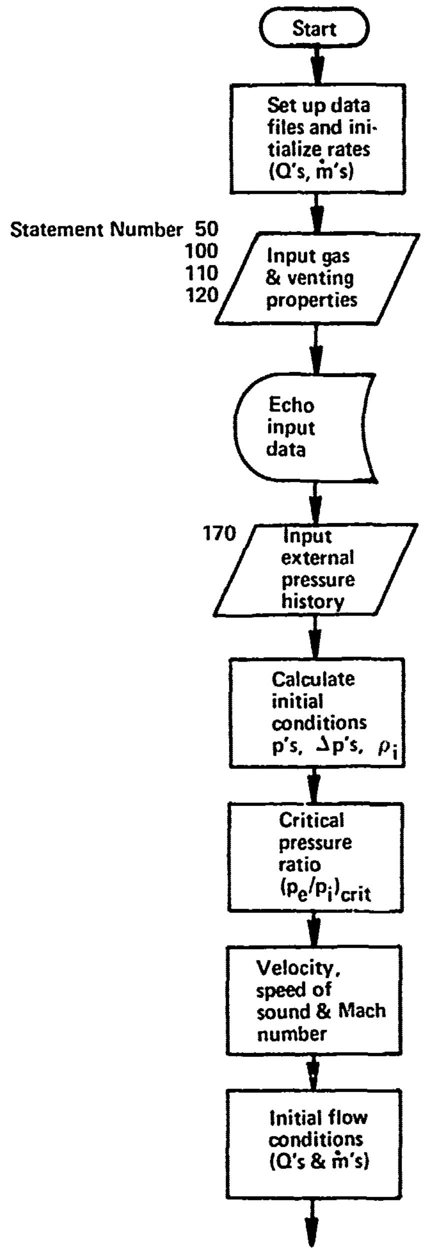
```
C-----TIME REFERENCES
      TIME=0.00
C-----ALLOCATE DATA FILES
      NIN=30
      NOUT=NIN+1
      NOUT2=NOUT+1
C-----INPUT AND OUTPUT OF VITAL INFORMATION
C-----GAS PROPERTIES
      READ(NIN,9000) TITLE
      READ(NIN,9000) GAS
      READ(NIN,9101) VOLUME,VOL,PINT,TEMP,RGAS,GAMMA
      WRITE(NOUT,9000) TITLE
      WRITE(NOUT,9200) GAS,VOLUME,PINT,TEMP,RGAS
      WRITE(NOUT2,9000) TITLE
      WRITE(NOUT2,9220)
C-----VALVE ONE PROPERTIES
   50 READ(NIN,9000) TITLE
      READ(NIN,9101) VALVS1,CRACK1,CHANG1,A1,A2,A3,A4
      WRITE(NOUT,9201) TITLE
      IF (VALVS1.EQ.0.) GO TO 100
      WRITE(NOUT,9202) VALVS1,CRACK1,CHANG1,A1,A2,A3,A4
C-----VALVE TWO PROPERTIES
  100 READ(NIN,9000) TITLE
      READ(NIN,9101) VALVS2,CRACK2,CHANG2,B1,B2,B3,B4
      WRITE(NOUT,9203) TITLE
      IF (VALVS2.EQ.0.) GO TO 110
      WRITE(NOUT,9202) VALVS2,CRACK2,CHANG2,B1,B2,B3,B4
C-----FILTER ONE PROPERTIES
  110 READ(NIN,9000) TITLE
      READ(NIN,9101) FILTRS,AFILT,C1,C2,C3,C4
      WRITE(NOUT,9206) TITLE
      IF (FILTRS.EQ.0.) GO TO 120
      WRITE(NOUT,9207) FILTRS,AFILT,C1,C2,C3,C4
C-----LEAK ONE PROPERTIES
  120 READ(NIN,9000) TITLE
      READ(NIN,9101) ALEAK
      WRITE(NOUT,9209) TITLE
      IF (ALEAK.EQ.0.) GO TO,170
      WRITE(NOUT,9210) ALEAK
C-----INPUT OF EXTERNAL PRESSURE HISTORY
  170 READ(NIN,9101) TIMEND,TSTEP,DIVIDE
      READ(NIN,9100) MAGNIT
      READ(NIN,9101) (PTIME(N),PREXT(N),N=1,MAGNIT)
C-----CONVERSION TO PROPER UNITS
      TEMP=TEMP+459.67
      PINT=PINT+PREXT(1)/144.
      PATM=PREXT(1)
C-----CALCULATION OF INITIAL CONDITONS
C-----INTERNAL GAS DENSITY
      MULT=RGAS*TEMP/VOLUME
      MASS=PINT*144./MULT
      DENSTY=MASS/VOLUME
C-----PRESSURE DIFFERENTIAL AND PRESSURE RATIO
      PEXT=PREXT(1)/144.
      DELTA=PINT-PEXT
      PRATIO=PEXT/PINT
C-----CRITICAL PRESSURE RATIO
      EXP1=(GAMMA-1.)/GAMMA
      EXP2=1./EXP1
      PRCRIT=(2./(GAMMA+1.))**EXP2
```

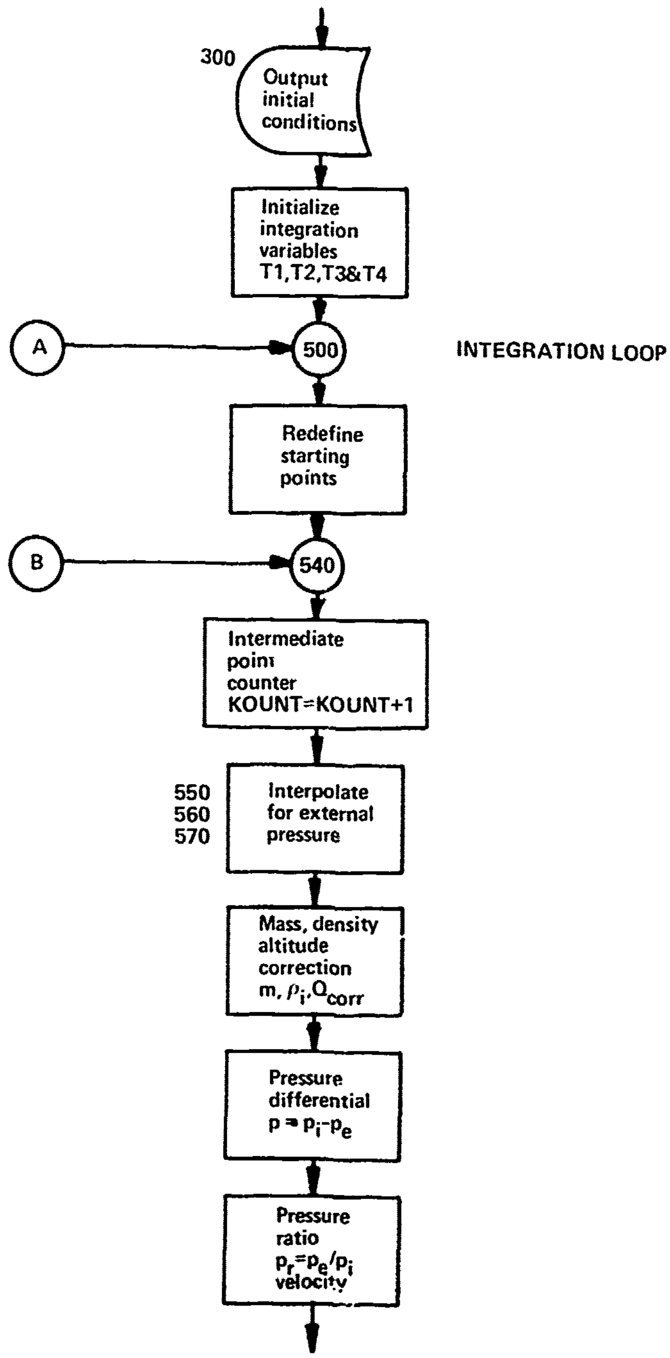
```
C-----THROAT VELOCITY AND SPEED OF SOUND
      VMULT=64.348*EXP2
      VEL=1.-PRATIO**EXP1
      VEL=SQRT(VMULT*PINT*144.*VEL/DENSTY)
      VSOUND=1.-PRCRIT**EXP1
      VSOUND=SQRT(VMULT*PINT*144.*VSOUND/DENSTY)
      VMACH=VEL/VSOUND
C####################################################################C
C#####                 INITIAL FLOW RATE CONDITIONS             #####C
C####################################################################C
C-----VALVE ONE FLOW RATE CALCULATION
      IF (VALVS1.EQ.0.) GO TO 205
      IF (DELTA.LT.CRACK1) GO TO 205
      IF (DELTA.GT.CHANG1) GO TO 200
      A5=A1
      A6=A2
      GO TO 201
  200 A5=A3
      A6=A4
  201 RATEV1=EXP(A5+A6*ALOG(DELTA))
      QRATE1=RATEV1/60.*VALVS1
      RATEV1=QRATE1*DENSTY
C-----VALVE TWO FLOW RATE CALCULATION
  205 IF (VALVS2.EQ.0.) GO TO 210
      IF (DELTA.LT.CRACK2) GO TO 210
      IF (DELTA.GT.CHANG2) GO TO 206
      B5=B1
      B6=B2
      GO TO 207
  206 B5=B3
      B6=B4
  207 RATEV2=EXP(B5+B6*ALOG(DELTA))
      RATEV2=RATEV2*MASS/60./VOLUME*VALVS2
      QRATE2=RATEV2/DENSTY
  210 RATEV=RATEV1+RATEV2
C-----FILTER FLOW RATE CALCULATION
      IF (FILTRS.EQ.0.) GO TO 220
      RATEF=C1+C2*DELTA+C3*DELTA**2+C4*DELTA**3
      RATEF=RATEF*AFILT*FILTRS
      RATEF=RATEF*MASS/60./VOLUME
      QRATEF=RATEF/DENSTY
C---- ADD IN LEAK CONTRIBUTION IF ANY
  220 IF (ALEAK.EQ.0.) GO TO 230
      RATEL=DCOEFF*ALEAK*SQRT(64.348*MASS*DELTA*144./VOLUME)
      QRATEL=RATEL/DENSTY
  230 RATE=RATEV+RATEL+RATEF
C-----OUTPUT INITIAL CONDITIONS
  300 WRITE(NOUT,9212) GAMMA,PRCRIT,VSOUND
      WRITE(NOUT,9215)
      WRITE(NOUT,9216) TIME,PEXT,PINT,DELTA,MASS,RATE
      WRITE(NOUT2,9221) TIME,PEXT,PINT,PRATIO,DELTA,VMACH,DENSTY,
     *                  QRATE1,RATEV1,QRATE2,RATEV2,QRATEF,RATEF,
     *                  QRATEL,RATEL
C####################################################################C
C#####            INTEGRATION OF DIFFERENTIAL EQUATION          #####C
C####################################################################C
C-----INITIALIZE VARIABLES
      H2=TSTEP/2.
      PINT=PINT*144.
      T1=0.
      T2=0.
```

