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TECHNICAL REPORT BRL-TR-2703

A LUMPED PARAMETER CODE FOR
REGENERATIVE LIQUID PROPELLANT GUNS

Terence P. Coffee

December 1985

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I. INTRODUCTION

In this paper we derive the governing equations for a lumped parameter model of a regenerative liquid propellant gun and discuss the numerical implementation. Morrison et. al. have covered the background and possible applications of liquid propellant guns.¹ Here the emphasis is on the derivation of a numerical model.

For solid propellant guns, there is a wide range of models.² Precomputer models involved approximations that allowed an analytic, closed-form solution, or else a simple numerical solution leading to tables. The advent of computers allowed the direct numerical solution of ordinary differential equations describing the interior ballistics on a case by case basis. More recently, one-dimensional and even two-dimensional models have been developed, involving the solution of partial differential equations. All of these procedures can give accurate results. The choice of a model depends on the detail desired in the solution.

For regenerative liquid propellant guns, much less work has been done. Pagan and Izod³ have developed an ordinary differential equation model. This code assumes a particular type of regenerative gun, and has a rather complicated model for the liquid injection into the combustion chamber. Cushman⁴ has written a model that has been extensively used at General Electric. The model normally used at the BRL is due to Paul

¹W.F. Morrison, J.D. Knapton, and G. Klingenberg, "Liquid Propellants for Gun Applications," Proceedings of the Seventh International Symposium on Ballistics, The Hague, The Netherlands, April, 1983.

²P.G. Baer, "Practical Interior Ballistic Analysis of Guns," Progress in Astronautics and Aeronautics, Interior Ballistics of Guns, (H. Krier and M. Summerfield, ed.), Vol 66, 1979.

³G. Pagan and D.C.A. Izod, "Regenerative Liquid Propellant Gun Modelling," Proceedings of the Seventh International Symposium on Ballistics, The Hague, The Netherlands, April, 1983.

⁴P.G. Cushman, "Regenerative Liquid Propellant Gun Simulation User's Manual," GE Report 84-POD-004, December, 1983.

Gough.⁵ This code uses a lumped parameter representation (ordinary differential equations) for the liquid reservoir and combustion chamber. The gun tube is represented by partial differential equations. This code has a number of options, including a traveling charge projectile. Since both the design of the regenerative liquid gun and the assumptions made in the model are under development, additional options are periodically added to the code.

The purpose of this report is twofold. First we develop a complete lumped parameter code (only ordinary differential equations) to describe the regenerative liquid propellant gun. This code is not as general as that developed by Gough. However, it runs much faster, which allows parametric studies to be made easily. Also, the code is written as far as possible in a modular form. Additional options can be added with a minimum amount of effort. As new gun designs are developed, or new assumptions about the behavior in the gun are tried, these can be tested fairly easily.

II. THE REGENERATIVE LIQUID PROPELLANT GUN

Figs. 1 and 2 show regenerative liquid propellant guns with an in-line piston. Another possible design is the reverse annular gun, where the piston is wrapped around the barrel and moves in the direction of the muzzle.⁵ The reverse annular gun includes an intermediate combustion chamber. While we will only consider in-line pistons, in order to be consistent with the notation used by Gough, the regions of the gun will be denoted as regions 1, 3, and 4.

Region 1 is the liquid propellant reservoir. The monopropellant is pumped into the reservoir at the beginning of the firing cycle. A primer is ignited in the combustion chamber (region 3). As the chamber is pressurized, the piston is forced back. Because of the piston area

⁵P.S. Gough, "A Model of the Interior Ballistics of Hybrid Liquid-Propellant Guns," Final Report, Contract DAAK11-82-C-0154, PGA-TR-83-4, September 1983.

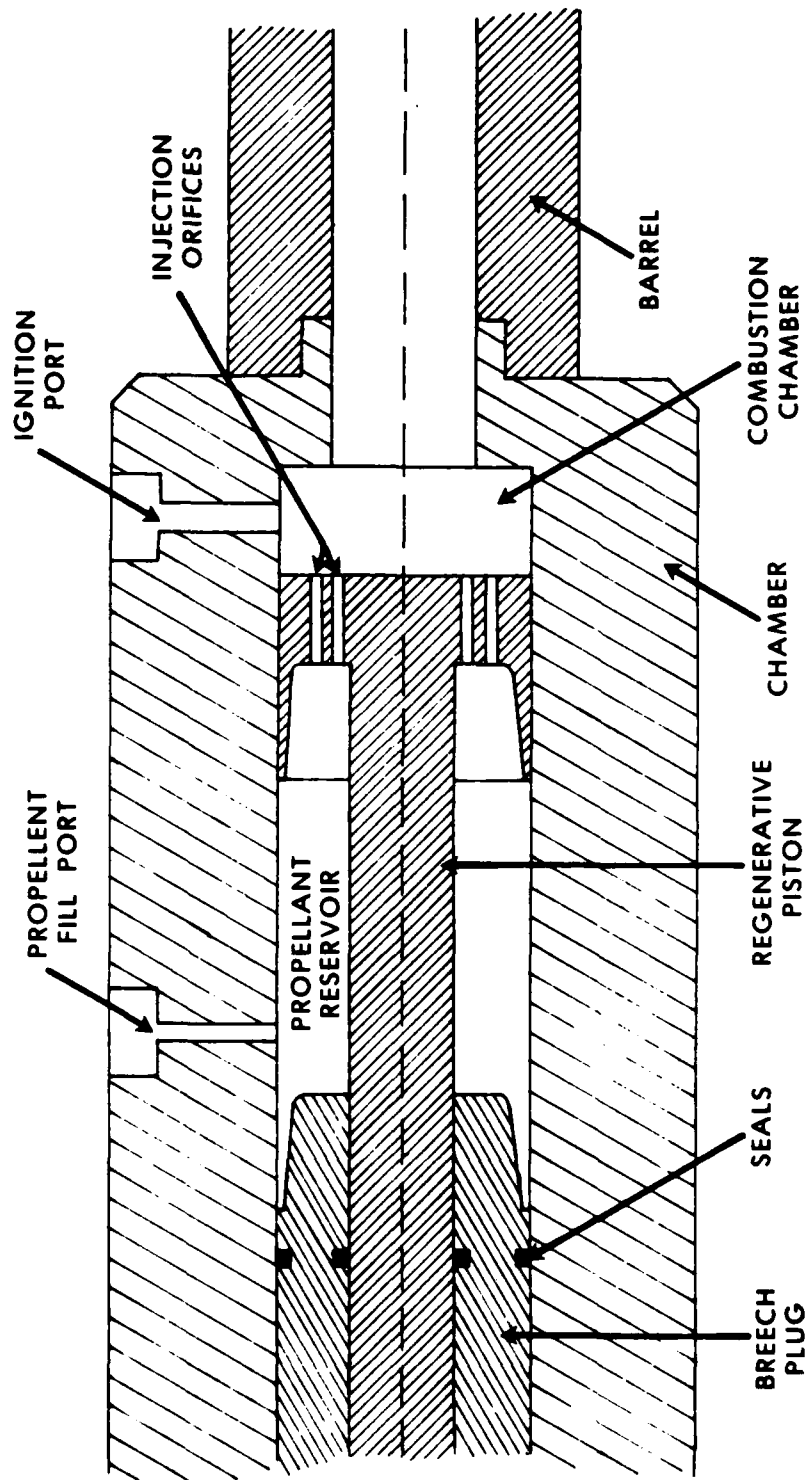


Figure 1. A Regenerative Liquid Propellant Gun

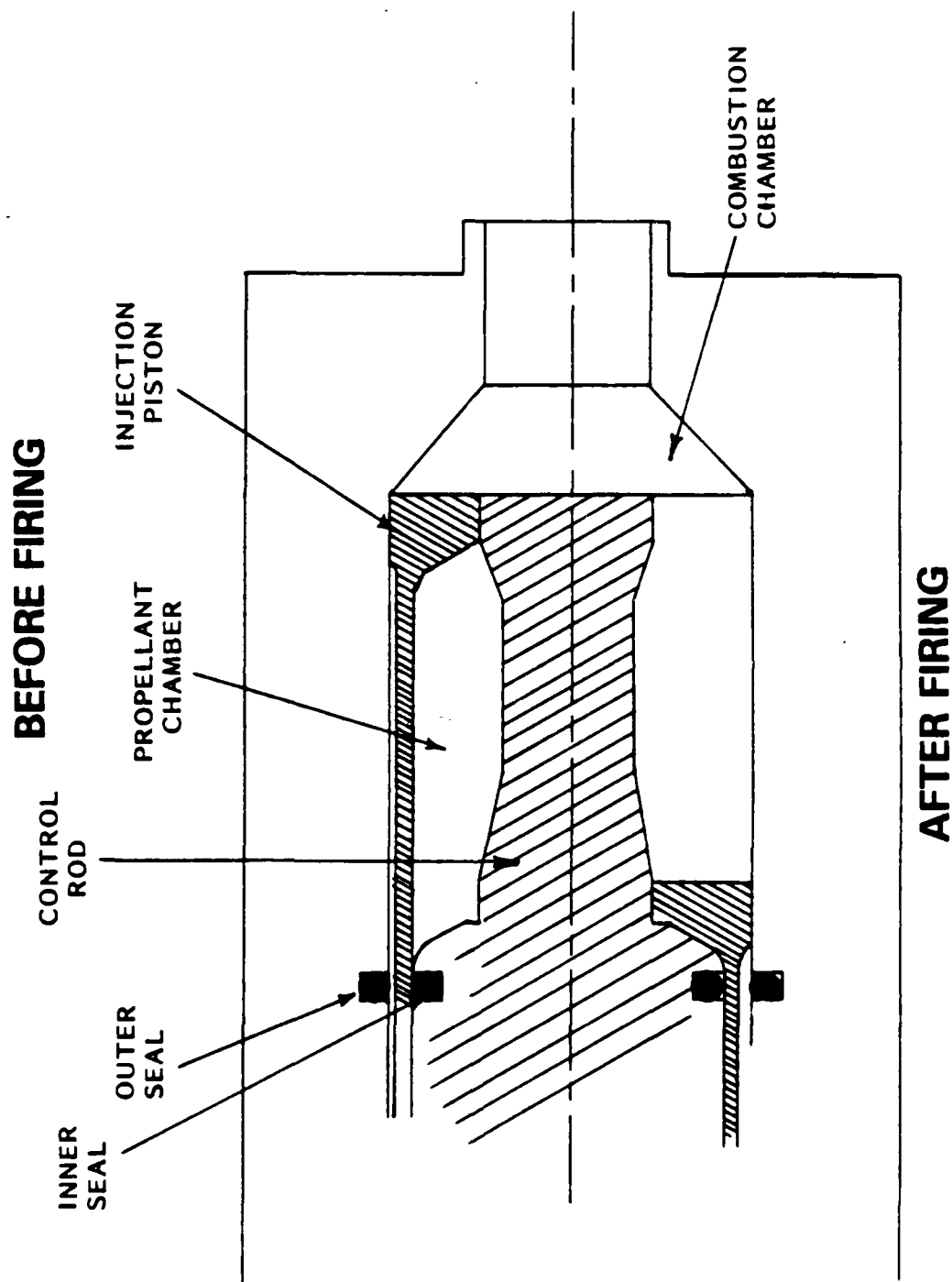


Figure 2. A Regenerative Liquid Propellant Gun with an Annular Piston

differential between the two regions, the liquid pressure is higher than the combustion chamber pressure. So liquid propellant is forced through circular holes in the piston face, and ignites and burns in the combustion chamber. Eventually, the pressure pushes the projectile down the gun tube (region 4).

In most problems involving liquids, the liquid can be considered incompressible. Because of the high pressures in a gun, this is not a good approximation, and the compressibility of the liquid propellant will be considered.

In the gun, it is possible that gas from the combustion chamber can be forced into the liquid chamber. This is most likely to occur at early times, when the primer causes the initial pressure rise in the combustion chamber. Because of the inertia of the piston, there may be a delay before the liquid pressure also rises. The modeling of bubbles in a compressible liquid is complicated, so we will assume that there is no mass flow into region 1. In the experimental fixture grease is used to block the holes so that flow into the liquid reservoir is less likely.

The orifice flow through the vents in the piston is quite complicated. Here we assume that the piston face is infinitely thin, and ignore the behavior in the orifice. The mass of the piston will be considered.

The piston design considered here was used in early test fixtures,^{6 7} but is not convenient for actual guns. Since the vent holes must be plugged before each shot, rapid fire is impossible. Other piston designs will be considered below.

⁶W.F. Morrison, M.J. Bulman, P.G. Baer, and C.F. Banz, "The Interior Ballistics of Regenerative Liquid Propellant Guns," 1984 JANNAF Propulsion Meeting, New Orleans, LA, CPIA Publication 390, February, 1984.

⁷P.G. Baer, C.F. Banz, I.W. May and W.F. Morrison, "A Propulsion System Comparison Study for the 120-MM Anti-Armor Cannon," 1984 JANNAF Propulsion Meeting, New Orleans, LA, CPIA Publication 390, February, 1984.

The behavior in the combustion chamber is very complicated. A primer is ignited in the chamber, leading to a gradual pressure rise. Liquid jets are forced out of the vent holes. These jets may break up into droplets because of hydrodynamic forces between the gas and the liquid or due to impact on the wall of the chamber. The droplets formed may break up further or coalesce. The propellant will eventually ignite, and may burn as individual droplets or as an envelope flame. These processes are not well understood at low pressure, and essentially no work has been done at gun pressures. Therefore, simplifying assumptions are necessary.

As a first approximation, we assume that the liquid burns instantaneously as soon as it enters the combustion chamber, releasing all its energy. The combustion chamber is treated as a homogeneous region.

The primer is assumed to be the same liquid as the propellant. Normally the combustion of the primer is not followed in detail. Instead the initial pressure in the combustion chamber is an input parameter. Then the amount of propellant needed to produce this pressure is calculated, and this is taken as the mass of the primer. The piston and projectile are not allowed to move during the burning of the primer. Later a somewhat more complicated primer option will be discussed.

There is some evidence that liquid accumulates in the combustion chamber at the beginning of the firing cycle, which changes the behavior of the pressure rise. Later we introduce finite burning rates for the liquid propellant, in an attempt to model, at least crudely, the effects of possible propellant accumulation.

Last, we have the behavior in the gun tube itself. In the Gough code, this region is modeled by one-dimensional partial differential equations. This is necessary because of the traveling charge option included in this code. We will consider this region as a lumped parameter region, using the

Lagrange pressure distribution. This has been successfully used to model the behavior of solid propellant guns.⁸

Below, we derive the governing equations for the simple lumped parameter model just described. Later, additional options will be considered.

III. GOVERNING EQUATIONS

With the above assumptions, the regenerative gun behavior can be modeled by 13 ordinary differential equations ([1] to [13]).

The equations governing the piston motion can be derived simply. Let V_1 be the volume of the fuel chamber, and A_1 be the area of the fuel side of the piston (this area includes the vent holes). Let V_{10} be the initial volume of the liquid chamber. Let S_{ps} be the piston travel (to the left) and V_{ps} be the piston velocity. Then

$$V_1 = V_{10} - S_{ps} A_1 . \quad (1)$$

Taking the derivative,

$$[1] \quad \frac{dV_1}{dt} = - V_{ps} A_1 . \quad (2)$$

The acceleration of the piston equals the force on the piston divided by the mass of the piston, that is

⁸J. Corner, Theory of the Interior Ballistics of Guns, Wiley, New York, 1950.

$$[2] \quad \frac{dv_{ps}}{dt} = \frac{g_o}{M_{ps}} [p_3(A_3 - A_v) - p_1(A_1 - A_v)] , \quad (3)$$

where A_3 is the area of the combustion side of the piston, A_v is the area of the vent holes, p_1 is the pressure in the liquid chamber, p_3 is the pressure in the combustion chamber, and M_{ps} is the mass of the piston. The quantity $g_o = 10^7$ gm/s-cm-MPa is a conversion constant to put the acceleration in the desired units of cm²/s. By assumption, the pressures are constant throughout the two chambers. Then the equation governing the piston travel is

$$[3] \quad \frac{ds_{ps}}{dt} = v_{ps} . \quad (4)$$

As the piston moves to the left, liquid propellant is forced through the vent holes. This is governed by Bernoulli's equation⁹

$$\frac{p_3 - p_1}{\rho_1} + \frac{v_3^2 - v_1^2}{2} = 0 \quad (5)$$

where ρ_1 is the density of the propellant in region 1, v_1 is the velocity of the fluid on the liquid side, and v_3 is the velocity of the injected fluid on the combustion chamber side of the piston. In using this equation, the flow in the orifices is assumed to be frictionless incompressible flow. The potential energy due to height differences has been left out of the equation.

⁹W.F. Hughes and J.A. Brighton, Fluid Dynamics, Schaum's Outline Series, McGraw-Hill, New York, 1967.

Since the liquid in region 1 is a homogeneous mixture, we take v_1 to be zero. Eq. (5) can be rewritten as

$$\rho_1 v_3 = \sqrt{2\rho_1 (p_1 - p_3)} . \quad (6)$$

The mass flow rate through the orifices, denoted by $\dot{m}_{13}$, equals $\rho_1 v_3 A_v$. There is usually some narrowing or constriction of the jet. This is taken into account by introducing a discharge coefficient C_D . Then

$$\begin{aligned} \dot{m}_{13} &= C_D A_v \sqrt{2g_o \rho_1 (p_1 - p_3)} , & p_1 > p_3 . \\ &= 0 & p_1 < p_3 . \end{aligned} \quad (7)$$

For short circular orifices at atmospheric pressure, the discharge coefficient should be about 0.61 to 0.63.¹⁰ The orifices are plugged at the beginning of the firing cycle, so that gas will not be forced into region 1. So the mass flux is set to zero if $p_1 < p_3$.

Now let M_1 be the mass of the liquid in region 1. By conservation of mass,

$$\frac{dM_1}{dt} = - \dot{m}_{13} . \quad (8)$$

The mass is equal to the density times the volume of region 1. Rearranging eq. (8),

¹⁰W. Kaufman, Fluid Mechanics, McGraw-Hill, New York, 1963.

$$[4] \quad \frac{d\rho_1}{dt} = -\frac{\rho_1}{V_1} \frac{dV_1}{dt} - \frac{\dot{m}_{13}}{V_1} . \quad (9)$$

This equation becomes singular as the volume approaches zero. This problem will be discussed below in the section on the numerical solution of the equations.

The bulk modulus K of a compressible fluid is defined by¹¹

$$\rho_1 \left(\frac{\partial p_1}{\partial \rho_1} \right)_T = K , \quad (10)$$

where the subscript T indicates that the derivative is evaluated with the temperature constant. The liquid is assumed to be isothermal. The bulk modulus does vary with pressure. For lack of better information, we assume a simple linear form

$$K = K_1 + K_2 p_1 . \quad (11)$$

Combining eq. (10) and (11), and solving for p_1 ,

$$p_1 = [(k\rho_1)^{K_2} - K_1]/K_2 , \quad (12)$$

where k is a constant. Let ρ_0 be the density at $p=0$. Usually the density is known at $p = 1$ atm., but compared to gun pressure ranges 1 atm. is essentially zero. Then solving for k and substituting into eq. (12)

$$p_1 = \frac{K_1}{K_2} \left[\left(\frac{\rho_1}{\rho_0} \right)^{K_2} - 1 \right] . \quad (13)$$

¹¹R.W. Fox and A.T. McDonald, Introduction to Fluid Mechanics, 2nd ed., John Wiley and Sons, NY, 1978.