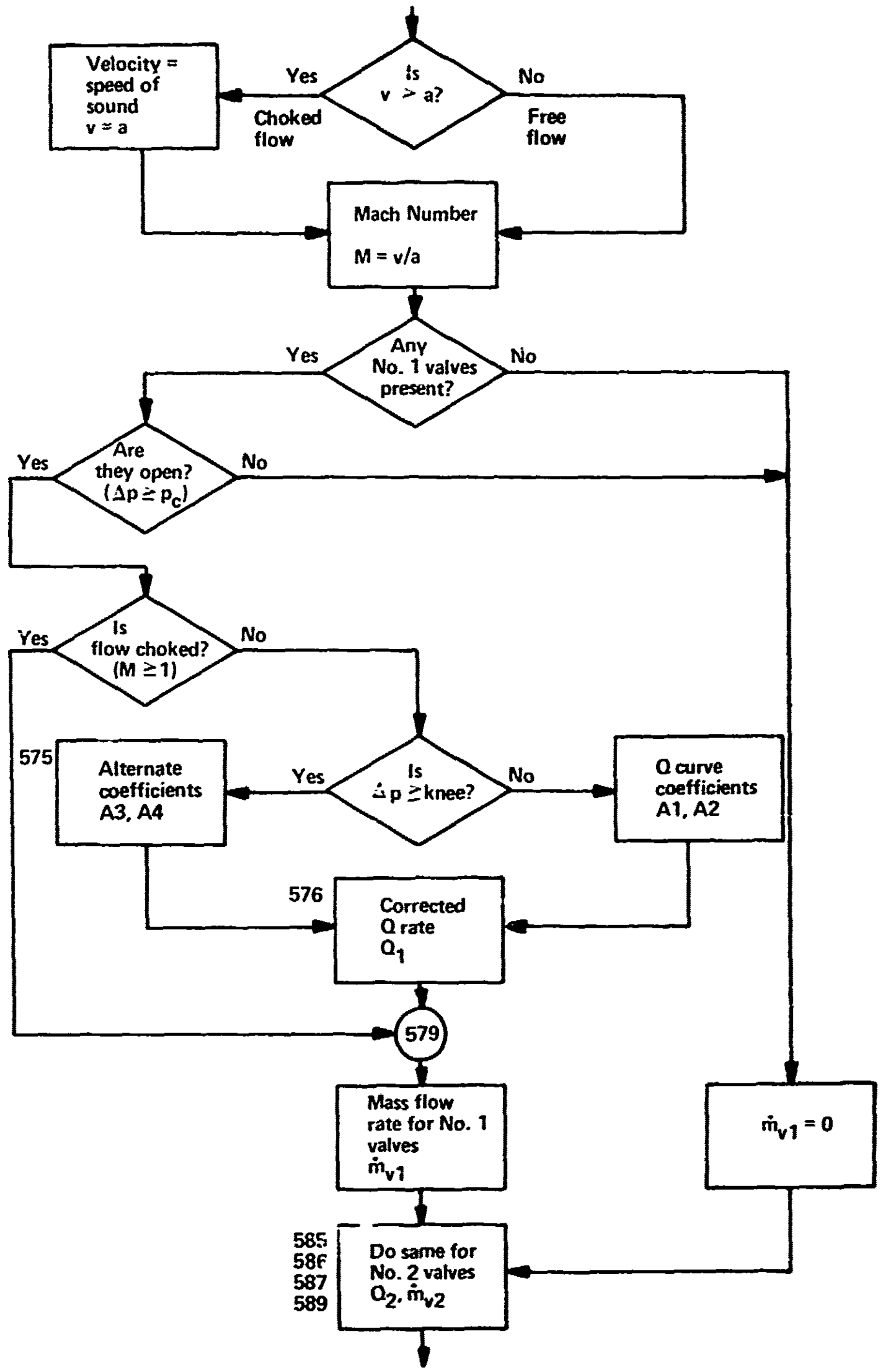
```
        T3=0.
        T4=0.
C-----INTEGRATION LOOP
 500    PRESS=PINT
        TIMES=TIME
        KOUNT=0.
C-----INTEGRATION POINT COUNTER
 540    KOUNT=KOUNT+1
C-----INTERPOLATE TABLE FOR EXTERNAL PRESSURE
 550    IF (TIMES.LE.PTIME(INDEX)) GO TO 560
        INDEX=INDEX+1
        GO TO 550
 560    IF (TIMES.GE.PTIME(INDEX-1)) GO TO 570
        INDEX=INDEX-1
        GO TO 560
 570    IF (INDEX.GT.MAGNIT) GO TO 1000
        FRACN=(TIMES-PTIME(INDEX-1))/(PTIME(INDEX)-PTIME(INDEX-1))
        PEXT=PREXT(INDEX-1)+(PREXT(INDEX)-PREXT(INDEX-1))*FRACN
C-----CALCULATE THE INTERNAL GAS MASS & QRATE CORRECTION FACTOR
        MASS=PRESS/MULT
        DENSTY=MASS/VOLUME
        QCORR=SQRT(PATM/PRESS)
        QCORR=SQRT(QCORR)
C-----CALCULATE THE PRESSURE DIFFERENCE
        KEY=0
        DELTA=(PRESS-PEXT)/144.
        IF (DELTA.LE.0.) KEY=1
        IF (DELTA.LE.0.) DELTA=0.000000
C-----CALCULATE PRESSURE RATIO AND THROAT VELOCITY
        PRATIO=PEXT/PRESS
        VEL=1.-PRATIO**EXP1
        IF (VEL.LT.0.) VEL=0.000000
        VEL=SQRT(VMULT*PRESS*VEL/DENSTY)
        IF (VEL.GT.VSOUND) VEL=VSOUND
        VMACH=VEL/VSOUND
C=====VALVE ONE CALCULATIONS
C-----CHECK WHETHER VALVE ONE IS OPEN OR CLOSED
        IF (VALVS1.EQ.0.) GO TO 580
        IF (DELTA.LT.CRACK1) GO TO 580
C-----VALVE ONE IS OPEN - FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW CONDITION
        IF (VMACH.GE.1.) GO TO 579
        IF (DELTA.GT.CHANG1) GO TO 575
        A5=A1
        A6=A2
        GO TO 576
 575    A5=A3
        A6=A4
 576    QRATE1=EXP(A5+A6*ALOG(DELTA))
        QRATE1=QRATE1/60.*VALVS1*QCORR
C-----CHOKED VALVE - FLOW RATE CALCULATION
 579    RATEV1=QRATE1*DENSTY
        GO TO 585
C-----VALVE ONE IS CLOSED
 580    RATEV1=0.0
C=====VALVE TWO CALCULATIONS
C-----CHECK WHETHER VALVE TWO IS CLOSED OR OPEN
 585    IF (VALVS2.EQ.0.) GO TO 590
        IF (DELTA.LT.CRACK2) GO TO 590
```

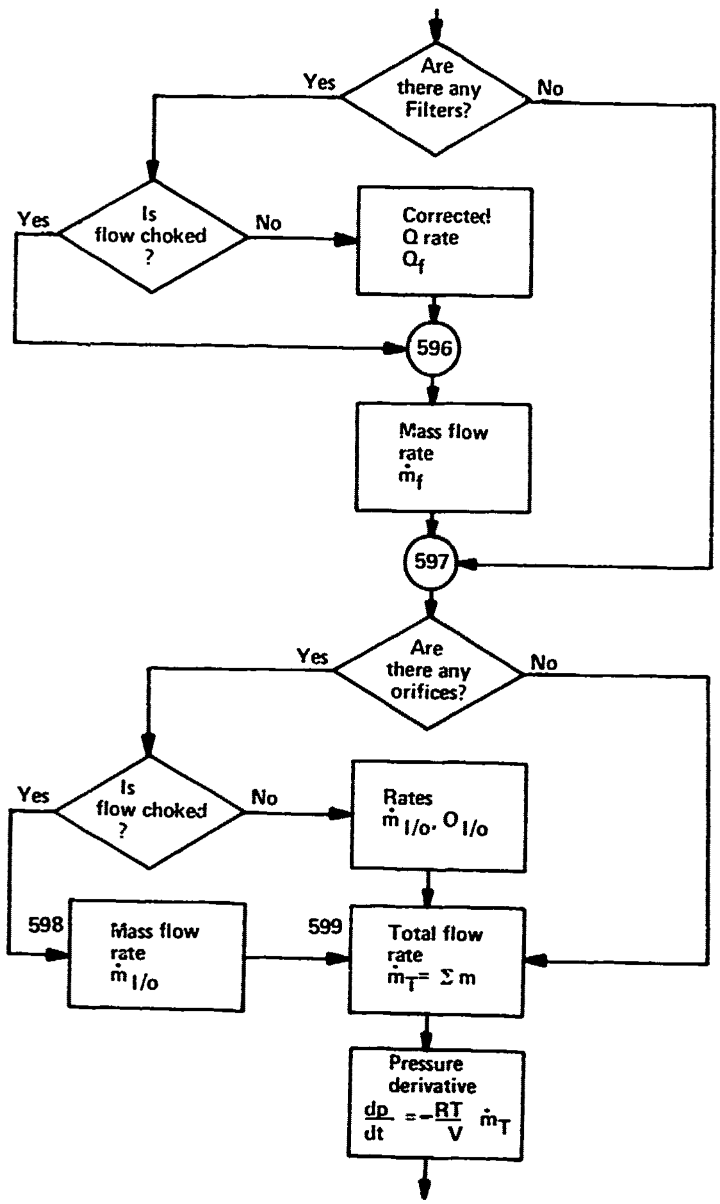
```
C-----VALVE TWO IS OPEN - FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW CONDITION
        IF (VMACH.GE.1.) GO TO 589
        IF (DELTA.GT.CHANG2) GO TO 586
        B5=B1
        B6=B2
        GO TO 587
  586   B5=B3
        B6=B4
  587   QRATE2=EXP(B5+B6*ALOG(DELTA))
        QRATE2=QRATE2/60.*VALVS2*QCORR
C-----CHOKED VALVE - FLOW RATE CALCULATION
  589   RATEV2=QRATE2*DENSTY
        GO TO 595
C-----VALVE TWO IS CLOSED
  590   RATEV2=0.0
C=====FILTER FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW
  595   IF (FILTRS.EQ.0.) GO TO 597
        IF (VMACH.GE.1.) GO TO 596
        QRATEF=C1+C2*DELTA+C3*DELTA**2+C4*DELTA**3
        IF (KEY.EQ.1.) QRATEF=0.00
        QRATEF=QRATEF*AFILT*FILTRS/60.*QCORR
C-----CHOKED FILTER - FLOW RATE CALCULATION
  596   RATEF=QRATEF*DENSTY
C=====ORIFICE FLOW RATE CALCULATIONS - ADD IN LEAK CONTRIBUTION IF ANY
C-----CHECK FOR CHOKED FLOW
  597   IF (ALEAK.EQ.0.) GO TO 599
        IF (VMACH.GE.1.) GO TO 598
        RATEL=DCOEFF*ALEAK*SQRT(64.348*MASS*DELTA*144./VOLUME)
        QRATEL=RATEL/DENSTY
        GO TO 599
C-----CHOKED CONDITION
  598   RATEL=QRATEL*DENSTY
C-----CALCULATE THE TOTAL FLOW RATE AND PRESSURE DERIVATIVE
  599   RATE=RATEV1+RATEV2+RATEL+RATEF
        PREDER=-MULT*RATE
C-----PERFORM INTEGRATION CALCULATIONS
  600   GO TO (650,700,800,900),KOUNT
  650   T1=TSTEP*PREDER
        PRESS=PINT+T1/2.
        TIMES=TIME+H2
        GO TO 540
  700   T2=TSTEP*PREDER
        PRESS=PINT+T2/2.
        TIMES=TIME+H2
        GO TO 540
  800   T3=TSTEP*PREDER
        PRESS=PINT+T3
        TIMES=TIME+TSTEP
        GO TO 540
  900   T4=TSTEP*PREDER
C-----CALCULATE NEW INTERNAL PRESSURE
        KOUNT=0
        PINT=PINT+(T1+2.*T2+2.*T3+T4)/6.
C-----CONTINUE THE INTEGRATION
 1000   TIME=TIME+TSTEP
        IF (TIME.GE.TIMEND) GO TO 1500
        LINDEX=LINDEX+1
        RRMARK=LINDEX/DIVIDE
```

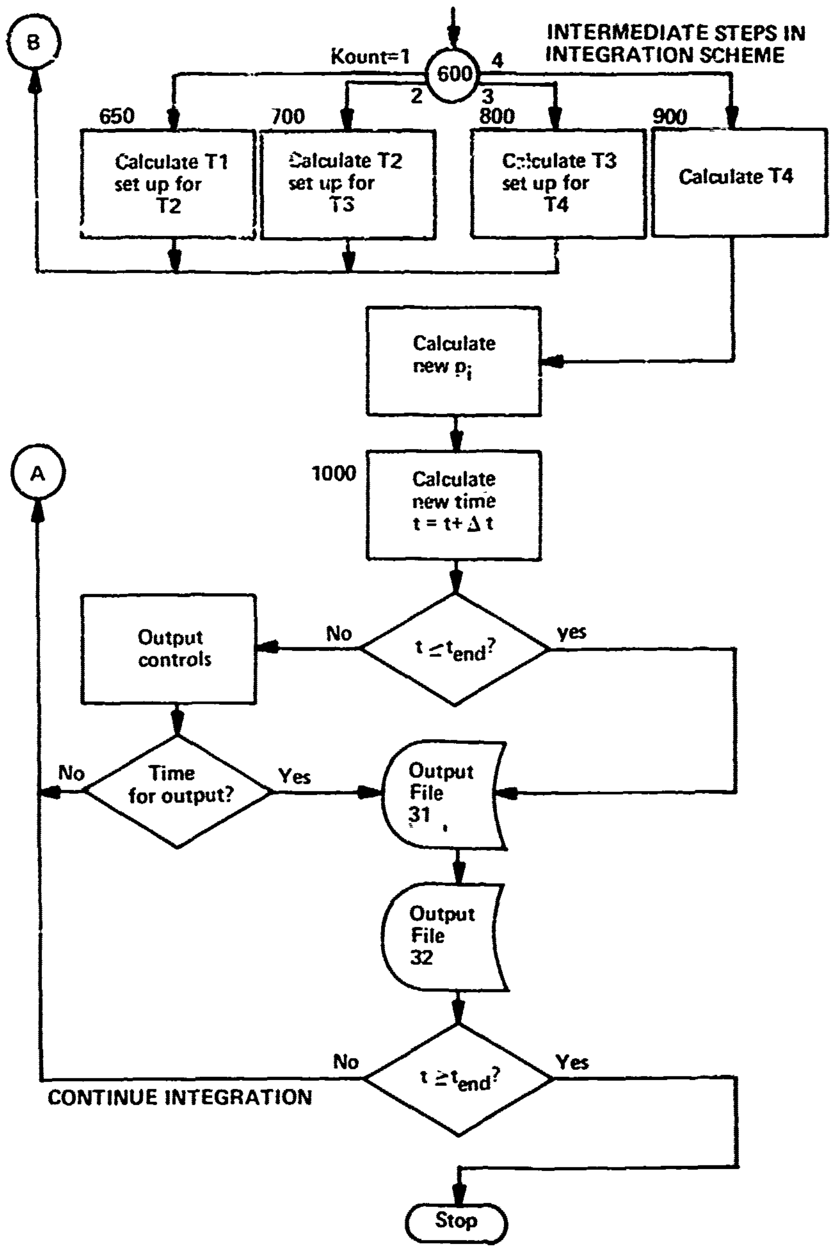
```
      LMARK=RRMARK
      RMARK=LMARK
      IF (RRMARK.NE.RMARK) GO TO 500
1500  WRITE(7,9216) TIME
      PINT=PINT/144.
      PEXT=PEXT/144.
      WRITE(NOUT,9216) TIME,PEXT,PINT,DELTA,MASS,RATE
      WRITE(NOUT2,9221) TIME,PEXT,PINT,PRATIO,DELTA,VMACH,DENSTY,
     *                  QRATE1,RATEV1,QRATE2,RATEV2,QRATEF,RATEF,
     *                  QRATEL,RATEL
      PINT=PINT*144.
      IF (TIME.LT.TIMEND) GO TO 500
      STOP 'END OF INTEGRATION'
      END
```


Start
Set up data files and initialize rates (Q's, ṁ's)
Statement Number 50
100
110
120
Input gas & venting properties
Echo input data
170
Input external pressure history
Calculate initial conditions p's, Δp's, ρ_i
Critical pressure ratio $(p_e/p_i)_{crit}$
Velocity, speed of sound & Mach number
Initial flow conditions (Q's & ṁ's)


300
Output initial conditions
Initialize integration variables T1,T2,T3&T4
A
500
INTEGRATION LOOP
Redefine starting points
B
540
Intermediate poin counter KOUNT=KOUNT+1
550
560
570
Interpolate for external pressure
Mass, density altitude correction m, ρ_i, Q_{corr}
Pressure differential $p = p_i - p_e$
Pressure ratio $p_r = p_e/p_i$ velocity


Is
v > a?
Yes
Choked
flow
No
Free
flow
Velocity =
speed of
sound
v = a
Mach Number
M = v/a
Any
No. 1 valves
present?
Yes
No
Are
they open?
(Δp ≥ p_c)
Yes
No
Is
flow choked?
(M ≥ 1)
Yes
No
Is
Δp ≥ knee?
Yes
No
575
Alternate
coefficients
A3, A4
Q curve
coefficients
A1, A2
576
Corrected
Q rate
Q1
579
Mass flow
rate for No. 1
valves
ṁv1
ṁv1 = 0
585
586
587
589
Do same for
No. 2 valves
Q2, ṁv2


Are there any Filters?
Yes
No
Is flow choked ?
Yes
No
Corrected Q rate Q_f
596
Mass flow rate $\dot{m}_f$
597
Are there any orifices?
Yes
No
Is flow choked ?
Yes
No
Rates $\dot{m}_{l/o}$, $Q_{l/o}$
598
Mass flow rate $\dot{m}_{l/o}$
599
Total flow rate $\dot{m}_T = \Sigma m$
Pressure derivative $\frac{dp}{dt} = -\frac{RT}{V} \dot{m}_T$



INTERMEDIATE STEPS IN INTEGRATION SCHEME
B
Kount=1
600
4
2
3
650
700
800
900
Calculate T1 set up for T2
Calculate T2 set up for T3
Calculate T3 set up for T4
Calculate T4
Calculate new p_i
A
1000
Calculate new time t = t+Δt
No
$t \geq t_{end}$?
yes
Output controls
No
Time for output?
Yes
Output File 31
Output File 32
No
$t \geq t_{end}$?
Yes
CONTINUE INTEGRATION
Stop

Appendix C

Listing and Flowchart of PRESSM.FOR

Computer Program PRESSM. FOR

Language:	FORTRAN IV	
Computer:	DEC PDP-11/34A	
Memory Requirements:	11K Words	
Fortran File Size:	22 Blocks	
Input File:	FTN30. DAT	
Output Files:	FTN31. DAT FTN32. DAT	Primary Volume
	FTN33. DAT FTN34. DAT	Secondary Volume
Subroutines:	RKGS	(integration routine)
	PREQNS	(called by RKGS)

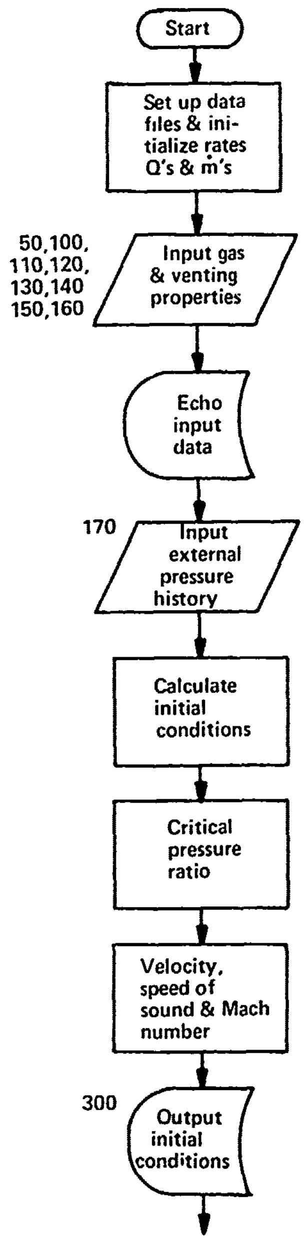
```
C-----PROGRAM PRESSM.FOR
C-----THIS IS AN ATTEMPT TO PREDICT THE INTERNAL PRESSURE OF A
C-----SOUNDING ROCKET AS IT ASCENDS THROUGH THE ATMOSPHERE.
C-----THE PROGRAM CALCULATES THE INTERNAL PRESSURE HISTORY OF A
C-----SET OF MULTIPLE INTERCONNECTED CHAMBERS.  AT PRESENT THE PROGRAM
C-----ALLOWS ONLY TWO VOLUMES.  THE PROGRAM INTEGRATES THE DIFFERENTIAL
C-----EQUATIONS NUMERICALLY USING A FOURTH-ORDER RUNGE-KUTTA SCHEME.
C-----THE INTEGRATION IS DONE IN THE "RKGS" SUBROUTINE CALLED BY THIS
C-----PROGRAM.  THE DIFFERENTIAL EQUATIONS ARE EVALUATED AT VARIOUS
C-----TIMES BY THE "PREQNS" SUBROUTINE WHICH IS CALLED BY "RKGS."
C-----AUTHOR: C. M. KREBS
      DIMENSION AUX(8,2),LIMITS(5),PRESS(2),PRDER(2)
      DIMENSION GAS(5),TITLE(20)
      COMMON /INPUTS/ VALVS1,CRACK1,CHANG1,A1,A2,A3,A4,
     *                VALVS2,CRACK2,CHANG2,B1,B2,B3,B4,
     *                VALVS3,CRACK3,CHANG3,C1,C2,C3,C4,
     *                VALVS4,CRACK4,CHANG4,D1,D2,D3,D4,
     *                LIMTS1,ALTIT1,F1,F2,F3,F4,ALFAN1,
     *                LIMTS2,ALTIT2,E1,E2,E3,E4,ALFAN2
      COMMON /OUTPUT/ TIME,PINT1,PEXT,RATE,DELTA1,DENS1,MASS1,VEL1,
     *                VMACH1,RATE1,RATEV1,RATEV2,RATEF1,RATEL1,QRATE1,
     *                QRATE2,QRATF1,QRATL1,PINT2,PRAT2,PRAT3,DELTA2,
     *                DELTA3,DENS2,MASS2,VEL2,VEL3,VMACH2,VMACH3,
     *                RATE2,RATE3,RATEV3,RATEV4,RATEF2,RATEL2,QRATE3,
     *                QRATE4,QRATF2,QRATL2
      COMMON /REFERS/ VOL1,VOL2,MULT1,MULT2,VMULT,EXPT,VSOUND,
     *                PREXT(100),PTIME(100),INDEX,DCOEFF,MAGNIT
      REAL LIMITS,MASS1,MASS2,MULT1,MULT2
      EXTERNAL PREQNS
      DATA QRATE1,QRATE2,QRATE3,QRATE4,QRATF1,QRATF2,QRATL1,QRATL2,
     *     RATE1,RATE2,RATE3,RATEF1,RATEF2,RATEL1,RATEL2,RATEV1,
     *     RATEV2,RATEV3,RATEV4,DCOEFF,INDEX,IINDEX,LMARK/19*0.,0.90,
     *     2,0,0/
C-----FORMAT STATEMENTS
 9000 FORMAT(20A4)
 9100 FORMAT(I10,7F10.0)
 9101 FORMAT(8F10.0)
 9200 FORMAT(/10X,'GAS PROPERTIES:'/
     *       15X,'TYPE:                         ',5A4/
     *       15X,'MAIN VOLUME              = ',F10.2,' CU FT'/
     *       15X,'SECOND VOLUME            = ',F10.2,' CU FT'/
     *       15X,'INITIAL PRESSURE         = ',F10.2,' PSI'/
     *       15X,'TEMPERATURE              = ',F10.1,' DEGREES F'/
     *       15X,'GAS CONSTANT               ',F10.2,' FT-LB/LB-DEG R'
     *       //)
 9201 FORMAT(/10X,'VALVE ONE PROPERTIES:'/
     *       15X,'TYPE:                       ',20A4)
 9202 FORMAT( 15X,'NUMBER OF RELIEF VALVES = ',F10.0/
     *       15X,'CRACKING PRESSURE        = ',F10.2,' PSI'/
     *       15X,'CURVE CHANGE POINT       = ',F10.2,' PSI'/
     *       15X,'COEFFICIENT 1              ',F10.3/
     *       15X,'COEFFICIENT 2            = ',F10.3/
     *       15X,'COEFFICIENT 3            = ',F10.3/
     *       15X,'COEFFICIENT 4            = ',F10.3/)
 9203 FORMAT(/10X,'VALVE TWO PROPERTIES:'/
     *       15X,'TYPE:                       ',20A4)
 9204 FORMAT(/10X,'VALVE THREE PROPERTIES:'/
     *       15X,'TYPE:                       ',20A4)
 9205 FORMAT(/10X,'VALVE FOUR PROPERTIES:'/
     *       15X,'TYPE:                       ',20A4)
```

```
9206 FORMAT(/10X,'FILTER ONE PROPERTIES: /
     *         15X,'TYPE:                            ',20A4)
9207 FORMAT( 15X,'NUMBER OF FILTERS           = ',F10.0/
     *         15X,'EXIT AREA                 = ',F10.5,' SQ IN'/
     *         15X,'COEFFICIENT 1             = ',F10.3/
     *         15X,'COEFFICIENT 2             = ',F10.3/
     *         15X,'COEFFICIENT 3             = ',F10.3/
     *         15X,'COEFFICIENT 4               ',F10.3/)
9208 FORMAT(/10X,'FILTER TWO PROPERTIES:'/
     *         15X,'TYPE:                            ',20A4)
9209 FORMAT(/10X,'DOOR LEAK ONE PROPERTIES:'/
     *         15X,'TYPE OF SEAL:                ',20A4)
9210 FORMAT( 15X,'EFFECTIVE AREA             = ',F10.8,' SQ FT'/)
9211 FORMAT(/10X,'DOOR LEAK TWO PROPERTIES:'/
     *         15X,'TYPE OF SEAL:                ',20A4)
9212 FORMAT(//10X,'CHOKING PROPERTIES:'/
     *          15X,'RATIO OF SPECIFIC HEATS   = ',F10.3/
     *          15X,'CRITICAL PRESSURE RATIO   = ',F10.4/
     *          15X,'SPEED OF SOUND            = ',F10.1,' FPS ///)
9213 FORMAT(  MAIN VOLUME CALCULATIONS'/)
9214 FORMAT(' SECONDARY VOLUME CALCULATIONS'/)
9215 FORMAT(12X, EXTERNAL   INTERNAL',14X,'INTERNAL',4X, TOTAL MASS'/
     *        5X, TIME  ',2(   PRESSURE'),3X,'DELTA P',4X,'GAS MASS',
     *        5X,'FLOW RATE'/5X,'SECS',6X, PSI',2(7X,'PSI'),9X,'LBM',
     *        8X, LBM/SEC'/)
9216 FORMAT(F9.1,2F10.2,F10.3,F13.5,F14.7)
9217 FORMAT(19X,'P R E S S U R E',11X,'PRESSURE DIFF',5X,'TOTAL MASS'/
     *        5X,'TIME',6X, EXT     MAIN VOL    SEC VOL',5X,'MAIN',
     *        5X, EXT',6X,'FLOW RATE'/5X, SECS',6X,'PSI',4(7X,'PSI'),
     *        7X, LBM/SEC'/)
9218 FORMAT(F9.1,3F10.2,2F10.3,F14.7)
9220 FORMAT(56X,'VALVE ONE',9X,'VALVE TWO',8X,'FILTER ONE',
     *        9X, LEAK ONE'/13X,'P R E S S U R E',19X,4(9X,'FLOW RATE')/
     *        2X, TIME    EXT    INT    RATIO  DIFFR',3X, MACH   DENSITY  ',
     *        4('VOLUME     MASS     ')/2X,'SECS',2(3X,'PSI'),3X,'PE/PI',
     *           PSI       NO    LBM/CU FT ',4(' CF/S     LBM/SEC  ')/)
9221 FORMAT(F6.1,1X,2F6.2,F7.4,F7.3,F8.3,F9.5,4(F8.4,F10.6))
9222 FORMAT(9X,'MAIN VOL REFFERENCE',4X,'EXTERNAL REFERENCE ,
     *        14X,'VALVE THREE',7X,'VALVE FOUR',8X,'FILTER TWO',
     *        9X,'LEAK TWO'/11X,'PRESSURE',14X,'PRESSURE',15X,
     *        4(9X, FLOW RATE )/2X,'TIME',2(3X,'RATIO  DIFFR   MACH'),
     *        2X,'DENSITY  ',3('VOLUME     MASS     '),'VOLUME     MASS'/2X,
     *        'SECS   P1/P2   PSI      NO     PE/P2   PSI      NO  LBM/CU',
     *        ' FT ',4(' CF/S     LBM/SEC  ')/)
9223 FORMAT(F6.1,2(F8.4,2F7.3),F9.5,4(F8.4,F10.6))
C-----TIME REFERENCES
      TIME=0.00
C-----ALLOCATE DATA FILES
      NIN=30
      NOUT=NIN+1
      NOUT2=NOUT+1
      NOUT3=NOUT+2
      NOUT4=NOUT+3
C ----INPUT AND OUTPUT OF VITAL INFORMATION
C-- - GAS PROPERTIES
      READ(NIN,9000) TITLE
      READ(NIN,9000) GAS
      READ(NIN,9101) VOL1,VOL2,PINI,TEMP,RGAS,GAMMA
      WRITE(NOUT,9000) TITLE
      WRITE(NOUT,9200) GAS,VOL1,VOL2,PINI,TEMP,RGAS
```