Taking derivatives,

$$\frac{dp_1}{dt} = \frac{K_1}{\rho_1} \left(\frac{\rho_1}{\rho_o} \right)^{K_2} \frac{d\rho_1}{dt} \quad (14)$$

and combining eq. (11) and (13) this can be rewritten as

$$\frac{dp_1}{dt} = \frac{K}{\rho_1} \frac{d\rho_1}{dt} . \quad (15)$$

This can be expressed in terms of the speed of sound in the liquid c_1 , which is given by¹²

$$c_1 = \sqrt{g_o \left(\frac{\partial p_1}{\partial \rho_1} \right)_s} \quad (16)$$

or

$$c = \sqrt{g_o K / \rho_1} . \quad (17)$$

Then eq. (15) becomes

$$[5] \quad \frac{dp_1}{dt} = \frac{c_1^2}{g_o} \frac{d\rho_1}{dt} . \quad (18)$$

Now consider the combustion chamber. By analogy with eq. [1],

¹²W. Band, Introduction to Mathematical Physics, D. Van Nostrand Company, Princeton, NJ., 1960.

$$[6] \quad \frac{dv_3}{dt} = v_{ps} A_3 . \quad (19)$$

The equation for conservation of mass is

$$- \frac{dM_3}{dt} = \dot{m}_{13} - \dot{m}_{34} , \quad (20)$$

where $\dot{m}_{34}$ is the mass flux from region 3 to region 4. It follows that

$$[7] \quad \frac{d\rho_3}{dt} = - \frac{\rho_3}{v_3} \frac{dv_3}{dt} + \frac{\dot{m}_{13} - \dot{m}_{34}}{v_3} . \quad (21)$$

Finally, we need an equation for the pressure in region 3. This will be based on the Noble-Abel equation of state⁸

$$p_3 = \rho_3 RT_3 / W(1 - \rho_3 b) , \quad (22)$$

where T_3 is the temperature in region 3, R is the universal gas constant, W is the molecular weight of the gas, and b is the covolume. This can also be written as

$$p_3 = \rho_3 (\gamma - 1) c_v T_3 / (1 - \rho_3 b) , \quad (23)$$

where c_v is the specific heat at constant volume and γ is the specific heat ratio c_p/c_v . It will again be useful to determine the speed of sound⁸

$$c_3 = \sqrt{g_o \left(\frac{\partial p_3}{\partial \rho_3} \right)_s} \quad (24)$$

where s is the entropy. Taking the partial derivative of eq. (23), after some algebra

$$\left(\frac{\partial p_3}{\partial \rho_3}\right)_s = \frac{\gamma p_3}{\rho_3(1 - b\rho_3)} \quad (25)$$

where we have used the fact that¹³

$$\left(\frac{\partial T_3}{\partial \rho_3}\right)_s = \frac{(\gamma - 1)T_3}{\rho_3(1 - \rho_3 b)} . \quad (26)$$

Combining eq. (24) and (25) results in

$$c_3 = \sqrt{\frac{g_o \gamma p_3}{\rho_3(1 - \rho_3 b)}} . \quad (27)$$

The energy equation for a homogeneous gas can be written as¹⁴

$$\rho_3 c_p \frac{dT_3}{dt} = \left(\frac{\partial \ln \hat{V}_3}{\partial \ln T_3}\right)_{p_3} \frac{\partial \rho_3}{\partial t} + S_3 \quad (28)$$

where the spatial terms and the viscosity have been ignored. The quantity $\hat{V} = 1/\rho_3$. Using the Noble-Abel equation,

$$\left(\frac{\partial \ln \hat{V}_3}{\partial \ln T_3}\right)_{p_3} = 1 - b\rho_3 , \quad (29)$$

¹³G.N. Lewis and M. Randall, Thermodynamics, McGraw-Hill, New York, 1961.

¹⁴R.B. Bird and W.E. Stewart, Transport Phenomena, John Wiley and Sons, New York, 1960.

and eq. (28) becomes

$$\rho_3 c_p \frac{\partial T_3}{\partial t} = (1 - b\rho_3) \frac{d\rho_3}{dt} + S_3 . \quad (30)$$

The source term S_3 is due to the energy release when the liquid combusts. In general,

$$S_3 = - \sum h_i R_i M_i \quad (31)$$

where h_i is the enthalpy of the quantity i , R_i is the rate of production of the quantity i , and M_i is the mass of the quantity i . The rate of production of gas in region 3 is $\dot{m}_{13}/V_3$, since the liquid combusts instantaneously when it enters the combustion chamber. The outflow is irrelevant since it does not cause a change in enthalpy.

Again from the Noble-Abel equation,

$$\rho_3 c_p \frac{dT_3}{dt} = \frac{\gamma}{\gamma - 1} \left[(1 - b\rho_3) \frac{dp_3}{dt} - \frac{p_3}{\rho_3} \frac{d\rho_3}{dt} \right] . \quad (32)$$

Substituting into eq. (28) and doing the algebra

$$[8] \quad \frac{dp_3}{dt} = \frac{c_3^2}{g_0} \frac{d\rho_3}{dt} + \frac{\dot{m}_{13}(h_1 - h_3)(\gamma - 1)}{V_3 - bM_3} \quad \dot{m}_{34} > 0 . \quad (33)$$

Normally, gas will flow from the combustion chamber into the gun tube. But if the gas flow from region 3 to region 4 ($\dot{m}_{34}$) is negative, there will be an additional source term. In this case

$$[8] \quad \frac{dp_3}{dt} = \frac{c_3^2}{g_0} \frac{dp_3}{dt} + \frac{\dot{m}_{13}(h_1 - h_3)(\gamma - 1)}{v_3 - bM_3} \quad \dot{m}_{34} < 0$$

$$- \frac{\dot{m}_{34}(h_4 - h_3)(\gamma - 1)}{v_3 - bM_3} . \quad (34)$$

The enthalpy of the liquid is given by

$$h_1 = e_1 + p_1/\rho_1 , \quad (35)$$

where e_1 is the chemical energy of the liquid. This is obtained from closed bomb tests. The enthalpy of the gas is given by

$$h_3 = c_v T_3 + p_3/\rho_3 = c_p T_3 + bp_3 . \quad (36)$$

Finally, we consider the gun tube (region 4). The volume has the standard equation

$$[9] \quad \frac{dv_4}{dt} = v_{pj} A_4 , \quad (37)$$

where v_{pj} is the velocity of the projectile and A_4 is the area of the gun tube. To model this as a lumped parameter region, we assume a Lagrange pressure distribution.⁸ That is, the density is constant with respect to space. Assuming that the gas velocity at the gun tube entrance is zero, it follows that the gas velocity is a linear function of distance. Since there is a mass flow into the gun tube, this is not strictly correct. However, the derivation with a velocity at the entrance is much more complicated, and the standard Lagrange distribution is used as a first approximation. This leads to

$$p(x) = p_R + (p_R - p_{RS}) \frac{M_4}{2M_{pj}} \left[1 - \left(\frac{x}{x_R} \right)^2 \right] \quad (38)$$

where x_R is the distance from the tube entrance to the base of the projectile. Integrating over the tube length,

$$p_4 = p_R \left(1 + \frac{M_4}{3M_{pj}} \right) - p_{RS} \frac{M_4}{3M_{pj}} \quad (39)$$

where p_4 is the average pressure in the tube. This can be rearranged as

$$p_R = \frac{p_4 + p_{RS} \frac{M_4}{(3M_{pj})}}{1 + \frac{M_4}{(3M_{pj})}} \quad p_R > p_{RS} \quad (40)$$

where p_R is the pressure at the right end of the gun tube (base of the projectile), M_4 is the mass of the gas in the tube, M_{pj} is the mass of the projectile, and p_{RS} is the resistance pressure. The latter is an input parameter, which takes into account the shot start engraving force and frictional forces between the projectile and the bore. The pressure at the gun tube entrance is

$$p_L = p_R \left(1 + \frac{M_4}{2M_{pj}} \right) - p_{RS} \frac{M_4}{2M_{pj}} \quad p_R > p_{RS} \quad (41)$$

The above two equations assume that the projectile has started to move, creating a pressure differential. If the projectile has not moved, then region 4 is treated as just an extension of region 3, that is,

$$p_4 = p_R = p_L = p_3 \quad (42)$$

Given the pressure on the projectile, the acceleration equation is

$$\begin{aligned}
 [10] \quad \frac{dv_{pj}}{dt} &= (P_R - P_{RS}) A_4 g_o / M_{pj} & P_R > P_{RS} & \quad (43) \\
 &= 0 & P_R < P_{RS} & .
 \end{aligned}$$

The projectile travel S_{pj} is then given by

$$[11] \quad \frac{dS_{pj}}{dt} = v_{pj} . \quad (44)$$

The final two differential equations are exactly analogous to region 3. That is,

$$[12] \quad \frac{d\rho_4}{dt} = - \frac{\rho_4}{v_4} \frac{dv_4}{dt} + \frac{\dot{m}_{34}}{v_4} \quad (45)$$

where ρ_4 is the density of the gas in region 4, and

$$[13] \quad \frac{dp_4}{dt} = \frac{c_4^2}{g_o} \frac{d\rho_4}{dt} + \frac{\dot{m}_{34}(h_3 - h_4)(\gamma - 1)}{v_4 - bM_4} \quad \dot{m}_{34} > 0 \quad (46)$$

$$\begin{aligned}
 &= \frac{c_4^2}{g_o} \frac{d\rho_4}{dt} & \dot{m}_{34} < 0
 \end{aligned}$$

where $\dot{m}_{34}$ is the mass flux into region 4, given by

$$\begin{aligned}
 \dot{m}_{34} &= C_D' A_4 \sqrt{2g_o \rho_3 (P_3 - P_4)} & P_3 > P_4 & \quad (47) \\
 &= - C_D' A_4 \sqrt{2g_o \rho_4 (P_4 - P_3)} & P_3 < P_4 & .
 \end{aligned}$$

The speed of sound in region 4 is given by

$$c_4 = \sqrt{\frac{g_o \gamma p_4}{\rho_4 (1 - b \rho_4)}} \quad (48)$$

IV. VENT OPTIONS

The model described above has a simple vent option. The vent area between the liquid chamber and the combustion chamber is fixed, and equals the total area of the holes drilled in the piston. Three vent options are included in the code, where the constant vent area is a special case of option 1. For each option, the input and the vent area calculation is in a separate subroutine, and other options can be added easily.

A. VENT 1

A table of vent areas is read in as a function of piston travel. Linear interpolation is used to determine the vent area for any given piston travel. The case of constant vent area is a special case of this option.

B. VENT 2

A standard concept in interior ballistics is that of the optimum (constant pressure) gun. That is, for a given gun design, we want to know the maximum possible performance (muzzle velocity) for a given limit on the breech pressure.² There can also be an acceleration limit on the projectile (base pressure). For a lumped parameter solid propellant gun, this is fairly straightforward. These models usually assume a Lagrange pressure distribution or a similar fixed pressure distribution. There is a known relation between the breech pressure and the pressure at the base of the projectile. Usually, the shot start pressure is chosen as equal to the desired base pressure, so the projectile does not move until the desired pressure is reached. The burning rate for the propellant is adjusted so as

to reach the desired maximum breech (base) pressure and remain at this level until propellant burnout.

For a liquid propellant gun, the relation between the breech pressure and the base pressure is not known analytically, because of the added complication of the piston motion. Also, the burning rate cannot be controlled directly, since this depends on the mass flux into the combustion chamber. What can be controlled is the vent area.

Our scheme assumes that there is a limit both on the breech pressure and the base pressure (projectile acceleration). The input parameters are AVMIN = initial vent area = minimum vent area, AVMAX = maximum vent area, and ACS = maximum acceleration (kilo-g). The desired base pressure is

$$P_D = M_{pj} (.098146) ACS/A_4 - P_{RS} \quad (49)$$

where the number .098146 is a conversion constant. Then we define

$$RATIO = (P_D - P_R)/P_D \quad (50)$$

and let

$$A_v (new) = A_v (old) (1 + AK * RATIO) \quad (51)$$

where AK is a proportionality constant (usually about one). However, the new vent area is overridden by AVMIN and AXMAX.

In practice, the vent area stays at AVMIN until the desired base pressure has been achieved. The projectile then starts moving, and the base pressure falls. The vent area then increases over several time steps to maintain the base pressure. There is a delay in increasing the vent area and a further delay until the pressure increase in the combustion chamber affects the pressure distribution in the gun tube. So the base pressure

falls and then increases again. AVMAX is normally chosen by trial and error so that the breech pressure does not exceed a desired limit. Once AVMAX is reached, the breech and base pressures again fall off.

There appears to be no way to implement exactly a constant pressure algorithm for the regenerative gun without major modifications in the piston motion algorithm. The above algorithm does give an approximation to the maximum performance possible for given restrictions on the breech pressure and the base pressure.

C. VENT 3

Recent regenerative guns have been designed with an annular piston (see fig. 2). The piston has a circular hole in the center around a central rod or bolt. The fuel is stored between the bolt and the piston. The bolt remains fixed as the piston moves. The motion of the piston opens a wider annular gap, and fuel is forced between the piston and the bolt.

We assume that the bolt is made of frustrums of cones. Let x_i be the distance from the combustion chamber end of the bolt to the junction between piece $i-1$ and i . Then the volume of the bolt is

$$V_b = \sum_{i=2}^N \frac{\pi}{3} (x_i - x_{i-1}) (r_i^2 + r_i r_{i-1} + r_{i-1}^2) . \quad (52)$$

Again we assume that the piston has zero thickness. Then the volume of the liquid is

$$V_l = \pi r_L^2 (x_N - x_1) - V_b \quad (53)$$

$$= \sum_{i=2}^N \pi (x_i - x_{i-1}) \left[r_L^2 - \frac{1}{3} (r_i^2 + r_i r_{i-1} + r_{i-1}^2) \right]$$

where r_L is the radius of the liquid chamber and $N-1$ is the number of pieces in the bolt.

The required information to determine the geometry is the x_i and the r_i values. In practice, we often want to specify the total liquid volume and the vent areas for parametric studies. So the actual input used is a table of distances and vent areas, as well as the volume and area of the liquid chamber, and the area of the hole in the piston. The radii and then the volume of the chamber can be computed. By equation (53), the volume V_1 is directly proportional to the distances x_i . So the x_i are scaled to give the desired V_1 . If the dimensions of an actual gun are used, where the input liquid volume matches the input dimensions, no adjustment is made.

There are several changes necessary in the previous governing equations. Let the piston travel satisfy the relation $x_{i-1} < S_{ps} < x_i$. The radius of the rod at this point can be found by linear interpolation

$$r = r_{i-1} + \frac{(S_{ps} - x_{i-1})}{(x_i - x_{i-1})} (r_i - r_{i-1}) . \quad (54)$$

Taking the derivative,

$$\frac{dr}{dt} = v_{ps} \frac{(r_i - r_{i-1})}{(x_i - x_{i-1})} . \quad (55)$$

Now the volume of the liquid reservoir is given by

$$V_1 = V_{10} - \pi r_L^2 (S_{ps} - x_1) + \frac{\pi}{3} (S_{ps} - x_{i-1}) (r^2 + r r_{i-1} + r_{i-1}^2) \quad (56)$$

$$+ \sum_{j=2}^{i-1} \frac{\pi}{3} (x_j - x_{j-1}) (r_j^2 + r_j r_{j-1} + r_{j-1}^2)$$

or taking derivatives

$$\begin{aligned} \frac{dv_1}{dt} = & - \pi r_L^2 \frac{ds_{ps}}{dt} + \frac{\pi}{3} \frac{ds_{ps}}{dt} (r^2 + r r_{i-1} + r_{i-1}^2) \\ & + \frac{\pi}{3} (s_{ps} - x_{i-1}) (2r \frac{dr}{dt} + r_{i-1} \frac{dr}{dt}) . \end{aligned} \quad (57)$$

Rearranging this,

$$\begin{aligned} [1] \quad \frac{dv_1}{dt} = & - v_{ps} A_1 + \frac{\pi}{3} \left[v_{ps} (r^2 + r r_{i-1} + r_{i-1}^2) \right. \\ & \left. + (s_{ps} - x_{i-1}) (2r + r_{i-1}) \frac{dr}{dt} \right] . \end{aligned} \quad (58)$$

Similarly,

$$\begin{aligned} [6] \quad \frac{dv_3}{dt} = & v_{ps} A_3 - \frac{\pi}{3} \left[v_{ps} (r^2 + r r_{i-1} + r_{i-1}^2) \right. \\ & \left. + (s_{ps} - x_{i-1}) (2r + r_{i-1}) \frac{dr}{dt} \right] . \end{aligned} \quad (59)$$

The piston acceleration is given by

$$[2] \quad \frac{dv_{ps}}{dt} = \frac{g_o}{M_{ps}} [p_3 (A_3 - A_h) - p_1 (A_1 - A_h)] \quad (60)$$

where A_h is the area of the hole in the piston. The acceleration on the piston no longer depends on the vent area. The vent area itself is given by

$$A_v(S_{ps}) = A_h - A_b(S_{ps}). \quad (61)$$

This is used to compute the mass flux $\dot{m}_{13}$. The other governing equations are unchanged.

V. DROPLET BURNING OPTIONS

So far we have assumed that the liquid combusts instantaneously upon entering the combustion chamber. There is some evidence, however, that liquid accumulates in the combustion chamber. To see what effect this may have on the gun performance, simple approximations for the formation and combustion of droplets in the combustion chamber are considered.

The behavior of the liquid as it enters the combustion chamber is very complicated. We will assume that the liquid instantaneously forms droplets of a fixed size. The droplets will then combust at some given rate. The initial size of the droplets is an input parameter.

In the above equations, we included the possibility that gas could flow from the gun tube back into the combustion chamber. In practice, this occurs only rarely, and the amounts involved are very small. Since the equations below are already very complicated, an additional assumption is made that the mass flux from the combustion chamber to the gun tube is positive. This eliminates some of the algebra, and has no noticeable effect on the results.

A. DROP 1

The liquid combusts instantaneously as it enters the combustion chamber, releasing all of its chemical energy. This is the option derived above.

B. DROP 2

Gough⁵ has implemented a simple droplet combustion scheme. The droplets have a fixed size at all times, and combustion simply reduces the number of drops. The effect of droplet accumulation may be considered, without implementing a whole distribution of droplet sizes. We will derive the appropriate equations for this scheme in our lumped parameter model.

Let M_{L3} be the liquid mass in region 3, V_{L3} be the liquid volume, M_{G3} be the gas mass, and V_{G3} be the gas volume. Then

$$\rho_{L3} = M_{L3}/V_{L3} \quad (62)$$

and

$$\rho_{G3} = M_{G3}/V_{G3} \quad (63)$$

where ρ_{L3} is the density of the liquid and ρ_{G3} is the density of the gas. Define the porosity

$$\epsilon_3 = V_{G3}/V_3 \quad (64)$$

Then

$$\rho_3 = M_3/V_3 \quad (65)$$

$$= (1 - \epsilon_3) \rho_{L3} + \epsilon_3 \rho_{G3} \quad .$$

Following eq. (17), the speed of sound in the liquid is

$$c_{L3} = \sqrt{g_0 K / \rho_{L3}} \quad (66)$$

and following eq. (27) the speed of sound in the gas is

$$c_{G3} = \sqrt{\frac{g_o \gamma p_3}{\rho_{G3} (1 - b \rho_{G3})}} \quad (67)$$

The liquid is still considered to be isothermal, so the internal energy does not change. The heat transfer to the liquid is ignored because of the complexity of including this effect. The enthalpy of the liquid is

$$h_{L3} = e_1 + p_3 / \rho_{L3} \quad (68)$$

where e_1 is the chemical energy of the liquid. Let $\dot{m}_3$ be the rate at which the liquid in region 3 is combusting and forming the final gas products.

The thirteen equations derived in Section III are the same except for the energy equations [8] and [13]. To derive the new equations, we need some preliminary results. Consider the mass conservation equations

$$\begin{aligned} \frac{dM_{L3}}{dt} &= \frac{d}{dt} [\rho_{L3} (1 - \epsilon_3) V_3] \\ &= \dot{m}_{13} - \frac{M_{L3}}{M_3} \dot{m}_{34} - \dot{m}_3 \end{aligned} \quad (69)$$

and

$$\begin{aligned} \frac{dM_{G3}}{dt} &= \frac{d}{dt} [\rho_{G3} \epsilon_3 V_3] \\ &= \dot{m}_3 - \frac{M_{G3}}{M_3} \dot{m}_{34} \end{aligned} \quad (70)$$

Expanding the equations,

$$\frac{d\rho_{L3}}{dt} (1 - \epsilon_3) V_3 - \rho_{L3} V_3 \frac{d\epsilon_3}{dt} + \rho_{L3} (1 - \epsilon_3) \frac{dV_3}{dt} \quad (71)$$

$$= \dot{m}_{13} - \frac{M_{L3}}{M_3} \dot{m}_{34} - \dot{m}_3$$

$$\frac{d\rho_{G3}}{dt} \epsilon_3 V_3 + \rho_{G3} V_3 \frac{d\epsilon_3}{dt} + \rho_{G3} \epsilon_3 \frac{dV_3}{dt} \quad (72)$$

$$= \dot{m}_3 - \frac{M_{G3}}{M_3} \dot{m}_{34} .$$

Combining the two equations,

$$\frac{d\rho_{L3}}{dt} \frac{(1 - \epsilon_3)}{\rho_{L3}} + \frac{d\rho_{G3}}{dt} \frac{\epsilon_3}{\rho_{G3}} + \frac{1}{V_3} \frac{dV_3}{dt} \quad (73)$$

$$= \frac{1}{\rho_{L3} V_3} [\dot{m}_{13} - \frac{M_{L3}}{M_3} \dot{m}_{34} - \dot{m}_3] + \frac{1}{\rho_{G3} V_3} [\dot{m}_3 - \frac{M_{G3}}{M_3} \dot{m}_{34}] .$$

Now consider the pressure equations. Assume that the gas and liquid pressures in the region are identical. The liquid pressure equation, following eq. (18), is

$$\frac{dp_3}{dt} = \frac{c_{L3}^2}{g_o} \frac{d\rho_{L3}}{dt} \quad (74)$$

and the gas phase equation, following eq. (33), is

$$\frac{dp_3}{dt} = \frac{c_{G3}^2}{g_o} \frac{d\rho_{G3}}{dt} + \frac{\dot{m}_3(h_{L3} - h_{G3})(\gamma - 1)}{v_{G3} - bM_{G3}} \quad (75)$$

Note the gas phase equation is no longer affected directly by the liquid injection into the chamber, but by the rate at which the liquid is turned into gas. Now we define the speed of sound in the mixture by the equation

$$\frac{1}{\rho_3 c_3^2} = \frac{\epsilon_3}{\rho_{G3} c_{G3}^2} + \frac{(1 - \epsilon_3)}{\rho_{L3} c_{L3}^2} \quad (76)$$

or

$$c_3 = \sqrt{\frac{1}{\rho_3} \left[\frac{1}{\epsilon_3/(\rho_{G3} c_{G3}^2) + (1 - \epsilon_3)/(\rho_{L3} c_{L3}^2)} \right]} \quad (77)$$

Combining eq. (74) and (75), and using eq. (76), the result is

$$\begin{aligned} [8] \quad \frac{dp_3}{dt} = \frac{\rho_3 c_3^2}{g_o v_3} & \left\{ \frac{dv_3}{dt} + \frac{\dot{m}_{13}}{\rho_{L3}} \right. \\ & \left. + \frac{\dot{m}_3}{\rho_{G3}} \left[1 - \frac{\rho_{G3}}{\rho_{L3}} + \frac{g_o (h_{L3} - h_{G3})(\gamma - 1)}{c_{G3}^2 (1 - b\rho_{G3})} \right] - \frac{\dot{m}_{34}}{\rho_3} \right\}. \end{aligned} \quad (78)$$

Now consider region 4. The mass conservation equations are

$$\frac{dM_{L4}}{dt} = \frac{M_{L3}}{M_3} \dot{m}_{34} - \dot{m}_4 \quad (79)$$

$$\frac{dM_{G4}}{dt} = \frac{M_{G3}}{M_3} \dot{m}_{34} + \dot{m}_4 \quad (80)$$

or expanding as before

$$\frac{d\rho_{L4}}{dt} (1 - \epsilon_4) V_4 - \rho_{L4} V_4 \frac{d\epsilon_4}{dt} \quad (81)$$

$$+ \rho_{L4} (1 - \epsilon_4) \frac{dV_4}{dt} = \frac{M_{L3}}{M_3} \dot{m}_{34} - \dot{m}_4$$

$$\frac{d\rho_{G4}}{dt} \epsilon_4 V_4 + \rho_{G4} V_4 \frac{d\epsilon_4}{dt} + \rho_{G4} \epsilon_4 \frac{dV_4}{dt} = \frac{M_{G3}}{M_3} \dot{m}_{34} + \dot{m}_4 \quad (82)$$

Again we assume that the gas and liquid pressures in the region are identical. Then the pressure equations are

$$\frac{dp_4}{dt} = \frac{c_{L4}^2}{g_o} \frac{d\rho_{L4}}{dt} \quad (83)$$

and

$$\begin{aligned} \frac{dp_4}{dt} = & \frac{c_{G4}^2}{g_o} \frac{d\rho_{G4}}{dt} + \frac{\dot{m}_4 (h_{L4} - h_{G4})(\gamma - 1)}{V_{G4} - bM_{G4}} \\ & + \frac{M_{G3}}{M_3} \frac{\dot{m}_{34} (h_{G3} - h_{G4})(\gamma - 1)}{V_{G4} - bM_{G4}} \end{aligned} \quad (84)$$

Note that the mixture in region 3 is assumed to be homogeneous, and the fluid that flows into region 4 has the same porosity as the fluid in region 3. In general, region 4 has a different porosity. So the gas phase

pressure equation for region 4 has to include the effect of that portion of the mixture in region 3 that is gas. Combining the equations as before

$$\begin{aligned}
 [13] \quad \frac{dp_4}{dt} = \frac{\rho_4 c_4^2}{g_o v_4} \left\{ - \frac{dv_4}{dt} + \frac{\dot{m}_4}{\rho_{G4}} \left[1 - \frac{\rho_{G4}}{\rho_{L4}} + \frac{g_o (h_{L4} - h_{G4})(\gamma - 1)}{c_{G4}^2 (1 - b\rho_{G4})} \right] \right. \\
 \left. + \frac{\dot{m}_{34}}{\rho_{G4} M_3} \left[M_{G3} + M_{L3} \frac{\rho_{G4}}{\rho_{L4}} + \frac{g_o M_{G3} (h_{L3} - h_{L4})(\gamma - 1)}{c_{G4}^2 (1 - b\rho_{G4})} \right] \right\}. \quad (85)
 \end{aligned}$$

To complete the system, equations are required to determine the liquid density and mass in the regions. The corresponding gas quantities can be easily derived. The liquid pressure equations (74) and (83) are rewritten as

$$[14] \quad \frac{d\rho_{L3}}{dt} = \frac{g_o}{c_{L3}^2} \frac{dp_3}{dt} \quad (86)$$

and

$$[16] \quad \frac{d\rho_{L3}}{dt} = \frac{g_o}{c_{L4}^2} \frac{dp_4}{dt}. \quad (87)$$

The mass conservation equations for the liquid are written as

$$[15] \quad \frac{dM_{L3}}{dt} = \dot{m}_{13} - \frac{M_{L3}}{M_3} \dot{m}_{34} - \dot{m}_3 \quad (88)$$

and

$$[17] \quad \frac{dM_{L4}}{dt} = \frac{M_{L3}}{M_3} \dot{m}_{34} - \dot{m}_4 . \quad (89)$$

To close the system, we need information on the rate at which the liquid droplets are combusting. The rate of surface regression is assumed to be of the form

$$\text{rate of surface regression} = A p^B . \quad (90)$$

Liquid propellant burning rates have been measured by McBratney.^{15 16} The rate of burning

$$\dot{m}_3 = \rho_{L3} S A p_3^B , \quad (91)$$

where S is the total surface area of the droplets in a region. All the droplets are assumed to have a constant diameter d .

The surface area of a single drop is given by

$$S_D = \pi d^2 . \quad (92)$$

and the volume of a single drop by

$$V_D = \frac{\pi}{6} d^3 . \quad (93)$$

¹⁵W.F. McBratney, "Windowed Chamber Investigation of the Burning Rate of Liquid Monopropellants for Guns," ARBRL-MR-03018, April 1980.

¹⁶W.F. McBratney, "Burning Rate Data, LPG 1845," ARBRL-MR-03128, August 1981.

If N_D is the total number of drops in region 3, then

$$N_D = V_{L3}/V_D . \quad (94)$$

So the total surface area in the region

$$S = 6V_{L3}/d \quad (95)$$

and eq. (91) can be written as

$$\dot{m}_3 = \rho_{L3} V_{L3} \frac{6}{d} A p_3^B \quad (96)$$

or

$$\dot{m}_3 = M_{L3} \frac{6}{d} A p_3^B . \quad (97)$$

For region 4, the pressure is no longer constant over the region, but follows the Lagrange pressure distribution. But this would be quite complicated to keep track of, and very little liquid goes into region 4 for most problems. So the combustion rate is assumed to depend on the average pressure P_4 , and

$$\dot{m}_4 = M_{L4} \frac{6}{d} A p_4^B . \quad (98)$$

C. DROP 3

The above representation assumes that all the droplets remain the same size at all locations and times. In practice, some distribution of droplets will exist as a function of space and time. In this section, we present a slight generalization of the above model.

The drops still form instantaneously as the fluid enters the combustion chamber, and all the droplets are initially the same size. However, the droplets will shrink as they burn. They will be represented by an approximation to a probability distribution. One advantage is that different probability distributions can be easily implemented using the formalism developed below. So alternate theories of droplet formation and combustion can easily be added.

A standard procedure is to define a probability distribution function $f(r)$ = the probable number of droplets with radius between r and $r + dr$.¹⁷ For our purposes it is more convenient to use the mass of the droplets rather than the number of droplets. So define $M(r)$ = the mass of the droplets in region 3 with diameter between r and $r + dr$. Since this is a lumped parameter region, there is no space dependency. Then let $\dot{m}(r)$ be the rate of consumption of drops with radius r , or

$$\dot{m}(r) = M(r) \frac{3}{r} A p_3^B . \quad (99)$$

Then we have the partial differential equation

$$\frac{\partial M(r)}{\partial t} = - \frac{M(r)}{M_3} \dot{m}_{34} - \dot{m}(r) + \frac{\partial M(r)}{\partial r} \frac{\partial r}{\partial t} . \quad (100)$$

¹⁷F.A. Williams, "Progress in Spray-Combustion Analysis," in The Eighth International Combustion Symposium, Williams and Wilkins Co., Baltimore, MD, 1962.

The first term is the loss term to region 4, the second term is the loss term to the gas phase, and the last term is the loss to smaller drops. There is also an input boundary condition for $r = \text{initial radius of the droplets}$ and an output boundary condition at $r = 0$.

Rather than solve the above partial differential equation, the distribution is discretized to obtain a set of ordinary differential equations. To be consistent with the previous notation, the diameter rather than the radius of the droplets will be used. More or less arbitrarily, the distribution is split into ten classes. Let d_{init} = the initial diameter of the droplets and $d_{\text{inc}} = d_{\text{init}}/10$ be the difference in diameter of the ten droplet classes. Then define $M_{L3}(i)$ = the mass of the droplets with diameter between $d_{\text{init}} - (i)d_{\text{inc}}$ and $d_{\text{init}} - (i+1)d_{\text{inc}}$. Then let $d_i = (1.05 - 0.1i)d_{\text{init}}$ be the working diameter for each class of droplets. That is, for purposes of obtaining burning rates, assume that this is the diameter of all droplets in the class. Then

$$\dot{m}_3(i) = M_{L3}(i) \frac{6}{d_i} A p_3^B \quad (101)$$

is the mass burning rate for each class, and

$$\dot{m}_3 = \sum_{i=1}^{10} \dot{m}_3(i) \quad (102)$$

is the total mass burning rate.

To derive the governing ordinary differential equations, assume that in any class, the mass is evenly distributed among the possible diameters. This will contradict the assumption above that all the droplets have an average diameter. But in the limit of infinitely many classes, it will be equivalent. Looking at the first class,

$$\Delta M_{L3}(1) = \dot{m}_{13} \Delta t - \frac{M_{L3}(1)}{M_3} \dot{m}_{34} \Delta t - \dot{m}_3(1) \Delta t - M_{L3}(1) \Delta d/d_{inc} \quad (103)$$

or the change in mass of class 1 = influx into region 3 - efflux to region 4 - loss to the gas phase - loss to the next smaller class. Since we assume that the mass is equally distributed over the possible diameters,

$\Delta d/d_{inc}$ of the mass will shrink into the next smaller class. Taking the limit

$$[18] \quad \frac{dM_{L3}(1)}{dt} = \dot{m}_{13} - \frac{M_{L3}(1)}{M_3} \dot{m}_{34} - \dot{m}_3(1) - \frac{M_{L3}(1)}{d_{inc}} 2Ap_3^B. \quad (104)$$

Note that the rate of change of the diameter = twice the surface regression rate = $2Ap_3^B$. Since we assume that all the droplets initially start in class one, all the influx from region 1 goes into class 1. For the other classes, the equations are

$$[19-27] \quad \frac{dM_{L3}(i)}{dt} = - \frac{M_{L3}(i)}{M_3} \dot{m}_{34} - \dot{m}_3(i) + \frac{M_{L3}(i-1) - M_{L3}(i)}{d_{inc}} 2Ap_3^B, \quad i = 2 \dots 10. \quad (105)$$

All the earlier equations [1] to [17] from the above section are the same, except for the new definition of $\dot{m}_3$ and the corresponding definition of $\dot{m}_4$. One of the equations in (105) is in fact redundant, since $M_{L3} = M_{L3}(1) + \dots + M_{L3}(10)$. The extra equation is included for the sake of simplicity.

The equations for region 4 are similar, except that there is no source term from region 1. The loss terms for region 3 are the source terms for

region 4. That is,

$$[28-37] \quad \frac{dM_{L4}(i)}{dt} = \frac{M_{L3}(i)}{M_3} \dot{m}_{34} - \dot{m}_4(i) \quad (106)$$

$$- \frac{M_{L4}(i)}{d_{inc}} 2Ap_4^B \quad i = 1 \dots 10.$$

VI. MASS AND ENERGY BALANCE

As a check on the equations derived, both mass and energy should be conserved. The mass balance is straightforward.

$$M_T = M_1 + M_3 + M_4 \quad (107)$$

where M_T is the total mass of the propellant and primer. This should be constant throughout the integration.

The energy balance is more complicated. The energy loss through friction is quite small, and is ignored. The code presently does not include heat loss or air resistance. The liquid is considered to be an isothermal fluid, and its internal energy e is just the chemical energy of the propellant. The total energy of the liquid is

$$E_l = e_l(M_1 + M_{L3} + M_{L4}) . \quad (108)$$

The internal energy of the gas in region 3 is given by

$$e_3 = c_v T_3 \quad (109)$$

and the total gas energy is

$$E_3 = c_v T_3 M_{G3} . \quad (110)$$

The average internal energy of the gas in region 4 is given by

$$e_4 = \frac{1}{x_R} \int_0^{x_R} c_v T_4 dx \quad (111)$$

or

$$e_4 = \frac{1}{x_R} \int_0^{x_R} \frac{p(x)(1 - b\rho_4)}{\rho_4(\gamma - 1)} dx \quad (112)$$

by the Noble-Abel equation. Using eq. (38) for the pressure function, this can be integrated to yield

$$e_4 = \frac{(1 - b\rho_4)}{\rho_4(\gamma - 1)} p_4 \quad (113)$$

and

$$E_4 = e_4 M_{G4} . \quad (114)$$

The kinetic energy of the piston is given by

$$EK_{ps} = 0.5 M_{ps} v_{ps}^2 / g_o \quad (115)$$

and the kinetic energy of the projectile by

$$EK_{pj} = 0.5 M_{pj} v_{pj}^2 / g_o . \quad (116)$$

By our assumptions, only the fluid in region 4 is moving. The kinetic energy of the gas is

$$EK_{G4} = \int_0^{x_R} 0.5 \rho_{G4} A_4 v^2 / g_o dx . \quad (117)$$

We ignore drag and assume that the liquid has the same velocity as the gas. Then the kinetic energy of the liquid is

$$EK_{L4} = \int_0^{x_R} 0.5 \rho_{L4} A_4 v^2 / g_o dx . \quad (118)$$

The Lagrange pressure distribution implies a linear velocity profile with the gas velocity at the tube entrance equal to zero. This implies that

$$v = v_{pj} x/x_R . \quad (119)$$

Substituting and integrating

$$EK_{G4} = 0.5 M_{G4} v_{pj}^2 x_R / (3g_o) \quad (120)$$

and

$$EK_{L4} = 0.5 M_{L4} v_{pj}^2 x_R / (3g_o) . \quad (121)$$

Then the total energy of the system is

$$E_T = E_1 + E_3 + E_4 + EK_{ps} + EK_{pj} + EK_{G4} + EK_{L4} . \quad (122)$$

This should be constant throughout the integration.

VII. NUMERICAL METHOD

The ordinary differential equations derived above are solved using the code EPISODE.¹⁸ This is a robust and efficient code for the solution of ordinary differential equations. EPISODE proper consists of the subroutines DRIVE to SING (see Appendix A).

Only two changes have been made in EPISODE proper. The first concerns the error control. Originally this could be either a relative or an absolute error control. A relative error control can be wasteful if some of the quantities being integrated become negligibly small. However, an absolute error control is inaccurate if the quantities integrated vary widely in magnitude.

A solution to this problem was developed during work on integrating chemical kinetics networks, where the concentrations of species differ by many orders of magnitude.¹⁹ This is a semi-relative error control. If the quantities are above some cutoff value (SREC) a relative error control is used. If they are below SREC, an absolute error control is used. While an absolute error control would be adequate for the simpler equations now being considered, the semi-relative error control has been left in the code. SREC has normally been chosen as 10^{-6} .

The other change is at the end of the routine TSTEP, which actually takes the integration steps. Several options have been included here. First, diagnostic printouts of the quantities of interest may be made after

¹⁸A.C. Hindmarsh and G.D. Byrne, "EPISODE: An Effective Package for the Integration of Systems of Ordinary Differential Equations," UCID-30112-Rev.1, Lawrence Livermore Laboratory, 1977.

¹⁹T.P. Coffee, "A Computer Code for the Solution of the Equations Governing a Laminar, Premixed, One-Dimensional Flame," ARBRL-MR-03165, April 1982.

each time step (KWRITE=1). Second, if the optimum gun option is being used (VENT 2), the vent area is updated at the end of each time step. Finally, some information about regions 1 and 4 must be included. Eq. [4] for the liquid density becomes singular as V_1 approaches zero. So when V_1 becomes some fraction VPER of the initial volume, the region is closed. That is, region 1 is ignored in the integration from then on. This will lead to a small error, due to the liquid propellant left in region 1 when the region is closed. However, VPER is an input parameter, and by trial and error can be chosen small enough that the error is negligible. If V_1 ever becomes negative, the step is rejected, and the integration starts again with a smaller time step. There is a similar problem with region 4, since the projectile may start at the throat, and V_4 will be zero. So region 4 starts out as closed. When the projectile is at least .01 cm. down the gun tube, the region is opened. Before this, region 4 is considered as an extension of region 3.

There are actually two integration routines included in EPISODE. The first is the Adams method, suitable for non-stiff problems (METH=1). The second is the backward differentiation method, suitable for stiff problems (METH=2). We have normally used METH=2. However, the governing equations are not very stiff, and METH=1 can also be used. The run times are about equivalent for the two methods.

There are also several methods for the solution of the nonlinear system of equations required at each step of the integration. We have used the Newton method with an internally computed finite difference approximation to the Jacobian. So the only subroutine that needs to be supplied by the user is DIFFUN. Given a set of values for the unknowns, DIFFUN computes the time derivatives of the unknowns.

Subroutine DIFFUN in this code only calls one of three subroutines (FDROP1, FDROP2, or FDROP3). These routines correspond to the instantaneous burning option, the fixed drop size option, and the shrinking drop size option. Since the governing equations are different, it is easier to set these up as separate subroutines.

The rest of the routines have to do primarily with input and output. The main routine RLGD read in the input data, sets the initial conditions, calls the integrator, and writes the main output file.

To make it easier to add or change options, some of the input is in separate subroutines. For instance, subroutines VENT1, VENT2, and VENT3 read in the required data for the three vent options. These routines also compute the vent area for a given piston travel. So if a new vent option is desired, it is only necessary to add a new subroutine and change the few lines that call the VENT subroutines.

Similarly, DROP2 and DROP3 read in the input parameters for the droplet options. PISRES reads in the piston resistance as a function of piston travel. DIS1 and DIS2 read in the discharge coefficients. These can be either a function of piston travel or a function of liquid pressure. PROJRES reads in the projectile resistance pressure as a function of projectile travel. Subroutine PRIM2 is a simple primer option. That is, the primer may be included as droplets in region 3 to follow the initial behavior of the system in more detail.

Subroutines CAPTION and OUT control the output files. Subroutine OUTGRA creates a graphics file, so that any of the quantities computed may later be graphed.

VIII. NUMERICAL COMPARISONS

As a check, we will compare our code with the numerical code developed by Gough.⁵ The sample problem used is discussed in ref. [6]. This is a 25 mm. gun with a constant vent area. The input data required is reproduced in Table 1.

Table 1. Baseline Input Data for Test Problems.

fuel side area of piston	13.00 cm ²
combustion side area of piston	15.48 cm ²
gun tube area	4.91 cm ²
initial fuel reservoir volume	96.00 cm ³
initial combustion chamber volume	35.40 cm ³
initial projectile offset in tube	1.27 cm
projectile travel	213.36 cm
projectile weight	194.40 gm
piston weight	480.82 gm
bore discharge coefficient	.95
piston discharge coefficient	.58
shot start pressure	36.00 MPa
liquid density (1 atm.)	1.23 gm/cm
bulk modulus	2413.10 MPa
liquid chemical energy	3330.90 joules/gm
ratio of specific heats	1.26
molecular weight of combustion gases	19.01 gm/mole
covolume	1.26 cm ³ /gm
initial liquid pressure	.10 MPa
initial gas pressure	81.00 MPa

The answer given here for the Gough code are slightly different than those reported in ref. 6. The Gough code controls the integration time step size based on the grid in the gun tube. The time step must be small enough not to violate the Courant-Friedrich-Levy condition.²⁰ The maximum number of grid points and the minimum grid spacing in the gun tube are input conditions. A smaller grid size than was used in ref. 6 was required to obtain convergence.