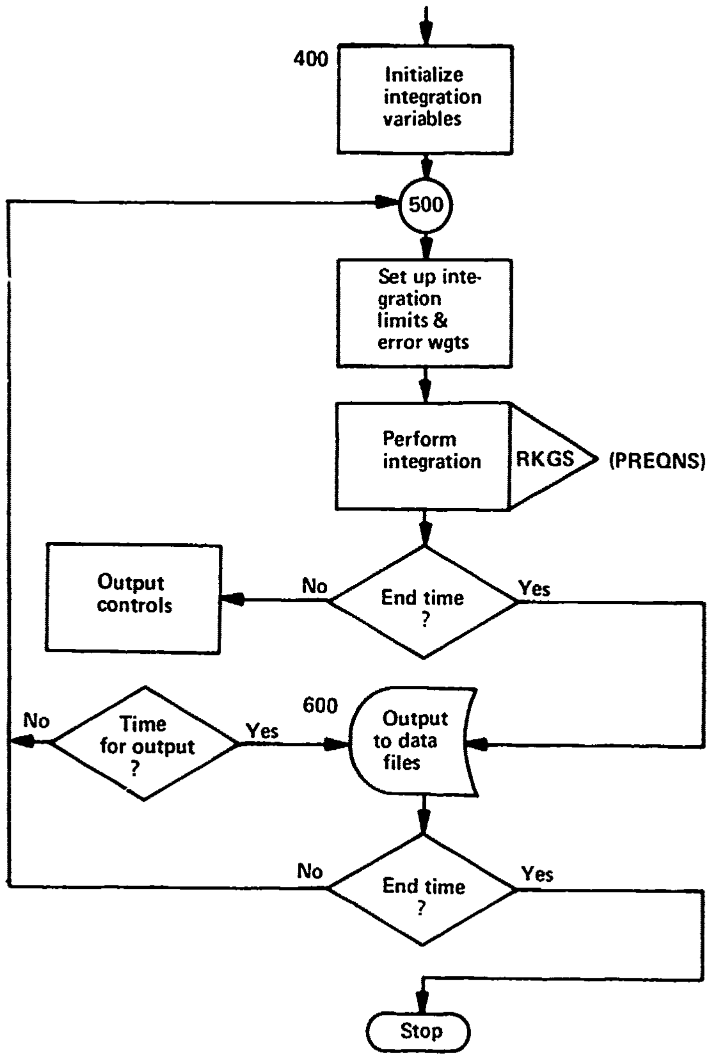
```
      WRITE(NOUT2,9000) TITLE
      WRITE(NOUT2,9213)
      WRITE(NOUT2,9220)
      IF (VOL2.EQ.0.) GO TO 50
      WRITE(NOUT3,9000) TITLE
      WRITE(NOUT4,9000) TITLE
      WRITE(NOUT4,9214)
      WRITE(NOUT4,9222)
C     -MAIN VOLUME PRESSURE SYSTEM
C-----VALVE ONE PROPERTIES
   50 READ(NIN,9000) TITLE
      READ(NIN,9101) VALVS1,CRACK1,CHANG1,A1,A2,A3,A4
      WRITE(NOUT,9201) TITLE
      IF (VALVS1.EQ.0.) GO TO 100
      WRITE(NOUT,9202) VALVS1,CRACK1,CHANG1,A1,A2,A3,A4
C-----VALVE TWO PROPERTIES
  100 READ(NIN,9000) TITLE
      READ(NIN,9101) VALVS2,CRACK2,CHANG2,B1,B2,B3,B4
      WRITE(NOUT,9203) TITLE
      IF (VALVS2.EQ.0.) GO TO 110
      WRITE(NOUT,9202) VALVS2,CRACK2,CHANG2,B1,B2,B3,B4
C-----FILTER ONE PROPERTIES
  110 READ(NIN,9000) TITLE
      READ(NIN,9101) FILTS1,AFILT1,E1,E2,E3,E4
      WRITE(NOUT,9206) TITLE
      IF (FILTS1.EQ.0.) GO TO 120
      WRITE(NOUT,9207) FILTS1,AFILT1,E1,E2,E3,E4
C-----LEAK ONE PROPERTIES
  120 READ(NIN,9000) TITLE
      READ(NIN,9101) ALEAK1
      WRITE(NOUT,9209) TITLE
      IF (ALEAK1.EQ.0.) GO TO 130
      WRITE(NOUT,9210) ALEAK1
C-----SECOND VOLUME PRESSURE SYSTEM
  130 IF (VOL2.EQ.0.) GO TO 170
C-----VALVE THREE PROPERTIES
      READ(NIN,9000) TITLE
      READ(NIN,9101) VALVS3,CRACK3,CHANG3,C1,C2,C3,C4
      WRITE(NOUT3,9204) TITLE
      IF (VALVS3.EQ.0.) GO TO 140
      WRITE(NOUT3,9202) VALVS3,CRACK3,CHANG3,C1,C2,C3,C4
C-----VALVE FOUR PROPERTIES
  140 READ(NIN,9000) TITLE
      READ(NIN,9101) VALVS4,CRACK4,CHANG4,D1,D2,D3,D4
      WRITE(NOUT3,9205) TITLE
      IF (VALVS4.EQ.0.) GO TO 150
      WRITE(NOUT3,9202) VALVS4,CRACK4,CHANG4,D1,D2,D3,D4
C-----FILTER TWO PROPERTIES
  150 READ(NIN,9000) TITLE
      READ(NIN,9101) FILTS2,AFILT2,F1,F2,F3,F4
      WRITE(NOUT3,9208) TITLE
      IF (FILTS2.EQ.0.) GO TO 160
      WRITE(NOUT3,9207) FILTS2,AFILT2,F1,F2,F3,F4
C-----LEAK TWO PROPERTIES
  160 READ(NIN,9000) TITLE
      READ(NIN,9101) ALEAK2
      WRITE(NOUT3,9211) TITLE
      IF (ALEAK2.EQ.0.) GO TO 170
      WRITE(NOUT3,9210) ALEAK2
```

```
C-----INPUT OF EXTERNAL PRES[illegible] HISTORY
  170   READ(NIN,9101) TIMEN[illegible],DIVIDE,LIMITS(4)
        READ(NIN,9100) MAG[illegible]
        READ(NIN,9101) (PI[illegible]REXT(N),N=1,MAGNIT)
C-----CONVERSION TO PROPER[illegible]S
        TEMP=TEMP+459.67
        PINT=PINT+PREXT(1[illegible]144.
C-----CALCULATION OF INI[illegible]L CONDITIONS
C-----MAIN VOLUME
C-----INTERNAL GAS DENSITY
        M[illegible]T1=RGAS*TEMP/VOL1
        MASS1=PINT*144./MULT1
        DENS1=MASS1/VOL1
C-----PRESSURE DIFFERENTIAL AND PRESSURE RATIO
        PEXT=PREXT(1)/144.
        DELTA1=PINT-PEXT
        PRAT1=PEXT/PINT
C-----CRITICAL PRESSURE RATIO
        EXP1=(GAMMA-1.)/GAMMA
        EXP2=1./EXP1
        PRCRIT=(2./(GAMMA+1.))**EXP2
C-----THROAT VELOCITY AND SPEED OF SOUND
        VMULT=64.348*EXP2
        VEL1=1.-PRAT1**EXP1
        VEL1=SQRT(VMULT*PINT*144.*VEL1/DENS1)
        VSOUND=1.-PRCRIT**EXP1
        VSOUND=SQRT(VMULT*PINT*144.*VSOUND/DENS1)
        VMACH1=VEL1/VSOUND
C-----SECOND VOLUME
        IF (VOL2.EQ.0.) GO TO 300
        MULT2=RGAS*TEMP/VOL2
        MASS2=PINT*144./MULT2
        DENS2=MASS2/VOL2
        DELTA2=PINT-PINT
        DELTA3=PINT-PEXT
        PRAT2=PINT/PINT
        PRAT3=PEXT/PINT
        VEL2=1.-PRAT2**EXP1
        VEL2=SQRT(VMULT*PINT*144.*VEL2/DENS2)
        VMACH2=VEL2/VSOUND
C-----OUTPUT INITIAL CONDITIONS
  300   WRITE(NOUT,9212) GAMMA,PRCRIT,VSOUND
        WRITE(NOUT,9213)
        WRITE(NOUT,9215)
        WRITE(NOUT,9216) TIME,PEXT,PINT,DELTA1,MASS1,RATE1
        WRITE(NOUT2,9221) TIME,PEXT,PINT,PRAT1,DELT[illegible]1,VMACH1,DENS1,
     *                    QRATE1,RATEV1,QRATE2,RATEV2,QRATF1,RATEF1,
     *                    QRATL1,RATEL1
        IF (VOL2.EQ.0.) GO TO 400
        WRITE(NOUT3,9214)
        WRITE(NOUT3,9217)
        WRITE(NOUT3,9218) TIME,PEXT,PINT,PINT,DELTA2,DELTA3,RATE3
        WRITE(NOUT4,9223) TIME,PRAT2,DELTA2,VMACH2,PRAT3,DELTA3,VMACH3,
     *                    DENS2,QRATE3,RATEV3,QRATE4,RATEV4,QRATF2,
     *                    RATEF2,QRATL2,RATEL2
C-----SET UP FOR INTEGRATION LOOP
C-----INITIAL VALUES
  400   PRESS(1)=PINT*144.
        PRESS(2)=PRESS(1)
```

```
C-----INTEGRATION LOOP
  500   LIMITS(1)=TIME
        LIMITS(2)=TIME+ISTEP
        LIMITS(3)=ISTEP
C-----RESET ERROR WEIGHTS
        PREDER(1)=0.50
        PREDER(2)=0.50
C-----CALL INTEGRATION ROUNTINE
        CALL RKGS(LIMITS,PRESS,PREDER,2,NSECT,PREQNS,AUX)
        IF (TIME.GE.TIMEND) GO TO 600
        LINDEX=LINDEX+1
        RRMARK=LINDEX/DIVIDE
        LMARK=RRMARK
        RMARK=LMARK
        IF (RRMARK.NE.RMARK) GO TO 500
  600   WRITE(7,9216) TIME
        WRITE(NOUT,9216) TIME,PEXT,PINT1,DELTA1,MASS1,RATE1
        WRITE(NOUT2,9221) TIME,PEXT,PINT1,PRAT1,DELTA1,VMACH1,DENS1,
     *                    QRATE1,RATEV1,QRATE2,RATEV2,QRATF1,RATEF1,
     *                    QRATL1,RATEL1
        IF (VOL2.EQ.0.) GO TO 700
        WRITE(NOUT3,9218) TIME,PEXT,PINT1,PINT2,DELTA2,DELTA3,RAT
        WRITE(NOUT4,9223) TIME,PRAT2,DELTA2,VMACH2,PRAT3,DELTA3,VMACH3,
     *                    DENS2,QRATE3,RATEV3,QRATE4,RATEV4,QRATF2,
     *                    RATEF2,QRATL2,RATEL2
  700   IF (TIME.LT.TIMEND) GO TO 500
        STOP 'END OF INTEGRATION'
        END
```