²⁰P.J. Roache, Computational Fluid Dynamics, Hermosa Publishers, 1972.

The results for these computations are given in Table 2. The agreement between the two codes is not very good.

Table 2. Comparison - Baseline Input Parameters.

	Gough	Coffee
Muzzle velocity (m/s)	1097	1161
Max. liquid pressure (MPa)	289	351
Max. combustion pressure (MPa)	231	277
Time until projectile exit (ms)	3.7	3.2
Computer time (s)	20.6	1.2

This can be partially explained by considering the way the Gough code computes the mass flux between the liquid chamber and the combustion chamber. If the combustion chamber pressure is higher, gas can flow into the liquid chamber. Since the liquid chamber is one phase, the code converts this into liquid, which defies conventional physics. The new code normally does not allow flow into the liquid chamber. However, it can be run with this option. The results are in Table 3.

Table 3. Comparison - Back Flow into Liquid Chamber.

	Gough	Coffee
Muzzle velocity (m/s)	1097	1140
Max. liquid pressure (MPa)	289	316
Max. combustion pressure (MPa)	231	251
Time until projectile exit (ms)	3.7	3.4
Computer time (s)	20.6	0.7

The agreement is better, but there are still noticeable differences. Another possible cause for error is the time step control in the Gough code, which is based solely on the conditions in the gun tube. However, in the present problem we are starting with a large pressure difference between the combustion chamber and the liquid reservoir. The time step must be reduced to resolve the interaction between these two chambers and the piston movement.

To check this hypothesis, the initial pressure conditions were changed to initial liquid pressure = 9 MPa and initial gas pressure = 10 MPa. This is less of a strain on the error control. As Table 3 shows, the two codes now give almost identical answers.

Table 4. Comparison - Initial Gas Pressure = 10 MPa.

	Gough	Coffee
Muzzle velocity (m/s)	1114	1133
Max. liquid pressure (MPa)	311	310
Max. combustion pressure (MPa)	247	247
Time until projectile exit (ms)	4.2	4.2
Computer time (s)	23.5	2.5

The only noticeable difference is in the muzzle velocity. The difference is in the expected direction. That is, the new code assumes a Lagrange pressure distribution in the gun tube. So any changes in pressure in the combustion chamber instantaneously effect the projectile, no matter how far down the gun tube it is located. The Gough code uses partial differential equations to describe the gun tube, and actually follows the pressure waves as they propagate. So there is a delay between the pressure rise in the combustion chamber and the corresponding pressure rise at the base of the projectile. This results in a slightly lower muzzle velocity.

Fig. 3 compares the combustion chamber pressures as a function of time, and fig. 4 compares the projectile velocities. These curves confirm the above analysis. The agreement is excellent at early times. But as the projectile moves down the gun tube, differences appear and become greater with time.

It is useful to know if these differences can become important. So we took the previous problem and increased the liquid reservoir volume to 300 cm and the projectile travel to 1000 cm. Results are given in Table 5 and in figs. 5 and 6. There is in fact a fairly large difference in muzzle velocities.

Table 5. Comparison - Long Gun Tube.

	Gough	Coffee
Muzzle velocity (m/s)	1556	1685
Max. liquid pressure (MPa)	264	261
Max. combustion pressure (MPa)	205	203
Time until projectile exit (ms)	10.0	10.2
Computer time (s)	32.8	2.4

In conclusion, the Gough code may be inaccurate if the mechanisms controlling the time step occur in the lumped parameter regions. The new code, however, will overpredict the muzzle velocity for a long gun tube. It may also be inaccurate for a high performance (large muzzle velocity) gun, if the projectile moves fast enough that the pressure increase in the throat of the gun tube cannot catch the projectile. The new code runs about 10 to 15 times faster than the Gough code. Several other comparisons have been made, and the above conclusions still hold.

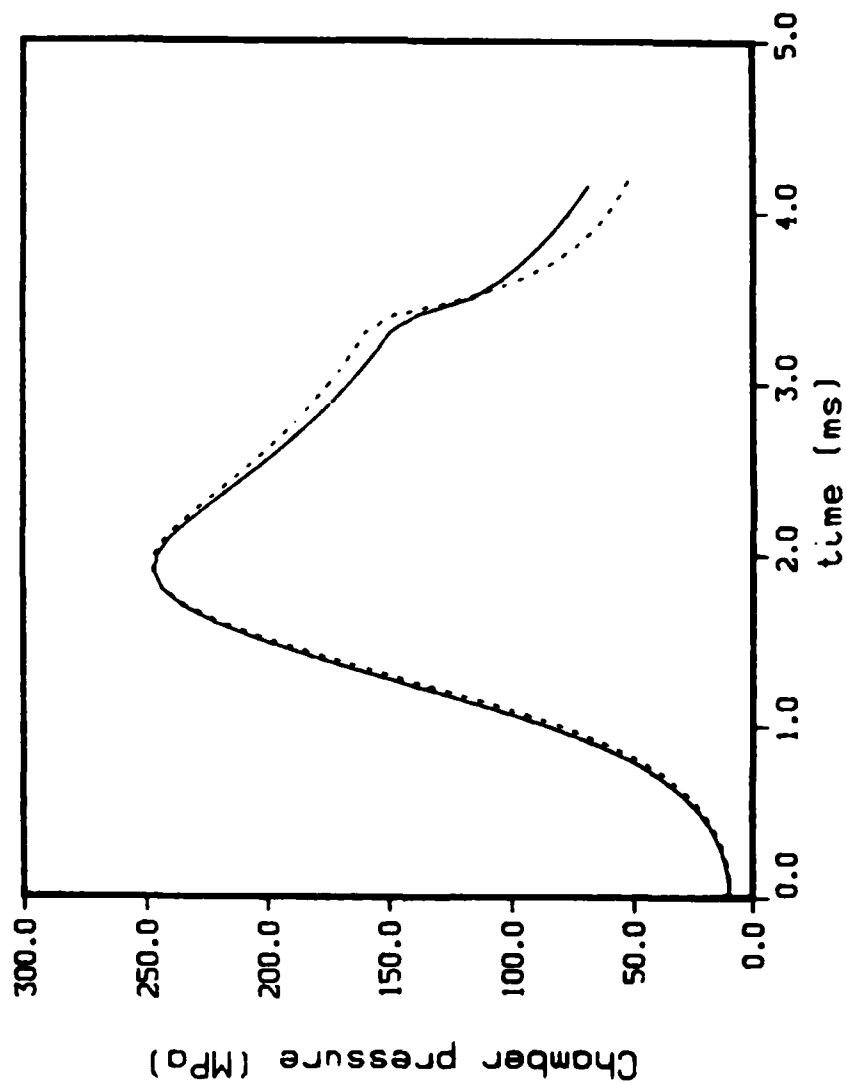


Figure 3. Baseline 25 mm Gun - Instantaneous Combustion - Initial Chamber Pressure = 10 MPa. - Chamber Pressures. Gough model (line); Gough model (dot)

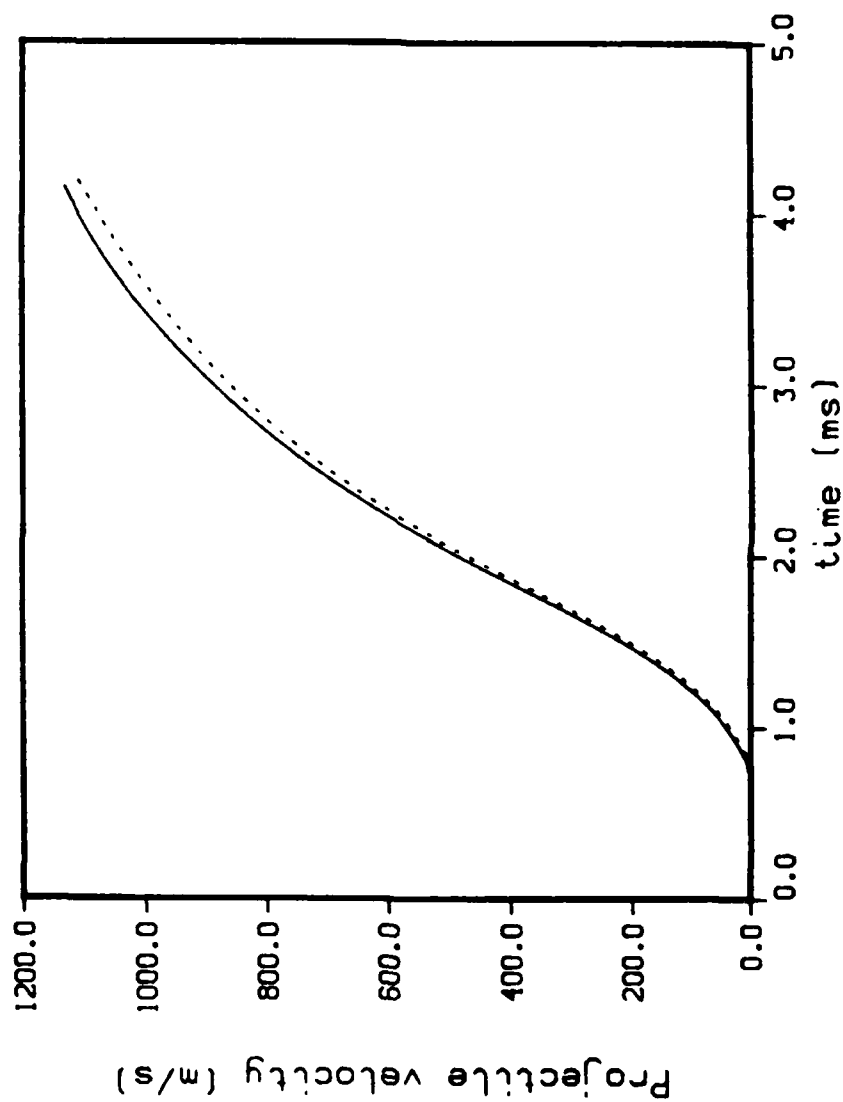


Figure 4. Baseline 25 mm Gun - Instantaneous Combustion - Initial Chamber Pressure = 10 MPa. - Projectile Velocities.
Coffee model (line); Gough model (dot)

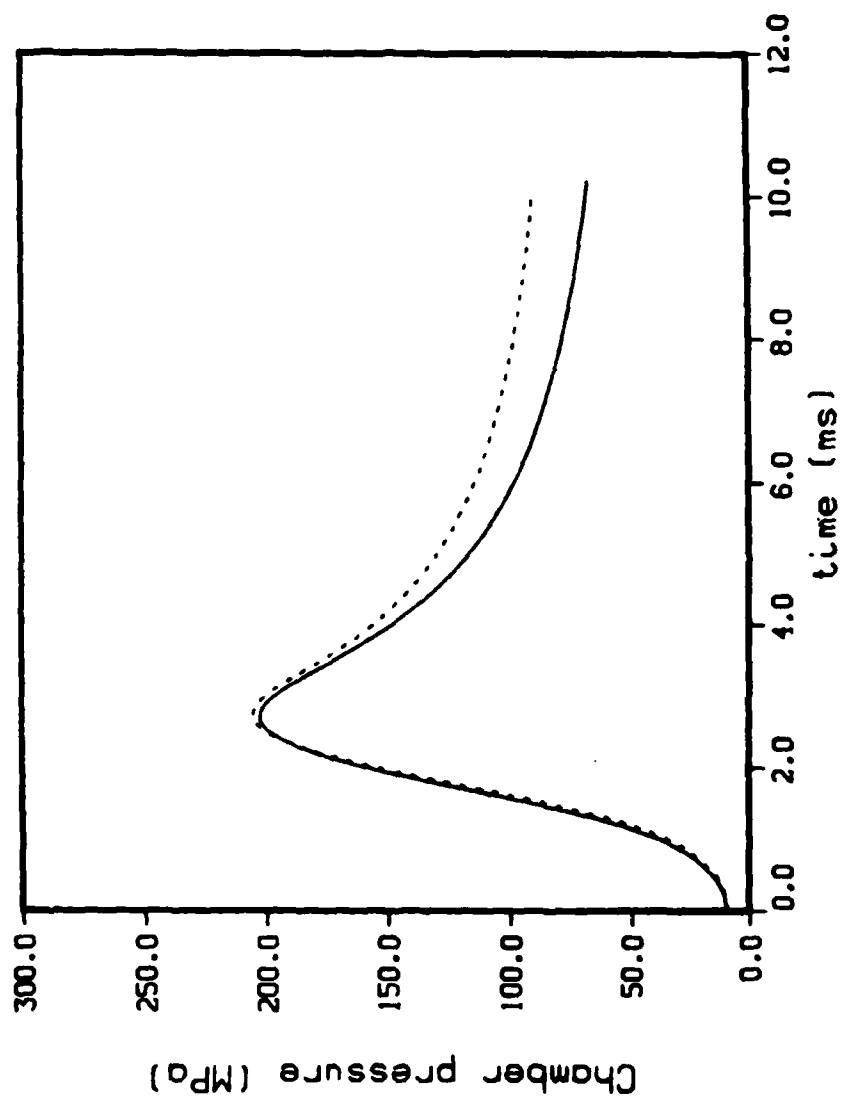


Figure 5. Long 25 mm Gun - Instantaneous Combustion - Initial Chamber Pressure = 10 MPa. - Chamber Pressures.
Coffee model (line); Gough model (dot)

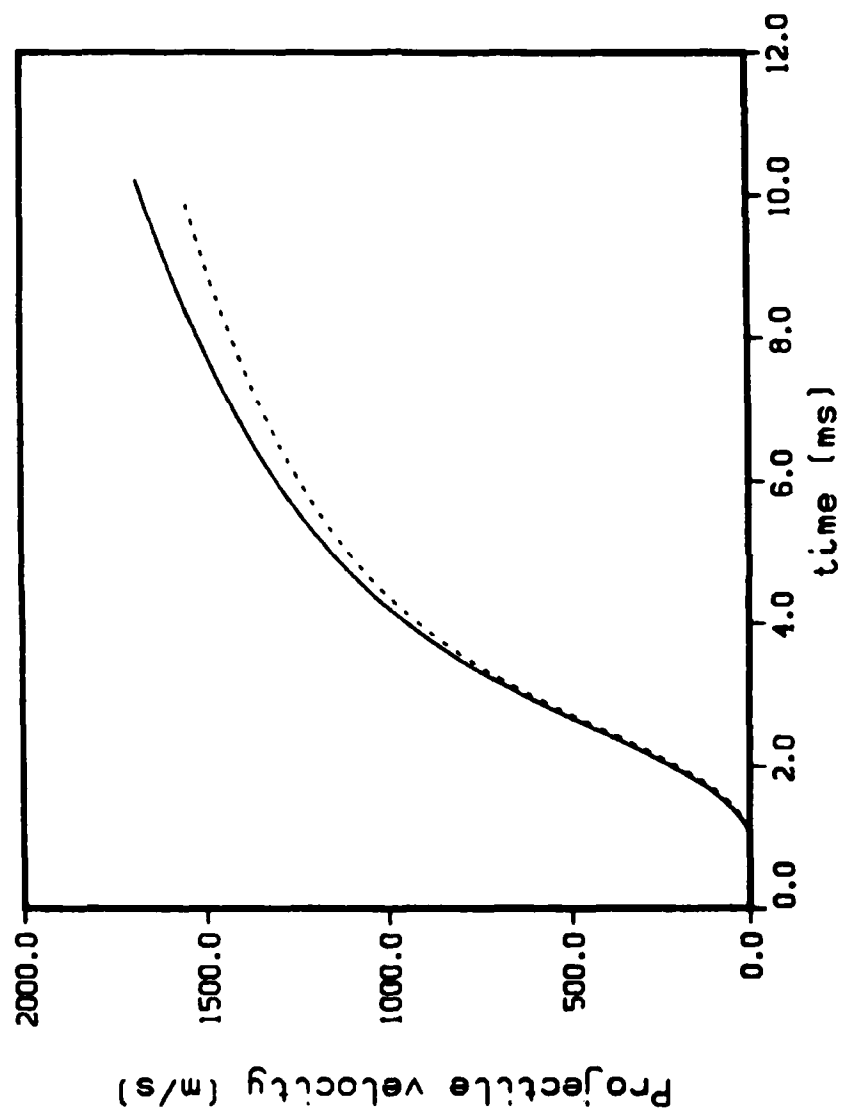


Figure 6. Long 25 mm Gun - Instantaneous Combustion - Initial Chamber Pressure = 10 MPa. - Projectile Velocities.
Coffee model (line); Gough model (dot)

REFERENCES

1. W.F. Morrison, J.D. Knapton, and G. Klingenberg, "Liquid Propellants for Gun Applications," Proceedings of the Seventh International Symposium on Ballistics, The Hague, The Netherlands, April 1983.
2. P.G. Baer, "Practical Interior Ballistic Analysis of Guns," Progress in Astronautics and Aeronautics, Interior Ballistics of Guns, (H. Krier and M. Summerfield, ed.), Vol. 66, 1979.
3. G. Pagan and D.C.A. Izod, "Regenerative Liquid Propellant Gun Modelling," Proceedings of the Seventh International Symposium on Ballistics, The Hague, The Netherlands, April 1983.
4. P.G. Cushman, "Regenerative Liquid Propellant Gun Simulation User's Manual," GE Report 84-POD-004, December 1983.
5. P.S. Gough, "A Model of the Interior Ballistics of Hybrid Liquid-Propellant Guns," Final Report, Contract DAAK11-82-C-0154, PGA-TR-83-4, September 1983.
6. W.F. Morrison, M.J. Bulman, P.G. Baer, and C.F. Banz, "The Interior Ballistics of Regenerative Liquid Propellant Guns," 1984 JANNAF Propulsion Meeting, New Orleans, LA, CPIA Publication 390, February 1984.
7. P. G. Baer, C.F. Banz, I.W. May and W.F. Morrison, "A Propulsion System Comparison Study for the 120-MM Anti-Armor Cannon," 1984 JANNAF Propulsion Meeting, New Orleans, LA, CPIA Publication 390, February 1984.
8. J. Corner, Theory of the Interior Ballistics of Guns, Wiley, New York, 1950.
9. W.F. Hughes and J.A. Brighton, Fluid Dynamics, Schaum's Outline Series, McGraw-Hill, New York, 1967.
10. W. Kaufman, Fluid Mechanics, McGraw-Hill, New York, 1963.
11. R.W. Fox and A.T. McDonald, Introduction to Fluid Mechanics, 2nd ed., John Wiley and Sons, NY, 1978.
12. W. Band, Introduction to Mathematical Physics, D. Van Nostrand Company, Princeton, NJ, 1960.
13. G.N. Lewis and M. Randall, Thermodynamics, McGraw-Hill, New York, 1961.
14. R.B. Bird, W.E. Stewart, and R.B. Bird, Transport Phenomena, John Wiley and Sons, New York, 1960.
15. W.F. McBratney, "Windowed Chamber Investigation of the Burning Rate of Liquid Monopropellants for Guns," ARBRL-MR-03018, April 1980.

16. W.F. McBratney, "Burning Rate Data, LPG 1845," ARBRL-MR- 03128, August 1981.
17. F.A. Williams, "Progress in Spray-Combustion Analysis," in The Eighth International Combustion Symposium, Williams and Wilkins Co., Baltimore, MD, 1962.
18. A.C. Hindmarsh and G.D. Byrne, "EPISODE: An Effective Package for the Integration of Systems of Ordinary Differential Equations," UCID-30112-Rev.1, Lawrence Livermore Laboratory, 1977.
19. T.P. Coffee, "A Computer Code for the Solution of the Equations Governing a Laminar, Premixed, One-Dimensional Flame," ARBRL-MR-03165, April 1982.
20. P.J. Roache, Computational Fluid Dynamics, Hermosa Publishers, 1972.

APPENDIX A

A listing of the computer code follows. Routines RLGD to PEDERV have been written for the regenerative liquid gun application. Routines DRIVE to SING comprise the code EDISODE.

61

```

40      WRITE(6,115)DA,A4
        WRITE(6,120)DC34
        READ(5,10)PJMT
        READ(5,10)PSWT
        WRITE(6,140)PJMT,PSWT
        READ(5,15)MRACK
        IF (MRACK.EQ.1)WRITE(6,142)MRACK
        IF (MRACK.EQ.0)WRITE(6,143)MRACK
        READ(5,10)VII,V31
        VOL=VII*V31
        WRITE(6,150)VII,V31,VOL
        READ(5,10)VPER
        WRITE(6,152)VPER
        READ(5,10)A1,A3
        WRITE(6,155)A1,A3
        ROPE=SOPT(4.0+A3/PI)
        READ(5,2)TVENT
        WRITE(6,158)TVENT

70      C VENT AREA TABLE
        IF (TVENT(1).EQ.10HVENT1) )CALL VENT1(1)
        C CONSTANT ACCELERATION OPTION - CHANGE VENT AREA BY 'MAG(C,
        IF (TVENT(1).EQ.10HVENT2) )CALL VENT2(1)
        C CENTRAL ROD OR BOLT - INFINITELY THIN PISTON
        IF (TVENT(1).EQ.10HVENT3) )CALL VENT3(1)
        RSS=ROPE/PSWTRAV
        WRITE(6,159)ROPE,RSS

75      C ESTIMATE LENGTH OF COMBUSTOR BY PASKO FORMULA.
        C 2.75*LENGTH LIQUID CHAMBER + LENGTH COMBUSTION CHAMBER
        C + PISTON THICKNESS (5.4 CM) + END PLATE (10.2 CM).
        CLEN=2.25*PSWTRAV*V31/A3+5.4+10.2
        WRITE(6,161)CLEN
        C PISTON RESISTANCE TABLE.
        CALL PISRES(1,0.0,PSRS)
        C DISCHARGE COEFFICIENT TABLE
        READ(5,2)TDIS
        WRITE(6,158)TDIS
        C DISCHARGE COEFFICIENT AS A FUNCTION OF PISTON TRAVEL.
        IF (TDIS(1).EQ.10DIS1) )CALL DIS1(1)
        C DISCHARGE COEFFICIENT AS A FUNCTION OF LIQUID PRESSURE.
        IF (TDIS(1).EQ.10DIS2) )CALL DIS2(1)
        C PROJECTILE RESISTANCE TABLE.
        CALL PROJRES(1,0.0,PJRS)
        READ(5,10)PHIT,RK1,RK2
        WRITE(6,165)PHIT,RK1,RK2
        READ(5,10)ENER,GAM
        WRITE(6,200)ENER,GAM
        READ(5,10)SIGMA
        WRITE(6,202)SIGMA
        READ(5,10)WGC,COV
        WRITE(6,205)WGC,COV
        READ(5,10)PLI,PGI
        WRITE(6,170)PLI,PGI
        C UNIVERSAL GAS CONSTANT.
        PU=9.31R
        C SPECIFIC GAS CONSTANT.
        PS=RU/RG
        C SPECIFIC HEAT OF THE GAS (CONSTANT VOLUME).

```


02/22/95 13.15.44

FTN 4.8-601

76/74 OPT=1 ROUND=0.0/ TRACE

PROGRAM BLGN

```

202 FORMAT(5X,'SURFACE TENSION =',1PE12.4)
205 FORMAT(5X,'VOL WT GAS =',1PE12.4,'5X','COVOLUME =',1PE12.4)
C *****
C INITIAL CONDITIONS.
C Y(1) IS THE LIQUID VOLUME.
  Y(1)=V11
C Y(2) IS THE PISTON VELOCITY.
  Y(2)=0.0
C Y(3) IS THE PISTON TRAVEL.
  Y(3)=0.0
C Y(4) IS THE LIQUID DENSITY AT THE GIVEN PRESSURE.
  IF(RM2.F0.0)Y(4)=RM1*EXP(PLI/RM1)
  IF(PK2.NE.0.0)Y(4)=RM1*((PK2*PLI/RK1+1.0)**(1.0/3RK2))
C Y(5) IS THE LIQUID PRESSURE.
  Y(5)=PLI
C Y(6) IS THE COMBUSTION CHAMBER VOLUME.
  Y(6)=V31
C Y(7) IS THE COMBUSTION CHAMBER DENSITY.
  RM3=PGI/ENER*(GAM-1.0)*COV*PGI
  Y(7)=RM3
C Y(8) IS THE COMBUSTION CHAMBER PRESSURE.
  Y(8)=PGI
  MOD1=1
  MOD4=1
C Y(9) IS THE TUBE VOLUME.
  IF(OFFSET.LT.0.0)MOD4=0
  Y(9)=OFFSET*AA
C Y(10) IS THE PROJECTILE VELOCITY
  Y(10)=0.0
C Y(11) IS THE PROJECTILE TRAVEL
  Y(11)=0.0
C Y(12) IS THE TUBE DENSITY
  Y(12)=RM3
C Y(13) IS THE TUBE PRESSURE
  Y(13)=PGI
C THIS SECTION ONLY FOR DROPLET MODEL.
C Y(14) IS THE LIQUID DENSITY IN REGION 3.
  Y(14)=Y(4)
C Y(15) IS THE LIQUID MASS IN REGION 3.
  Y(15)=0.0
C Y(16) IS THE LIQUID DENSITY IN REGION 4.
  Y(16)=Y(4)
C Y(17) IS THE LIQUID MASS IN REGION 4.
  Y(17)=0.0
C THIS SECTION ONLY FOR SHRINKING DROPLET MODEL.
C Y(18) TO Y(27) ARE THE PARTITIONED LIQUID MASS IN REGION 3.
C Y(18) TO Y(37) ARE THE PARTITIONED LIQUID MASS IN REGION 4.
C THESE ARE THE MASSES OF THE DROPLETS WITH DIAMETER DDOR(I).
  DO 205 I=1A,37
205 Y(11)=0.0
C *****
C IF PRIME OPTION 2, CHANGE THE INITIAL CONDITIONS.
  PRIMER=V31*RM3*Y(9)*RM3
  IF(TDPRIM(1).EQ.1000)PR2
    )CALL PRIN2(NPRIM,DDOR,PGI,Y)
C *****
C SFT THE INTEGRATOR PARAMETERS.
  IF(TDPRIM(1).EQ.1000)PR1
    )PR=13

```

```

001A10
001A20
001A30
001A40
001A50
001A60
001A70
001A80
001A90
001900
001910
001920
001930
001940
001950
001960
001970
001980
001990
002000
002010
002020
002030
002040
002050
002060
002070
002080
002090
002100
002110
002120
002130
002140
002150
002160
002170
002180
002190
002200
002210
002220
002230
002240
002250
002260
002270
002280
002290
002300
002310
002320
002330
002340
002350
002360
002370

```

02/22/85 13.15.44

FTN 4.8.401

TRACE

74/76

PROGRAM PLGD

210

```

IF (TDRP(1).EQ.10)DRP2      NM=17
IF (TDRP(1).EQ.10)DRP3      NM=37
T0=0.0
TOUT=TIME
TMC=0.0
MO=1.0E-10
JERRP=2
NSTFP=0
WFE=0
NJE=0
NMI=0
INDEX=1
LSKIP=0
LPAGE=0

```

```

DO 300 K=1,10
  RMX(K)=0.0
  CALL DIFFUN(N,0.0,Y,YDOT)
  PRIMER=RM3*RNA
  CHPASS=(RM1*RM3*RNA)/PJMT
  WRITE(6,225)RM1,PRIMER,CHPASS
  FORMAT(1/5X,'CHARGE =',1PE12.4,'5X','PRIMER =',1PE12.4,'5X',
    *,'C/M =',1PE12.4)
  DENS=(RM1*RM3*RNA)/VOL
  WRITE(6,240)DENS
  FORMAT(1/5X,'LOADING DENSITY =',1PE12.4)
  PRINT=RM5SUM
  FINT=ESUM

```

```

C *****
C CALL THE INTEGRATOR.
CALL CAPTION

```

```

CALL OUT
CALL DRIVE(N,T0,M0,Y,TOUT,EPS,IERROR,MF,INDEX)
IF (INDEX.NE.0)STOP
CALL DIFFUN(N,TOUT,Y,YDOT)
TMS=TOUT-1000.
IF (SPJ.GE.TRAVEL)GO TO 500
CALL OUT
IF (MOD1.EQ.0.AND.VPJ.EQ.0.0)GO TO 550
TOUT=TOUT-TINC
GO TO 390

```

```

500 CONTINUE
C FIND THE TIME CORRESPONDING TO THE PROJECTILE LEAVING THE MUZZLE.
TINC=TIME/5.0
TOUT=TOUT-TINC
CALL DRIVE(N,T0,M0,Y,TOUT,EPS,IERROR,MF,INDEX)
CALL DIFFUN(N,TOUT,Y,YDOT)
IF (SPJ.GT.TRAVEL)GO TO 505
TINC=TIME/5.0
TOUT=TOUT-TINC
CALL DRIVE(N,T0,M0,Y,TOUT,EPS,IERROR,MF,INDEX)
CALL DIFFUN(N,TOUT,Y,YDOT)
IF (SPJ.LT.TRAVEL)GO TO 510
TMS=TOUT-1000.
CALL OUT
550 CONTINUE
C WRITE THE MAX VALUES.
C CHANGE MUZZLE VELOCITY TO 4/SEC.

```

```

225
240
245
250
255
260
265
270
275
280
285

```

```

002380
002390
002400
002410
002420
002430
002440
002450
002460
002470
002480
002490
002500
002510
002520
002530
002540
002550
002560
002570
002580
002590
002600
002610
002620
002630
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002900
002910
002920
002930
002940

```

02/22/85 13.15.44

FTN 4.0.001

76/74 NPT=1 MOUND=.../ TOACE

PROGRAM PLGN

```

C CHANGE MASS AND ENERGY ERRORS TO PERCENTAGES.
VM=VPJ/100.
RMAX(6)=RMAX(6)*100.
RMAX(7)=RMAX(7)*100.
290  WRITE(6,590)VM
    WRITE(6,600)RMAX(1)
    WRITE(6,610)RMAX(2)
    WRITE(6,620)RMAX(3)
    WRITE(6,630)RMAX(4)
    WRITE(6,640)RMAX(5)
    WRITE(6,650)RMAX(6)
    WRITE(6,660)RMAX(7)
    FORMAT(1H1,4X,'MUZZLE VEL (M/SEC)  ',F10.1)
    FORMAT(//5X,' MAX P1 (MPA)          ',F10.1)
    FORMAT(//5X,' MAX P3 (MPA)          ',F10.1)
    FORMAT(//5X,' MAX PL (MPA)         ',F10.1)
    FORMAT(//5X,' MAX PH (MPA)         ',F10.1)
    FORMAT(//5X,' MAX ACC (K-G)         ',F10.1)
    FORMAT(//5X,' MAX MASS ERROR       ',F10.2)
    FORMAT(//5X,' MAX ENERGY ERROR   ',F10.2)
    GT=SECOND(CP)
    NT=GT-FT
    WRITE(6,575)HT,NSTEP
    275 FORMAT(//5X,'RUIN TIME =',F12.1,5X,'NSTEP =',I4)
    STOP
    END
300
305
310

```

02/22/85 13.15.44

FTN 4.9-501

74/76 OPT=1 ROUNDO=.../ TRACE

```

1  SURROUTINE VENT1(IISW)
   COMMON/TAB1/G0,GAM,COV,FNFR,OFFSET
   COMMON/TAB2/RK1,RK2,RH1,VII,VPER
   COMMON/TAB3/OC,AVENT,A1,A3,A6,AHOLF,VCOR
   COMMON/TAB4/PSVT,PSTPAV,MOD1,NNHACK,MOD4
   COMMON/TAB5/C3,C4,RMD13,RMD34,RMD3,RMD4,PM1,RM3,RM4,RMSUM,PMINT
   COMMON/TAB6/V1,VPS,SPS,RH1,P1,V3,RH3,P3,V4,VPJ,SPJ,APJ,PM4,P4
   COMMON/TAB7/PJMT,TRAVEL
   COMMON/TAB8/PSRS,PJRS,PL,PR,DC34
   COMMON/TAB9/EL1,EG3,EG4,EKPS,EKPJ,EKG4,FSUM,EINT
   COMMON/TAB10/RH1,WR,RS,CP,CV,TEMP3,TEMP4,HL1,HL3,HL4,H3,H4
   COMMON/TAB11/LSKIP,LPA6F,TMS,RMAX(10)
   COMMON/TAB12/VVENT,NVENT,AVM[V,AVMAX,AP,ACS
   COMMON/TAB13/P1
   COMMON/TAB14/ADR,ADR,RDR
   COMMON/TAB15/CL1,CL3,CG3,CL4,CG4,PMG3,PM13,PMG4,RML4
   COMMON/TAB16/RMG3,RML3,RMG4,RML4,EL3,EL4,EKL4
   COMMON/TAB17/VG3,VL3,VG4,VL4,EP53,EP54
   COMMON/TAB18/DINC,PDDR(10),PML3(10),PMD3(10),PML4(10),PMD4(10)
   COMMON/TAB19/SIGMA,U13,WE
   COMMON/TAB20/WRITE,KWRITE,KOUTD,SPREC,TITLE(R),TVENT(8),TOROP(R),TDIS(R)
   DIMENSION SVT(30),AVT(30)
   C READ IN A TABLE OF VENT OPENINGS.
   C LINEAR INTERPOLATION TO GET VENT OPENING
   C FOR ANY DESIRED PISTON TRAVEL.
   C VENT AREA CHANGES BY "MAGIC" IN PISTON FACT.
   C DOES NOT AFFECT THE LIQUID RESERVOIR VOLUME.
   IF(IISW.FO.2)GO TO 100
   C READ IN THE REQUIRED PARAMETERS.
   READ(5,15)NVENT
   WRITE(6,1014)
   15 FORMAT(1014)
   20 FORMAT(15X,NVENT =,I4/)
   DO 30 I=1,NVENT
   READ(5,25)SVT(I),AVT(I)
   25 FORMAT(1PSE12.4)
   HYD=(A3-AVT(I))/(A1-AVT(I))
   WRITE(6,2R1)SVT(I),AVT(I),HYD
   2R FORMAT(5X,PIS TRAV =,1PE12.4,5X,VENT AREA =,1PE12.4,5X,
   * HYDROLIC DIFF =,1PE12.4)
   30 CONTINUE
   C FIND THE MAX PISTON TRAVEL.
   PSTPAV=V1/A1
   WRITE(6,40)PSTPAV
   40 FORMAT(5X,MAX PISTON TRAVEL =,1PE12.4/)
   SPS=0.0
   100 CONTINUE
   C FIND THE VENT AREA FROM THE TABLE.
   DO 120 I=2,NVENT
   IM=I-1
   IF(SPS.LT.SVT(IM).OR.SPS.GE.SVT(IM))GO TO 115
   DP=(SPS-SVT(IM))/(SVT(I)-SVT(IM))
   AVENT=AVT(IM)+DP*(AVT(I)-AVT(IM))
   115 CONTINUE
   120 CONTINUE
   IF(SPS.GT.SVT(NVENT))AVENT=AVT(NVENT)
   RETURN

```

SUBROUTINE VFNT1 76/76 OPT=1 40IND=0-0/ TPAGE 92/22/85 13.15.44. PAGE 9

003790

END

69

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FTN 4.8-601

TRACE

74/75

SUBROUTINE VENT3

VENT3

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1  SUBROUTINE VENT3(ISW)
   COMMON/TAB1/GO,GAM,COV,ENER,OFFSET
   COMMON/TAB2/RK1,RK2,RH11,V11,VPER
   COMMON/TAB3/DC,AVENT,A1,A3,A4,AHOLE,VCOR
   COMMON/TAB4/PSWT,PSWTRAV,MOD1,WBACK,MOD4
   COMMON/TAB5/C3,C4,RMD13,RMD3,RMD4,RM1,RM3,RM4,RMSUM,PMINT
   COMMON/TAB6/V1,VPS,SPS,RH1,PL,V3,RH3,P3,V4,VPJ,SPJ,APJ,PHA,PA
   COMMON/TAB7/PJMT,TRAVEL
   COMMON/TAB8/PJRS,PJRS,PL,PR,DC34
   COMMON/TAB9/EL1,EG3,EG4,EKPS,EKPJ,EKG4,ESUM,EINT
   COMMON/TAB10/PU,WG,RS,CP,CV,TEMP3,TEMP4,HLL,HLL3,HLL4,H3,H4
   COMMON/TAB11/LSKTP,LPAGE,TMS,RMAX(10)
   COMMON/TAB12/NVENT,NVENT,AVMIN,AVMAX,AK,ACS
   COMMON/TAB13/PI
   COMMON/TAB14/DDR,ADR,BDR
   COMMON/TAB15/CL1,CL3,CG3,CL4,CG4,RMG3,RML3,RMG4,RML4
   COMMON/TAB16/RMG3,RHL3,RMG4,RHL4,FL3,EL4,EKL4
   COMMON/TAB17/VG3,VL3,VG4,VL4,EPS3,EPS4
   COMMON/TAB18/DINC,PDDR(10),PML3(10),PMD4(10),PMD4(10)
   COMMON/TAB19/SIGMA,U13,WE
   COMMON/TAB20/WRITE,KOUTD,SPREC,TITLE(R),TVENT(8),TDROP(8),TDIS(8)
   DIMENSION SVT(30),AVT(30),AROD(30),PROD(30)
   C CENTRAL ROD OR BOLT OPTION.
   C ASSUME INFINITELY THIN PISTON.
   C A1 IS THE AREA OF THE FUEL SIDE (INCLUDING BOLT HOLE).
   C A3 IS THE AREA OF THE COMBUSTION SIDE (INCLUDING BOLT HOLE).
   C PEAD IN THE AREA OF THE BOLT HOLE
   C AND THE TABLE OF VENT AREAS.
   C IF (ISW.EQ.2)GO TO 100
   C READ IN THE REQUIRED PARAMETERS.
   15 FORMAT(10I4)
   WRITE(6,20)NVENT
   20 FORMAT(5X,'NVENT =',I4/)
   DO 30 I=1,NVENT
   READ(5,25)SVT(I),AVT(I)
   25 FORMAT(1P5E12.4)
   WRITE(6,26)SVT(I),AVT(I)
   26 FORMAT(5X,'PISTON TRAV =',1PE12.4,5X,'VENT AREA =',1PE12.4)
   30 CONTINUE
   READ(5,25)AHOLE
   WRITE(6,35)AHOLE
   35 FORMAT(5X,'AREA OF CENTER HOLE =',1PE12.4)
   MYD=(A3-AHOLE)/(A1-AHOLE)
   WRITE(6,38)MYD
   38 FORMAT(5X,'HYDROLOGIC DIFF =',1PE12.4/)
   C COMPUTE THE AREAS OF THE ROD AND THE CORRESPONDING RADII.
   DO 50 I=1,NVENT
   APDD(I)=AHOLE-AVT(I)
   50 PPOR(I)=SQRT(APDD(I)/PI)
   C COMPUTE THE VOLUME OF THE LIQUID RESERVOIR.
   VL=0.0
   P1=SQRT(A1/PI)
   DO 60 I=2,NVENT
   IM=I-1
   60 VL=VL+PI*(SVT(I)-SVT(IM))*P1*(P1-PPOR(IM))*PPOR(IM)/1.0
   * ROR(I)=PPOR(IM)*PPOR(IM)/1.0

```

```

C SCALE THE DISTANCES SO THAT THE LIQUID VOLUME MATCHES
C THE INPUT LIQUID VOLUME (V1).
60 SC=V1/VL
   DO 62 I=1,NVENT
   A2 SVT(I)=SVT(I)*SC
   DO 64 I=1,NVENT
   RVENT=SQRT((AVT(I)-AROD(I))/3.141592654)
   GAP=PVENT-AROD(I)
65 WRITE(6,70)SVT(I),AVT(I),AROD(I),PROD(I),GAP
70 FORMAT(5X,'PIS TRAV =',IPE12.4,'SX',AVT =',IPE12.4,'SX',
   * ,AROD =',IPE12.4,'SX',PROD =',IPE12.4,'SX',GAP =',IPE12.4)
   PSTRAV=SVT(NVENT)
   WRITE(6,75)PSTRAV
75 FORMAT(5X,'MAX PISTON TRAVEL =',IPE12.4)
   SPS=0.0
100 CONTINUE
C FIND THE VENT AREA.
   DO 120 I=2,NVENT
   IM=I-1
   IF(SPS.LT.SVT(IM).OR.SPS.GE.SVT(I))GO TO 115
   PP=(SPS-SVT(IM))/(SVT(I)-SVT(IM))
C INTERPOLATE THE ROD RADIUS.
   RR=PROD(IM)+PP*(PROD(I)-PROD(IM))
   RIM=PROD(IM)
   AR=PI*RR*RR
   AVENT=AMOLE-AR
C FIND THE CORRECTION FOR THE RATE OF CHANGE OF V1 AND V3
C DUE TO THE CENTER ROD.
C DONE BY REPRESENTING VOLUME AS FUEL CHAMBER VOLUME MINUS
C ROD VOLUME AND COMPUTING THE RATE OF CHANGE OF THE ROD VOLUME.
   RRDY=VPS*(PROD(I)-PROD(IM))/(SVT(I)-SVT(IM))
   VCOR=(PI/3.0)*(VPS*(RR*RR*PROD(IM)+RIM*2.0*RR))
   * (SPS-SVT(IM))*PROD(I)+RIM*2.0*RR)
90 115 CONTINUE
120 CONTINUE
   RETURN
   END

```