Start
Set up data files & initialize rates Q's & ṁ's
50,100, 110,120, 130,140 150,160
Input gas & venting properties
Echo input data
170
Input external pressure history
Calculate initial conditions
Critical pressure ratio
Velocity, speed of sound & Mach number
300
Output initial conditions


400
Initialize integration variables
500
Set up integration limits & error wgts
Perform integration
RKGS
(PREQNS)
Output controls
No
End time ?
Yes
600
No
Time for output ?
Yes
Output to data files
No
End time ?
Yes
Stop

Subroutine RKGS. FOR

Modified RKGS routine of Reference 4; called by main program to integrate the differential equations.

The following lines nave been modified to eliminate the use of the external output routine:

RKGS 1050
RFGS 1530
RKGS 2280
RKGS 2570

Integration Technique: Self-starting fourth-order Runge-Kutta solution of a system of first-order ordinary differential equations.

Subroutine PREQNS. FOR

Called by RKGS subroutine to evaluate the differential equations during integration process.

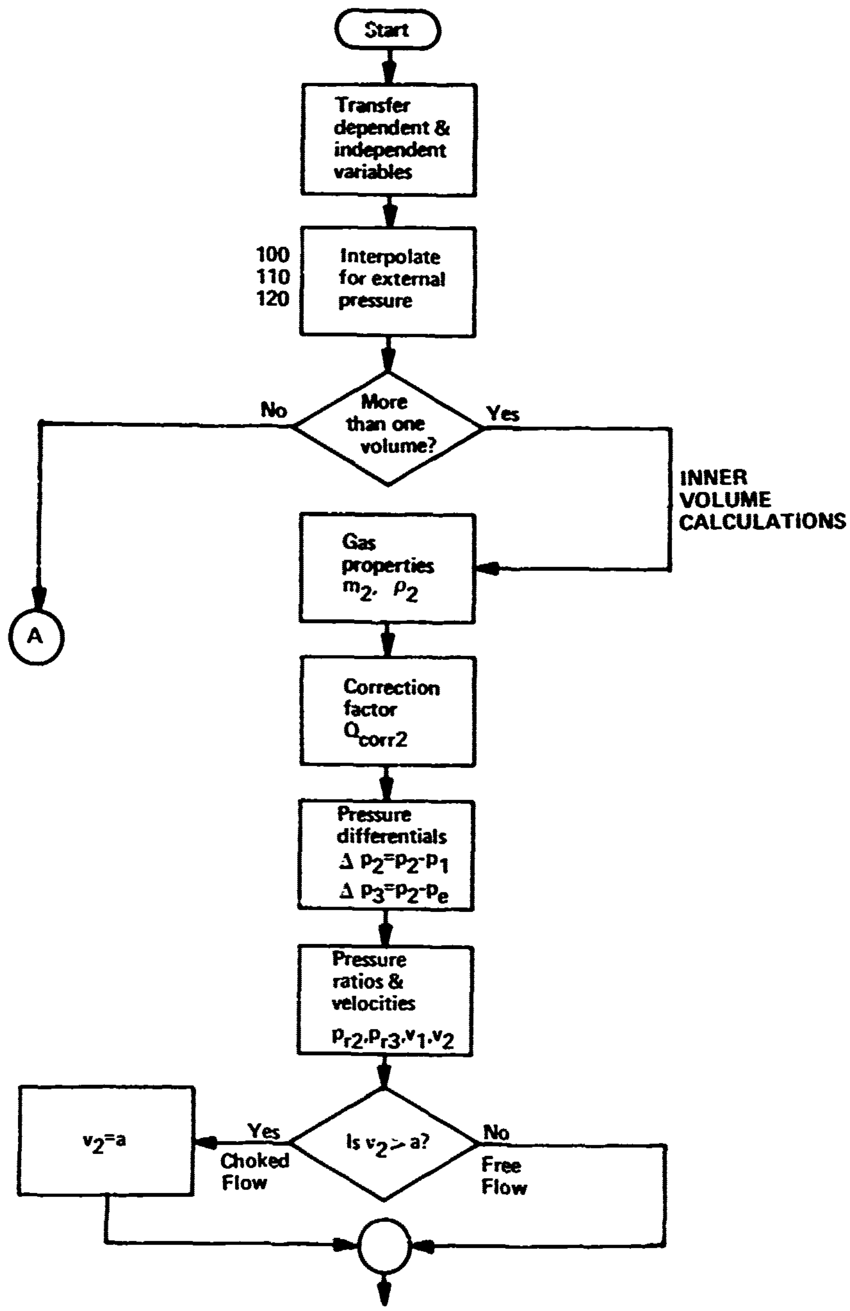
Major Equations Used: Equations (12), (13), (14), (A11), (A18), (A25), and those of Table A1.