```

1      SUBROUTINE D90P2
      COMMON/TAB14/DDR,ADR,RDP
      C DROPLET - CONSTANT SIZE.
      C READ IN THE INPUT PARAMETERS.
5      READ(5,10)DDR,ADR,RDP
      10 FORMAT(1P5E12.4)
      WRTF(6,20)DDR,ADR,RDP
      20 FORMAT(/5X,'DDR =',1PE12.4,'SX,ADR =',1PE12.4,'SX,
      * ,RDP =',1PE12.4)
      RETURN
      END
10

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02/22/85 13.15.44

FTN 4.2.401

TRACE

74/76

SUBROUTINE DROP3

OPT=1 ROUND=0.0

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1  SUPROUTINE DROP3
   COMMON/TAB14/DOQ,ADR,BDR
   COMMON/TAB18/DINC,PDDR(10),PWL3(10),PWL4(10),PWL4(10),PWL4(10)
   COMMON/TAB19/SGMA,II,WE
5  C DROPLETS - SHPINK WHILE BURNING.
   C READ IN THE INPUT PARAMETERS.
   READ(5,10)DOQ,ADR,BDR
10  FORMAT(1P5F12.4)
   WRITE(6,20)DOQ,ADR,BDR
20  FORMAT(15X,'DOQ =',1PE12.4,5X,'ADR =',1PE12.4,5X,
   *,'BDR =',1PF12.4)
   I=1
   PDDR(1)=DOQ*0.95
   DINC=DOQ/10.0
   WRITE(6,50)I,PDDR(1)
   DO 30 I=2,10
     IM=I-1
     PDDR(I)=PDDR(IM)-DINC
     WRITE(6,60)I,PDDR(I)
30  CONTINUE
   50  FORMAT(15X,'PDDR',I4,' =',1PE12.4)
   60  FORMAT(15X,'PDDR',I4,' =',1PE12.4)
   RETURN
   END
005290
005290
005300
005310
005320
005330
005340
005350
005360
005370
005380
005390
005400
005410
005420
005430
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005470
005480
005490
005500
005510

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02/22/45 13.15.46

FTN 4.8.4.01

SUBROUTINE PISWFS

74/74

NPT=1 NOUN=000/ TOPCE

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1      SUBROUTINE PISWFS(I5W,SPS,PPS)
      COMMON/TARA/PSWT,PSTHAY,MORI,ACHACK,NDA
      DIMENSION SFRAC(10),SPIS(10),JCS(10)
      IF(I5W.EQ.2)GO TO 100
      READ I5 THE PISTON RESISTANCE.
      READ(5,10)NPIS
      10 FORMAT(10I4)
      WRITE(6,12)NPIS
      12 FORMAT(5X,'NPIS =',4.5X/)
      DO 25 I=1,NPIS
      20 FORMAT(1P10E12.4)
      25 CONTINUE
      C NORMALIZE TO MAX PISTON TRAVEL.
      DO 35 I=1,NPIS
      30 FORMAT(5X,'SFRAC(I)/SFRAC(NPIS))*PSTHAY
      35 CONTINUE
      RETURN
      100 CONTINUE
      C FIND THE PISTON RESISTANCE PRESSURE.
      DO 110 I=2,NPIS
      IM=I-1
      IF(SPS.LT.SPIS(IM).OR.SPS.GE.SPIS(I))GO TO 104
      PP=(SPS-SPIS(IM))/(SPIS(I)-SPIS(IM))
      PPS=PPS(IM)+PP*(PPS(I)-PPS(IM))
      108 CONTINUE
      110 RETURN
      END

```

02/22/85 13.15.44

FTN 4.9.4.01

T6/T6 OPT=1 ROUND=0.0/ TRACE

SUBROUTINE DIS1

```

1  SUBROUTINE DIS1(I)
COMMON/TAB3/OC,AVENT,A1,A3,A4,AMOLF,VCONP
COMMON/TAB4/PSWT,PSTRAV,MOD1,WRACP,MOD4
COMMON/TAB6/V1,VPS,SPS,PHI,PL,V3,PH3,P3,V4,VPJ,SPJ,APJ,PH4,PA
DIMENSION SFRAC(30),SPIS(30),DCF(30)
C DISCHARGE COEFFICIENT AS A FUNCTION OF PISTON TRAVEL.
IF (I5M.EQ.2) GO TO 100
C READ IN THE DISCHARGE COEFFICIENT TABLE.
READ(5,10)NDC
10 FORMAT(10I4)
WRITE(6,12)NDC
12 FORMAT(5X,NDC=,I4.5X/)
DO 25 I=1,NDC
READ(5,20)SFRAC(I),DCF(I)
20 FORMAT(1P10E12.4)
25 CONTINUE
C NORMALIZE TO MAX PISTON TRAVEL.
DO 35 I=1,NDC
SPIS(I)=(SFRAC(I)/SFRAC(NDC))*PSTPAV
WRITE(6,30)SFRAC(I),SPIS(I),DCF(I)
30 FORMAT(5X,IFRAC PIS TRAV =,1PE12.4,SPIS TRAV =,1PE12.4,
.5X,DIS COEFF =,1PE12.4)
35 CONTINUE
RETURN
100 CONTINUE
C FIND THE DISCHARGE COEFFICIENT.
DO 110 I=2,NDC
IM=I-1
IF (SPS-SPIS(IM).OR.SPS.GE.SPIS(IM)) GO TO 108
PA=(SPS-SPIS(IM))/(SPIS(IM)-SPIS(IM))
DC=DCF(IM) + PA*(DCF(I)-DCF(IM))
108 CONTINUE
110 CONTINUE
RETURN
END

```

```

1      SUBROUTINE DISC (ISW)
      COMMON/TAB3/DC,AVENT,A1,A3,A4,ANOLF,VCOR
      COMMON/TAP4/PSWT,PSSTRAV,MND1,VBACK,MND4
      COMMON/TAB6/V1,VPS,SPS,RH1,PL,V3,PM3,P3,V4,VPJ,SPJ,APJ,RM4,PA
5      DIMENSION PLIQ(30),OCF(30)
      C DISCHARGE COEFFICIENT AS A FUNCTION OF LIQUID PRESSURE.
      IF (ISW.F0.2) GO TO 100
      C READ IN THE DISCHARGE COEFFICIENT TABLE.
      READ(5,10)NDC
10     10 FORMAT(10I4)
      WRITE(6,12)NDC
12     FORMAT(5X,'NDC =',I4,5X/)
      DO 25 I=1,NDC
15     READ(5,20)PLIQ(I),OCF(I)
      20 FORMAT(1P10E12.4)
      WRITE(6,30)PLIQ(I),OCF(I)
30     FORMAT(5X,'LIQUID PRESSURE =',1PE12.4,5X,'DIS COEFF =',1PE12.4)
25     CONTINUE
      PMAX=0.0
      RETURN
20     100 CONTINUE
      C FIND THE DISCHARGE COEFFICIENT.
      DO 110 I=2,NDC
      IM=I-1
      IF (PL1,PLIQ(IM),OR,PL1,OCF,PLIQ(I)) GO TO 104
      PP=(PL1-PLIQ(IM))/(PLIQ(I)-PLIQ(IM))
      OCF=OCF(IM) + PP*(OCF(I)-OCF(IM))
25     108 CONTINUE
110     RETURN
      END
30

```

```

1      SUBROUTINE PROJRES(I5W,SPJ,PJRS)
        DIMENSION STR(10),PTR(10)
        IF(I5W.EQ.2)GO TO 100
C      FIND THE PROJECTILE RESISTANCE PRESSURE.
5      READ(S,10)NPROJ
        10 FORMAT(10I4)
        WRITE(6,12)NPROJ
        12 FORMAT(5X,'NPROJ =',I4/)
        DO 25 I=1,NPROJ
10      READ(5,20)STR(I),PTR(I)
        20 FORMAT(10I0E12.4)
        WRITE(6,22)STR(I),PTR(I)
        22 FORMAT(5X,'TRAVEL =',IPE12.4,5X,'RESISTIVE PRESS =',IPE12.4)
        25 CONTINUE
15      RETURN
        100 CONTINUE
C      FIND THE RESISTANCE PRESSURE.
        DO 110 I=2,NPROJ
18      IM=I-1
        IF(SPJ.LT.STR(I-1).OR.SPJ.GT.STR(I))GO TO 100
        PP=(SPJ-STR(IM))/(STR(I)-STR(IM))
        PJRS=PTR(IM) + PP*(PTR(I)-PTR(IM))
100      CONTINUE
110      IF(SPJ.GT.STR(NPROJ))PJRS=0.0
        RETURN
        END
006500
006510
006520
006530
006540
006550
006560
006570
006580
006590
006600
006610
006620
006630
006640
006650
006660
006670
006680
006690
006700
006710
006720
006730
006740
006750
006760

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```

1      SURROUTINE PRIM2(NPRIM,PRIMER,PGI,Y)
      DIMENSION Y(50)
      C PRIMER REGINS AS LIQUID DROPLETS.
      C SET CHAMBER PRESSURE BACK TO ATMOSPHERIC PRESSURE.
      Y(8)=.10135
      Y(13)=.10135
      C SPLIT THE PRIMER UP BETWEEN REGION 3 AND REGION 4.
      V3=Y(6)
      V4=Y(9)
      Y(15)=PRIMER*V3/(V3+V4)
      Y(17)=PRIMER*V4/(V3+V4)
      C SUBTRACT OFF SOME OF THE MASS FOR THE GAS COMPONENT.
      Y(15)=Y(15)*(1.0-.10135/PGI)
      Y(17)=Y(17)*(1.0-.10135/PGI)
      C IF SHRINKING DROPLET OPTION, SET LIQUID INTO DESIRED CLASS.
      I=17*NPRIM
      Y(17+I)=Y(15)
      I=27*NPRIM
      Y(17+I)=Y(17)
      RETURN
      END
20

```



```

1  SUBROUTINE OUT
COMMON/EPCON9/MUSED,NUSED,NSTEP,NFE,NJE,NMI
COMMON/TAB1/GR,GAM,COV,EMER,OFFSET
COMMON/TAB2/PK1,PK2,MH1,MH2,VPER
COMMON/TAB3/DC,AVENT,A1,A3,A4,AHOLE,VCOP
COMMON/TAB4/PSWT,STRAY,MOD1,MACK,MOD4
COMMON/TAB5/C3,C4,RMD13,RMD34,RMD4,RH1,RH3,RH4,RMSUM,PINT
COMMON/TAB6/V1,VPS,SPS,RH1,PI,V3,RH3,P3,V4,VPJ,SPJ,APJ,RH4,PA
COMMON/TAB7/PJNT,TRAVEL
COMMON/TAB8/PSRS,PJRS,PL,PP,DC34
COMMON/TAB9/EL1,EG3,EG4,FKPS,EKPJ,EKG4,FSUM,EINT
COMMON/TAB10/RJ,NG,RS,CP,CV,TEMP3,TEMP4,HL1,HL3,HL4,M3,M4
COMMON/TAB11/LSKIP,LPAGE,TMS,PMAX(10)
COMMON/TAB12/MVENT,NVENT,AVMIN,AVMAX,AK,ACS
COMMON/TAB13/PI
COMMON/TAB14/DDR,ADR,RDR
COMMON/TAB15/CL1,CL3,CG3,CL4,CG4,PMG3,RML3,RMG4,RML4
COMMON/TAB16/PMG3,PHL3,RHG4,PHL4,EL3,EL4,EKL4
COMMON/TAB17/VG3,VL3,VG4,VL4,EPS3,FP54
COMMON/TAB18/DINC,PODR(10),PHL3(10),PMD3(10),PMD4(10)
COMMON/TAB19/SIGMA,U13,WE
COMMON/TABINT/KWRITE,KOUTD,SPEC,TITLE(R),TVENT(R),TDIS(H)
C WRITE OUT THE DATA AT THE END OF EACH TIME STEP.
WRITE(6,510)TMS,P1,P3,PL,P4,PR,SPS,VPS,SPJ,VPJ,APJ
WRITE(7,512)TMS,RH1,RH3,RHG3,RH3,RH4,RHG4,RH4
WRITE(8,510)TMS,V1,VL3,VG3,V3,VL4,VG4,V4,EPS3,EPS4,AVENT
WRITE(9,510)TMS,RH1,RH3,RMG3,RH3,RH4,RHG4,RH4,RMSUM
WRITE(10,510)TMS,RMD13,RMD34,RMD34,PMD4,HL1,HL3,HL4,M4
WRITE(11,510)TMS,CL1,CL3,CG3,C3,CL4,CG4,C4,TEMP3,TEMP4
WRITE(12,510)TMS,EL1,EL3,EG3,EL4,EG4,EKPS,EKPJ,EKL4,EKG4,FSUM
WRITE(13,510)TMS,PHL3(1),I=1,10
WRITE(14,510)TMS,PHL3(1),I=1,10
WRITE(15,510)TMS,PHL4(1),I=1,10
WRITE(16,510)TMS,PHL4(1),I=1,10
WRITE(17,510)TMS,U13,WE,OC
CALL OUTGRA
510 FORMAT(1F11.3)
512 FORMAT(1F11.4)
PMAX(1)=AMAX1(P1,PMAX(1))
PMAX(2)=AMAX1(P3,PMAX(2))
PMAX(3)=AMAX1(PL,PMAX(3))
PMAX(4)=AMAX1(PR,PMAX(4))
PMAX(5)=AMAX1(APJ,PMAX(5))
PMAX(6)=AMAX1(RH1,PMAX(6))
PMAX(7)=AMAX1(RH3,PMAX(7))
LSKIP=LSKIP+1
LPAGE=LPAGE+1
IF (LPAGE.EQ.45)GO TO 550
IF (LSKIP.LT.5)RETURN
LSKIP=0
WRITE(6,525)
WRITE(7,525)
WRITE(8,525)
WRITE(9,525)
WRITE(10,525)
WRITE(11,525)
WRITE(12,525)

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FTM 4.8.501

OPT=1 MOUND=0.0/ TRACE

76/76

SUBROUTINE OUT

007490 -
007900
007910
007920
007930
007940
007950
007960
007970
007980
007990
008000

WRITE (13.525)
WRITE (14.525)
WRITE (15.525)
WRITE (16.525)
WRITE (17.525)
FORMAT (10X)
RETURN
CALL CAPTION
LPAGE=0
LSKIP=0
RETURN
END

40

525

45

550

07/27/85 13.15.46

FTN 4.8.401

TRACF

76/76

SUBROUTINE OUTGPA

```

1  SUBROUTINE OUTGPA
COMMON/EPICOM9/HUSED,NUSED,NSTEP,NFE,NJE,NMI
COMMON/TAR1/G0,GAN,C0V,ENER,OFFSET
COMMON/TAR2/PK1,PK2,RH11,V11,VPER
COMMON/TAR3/OC,AVENT,A1,A3,A4,AHOLF,VCOR
COMMON/TAR4/PSWT,PSRAV,MOD1,MBACK,MOD4
COMMON/TAR5/C7,C4,RMD13,RMD34,RMD3,RMD4,RM1,RM3,RM4,RMSIM,PMINT
COMMON/TAR6/V1,VPS,SPS,RH1,PI,V3,RH3,P3,V4,VPJ,SPJ,APJ,PH4,P4
COMMON/TAR7/PJMT,TRAVEL
COMMON/TAR8/PPSPS,PJRS,PL,PR,DC34
COMMON/TAR9/EL1,EG3,EG4,EKPS,EKPJ,EKG4,ESUM,EINT
COMMON/TAR10/PH,MG,RS,CP,CV,TEMP3,TEMP4,HL1,HL3,HL4,H3,H4
COMMON/TAR11/LSKIP,LPAGE,TMS,RMAX(10)
COMMON/TAR12/MVENT,NVENT,AVMIN,AVMAX,AK,ACS
COMMON/TAR13/PI
COMMON/TAR14/DDR,ADR,RDR
COMMON/TAR15/CL1,CL3,CG3,CL4,CG4,RMG3,RML3,RMG4,RML4
COMMON/TAR16/RMG3,RML3,RMG4,PHL4,EL3,EL4,EKL4
COMMON/TAR17/VG3,VL3,VG4,VL4,EPS3,FPS4
COMMON/TAR18/DINC,PDP(10),PML3(10),PMD3(10),PMD4(10)
COMMON/TAR19/SIGNA,V13,WE
COMMON/TAR20/WRRITE,KOUTD,SPEC,TITLE(8),TVFNT(9),TDROP(8),TDIS(8)
COMMON/TAR21/
DIMENSION COLTIT(5),PV(5),TIM(5),DAY(5)
DATA KOUNT/1/
25  C  CREATE UNFORMATTED GRAPH TRAJECTORY FILE ON TAPE17.
      IF(KOUNT.GT.1)GO TO 100
C  FILE HEADINGS.
      PV(1)=RHPLGN GIIN
      PV(2)=4HCODE
      PV(3)=7HVEPSION
      PV(4)=9H07/24/84
      PV(5)=1H
      CALL DATE(DAY(1))
      CALL CLOCK(TIM(1))
      KOLS=107
      COLS=FLOAT(KOLS)
      DUM=0.0
      WRITE(2)TITLE,(PV(5),J=1,12),DAY,TIM,DUM,COLS,PV,DUM,
      * DUM,DUM,DUM,DUM
      DO 40 I=1,KOLS
      COLMIN=-1.E4
      COLMAX=1.E4
      DO 30 J=1,5
      COLTIT(J)=5HXXXXXX
30  CONTINUE
      WRITE(2)COLMIN,COLMAX,COLTIT
40  CONTINUE
      KOUNT=2
100 CONTINUE
      VPSM=VPS/100.
      VPJM=VPJ/100.
      SPJM=SPJ/100.
      CL1M=CL1/100.
      CL3M=CL3/100.
      CL4M=CL4/100.
      CG3M=CG3/100.
      CG4M=CG4/100.

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008540
008590
008600
008610
008620
008630
008640
008650
008660
008670
008680
008690
008700
008710
008720

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C3M=C3/100.
C4M=C4/100.
U13M=U13/100.
WRITE(2)TMS,P1,P1,P1,P4,PR,SPS,VPSM,SPJM,VPJM,APJ,
* PM1,RHL3,RHG3,RH3,RHL4,RHG4,RH4,V1,VL3,VG3,V3,VL4,VG4,V4,
* EPS3,EPS4,
* AVENT,PM1,RML3,RML3,RHG3,PM3,PM4,PM4,PM4,RMSJM,RMD17,RMD17,PMO34,
* RMD4,RML1,RML3,RH3,RH4,RH4,CL1M,CL3M,CG3M,C3M,CL4M,CG4M,C4M,
* TFM3,TFM4,
* FL1,FL3,EG3,EL4,EG4,EKPS,EKPJ,EKL4,EXG4,ESJM,
* (PM1(1),I=1,10),(PM3(1),I=1,10),
* (PM4(1),I=1,10),(PMO4(1),I=1,10),
* U13M,WF,NC
PETIOPH
END

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70

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1  SURROU TIME DIFFIN(N,TIME,Y,YDOT)
COMMON/TARINT/KUPITE,KOINTD,SPEC,TITLE(A),TVENT(A),TOROP(8),TDIS(B)008730
IF (TOROP(1).EQ.10MDROP1) )CALL FDRDP1(N,TIME,Y,YDOT) 008740
IF (TOROP(1).EQ.10MDROP2) )CALL FDRDP2(N,TIME,Y,YDOT) 008750
IF (TOROP(1).EQ.10MDROP3) )CALL FDRDP3(N,TIME,Y,YDOT) 008760
RETURN 008770
END 008780

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02/22/85 13.15.44

FTN 4.8.401

SUBROUTINE FDRPPI 76/76 OPT=1 ROUND=0.0 / TRACE

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1  SUBROUTINE FDRPPI(N,TIME,Y,YDOT)
   DIMENSION Y(N),YDOT(N)
   COMMON/FPCOM/NUSED,NUSTEP,NFE,NJF,NMI
   COMMON/TAB1/G0,GAM,COV,FNER,OFFSET
   COMMON/TAB2/RK1,PK2,RH11,VII,VPER
   COMMON/TAB3/DC,AVENT,A1,A3,A4,AHOLE,VCOR
   COMMON/TAB4/PSVT,PSHAV,MOD1,MRACK,MOD4
   COMMON/TAB5/C3,C4,RMD13,RMD34,RMD4,RM1,RM3,RM4,RMSUM,RMINT
   COMMON/TAB6/V1,VPS,SPS,RH1,P1,V3,PH3,P3,V4,VPJ,SPJ,APJ,PM4,P4
   COMMON/TAB7/PJMT,TRAVEL
   COMMON/TAB8/PPSPS,PJMS,PL,PR,DC34
   COMMON/TAB9/ELI,EG3,EG4,EKPS,EKPJ,EKG4,ESUM,FINT
   COMMON/TAB10/RH,NG,RS,CP,CV,TEVP3,TEMPA,HL1,HL3,HL4,M3,M4
   COMMON/TAB11/LSKIP,LPAGE,TWS,OMAX(10)
   COMMON/TAB12/MVENT,MVENT,AVMIN,AVMAX,AF,ACS
   COMMON/TAB13/PI
   COMMON/TAB14/NDP,ADP,BOP
   COMMON/TAB15/CL1,CL3,CG3,CL4,CG4,RHG3,PHL3,RMG4,RML4
   COMMON/TAB16/RHG3,RHL3,RHG4,PHL4,FL3,EL4,EKL4
   COMMON/TAB17/VG3,VL3,VG4,VL4,EP53,EPS4
   COMMON/TAB18/DINC,PDDR(10),PHL3(10),PHL4(10),PHN4(10)
   COMMON/TAB19/SIGMA,U13,WE
   COMMON/TAB20/TWRITE,KOUTD,SPEC,TITLE(R),TVENT(R),TOPOP(R),TOIS(R)
   *****
25  C *****
   C INSTANTANEOUS BURNING MODEL.
   C *****
   C VOLUME OF LIQUID CHAMBER.
   V1=Y(1)
   C PISTON VELOCITY.
   VPS=Y(2)
   IF(MOD1.EQ.0) VPS=0.0
   C PISTON TRAVEL
   SPS=Y(3)
   C LIQUID DENSITY.
   PH1=Y(4)
   C LIQUID PRESSURE.
   P1=Y(5)
   IF(MOD1.EQ.0) P1=0.0
   C VOLUME OF COMBUSTION CHAMBER.
   V3=Y(6)
   C DENSITY IN COMBUSTION CHAMBER.
   RH3=Y(7)
   C PRESSURE IN COMBUSTION CHAMBER.
   P3=Y(8)
   C VOLUME OF TUBE.
   VA=Y(9)
   C PROJECTILE VELOCITY.
   VPJ=Y(10)
   C PROJECTILE TRAVEL
   SPJ=Y(11)
   C DENSITY IN TUBE
   RH4=Y(12)
   C AVERAGE PRESSURE IN THE TUBE.
   PA=Y(13)
   C FIND THE DISCHARGE COEFFICIENT.
   IF(TOIS(1).EQ.1000151) CALL DIS1(2)
   IF(TOIS(1).EQ.1000152) CALL DIS2(2)

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C FIND THE PISTON RESISTANCE PRESSURE.
C CALL PISRES(2,SPS,PSRS)
C FIND THE PROJECTILE RESISTANCE PRESSURE.
CALL PROJRES(2,SPJ,PSJRS)
IFITVENT(1)=EQ.10HVENT1 )CALL VENT1(2)
IFITVENT(1)=EQ.10HVENT2 )CALL VENT2(2)
IFITVENT(1)=EQ.10HVENT3 )CALL VENT3(2)
C RM1 IS THE MASS IN REGION 1.
RM1=DM1*V1
C RM3 IS THE MASS IN REGION 3.
RM3=DM3*V3
C RM4 IS THE MASS IN REGION 4.
RM4=DM4*V4
C RMSUM IS THE TOTAL MASS
RMSUM=RM1+RM3+RM4
C PRESSURE AT BASE OF PROJECTILE.
PR=(PA+PJRS*RM4/(3.0*PJMT))/(1.0+QMA/(3.0*PJMT))
IF(PR.LT.PJRS)PR=PA
C PRESSURE AT LEFT OF TUBE.
PL=PR*(1.0+RM4/(2.0*PJMT)) - PJRS*RM4/(2.0*PJMT)
IF(PR.LT.PJRS)PL=PA
C INTERNAL ENERGY PER GRAM FOR GAS IN REGION 3.
ENER3=P3*(1.0+COV*RH3)/(RH3*(GAM-1.0))
C AVERAGE INTERNAL ENERGY PER GRAM FOR GAS IN REGION 4.
ENER4=P4*(1.0+COV*RH4)/(RH4*(GAM-1.0))
IF(EMD4.EQ.1)GO TO 30
PL=PA
PR=PA
30 CONTINUE
C C3 IS THE SPEED OF SOUND IN THE COMBUSTION CHAMBER GAS.
C3=SQRT(G0*GAM*P3/(1.0+COV*RH3)*RH3)
C C4 IS THE SPEED OF SOUND IN THE TUBE GAS.
C4=SQRT(G0*GAM*P4/(1.0+COV*RH4)*RH4)
C CL1 IS THE SPEED OF SOUND IN THE LIQUID CHAMBER.
CL1=SQRT(G0*(RK1+RK2*0.1)/RH1)
C RMD13 IS THE MASS FLUX FROM REGION 1 TO REGION 3.
DLP=P1-P3
IF(DLP.LT.0.0.AND.*BACK.EQ.1)RMD13=-DC*AVENT*SQRT(-2.0*RH3*G0*DLP)
IF(DLP.LT.0.0.AND.*BACK.EQ.0)RMD13=0.0
IF(DLP.GE.0.0)RMD13=DC*AVENT*SQRT(2.0*RH1*G0*DLP)
IF(MD1.EQ.0)RMD13=0.0
C LIQUID INJECTION VELOCITY INTO REGION 3.
U13=RMD13/(RM1*AVENT)
C RMD34 IS THE MASS FLUX FROM REGION 3 TO REGION 4.
DLP=P3-PL
IF(DLP.LT.0.0)RMD34=-DC34*A4*SQRT(-2.0*RH4*G0*DLP)
IF(DLP.GE.0.0)RMD34=DC34*A4*SQRT(2.0*RH3*G0*DLP)
IF(MD4.EQ.0)RMD34=0.0
C ELL IS THE TOTAL ENERGY IN REGION 1.
ELL=ENER*RM1
C EG3 IS THE TOTAL INTERNAL GAS ENERGY IN REGION 3.
EG3=ENER3*RM3
C EG4 IS THE TOTAL INTERNAL GAS ENERGY IN REGION 4.
EG4=ENER4*RM4
C EKPS IS THE KINETIC ENERGY OF THE PISTON.
EKPS=0.5*PSWT*VPS*VPS/G0
C EKQJ IS THE KINETIC ENERGY OF THE PROJECTILE.

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115      FKPJ=0.5*PJ*VPJ/GO
      C EKG4 IS THE KINETIC ENERGY OF THE GAS IN REGION 4.
      C ASSUME THAT THE DENSITY IS CONSTANT.
      C ASSUME THAT THE VELOCITY IS A LINEAR FUNCTION.
      C SO USE THE AVERAGE VELOCITY TO COMPUTE THE KINETIC ENERGY.
      EKG4=0.0
      IF (MOD4.EQ.0) GO TO 32
      UL=0.0
      UR=VPJ
      U=0.5*(UL+UR)
      EKG4=0.5*RM4*UR*(3.0*GO)
125      32 CONTINUE
      C ESUM IS THE SUM OF THE ENERGIES.
      ESUM=EL1*EG3*EG4*EKPS*EKPJ*EKG4
      C TEMP3 IS THE GAS TEMPERATURE IN REGION 3.
      TEMP3=P3*(1.0-COV*RM3)/(RM3*(GAM-1.0)*CV)
      C TEMP4 IS THE AVERAGE GAS TEMPERATURE IN REGION 4.
      TEMP4=P4*(1.0-COV*RM4)/(RM4*(GAM-1.0)*CV)
      C HL1 IS THE ENTHALPY OF THE LIQUID IN REGION 1.
      HL1=ENER * P1/RH1
      C H3 IS THE ENTHALPY OF THE GAS IN REGION 3.
      H3=CP*TEMP3 * P3/COV
      C H4 IS THE ENTHALPY OF THE GAS IN REGION 4.
      H4=CP*TEMP4 * P4/COV
      C *****
140      IF (MOD1.EQ.0) GO TO 50
      IF (MOD4.EQ.0) GO TO 40
      C REGION 1 IS OPEN.
      C REGION 4 IS OPEN.
      YDOT(1)=-VPS*A1
      IF (TVENT(1).EQ.10HVENT3 ) YDOT(1)=YDOT(1)+VCOR
      FORC=P3*(A3-AVENT) - P1*(A1-AVENT)
      FORR=PSRS*(A1-AVENT)
      IF (TVENT(1).EQ.10HVENT3 ) FORC=P3*(A3-AHOLE)-P1*(A1-AHOLE)
      IF (TVENT(1).EQ.10HVENT3 ) FORR=PSRS*(A1-AHOLE)
      IF (FORC.GE.FORR) YDOT(2)=(GO/PSWT)*(FORC-FORR)
      IF (FORC.LT.FORR) YDOT(2)=0.0
      IF (FORC.LT.0.0) YDOT(2)=(GO/PSWT)*FORC
      YDOT(3)=VPS
      IF (SP5.LT.0.0.AND.YDOT(2).LT.0.0) YDOT(2)=0.0
      IF (SP5.LT.0.0.AND.YDOT(3).LT.0.0) YDOT(3)=0.0
      YDOT(4)=-PH1*YDOT(1)/V1 - RMD13/V1
      YDOT(5)=CL1*CL1*YDOT(4)/GO
      YDOT(6)=VPS*A3
      IF (TVENT(1).EQ.10HVENT3 ) YDOT(4)=YDOT(4)-VCOR
      YDOT(7)=-RM3*YDOT(6)/V3 + RMD13/V3 - RMD34/V3
      YDOT(8)=C3*C3*YDOT(7)/GO
      IF (RMD13.GE.0.0) YDOT(8)=YDOT(8)+RMH13*(HL1-H3)*(GAM-1.0)/
      * (V3-COV*RM3)
      IF (RMD13.LE.0.0) YDOT(8)=YDOT(8)-RMH13*(H4-H3)*(GAM-1.0)/
      * (V3-COV*RM3)
      YDOT(9)=VPJ*A4
      IF (PD.GE.PJPS) YDOT(10)=(PD-PJPS)*A4*GO/PJMT
      IF (PD.LT.PJPS) YDOT(10)=0.0
      APJ=YDOT(10)/(1.09-146*1.0E7)
      YDOT(11)=VPJ
      YDOT(12)=-RM4*YDOT(9)/V4 + RMH34/V4

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FTN 4.8.401

TRACE

OPT=1 ROUND=0.0/

76/76

SIBBOUTIME F880P1

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230      YDOT(12)=YDOT(7)
      YDOT(13)=YDOT(8)
      RETURN
      CONTINUE
60      C REGION 1 IS CLOSED.
      C REGION 4 IS OPEN.
235      YDOT(1)=0.0
      YDOT(2)=0.0
      YDOT(3)=0.0
      YDOT(4)=0.0
      YDOT(5)=0.0
      YDOT(6)=0.0
      YDOT(7)=-RM3*YDOT(6)/V3 -RMD34/V3
      YDOT(8)=C3*C3*YDOT(7)/G0
      IF (RMD34-LE-0.0) YDOT(8)=YDOT(8)-(M4-M3)*(GAM-1.0)/
      * (V3-COV*RM3)
      YDOT(9)=VPJ*A4
      IF (PR-GE-PJRS) YDOT(10)=(PR-PJRS)*A4*G0/PJMT
      IF (PR-LT-PJRS) YDOT(10)=0.0
      APJ=YDOT(10)/(.098146*1.0E7)
      YDOT(11)=VPJ
      YDOT(12)=-RM4*YDOT(9)/V4 + RMD34/V4
      YDOT(13)=C4*C4*YDOT(12)/G0
      IF (RMD34-GE-0.0) YDOT(13)=YDOT(13)+PM334*(M3-M4)*(GAM-1.0)/
      * (V4-COV*RM4)
      RETURN
100      CONTINUE
      RETURN
      END

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011080
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011120
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011190
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1  SUBROUTINE FPROP2(IN,TIME,Y,YDOT)
   DIMENSION Y(N),YDOT(N)
   COMMON/PCOM9/HUSED,NUUSED,MSTEP,IFE,NJE,NMI
   COMMON/TAB1/G0,GA4,COV,ENER,OFFSET
   COMMON/TAB2/PK1,PK2,MH1I,VII,VPER
   COMMON/TAB3/DC,AVENT,AL,A3,A4,AMOLE,VCOR
   COMMON/TAB4/PSVT,PSTHAV,MOD1,M9ACK,MOR4
   COMMON/TAB5/C3,C4,RMD13,RMD34,RMD3,RMD4,RM1,RM3,RM4,RMSUM,PWINT
   COMMON/TAB6/V1,VPS,SPS,RH1,PI,V3,RH3,P3,VA,VPJ,SPJ,APJ,PHA,PA
   COMMON/TAB7/CJMT,TRAVEL
   COMMON/TAB8/PPSPS,PJRS,PL,PR,DC34
   COMMON/TAB9/EL1,EG3,EG4,EKPS,EKPJ,EKG4,ESUM,ETMT
   COMMON/TAB10/RH,W6,HS,CP,CV,TEMP3,TEMP4,ML1,ML3,ML4,M7,M4
   COMMON/TAB11/LSKIP,LPAGE,T4S,RMAX(10)
   COMMON/TAB12/MVENT,NVENT,AVMIN,AVMAX,AK,ACS
   COMMON/TAB13/PI
   COMMON/TAB14/DDR,ADR,BDR
   COMMON/TAB15/CL1,CL3,CG3,CL4,CG4,PMG3,PMG4,RMG4,RML4
   COMMON/TAB16/RMG3,RML3,RMG4,RHL4,EL3,EL4,EKL4
   COMMON/TAB17/VG3,VL3,VG4,VL4,EPS3,FPS4
   COMMON/TAB18/DINC,PDDP(10),PML3(10),PMD4(10)
   COMMON/TAB19/SIGNA,U13,WE
   COMMON/TABINT/KWRITE,KOUTD,SPEC,TITLE(8),TVENT(8),TDROP(8),TDIS(8)
   *****
25  C DROPLET BURNING - CONSTANT SIZE DROPLETS
   C *****
   C VOLUME OF LIQUID CHAMBER.
     V1=Y(1)
   C PISTON VELOCITY.
     VPS=Y(2)
     IF (MOD1.EQ.0) VPS=0.0
   C PISTON TRAVEL
     SPS=Y(3)
   C LIQUID DENSITY.
     RML=Y(4)
   C LIQUID PRESSURE.
     P1=Y(5)
     IF (MOD1.EQ.0) P1=0.0
   C VOLUME OF COMBUSTION CHAMBER.
     V3=Y(6)
   C DENSITY IN COMBUSTION CHAMBER.
     RM3=Y(7)
   C PRESSURE IN COMBUSTION CHAMBER.
     P3=Y(8)
   C VOLUME OF TUBE.
     VA=Y(9)
   C PROJECTILE VELOCITY.
     VPJ=Y(10)
   C PROJECTILE TRAVEL
     SPJ=Y(11)
   C DENSITY IN TUBE
     RM4=Y(12)
   C AVERAGE PRESSURE IN THE TUBE.
     PA=Y(13)
   C LIQUID DENSITY IN REGION 3.
     RML3=Y(14)
   C LIQUID MASS IN REGION 3.

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011370
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011930

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      RML3=V(15)
      C LIQUID DENSITY IN REGION 4.
      RML4=V(16)
      C LIQUID MASS IN REGION 4.
      RML4=V(17)
      C FIND THE DISCHARGE COEFFICIENT.
      IF (DIS(1).EQ.10H01S1) ICALL DIS1(2)
      IF (DIS(1).EQ.10H01S2) ICALL DIS2(2)
      C FIND THE PISTON RESISTANCE PRESSURE.
      CALL PISRES(2,SPS,PSRS)
      C FIND THE PROJECTILE RESISTANCE PRESSURE.
      CALL PROJRES(2,SPJ,PJRS)
      IF (VENT(1).EQ.10HVENT1) ICALL VENT1(2)
      IF (VENT(1).EQ.10HVENT2) ICALL VENT2(2)
      IF (VENT(1).EQ.10HVENT3) ICALL VENT3(2)
      C RM1 IS THE MASS IN REGION 1.
      RM1=DM1*V1
      C VL3 IS THE LIQUID VOLUME OF REGION 3.
      VL3=DM13/RML3
      C VG3 IS THE GAS VOLUME IN REGION 3.
      VG3=V3-VL3
      C EPS3 IS THE POROSITY IN REGION 3.
      EPS3=VG3/V3
      C RMG3 IS THE GAS DENSITY IN REGION 3.
      RMG3=(RM3-(1.0-EPS3)*RML3)/EPS3
      C RMG3 IS THE GAS MASS IN REGION 3.
      RMG3=RMG3*VG3
      C RM3 IS THE MASS IN REGION 3.
      RM3=RMG3*DM13
      C VLA IS THE LIQUID VOLUME OF REGION 4.
      VLA=DM14/RML4
      C VGA IS THE GAS VOLUME IN REGION 4.
      VGA=V4-VLA
      C EPS4 IS THE POROSITY OF REGION 4.
      EPS4=EPS3
      IF (V4.GT.1.0E-4) EPS4=VGA/V4
      C RMGA IS THE GAS DENSITY OF REGION 4.
      RMGA=(RMA-(1.0-EPS4)*RML4)/EPS4
      C RMGA IS THE GAS MASS IN REGION 4.
      RMGA=RMGA*VGA
      C RMA IS THE MASS IN REGION 4.
      RMA=RMGA*DM14
      C RMSUM IS THE TOTAL MASS
      RMSUM=RM1+RM3+RM4
      C PRESSURE AT BASE OF PROJECTILE.