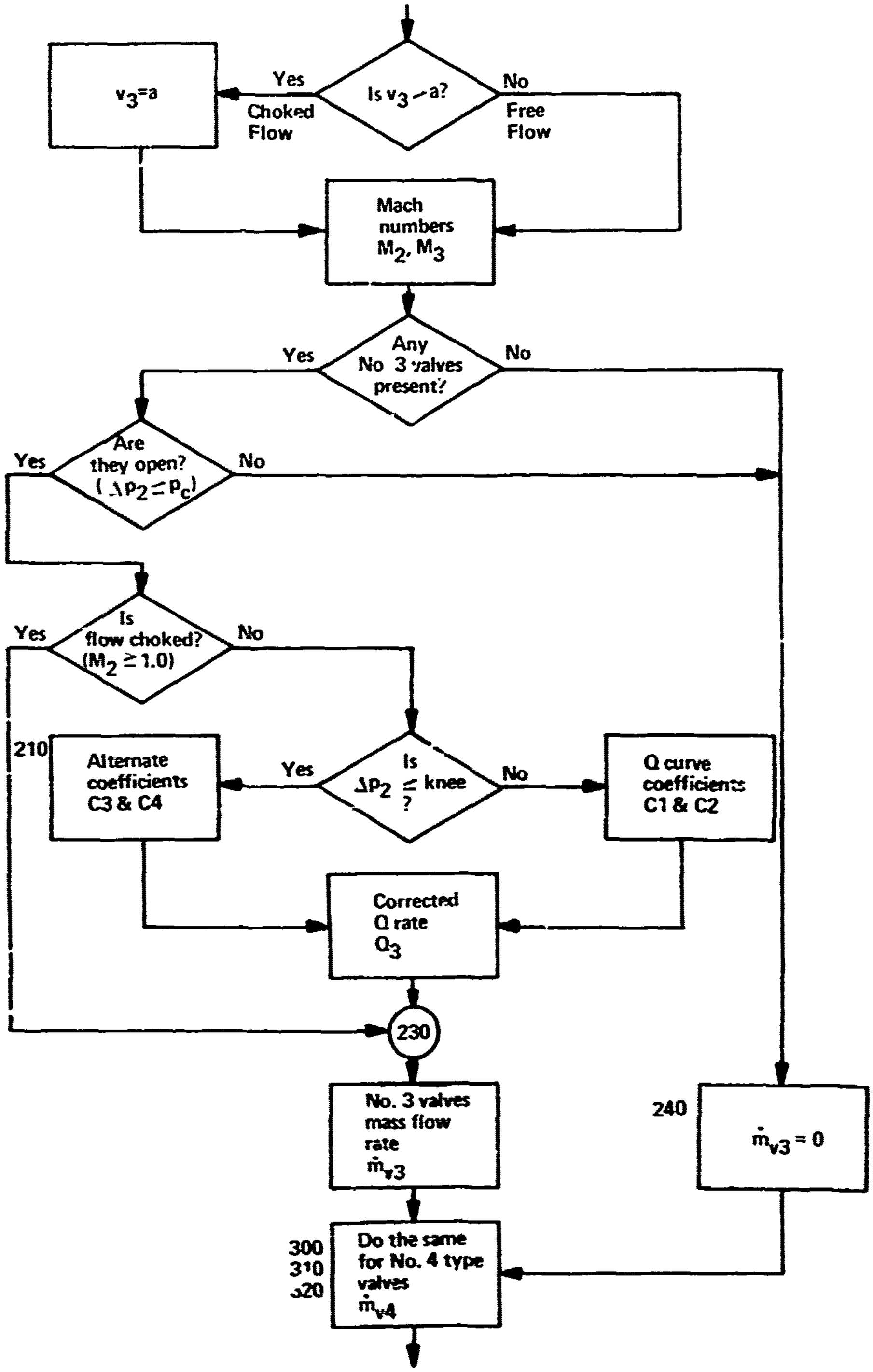
```
      SUBROUTINE PREQNS(TIMEIN,PRESS,PREDER)
C-----PREQNS.FOR
C-----THIS SUBROUTINE IS USED WITH THE 'PRESSM' PROGRAM TO PREDICT THE
C-----INTERNAL PRESSURE OF A SOUNDING ROCKECT PAYLOAD.  IT CALCULATES
C-----THE FLOW CHARACTERISTICS OF THE PRESSURE RELIEF VALVES, FILTERS AND
C-----ORIFICES USING THE EMPIRICALLY DERIVED FLOW CURVES.  IT EVALUATES
C-----THE DIFFERENTIAL EQUATIONS FOR THE INTEGRATION SUBROUTINE 'RKGS'
C---- WHICH IS CALLED FROM THE MAIN PROGRAM.
C ----AUTHOR: C. F. KREBS
      DIMENSION PRESS(2),PREDER(2)
      COMMON /INPUTS/ VALVS1,CRACK1,CHANG1,A1,A2,A3,A4,
     *                VALVS2,CRACK2,CHANG2,B1,B2,B3,B4,
     *                VALVS3,CRACK3,CHANG3,C1,C2,C3,C4,
     *                VALVS4,CRACK4,CHANG4,D1,D2,D3,D4,
     *                FILTS1,AFILT1,E1,E2,E3,E4,ALEAK1,
     *                FILTS2,AFILT2,F1,F2,F3,F4,ALEAK2
      COMMON /OUTPUT/ TIME,PINT1,PEXT,PRAT1,DELTA1,DENS1,MASS1,VEL1,
     *                VMACH1,RATE1,RATEV1,RATEV2,RATEF1,RATEL1,QRATE1,
     *                QRATE2,QRATF1,QRATL1,PINT2,PRAT2,PRAT3,DELTA2,
     *                DELTA3,DENS2,MASS2,VEL2,VEL3,VMACH2,VMACH3,
     *                RATE2,RATE3,RATEV3,RATEV4,RATEF2,RATEL2,QRATE3,
     *                QRATE4,QRATF2,QRATL2
      COMMON /REFERS/ VOL1,VOL2,MULT1,MULT2,VMULT,EXP1,VSOUND,
     *                PREXT(100),PTIME(100),INDEX,DCOEFF,MAGNIT
      REAL MASS1,MASS2,MULT1,MULT2
C-----TRANSFER THE TIME
      TIME=TIMEIN
      TIMES=TIME
C-----TRANSFER THE INTERNAL PRESSURES
      PRESS1=PRESS(1)
      PRESS2=PRESS(2)
      PINT1=PRESS(1)/144.
      PINT2=PRESS(2)/144.
C-----INTERPOLATE TABLE FOR EXTERNAL PRESSURE
  100 IF (TIMES.LE.PTIME(INDEX)) GO TO 110
      INDEX=INDEX+1
      GO TO 100
  110 IF (TIMES.GE.PTIME(INDEX-1)) GO TO 120
      INDEX=INDEX-1
      GO TO 110
  120 IF (INDEX.GT.MAGNIT) STOP 'INDEX TOO LARGE
      FRACN=(TIMES-PTIME(INDEX-1))/(PTIME(INDEX)-PTIME(INDEX-1))
      PEXT=PREXT(INDEX-1)+(PREXT(INDEX)-PREXT(INDEX-1))*FRACN
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$C
C$$$$$                   INNER VOLUME CALCULATIONS                   $$$$$C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$C
      IF (VOL2.EQ.0.) GO TO 800
C---- CALCULATE GAS PROPERTIES
      MASS2=PRESS2/MULT2
      DENS2=MASS2/VOL2
C-----CALCULATE THE QRATE CORRECTION FACTOR
      QCORR2=SQRT(PREXT(1)/PRESS2)
      QCORR2=SQRT(QCORR2)
C-----CALCULATE THE PRESSURE DIFFERENCES
      KEY3=0
      DELTA2=(PRESS2-PRESS1)/144.
      DELTA3=(PRESS2-PEXT)/144.
      IF (DELTA3.LE.0.) KEY3=1
      IF (DELTA2.LE.0.) DELTA2=0.000000
      IF (DELTA3.LE.0.) DELTA3=0.000000
```

```
C-----CALCULATE PRESSURE RATIOS AND THROAT VELOCITIES
      PRAT2=PRESS1/PRESS2
      PRAT3=PEXT/PRESS2
      VEL2=1.-PRAT2**EXP1
      IF (VEL2.LE.0.) VEL2=0.000000
      VEL2=SQRT(VMULT*PRESS2*VEL2/DENS2)
      VEL3=1.-PRAT3**EXP1
      IF (VEL3.LE.0.) VEL3=0.000000
      VEL3=SQRT(VMULT*PRESS2*VEL3/DENS2)
      IF (VEL2.GT.VSOUND) VEL2=VSOUND
      IF (VEL3.GT.VSOUND) VEL3=VSOUND
      VMACH2=VEL2/VSOUND
      VMACH3=VEL3/VSOUND
C=====VALVE THREE FLOW CALCULATIONS
C-----CHECK WHETHER VALVE THREE IS OPEN OR CLOSED
      IF (VALVS3.EQ.0.) GO TO 240
      IF (DELTA2.LT.CRACK3) GO TO 240
C-----VALVE THREE IS OPEN - FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW CONDITION
      IF (VMACH2.GE.1.) GO TO 230
      IF (DELTA2.GT.CHANG3) GO TO 210
      C5=C1
      C6=C2
      GO TO 220
  210 C5=C3
      C6=C4
  220 QRATE3=EXP(C5+C6*ALOG(DELTA2))
      QRATE3=QRATE3/60.*VALVS3*QCORR2
C-----CHOKED VALVE - FLOW RATE CALCULATION
  230 RATEV3=QRATE3*DENS2
      GO TO 300
C-----VALVE THREE IS CLOSED
  240 RATEV3=0.0
C=====VALVE FOUR FLOW CALCULATIONS
C-----CHECK WHETHER VALVE FOUR IS CLOSED OR OPEN
  300 IF (VALVS4.EQ.0.) GO TO 340
      IF (DELTA2.LT.CRACK4) GO TO 340
C-----VALVE FOUR IS OPEN - FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW CONDITION
      IF (VMACH2.GE.1.) GO TO 330
      IF (DELTA2.GT.CHANG4) GO TO 310
      D5=D1
      D6=D2
      GO TO 320
  310 D5=D3
      D6=D4
  320 QRATE4=EXP(D5+D6*ALOG(DELTA2))
      QRATE4=QRATE4/60.*VALVS4*QCORR2
C-----CHOKED VALVE - FLOW RATE CALCULATION
  330 RATEV4=QRATE4*DENS2
      GO TO 400
C-----VALVE FOUR IS CLOSED
  340 RATEV4=0.0
C-----TOTAL VALVE FLOW RATE
  400 RATE2=RATEV3+RATEV4
C=====FILTER TWO FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW
      IF (FILTS2.EQ.0.) GO TO 610
      IF (VMACH3.GE.1.) GO TO 510
```

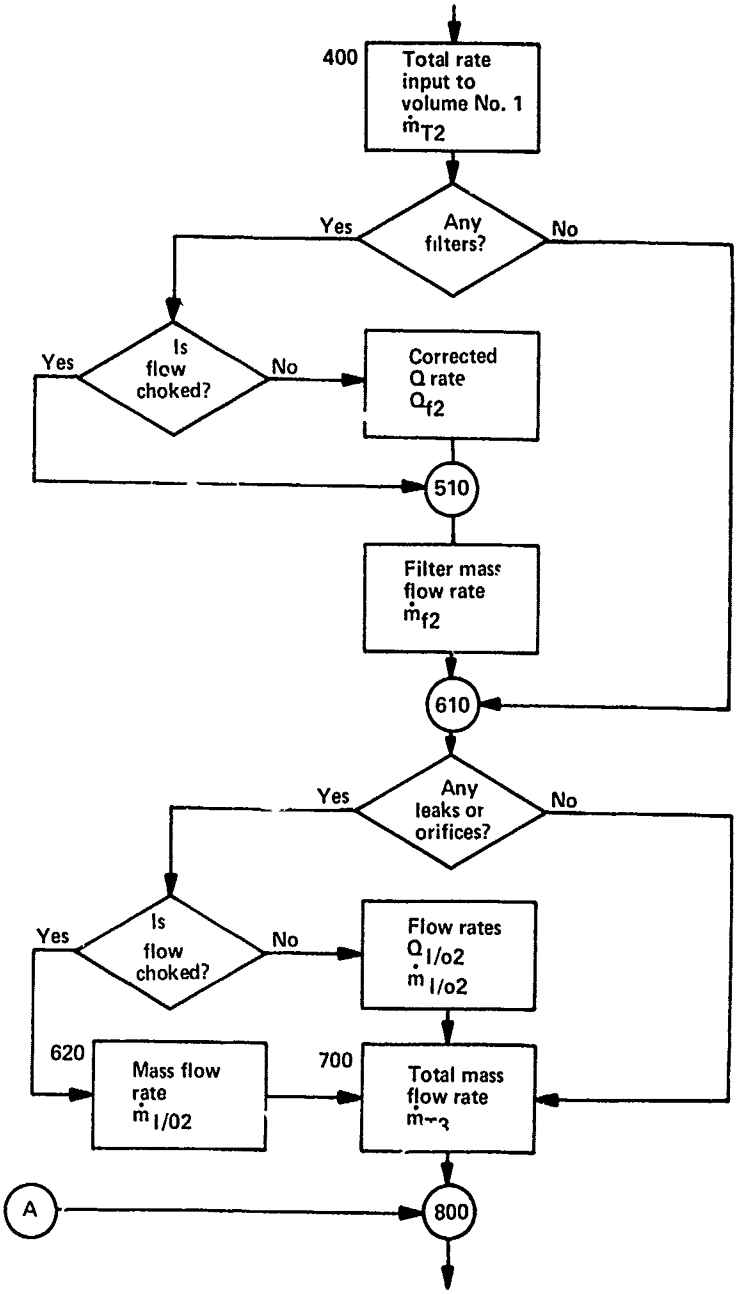
```
      QRATF2=F1+F2*DELTA3+F3*DELTA3**2+F4*DELTA3**3
      IF (KEY3.EQ.1) QRATF2=0.00
      QRATF2=QRATF2*AFILT2*FILTS2/60.*QCORR2
C-----CHOKED FILTER - FLOW RATE CALCULATION
  510 RATEF2=QRATF2*DENS2
C=====ORIFICE TWO FLOW CALCULATION - ADD IN LEAK CONTRIBUTION IF ANY
C-----CHECK FOR CHOKED FLOW
  610 IF (ALEAK2.EQ.0.) GO TO 700
      IF (VMACH3.GE.1.) GO TO 620
      RATEL2=DCOEFF*ALEAK2*SQRT(64.348*DENS2*DELTA3*144.)
      QRATL2=RATEL2/DENS2
      GO TO 700
C-----CHOKED CONDITION
  620 RATEL2=QRATL2*DENS2
C-----CALCULATE THE TOTAL FLOW RATE AND PRESSURE DERIVATIVE
  700 RATE3=RATE2+RATEL2+RATEF2
  800 PREDER(2)=-MULT2*RATE3
C*****************************************************************C
C*****                 OUTER VOLUME CALCULATIONS             *****C
C*****************************************************************C
C-----CALCULATE GAS PROPERTIES
      MASS1=PRESS1/MULT1
      DENS1=MASS1/VOL1
C-----CALCULATE THE QRATE CORRECTION FACTOR
      QCORR1=SQRT(PREXT(1)/PRESS1)
      QCORR1=SQRT(QCORR1)
C-----CALCULATE THE PRESSURE DIFFERENCE
      KEY1=0
      DELTA1=(PRESS1-PEXT)/144.
      IF (DELTA1.LE.0.) KEY1=1
      IF (DELTA1.LE.0.) DELTA1=0.000000
C-----CALCULATE PRESSURE RATIO AND THROAT VELOCITY
      PRAT1=PEXT/PRESS1
      PEXT=PEXT/144.
      VEL1=1.-PRAT1**EXP1
      IF (VEL1.LE.0.) VEL1=0.000000
      VEL1=SQRT(VMULT*PRESS1*VEL1/DENS1)
      IF (VEL1.GT.VSOUND) VEL1=VSOUND
      VMACH1=VEL1/VSOUND
C=====VALVE ONE FLOW CALCULATIONS
C-----CHECK WHETHER VALVE ONE IS OPEN OR CLOSED
      IF (VALVS1.EQ.0.) GO TO 1040
      IF (DELTA1.LT.CRACK1) GO TO 1040
C-----VALVE ONE IS OPEN - FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW CONDITION
      IF (VMACH1.GE.1.) GO TO 1030
      IF (DELTA1.GT.CHANG1) GO TO 1010
      A5=A1
      A6=A2
      GO TO 1020
 1010 A5=A3
      A6=A4
 1020 QRATE1=EXP(A5+A6*ALOG(DELTA1))
      QRATE1=QRATE1/60.*VALVS1*QCORR1
C-----CHOKED VALVE - FLOW RATE CALCULATION
 1030 RATEV1=QRATE1*DENS1
      GO TO 1100
C-----VALVE ONE IS CLOSED
 1040 RATEV1=0.0
C=====VALVE TWO FLOW CALCULATIONS
```

```
C-----CHECK WHETHER VALVE TWO IS CLOSED OR OPEN
 1100   IF (VALVS2.EQ.0.) GO TO 1140
        IF (DELTA1.LT.CRACK2) GO TO 1140
C-----VALVE TWO IS OPEN - FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW CONDITION
        IF (VMACH1.GE.1.) GO TO 1130
        IF (DELTA1.GT.CHANG2) GO TO 1110
        B5=B1
        B6=B2
        GO TO 1120
 1110   B5=B3
        B6=B4
 1120   QRATE2=EXP(B5+B6*ALOG(DELTA1))
        QRATE2=QRATE2/60.*VALVS2*QCORR1
C-----CHOKED VALVE - FLOW RATE CALCULATION
 1130   RATEV2=QRATE2*DENS1
        GO TO 1200
C-----VALVE TWO IS CLOSED
 1140   RATEV2=0.0
C=====FILTER ONE FLOW RATE CALCULATION
C-----CHECK FOR CHOKED FLOW
 1200   IF (FILTS1.EQ.0.) GO TO 1410
        IF (VMACH1.GE.1.) GO TO 1310
        QRATF1=E1+E2*DELTA1+E3*DELTA1**2+E4*DELTA1**3
        IF (KEY1.EQ.1) QRATF1=0.00
        QRATF1=QRATF1*AFILT1*FILTS1/60.*QCORR1
C-----CHOKED FILTER - FLOW RATE CALCULATION
 1310   RATEF1=QRATF1*DENS1
C=====ORIFICE ONE FLOW CALCULATION - ADD IN LEAK CONTRIBUTION IF ANY
C-----CHECK FOR CHOKED FLOW
 1410   IF (ALEAK1.EQ.0.) GO TO 1500
        IF (VMACH1.GE.1.) GO TO 1420
        RATEL1=DCOEFF*ALEAK1*SQRT(64.348*DENS1*DELTA1*144.)
        QRATL1=RATEL1/DENS1
        GO TO 1500
C-----CHOKED CONDITION
 1420   RATEL1=QRATL1*DENS1
C-----CALCULATE THE TOTAL FLOW RATE AND PRESSURE DERIVATIVE
 1500   RATE1=RATEV1+RATEV2+RATEL1+RATEF1
        PREDER(1)=-MULT1*(RATE1-RATE2)
        RETURN
        END
```

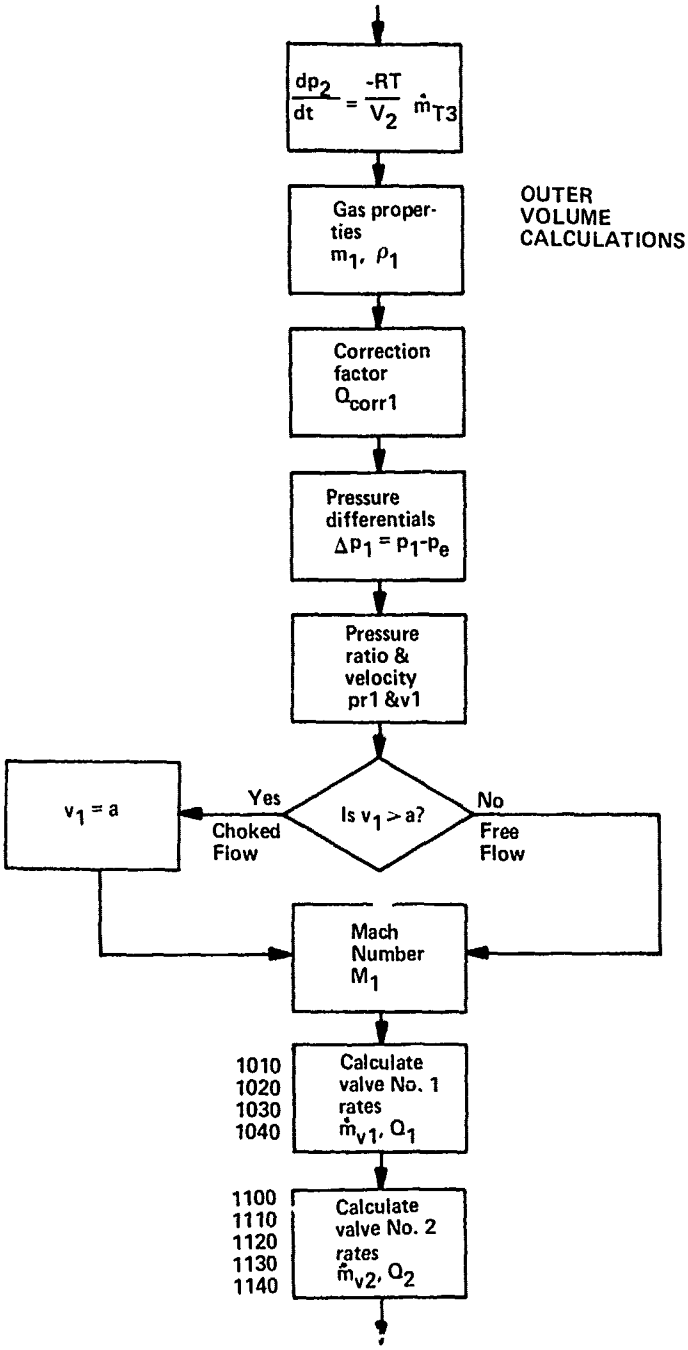

Start
Transfer dependent & independent variables
100
110
120
Interpolate for external pressure
More than one volume?
No
Yes
INNER VOLUME CALCULATIONS
Gas properties m_2, ρ_2
A
Correction factor Q_{corr2}
Pressure differentials
$\Delta p_2 = p_2 - p_1$
$\Delta p_3 = p_2 - p_e$
Pressure ratios & velocities
p_{r2}, p_{r3}, v_1, v_2
Is $v_2 \geq a$?
Yes
Choked Flow
$v_2 = a$
No
Free Flow



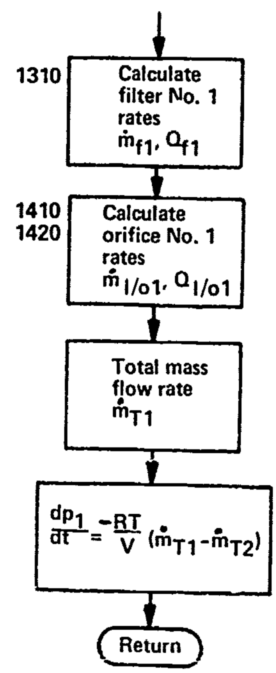
Is $v_3 \sim a$?
Yes
Choked Flow
No
Free Flow
$v_3 = a$
Mach numbers M_2, M_3
Any No 3 valves present?
Yes
No
Are they open? ($\Delta p_2 \leq p_c$)
Yes
No
Is flow choked? ($M_2 \geq 1.0$)
Yes
No
210
Alternate coefficients C3 & C4
Is $\Delta p_2 \leq$ knee ?
Yes
No
Q curve coefficients C1 & C2
Corrected Q rate Q_3
230
No. 3 valves mass flow rate $\dot{m}_{v3}$
240
$\dot{m}_{v3} = 0$
300
310
320
Do the same for No. 4 type valves $\dot{m}_{v4}$



400
Total rate input to volume No. 1 ṁT2
Any filters?
Yes
No
Is flow choked?
Yes
No
Corrected Q rate Qf2
510
Filter mass flow rate ṁf2
610
Any leaks or orifices?
Yes
No
Is flow choked?
Yes
No
Flow rates Q l/o2 ṁ l/o2
620
Mass flow rate ṁ l/02
700
Total mass flow rate
A
800



$\frac{dp_2}{dt} = \frac{-RT}{V_2} \dot{m}_{T3}$
Gas properties m_1, ρ_1
OUTER VOLUME CALCULATIONS
Correction factor Q_{corr1}
Pressure differentials $\Delta p_1 = p_1 - p_e$
Pressure ratio & velocity pr1 &v1
Is $v_1 > a$?
Yes
Choked Flow
$v_1 = a$
No
Free Flow
Mach Number M_1
1010
1020
1030
1040
Calculate valve No. 1 rates $\dot{m}_{v1}, Q_1$
1100
1110
1120
1130
1140
Calculate valve No. 2 rates $\dot{m}_{v2}, Q_2$



1310
Calculate filter No. 1 rates
ṁf1, Qf1
1410
1420
Calculate orifice No. 1 rates
ṁl/o1, Ql/o1
Total mass flow rate
ṁT1
dp1/dt = RT/V (ṁT1 - ṁT2)
Return

Appendix D

Sample Input and Output Data Files

Format for Input Data File FTN30.DAT

Line	Format	
1	20A4	Title
2	5A4	Gas type
3	6F10.0	Volume #1, volume #2, initial pressure, initial temperature, gas constant, ratio of specific heats
4	20A4	Valve type #1
5	7F10.0	Number of valves, cracking pressure, knee pressure, curve coefficients A & B (below knee pressure), curve coefficients C & D (above knee pressure)
6	20A4	Valve type #2
7	7F10.0	Same as line 5 except for valve type #2
8	20A4	Filter type
9	6F10.0	Number of filters, filter area/multiplier (for RA-2500 is exit area; for CW-19 is length multiplier) curve coefficients A, B, C, & D
10	20A4	Leak/orifice title
11	F10.0	Effective area of leak or orifice

12	4F10.0	Ending time of calculations, timestep = 0.01 seconds, print interval multiplier = 100., accuracy requirement = 0.001
13	I10	Number of entries to follow in external pressure table
14	8F10.0	Time, external pressure

Notes: For valves, filters, and orifices not present include a title but leave numerical data line blank.

In line 12, the timestep and print interval multiplier. determine printout time: 100 × 0.01 = 1 second printout.

In line 14, 4 pairs per line, repeating if necessary.

For PRESSM.FOR, repeat lines 4 through 11 for second volume with primary volume data first and secondary volume data following (see IRBS Payload input file).

Units for Input Data File

Gas volume	cubic feet
Initial pressure	pounds per square inch
Initial temperature	degrees F
Gas constant	foot-pounds per pound-degree R
Valve cracking & knee pressure	pounds per square inch
Filter area	square inches
Leak area	square feet
End time	seconds
External pressure table:	
time	seconds
pressure	pounds per square foot

**Sample Input Data File (FTN30.DAT)
for ZIP Payload – PRESS4.FOR**

```
  IP PAYLOAD INTERNAL PRESSURE HISTORY
 NITROGEN
      6.80                    0.12        35.0       55.20      1.400
 CIRCLE SEAL  P-249  0.10 PSI MARKED CRACKING PRESSURE
        6.   0.0387           0.10   10.8789     4.7952     0.9767      0.4956
 CIRCLE SEAL  P7-637  0.50 PSI MARKED CRACKING PRESSURE
        0.     0.325          0.59   12.7900    17.3978     3.8647      0.4786
 MILLIPORE  RA  1.2 MICROMETER PORE SIZE
        2.   0.11045 -0.007017  2.018104
 PERFECT SEAL -- NO LEAK

100.       0.01        100.       0.001
  72
 0.0     1827.7         1.0     1826.1          2.0     1821.0          3.0    1812.3
 4.0     1799.8         5.0     1783.6          6.0     1763.5          7.0    1739.4
 8.0     1711.1         9.0     1678.6         10.0     1642.1         11.0    1601.4
12.0     1557.1        13.0     1509.0         14.0     1457.6         15.0    1403.2
16.0     1346.5        17.0     1287.9         18.0     1227.7         19.0    1166.5
20.0     1104.6        21.0     1042.1         22.0      979.3         23.0     916.7
24.0      854.4        25.0      792.7         26.0      731.9         27.0     672.3
28.0      614.0        29.0      557.5         30.0      502.8         31.0     450.4
32.0      401.1        33.0      355.4         34.0      313.0         35.0     274.0
36.0      238.3        37.0      205.9         38.0      176.7         39.0     150.5
40.0      127.3        41.0      106.7         42.0       88.8         43.0      73.2
44.0       59.8        45.0       48.5         46.0       39.0         47.0      31.2
48.0       24.8        49.0       19.6         50.0       15.5         51.0      12.1
52.0        9.4        53.0        7.3         54.0        5.6         55.0       4.3
56.0        3.3        57.0        2.5         58.0        1.8         59.0       1.4
60.0        1.0        61.0        0.7         62.0        0.5         63.0       0.3
64.0        0.2        65.0        0.2         66.0        0.1         67.0       0.1
68.0       0.05        69.0        0.0         70.0        0.0        360.0       0.0
```

Sample Input Data File (FTN30.DAT)
for IRBS Payload--PRESSM.FOR

```
 IRBS PAYLOAD INTERNAL PRESSURE HISTORY
AIR
     46.80     0.1777       0.50        70.0       53.35       1.400
CIRCLE SEAL  P7-637  0.50 PSI MARKED CRACKING PRESSURE
        3.     0.325        0.59   12.7900   17.3978     3.8647     0.4786
NO SECOND VALVE TYPE PRESENT

NO FILTERS PRESENT

PERFECT SEAL -- NO LEAKS

CIRCLE SEAL  P-249  0.10 PST MARKED CRACKING PRESSURE
        2.    0.0387        0.10   10.8789    4.7952     0.9767     0.4956
NO SECOND VALVE PRESENT

NO FILTERS PRESENT

DOOR LEAK DUE TO SEAM SEAL
  0.000042
100.        0.01        100.       0.001
  89
  0.0     1827.7        1.0     1827.7          2.0     1816.7         3.0     1809.8
  4.0     1798.8        5.0     1785.4          6.0     1768.2         7.0     1747.7
  8.0     1723.2        9.0     1695.5         10.0     1663.9        11.0     1628.7
 12.0     1589.6       13.0     1547.9         14.0     1502.1        15.0     1453.9
 16.0     1402.5       17.0     1348.8         18.0     1292.8        19.0     1236.0
 20.0     1178.8       21.0     1121.3         22.0     1063.6        23.0     1005.5
 24.0     947.25       25.0     889.07         26.0     830.89        27.0     773.17
 28.0     715.94       29.0     659.67         30.0     604.40        31.0     550.43
 32.0     498.10       33.0     447.64         34.0     400.17        35.0     355.76
 36.0     314.45       37.0     276.25         38.0     241.40        39.0     209.09
 40.0     180.08       41.0     153.95         42.0     130.62        43.0     109.96
 44.0     91.890       45.0     76.198         46.0     62.720        47.0     51.207
 48.0     41.468       49.0     33.300         50.0     26.506        51.0     20.907
 52.0     16.354       53.0     12.708         54.0     9.8087        55.0     7.5328
 56.0     5.7511       57.0     4.3639         58.0     3.2927        59.0     2.4401
 60.0     1.6404       61.0     1.3554         62.0     0.9910        63.0     0.7203
 64.0     0.5213       65.0     0.3756         66.0     0.2685        67.0     0.1897
 68.0     0.1323       69.0     0.0911         70.0     0.0617        71.0     0.0411
 72.0     0.0269       73.0     0.0173         74.0     0.0111        75.0     0.0072
 76.0     0.0046       77.0     0.0030         78.0     0.0020        79.0     0.0013
 80.0     0.0009       81.0     0.0001         82.0     0.0000        90.0     0.0000
100.0     0.0000      150.0     0.0000        200.0     0.0000       350.0     0.0000
360.0     0.0000
```

Sample Output Data File (FTN31.DAT)
for ZIP Payload – PRESS4.FOR

```
ZIP PAYLOAD INTERNAL PRESSURE HISTORY

        GAS PROPERTIES:
             TYPE:                          NITROGEN
             MAIN VOLUME              =           6.80 CU FT
             INITIAL PRESSURE         =           0.12 PSI
             TEMPERATURE              =          35.0 DEGREES F
             GAS CONSTANT             =          55.20 FT-LB/LB-DEG R


        VALVE ONE PROPERTIES:
             TYPE:                          CIRCLE SEAL  P-249  0.10 PSI MARKED
             NUMBER OF RELIEF VALVES  =           6.        CRACKING PRESSURE
             CRACKING PRESSURE        =           0.04 PSI
             CURVE CHANGE POINT       =           0.10 PSI
             COEFFICIENT 1            =          10.979
             COEFFICIENT 2            =           4.795
             COEFFICIENT 3            =           0.977
             COEFFICIENT 4            =           0.496


        VALVE TWO PROPERTIES:
             TYPE:                          CIRCLE SEAL  P7-637  0.50 PSI MARKED

        FILTER PROPERTIES:
             TYPE:                          MILLIPORE  RA  1.2 MICROMETER PORE SIZE
             NUMBER OF FILTERS        =           2.          CRACKING PRESSURE
             EXIT AREA                =        0.11045 SQ IN
             COEFFICIENT 1            =          -0.007
             COEFFICIENT 2            =           2.018
             COEFFICIENT 3            =           0.000
             COEFFICIENT 4            =           0.000


        DOOR LEAK PROPERTIES:
             TYPE OF SEAL:                  PERFECT SEAL -- NO LEAK
       CHOKING PROPERTIES:
           RATIO OF SPECIFIC HEATS    =        1.400
           CRITICAL PRESSURE RATIO    =        0.5283
           SPEED OF SOUND             =        1012.4 FPS
```

TIME SECS	EXTERNAL PRESSURE PSI	INTERNAL PRESSURE PSI	DELTA P PSI	INTERNAL GAS MASS LBM	TOTAL MASS FLOW RATE LBM/SEC
0.0	12.69	12.81	0.120	0.45946	0.0063326
1.0	12.68	12.75	0.066	0.45712	0.0008095
2.0	12.65	12.72	0.072	0.45606	0.0012052
3.0	12.59	12.67	0.081	0.45423	0.0021200
4.0	12.50	12.59	0.088	0.45136	0.0030970
5.0	12.39	12.48	0.093	0.44751	0.0040261
6.0	12.25	12.34	0.098	0.44267	0.0049980
7.0	12.08	12.19	0.108	0.43702	0.0057598

8.0	11.88	12.02	0.134	0.43092	0.0063605
9.0	11.66	11.83	0.171	0.42414	0.0070972
10.0	11.40	11.62	0.214	0.41662	0.00785[illegible]
11.0	11.12	11.39	0.256	0.40834	0.0086[illegible]35
12.0	10.81	11.14	0.322	0.39933	0.0093387
13.0	10.48	10.86	0.385	0.38961	0.0100314
14.0	10.12	10.58	0.453	0.37923	0.0106656
15.0	9.74	10.27	0.525	0.36826	0.0112376
16.0	9.35	9.95	0.598	0.35676	0.0117218
17.0	8.94	9.62	0.672	0.34482	0.0121226
18.0	8.53	9.27	0.747	0.33252	0.0124483
19.0	8.10	8.92	0.821	0.31994	0.0126894
20.0	7.67	8.57	0.895	0.30716	0.0128552
21.0	7.24	8.21	0.969	0.29424	0.0129607
22.0	6.80	7.84	1.043	0.28126	0.0130073
23.0	6.37	7.48	1.115	0.26825	0.0129894
24.0	5.93	7.12	1.186	0.25530	0.0129185
25.0	5.50	6.76	1.256	0.24244	0.0127962
26.0	5.08	6.41	1.324	0.22973	0.012624
27.0	4.67	6.06	1.389	0.21721	0.0124050
28.0	4.26	5.71	1.451	0.20494	0.0121463
29.0	3.87	5.38	1.509	0.19294	0.0118442
30.0	3.49	5.05	1.563	0.18127	0.0115091
31.0	3.13	4.74	1.611	0.16995	0.0111377
32.0	2.79	4.43	1.649	0.15902	0.0107225
33.0	2.47	4.14	1.674	0.14853	0.0102657
34.0	2.17	3.86	1.689	0.13851	0.0097862
35.0	1.90	3.60	1.694	0.12897	0.0092904
36.0	1.65	3.35	1.692	0.12001	0.0086471
37.0	1.43	3.11	1.684	0.11166	0.0080459
38.0	1.23	2.90	1.670	0.10390	0.0074866
39.0	1.05	2.70	1.651	0.09668	0.0069661
40.0	0.88	2.51	1.624	0.08996	0.0064818
41.0	0.74	2.33	1.593	0.08370	0.0060312
42.0	0.62	2.17	1.555	0.07786	0.0056119
43.0	0.51	2.02	1.512	0.07247	0.0052218
44.0	0.42	1.88	1.465	0.06743	0.0048587
45.0	0.34	1.75	1.413	0.06274	0.0045210
46.0	0.27	1.63	1.357	0.05838	0.0042067
47.0	0.22	1.51	1.298	0.05432	0.0039142
48.0	0.17	1.41	1.237	0.05055	0.0036421
49.0	0.14	1.31	1.175	0.04703	0.0033889
50.0	0.11	1.22	1.113	0.0437[illegible]	0.0031533
51.0	0.08	1.14	1.051	0.040[illegible]	0.0029341
52.0	0.07	1.06	0.991	0.03789	0.0027301
53.0	0.05	0.98	0.932	0.03526	0.0025403
54.0	0.04	0.91	0.876	0.03280	0.0023637
55.0	0.03	0.85	0.821	0.03052	0.0021994
56.0	0.02	0.79	0.769	0.02840	0.0020465
57.0	0.02	0.74	0.720	0.02643	0.0019042
58.0	0.01	0.69	0.673	0.02459	0.0017719
59.0	0.01	0.64	0.628	0.02288	0.0016486
60.0	0.01	0.59	0.587	0.02129	0.0015340
61.0	0.00	0.55	0.548	0.01981	0.0014274
62.0	0.00	0.51	0.511	0.01843	0.0013282
63.0	0.00	0.48	0.476	0.01715	0.001235
64.0	0.00	0.45	0.444	0.01596	0.0011499
65.0	0.00	0.41	0.413	0.01485	0.0010700
66.0	0.00	0.39	0.385	0.01382	0.0009956
67.0	0.00	0.36	0.359	0.0128[illegible]	0.00092[illegible]4

68.0	0.00	0.33	0.333	0.01196	0.0008620
69.0	0.00	0.31	0.310	0.01113	0.0008020
70.0	0.00	0.29	0.289	0.01036	0.0007463
71.0	0.00	0.27	0.269	0.00964	0.0006944
72.0	0.00	0.25	0.250	0.00897	0.0006461
73.0	0.00	0.23	0.233	0.00834	0.0006012
74.0	0.00	0.22	0.216	0.00776	0.0005594
75.0	0.00	0.20	0.201	0.00722	0.0005205
76.0	0.00	0.19	0.187	0.00672	0.0004843
77.0	0.00	0.17	0.174	0.00625	0.0004507
78.0	0.00	0.16	0.162	0.00582	0.0004193
79.0	0.00	0.15	0.151	0.00542	0.0003902
80.0	0.00	0.14	0.141	0.00504	0.0003631
81.0	0.00	0.13	0.131	0.00469	0.0003378
82.0	0.00	0.12	0.122	0.00436	0.0003143
83.0	0.00	0.11	0.113	0.00406	0.0002925
84.0	0.00	0.11	0.105	0.00378	0.0002721
85.0	0.00	0.10	0.098	0.00351	0.0002532
86.0	0.00	0.09	0.091	0.00327	0.0002356
87.0	0.00	0.08	0.085	0.00304	0.0002192
88.0	0.00	0.08	0.079	0.00283	0.0002040
89.0	0.00	0.07	0.073	0.00263	0.0001898
90.0	0.00	0.07	0.068	0.00245	0.0001766
91.0	0.00	0.06	0.064	0.00228	0.0001643
92.0	0.00	0.06	0.059	0.00212	0.0001529
93.0	0.00	0.06	0.055	0.00197	0.0001423
94.0	0.00	0.05	0.051	0.00184	0.0001324
95.0	0.00	0.05	0.048	0.00171	0.0001232
96.0	0.00	0.04	0.044	0.00159	0.0001146
97.0	0.00	0.04		0.00148	0.0001067
98.0	0.00	0.04	[illegible]	0.00139	0.0000035
99.0	0.00	0.04	0.039	0.00138	0.0000035
100.0	0.00	0.04	0.038	0.00138	0.0000035

Nomenclature

A	Area
a	Speed of sound
C	Constant
c_p	Pressure coefficient
M	Mach number
m	Mass
$\dot{m}$	Mass flow rate
n	Correction factor exponent
p	Pressure
p_c	Cracking pressure differential
Q	Volume flow rate
R	Gas constant
T	Temperature
t	Time
V	Volume
v	Velocity
γ	Ratio of specific heats
ρ	Density

Subscripts

atm	Atmospheric conditions
crit	Critical (at $M = 1$)
e	Exit, external
f	Filters
i	Inlet, internal
l	Leaks
o	Orifices
T	Total
v	Valves
1	Primary volume internal
2	Secondary volume internal