      PP=(P4+PJRS*DM4/(3.0*PJMT))/(1.0+DM4/(3.0*PJMT))
      IF (PP.LT.PJRS) PP=P4
      C PRESSURE AT LEFT OF TURE.
      PL=PP*(1.0+RM4/(2.0*PJMT)) - PJRS*RM4/(2.0*PJMT)
      IF (PP.LT.PJRS) PL=P4
      C INTERNAL ENERGY DEP GRAM FOR GAS IN REGION 3.
      EMEP3=P3*(1.0-COV*RMG3)/(DMG3*(GAM-1.0))
      C AVERAGE INTERNAL ENERGY PER GRAM FOR GAS IN REGION 4.
      EMEP4=P4*(1.0-COV*RMGA)/(DMGA*(GAM-1.0))
      IF (MM04.EQ.1) GO TO 30
      PL=P4
      PP=P4

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FTN 4.R.401

76/76 OPT=1 SOUND=0.0/ TRACE

SUBROUTINE FRMP2

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115 30 CONTINUE
C CG3 IS THE SPEED OF SOUND IN THE COMBUSTION CHAMBER GAS.
CG3=SQRT(G0*GAM*P3/(1.0-COV*RHG3)*RHG3))
C CG4 IS THE SPEED OF SOUND IN THE TURE GAS.
CG4=SQRT(G0*GAM*P4/(1.0-COV*RHG4)*RHG4))
C CL1 IS THE SPEED OF SOUND IN THE LIQUID CHAMBER.
CL1=SQRT(G0*(RK1*RK2*P1)/RH1)
C CL3 IS THE SPEED OF SOUND IN THE LIQUID IN REGION 3.
CL3=SQRT(G0*(PK1*PK2*P3)/RHL3)
C CL4 IS THE SPEED OF SOUND IN THE LIQUID IN REGION 4.
CL4=SQRT(G0*(RK1*RK2*P4)/RHL4)
C C3 IS THE MIXTURE SPEED OF SOUND IN REGION 3.
C3=SQRT(1.0/(RH3*(EPS3/(RHG3*CS3*CG3) +
* (1.0-EPS3)/(RHL3*CL3*CL3))))
C C4 IS THE MIXTURE SPEED OF SOUND IN REGION 4.
C4=SQRT(1.0/(RH4*(EPS4/(RHG4*CG4*CG4) +
* (1.0-EPS4)/(RHL4*CL4*CL4))))
C RMD13 IS THE MASS FLUX FROM REGION 1 TO REGION 3.
DLP=P1-P3
IF(DLP.LT.0.0.AND.MBACK.EQ.1)RMD13=-DC*AVENT*SQRT(-2.0*RH3*G0*DLP)
IF(DLP.LT.0.0.AND.MBACK.EQ.0)RMD13=0.0
IF(DLP.GE.0.0)RMD13=DC*AVENT*SQRT(2.0*RH1*G0*DLP)
IF(MOD1.EQ.0)RMD13=0.0
C LIQUID INJECTION VELOCITY INTO REGION 3.
U13=RMD13/(RH1*AVENT)
C WERER NUMBER
WE=RHG3*U13*U13*DDR/12.0*SIGMA)
C RMD34 IS THE MASS FLUX FROM REGION 3 TO REGION 4.
DLP=P3-PL
IF(DLP.LT.0.0)RMD34=-DC34*A4*SQRT(-2.0*RH4*G0*DLP)
IF(DLP.GE.0.0)RMD34=DC34*A4*SQRT(2.0*RH3*G0*DLP)
IF(MOD4.EQ.0)RMD34=0.0
C EL1 IS THE TOTAL ENERGY IN REGION 1.
EL1=ENER*RM1
C EL3 IS THE LIQUID ENERGY IN REGION 3.
EL3=ENER*RML3
C E03 IS THE TOTAL INTERNAL GAS ENERGY IN REGION 3.
EG3=ENER3*RMG3
C FL4 IS THE LIQUID ENERGY IN REGION 4.
EL4=ENER*RML4
C EG4 IS THE TOTAL INTERNAL GAS ENERGY IN REGION 4.
EG4=ENER4*RMG4
C EKPS IS THE KINETIC ENERGY OF THE PISTON.
EKPS=0.5*PS*VPS*VPS/G0
C EKPJ IS THE KINETIC ENERGY OF THE PROJECTILE.
EKPJ=0.5*PJ*VPJ*VPJ/G0
C EKGA IS THE KINETIC ENERGY OF THE GAS IN REGION 4.
C ASSUME THAT THE DENSITY IS CONSTANT.
C ASSUME THAT THE VELOCITY IS A LINEAR FUNCTION.
C SO USE THE AVERAGE VELOCITY TO COMPUTE THE KINETIC ENERGY.
EKGA=0.0
IF(RMD4.FO.0)GO TO 32
UL=0.0
UR=VPJ
U=0.5*(UL+UR)
EKGA=0.5*RMGA*UR*UR/13.0*G0)
C EKL4 IS THE KINETIC ENERGY OF THE LIQUID IN REGION 4.

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C IGNOPE DRAG.
  EKL4=0.5*RM4*PI*PI/(3.0*GN)
32  CONTINUE
C ESUM IS THE SUM OF THE ENERGIES.
  ESUM=EL1*EL3*EG3*EL4*EG4*EKPS*EXPJ*EKGA*EKL4
C TEMP3 IS THE GAS TEMPERATURE IN REGION 3.
  TEMP3=P3*(1.0-COV*RHG3)/(RHG3*(GAM-1.0)*CV)
C TEMP4 IS THE AVERAGE GAS TEMPERATURE IN REGION 4.
  TEMP4=P4*(1.0-COV*RHG4)/(RHG4*(GAM-1.0)*CV)
C ML1 IS THE ENTHALPY OF THE LIQUID IN REGION 1.
  ML1=FNER * P1/PH1
C ML3 IS THE ENTHALPY OF THE LIQUID IN REGION 3.
  ML3=ENER * P3/PH3
C ML4 IS THE ENTHALPY OF THE LIQUID IN REGION 4.
  ML4=ENER * P4/PH4
C M3 IS THE ENTHALPY OF THE GAS IN REGION 3.
  H3=CP*TEMP3 * P3*COV
C M4 IS THE ENTHALPY OF THE GAS IN REGION 4.
  H4=CP*TEMP4 * P4*COV
C *****
C DROPLET FORMATION.
C ASSUME THAT THE GAS CANNOT FLOW FROM REGION 4 TO REGION 3.
  IF(RMD3A.LT.0.0)RMD3A=0.0
C RMD3 IS THE RATE OF CHANGE OF LIQUID TO GAS IN REGION 3.
  RMD3=RML3*(6.0/DDR)*ADR*(P3**8DR)
C RMD4 IS THE RATE OF CHANGE OF LIQUID TO GAS IN REGION 4.
  RMD4=RML4*(6.0/DDR)*ADR*(P4**8DR)
  IF(RMD1.EQ.0)GO TO 150
  IF(RMD4.EQ.0)GO TO 140
C REGION 1 IS OPEN.
C REGION 4 IS OPEN.
  YDOT(1)=VPS*A1
  IF(TVENT(1).EQ.10HVENT3 )YDOT(1)=YDOT(1)+VCOR
  FORC=P3*(A3-AVENT) - P1*(A1-AVENT)
  FORC=PSPS*(A1-AVENT)
  IF(TVENT(1).EQ.10HVENT3 )FORC=P3*(A3-AHOLE)-P1*(A1-AHOLE)
  IF(TVENT(1).EQ.10HVENT3 )FORC=PSPS*(A1-AHOLE)
  IF(FORC.GE.FORR)YDOT(2)=(G0/PSWT)*FORC
  IF(FORC.LT.FORR)YDOT(2)=0.0
  IF(FORC.LT.0.0)YDOT(2)=(G0/PSWT)*FORC
  YDOT(3)=VPS
  IF(SPS.LT.0.0.AND.YDOT(2).LT.0.0)YDOT(2)=0.0
  IF(SPS.LT.0.0.AND.YDOT(3).LT.0.0)YDOT(3)=0.0
  YDOT(4)=-RH1*YDOT(1)/V1 - RMD13/V1
  YDOT(5)=CL1*CL1*YDOT(4)/G0
  YDOT(6)=VPS*A3
  IF(TVENT(1).EQ.10HVENT3 )YDOT(4)=YDOT(4)-VCOR
  YDOT(7)=-RH3*YDOT(6)/V3 + RMD13/V3 -RMD34/V3
  YDOT(8)=(RH3*C3*G0) * (-YDOT(6)/V3 +
    * P4D13/(RML3*V3) + (RMD3/(RHG3*V3)) *
    * (1.0 - RHG3/PH3 + G0*(ML3-H3)*(GAM-1.0)/
    * (CG3*CG3*(1.0-COV*RHG3)) - RMD34/G43)
  YDOT(9)=VPS*A4
  IF(PD*CF.PJRS)YDOT(10)=(PD*PJRS)*G0*GN/PJMT
  IF(PD.LT.PJRS)YDOT(10)=0.0
  APJ=YDOT(10)/(1.09414e*1.057)
  YDOT(11)=VPJ

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FTN 4.9.401

76/76 OPT=1 ROUND=0.0/ TRACE

SUBROUTINE FNDOP2

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290      YDOT(4)=0.0
      YDOT(5)=0.0
      YDOT(6)=0.0
      V34=V3+V4
      YDOT(9)=VPJ+A4
      YDOT(7)=-RM3*(YDOT(6)+YDOT(9))/V34
      YDOT(8)=(RM3*CG3/G0)*(-YDOT(6)+YDOT(9))/V3 +
      * ((PMD3*PMD4)/(RMG3*V34))*((1.0 - RMG3/OHL3) +
      * G0*(HL3-H3)*(GAM-1.0)/(CG3*CG3*(1.0-COV*RMG3))) )
295      IF (PP.GE.PJRS) YDOT(10)=(PR-PJRS)*A4*G0/PJMT
      IF (PP.LT.PJRS) YDOT(10)=0.0
      APJ=YDOT(10)/(0.098146*1.0E7)
      YDOT(11)=VPJ
      YDOT(12)=YDOT(7)
      YDOT(13)=YDOT(8)
      YDOT(14)=G0*YDOT(8)/(CL3*CL3)
      YDOT(15)=(-PMD3-RMD4)*V3/V34
      YDOT(16)=YDOT(14)
      YDOT(17)=YDOT(15)*V4/V3
300      RETURN
305      160 CONTINUE
      C REGION 1 IS CLOSED.
      C REGION 4 IS OPEN.
      YDOT(1)=0.0
      YDOT(2)=0.0
      YDOT(3)=0.0
      YDOT(4)=0.0
      YDOT(5)=0.0
      YDOT(6)=0.0
      YDOT(7)=-RM3*YDOT(6)/V3 -PMD34/V3
      YDOT(8)=(RM3*CG3/G0)*(-YDOT(6)/V3 +
      * (PMD3/(RMG3*V3))*((1.0 - RMG3/OHL3) +
      * G0*(HL3-H3)*(GAM-1.0)/(CG3*CG3*(1.0-COV*RMG3))) -
      * RMD34/PMD3)
      YDOT(9)=VPJ+A4
      IF (PP.GE.PJRS) YDOT(10)=(PR-PJRS)*A4*G0/PJMT
      IF (PP.LT.PJRS) YDOT(10)=0.0
      APJ=YDOT(10)/(0.098146*1.0E7)
      YDOT(11)=VPJ
      YDOT(12)=-RM4*YDOT(9)/V4 + RMD34/V4
      YDOT(13)=(RM4*CG4/G0*(G0*V4)) * (-YDOT(9) +
      * (PMD4/RMG4) * (1.0-RMG4/OHL4) +
      * G0*(HL4-H4)*(GAM-1.0)/(CG4*CG4*(1.0-COV*RMG4))) +
      * (RMD34/(RMG4*V4)) * (PMD3*RMG4/OHL4 + RMG3 +
      * G0*RMG3*(H3-H4)*(GAM-1.0)/(CG4*CG4*(1.0-COV*RMG4))) )
320      YDOT(14)=G0*YDOT(8)/(CL3*CL3)
      YDOT(15)=-PMD3*PMD34/PMD3 - RMD3
      YDOT(16)=G0*YDOT(13)/(CL4*CL4)
      YDOT(17)=RML3*PMD34/RM3 - RMD4
      PETIUPH
      ENH

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FTU 4.8401

74/74 OPT=1 ROUNDO=0.0 TPADE

SUBROUTINE FPROP3

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1  SUPROUTINE FPROP3(M,TIME,Y,YDOT)
   DIMENSION Y(N),YDOT(N)
   COMMON/EPICOM9/HUSED,NUSED,MSTEP,MFE,NJE,NMI
5  COMMON/TAB1/G0,GAM,COV,ENER,OFFSET
   COMMON/TAB2/RK1,RK2,RH1,VII,VPER
   COMMON/TAB3/DC,AVENI,A1,A3,A4,AHOLE,VCOR
   COMMON/TAB4/PSMT,PSTRAV,MOD1,WRACK,MOD4
   COMMON/TAB5/C3,C4,RMD13,RMD3A,RMD3,RMD4,RM1,RM3,RM4,RMSUM,RMINT
   COMMON/TAB6/V1,VPS,SPS,RH1,P1,V3,RH3,P3,V4,VPJ,SPJ,APJ,RH4,P4
10  COMMON/TAB7/PJMT,TRAVEL
   COMMON/TAB8/PSPS,PJRS,PL,PR,DC34
   COMMON/TAB9/EL1,EG3,EG4,EKPS,EKPJ,EKGA,FSUM,EJNT
   COMMON/TAB10/RH1,RG,PS,CP,CV,TEMP3,TEMP4,HL1,HL3,HL4,H3,H4
   COMMON/TAB11/LSKIP,LPAGE,TMS,RMAX(10)
15  COMMON/TAB12/MVENT,NVENT,AVMIN,AVMAX,AK,ACS
   COMMON/TAB13/PI
   COMMON/TAB14/DDR,ADR,RDR
   COMMON/TAB15/CL1,CL3,CG3,CL4,CG4,PMG3,PML3,PMG4,PML4
   COMMON/TAB16/RHG3,PHL3,PHG4,PHL4,FL3,FL4,EKL4
20  COMMON/TAB17/VG3,VL3,VG4,VL4,EPS3,FPS4
   COMMON/TAB18/DINC,PDDR(10),PHL3(10),PHD3(10),PHL4(10),PHD4(10)
   COMMON/TAB19/SIGMA,U13,WE
   COMMON/TABINT/KWITE,KOUTD,SPEC,TITLE(R),TVENT(9),TOROP(R),TDIS(H)
25  C VOLUME OF LIQUID CHAMBER.
   VL=Y(1)
   C PISTON VELOCITY.
   VPS=Y(2)
   IF (MOD1.EQ.0) VPS=0.0
30  C PISTON TRAVEL
   SPS=Y(3)
   C LIQUID DENSITY.
   PH1=Y(4)
   C LIQUID PRESSURE.
   P1=Y(5)
   IF (MOD1.EQ.0) P1=0.0
35  C VOLUME OF COMBUSTION CHAMBER.
   V3=Y(6)
   C DENSITY IN COMBUSTION CHAMBER.
   PH3=Y(7)
   C PRESSURE IN COMBUSTION CHAMBER.
   P3=Y(8)
40  C VOLUME OF TUBE.
   V4=Y(9)
   C PROJECTILE VELOCITY.
   VPJ=Y(10)
   C PROJECTILE TRAVEL
   SPJ=Y(11)
   C DENSITY IN TUBE
   PH4=Y(12)
45  C AVERAGE PRESSURE IN THE TUBE.
   PA=Y(13)
   C LIQUID DENSITY IN REGION 3.
   PHL3=Y(14)
50  C LIQUID MASS IN REGION 3.
   RML3=Y(15)
55  C LIQUID DENSITY IN REGION 4.
   PHL4=Y(16)

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C LIQUID MASS IN REGION 4.
  RML4=Y(17)
C PARTITIONED LIQUID MASS IN REGION 3.
C PARTITIONED LIQUID MASS IN REGION 4.
  DO 2 I=1,10
    IP=I+17
    PML3(I)=Y(IP)
    PML4(I)=Y(IP)
  2 PML4(I)=Y(IP)
  5 CONTINUE
C FIND THE DISCHARGE COEFFICIENT.
  IF(TDIS(1).EQ.10MDIS1) )CALL DIS1(2)
  IF(TDIS(1).EQ.10MDIS2) )CALL DIS2(2)
C FIND THE PISTON RESISTANCE PRESSURE.
  CALL PISRES(2,SPS,PSHS)
C FIND THE PROJECTILE RESISTANCE PRESSURE.
  CALL PROJRES(2,SPJ,PJPS)
C FIND THE VENT AREA.
  IF(TVENT(1).EQ.10HVENT1) )CALL VENT1(2)
  IF(TVENT(1).EQ.10HVENT2) )CALL VENT2(2)
  IF(TVENT(1).EQ.10HVENT3) )CALL VENT3(2)
C RML IS THE MASS IN REGION 1.
  RM1=RM1+V1
C VL3 IS THE LIQUID VOLUME OF REGION 3.
  VL3=PML3/RML3
C VG3 IS THE GAS VOLUME IN REGION 3.
  VG3=V3-VL3
  EPS3=VG3/V3
C RMG3 IS THE GAS DENSITY IN REGION 3.
  RMG3=(RH3-(1.0-EPS3)*RML3)/EPS3
C RMG3 IS THE GAS MASS IN REGION 3.
  RMG3=RMG3*VG3
C RM3 IS THE MASS IN REGION 3.
  RM3=RMG3+RML3
C VL4 IS THE LIQUID VOLUME OF REGION 4.
  VL4=RML4/RML4
C VG4 IS THE GAS VOLUME IN REGION 4.
  VG4=V4-VL4
C EPS4 IS THE POROSITY OF REGION 4.
  EPS4=EPS3
  IF(V4.GT.1.0E-4)EPS4=VG4/V4
C RMG4 IS THE GAS DENSITY OF REGION 4.
  RMG4=(RH4-(1.0-EPS4)*RML4)/EPS4
C RMG4 IS THE GAS MASS IN REGION 4.
  RMG4=RMG4*VG4
C RMA IS THE MASS IN REGION 4.
  RMA=RMG4+RML4
C RMSUM IS THE TOTAL MASS
  RMSUM=RM1+RM3+RMA
C PRESSURE AT BASE OF PROJECTILE.
  PR=(PA+PJPS+RMA/(1.0*PJMT))/(1.0*PM4/(1.0*PJMT))
  IF(PD.LT.PJPS)PR=PA
C PRESSURE AT LEFT OF TUBE.
  PL=PB*(1.0*PM4/(2.0*PJMT)) - PJPS+RMA/(2.0*PJMT)
  IF(PD.LT.PJPS)PL=PA
C INTERNAL ENERGY PER GRAM FOR GAS IN REGION 3.

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FTN 4.0.401

TRACE

74/74

SIMROUTINE F000P3

115

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ENER3=P3*(1.0-COV*RMG3)/(RMG3*(GAM-1.0))
C AVERAGE INTERNAL ENERGY PER DAM FOR GAS IN REGION 4.
ENEP4=PA*(1.0-COV*RMG4)/(RMG4*(GAM-1.0))
IF (MOD4.EQ.1) GO TO 30
PL=PA
PR=PA

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CONTINUE

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30 C CG3 IS THE SPEED OF SOUND IN THE COMBUSTION CHAMBER GAS.
CG3=SQRT(G0*GAM*P3/((1.0-COV*RMG3)*RMG3))

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C CG4 IS THE SPEED OF SOUND IN THE TUBE GAS.
CG4=SQRT(G0*GAM*P4/((1.0-COV*RMG4)*RMG4))

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C CL1 IS THE SPEED OF SOUND IN THE LIQUID CHAMBER.
CL1=SQRT(G0*(RK1*RK2*P1)/RMI)

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C CL3 IS THE SPEED OF SOUND IN THE LIQUID IN REGION 3.
CL3=SQRT(G0*(RK1*RK2*P3)/RML3)

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C CL4 IS THE SPEED OF SOUND IN THE LIQUID IN REGION 4.
CL4=SQRT(G0*(RK1*RK2*P4)/RML4)

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C C3 IS THE MIXTURE SPEED OF SOUND IN REGION 3.
C3=SQRT(1.0/(RHS*(EPS3/(RMG3*CG3*CG3) +

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* (1.0-EPS3)/(RML3*CL3*CL3)))

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C C4 IS THE MIXTURE SPEED OF SOUND IN REGION 4.
C4=SQRT(1.0/(RHS*(EPS4/(RMG4*CG4*CG4) +

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* (1.0-EPS4)/(RML4*CL4*CL4)))

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C RMD13 IS THE MASS FLUX FROM REGION 1 TO REGION 3.
DLP=P1-P3

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IF (DLP.LT.0.0) DMD13=0.0
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175 IF(MOD4.EQ.0)GO TO 32
    UL=0.0
    UR=VPJ
    U=0.5*(UL+UR)
    EKA=0.5*RG4*UR/(3.0*G0)
    C EKA IS THE KINETIC ENERGY OF THE LIQUID IN REGION 4.
    C IGNOPE DRAG.
    EKL=0.5*RL4*UR/(3.0*G0)
180 32 CONTINUE
    C ESUM IS THE SUM OF THE ENERGIES.
    ESUM=EL1+EL3+EG3+EL4+EG4+EKPS+EKPJ+EKGA+EKL4
    C TEMP3 IS THE GAS TEMPERATURE IN REGION 3.
    TEMP3=P3*(1.0-COV*RG3)/(RHG3*(GAM-1.0)*CV)
185 C TEMP4 IS THE AVERAGE GAS TEMPERATURE IN REGION 4.
    TEMP4=P4*(1.0-COV*RG4)/(RHG4*(GAM-1.0)*CV)
    C ML1 IS THE ENTHALPY OF THE LIQUID IN REGION 1.
    ML1=ENER + P1/RH1
    C ML3 IS THE ENTHALPY OF THE LIQUID IN REGION 3.
    ML3=ENER + P3/RH3
190 C ML4 IS THE ENTHALPY OF THE LIQUID IN REGION 4.
    ML4=ENER + P4/RH4
    C M3 IS THE ENTHALPY OF THE GAS IN REGION 3.
    M3=CP*TEM 3 + P3*COV
195 C M4 IS THE ENTHALPY OF THE GAS IN REGION 4.
    M4=CP*TEM4 + P4*COV
    C *****
    C DROPLET FORMATION.
    C ASSUME THAT THE GAS CANNOT FLOW FROM REGION 4 TO REGION 3.
    IF(PMD34.LT.0.01)PMD34=0.0
200 C PMD3 IS THE RATE OF CHANGE OF LIQUID TO GAS IN REGION 3.
    PMD3=0.0
    DO 105 I=1,10
        PMD3(I)=PML3(I)*(6.0/PDDR(I))*ADR*(P3**SDR)
        PMD3=PMO3+PMD3(I)
205 105 CONTINUE
    C OD3 IS THE RATE OF CHANGE OF THE DIAMETER IN REGION 3.
    OD3=2.0*ADR*(P3**QDR)
210 C RMD4 IS THE RATE OF CHANGE OF LIQUID TO GAS IN REGION 4.
    RMD4=0.0
    DO 110 I=1,10
        RMD4(I)=PML4(I)*(6.0/PDDR(I))*ADR*(P4**BDR)
        RMD4=RMO4+PMD4(I)
215 110 CONTINUE
    C D04 IS THE RATE OF CHANGE OF THE DIAMETER IN REGION 4.
    D04=2.0*ADR*(P4**QDR)
    IF(MOD1.EQ.0)GO TO 150
    IF(MOD4.EQ.0)GO TO 140
220 C REGION 1 IS OPEN.
    C REGION 4 IS OPEN.
    YDOT(1)=-VPS*A1
    IF(TVENT(1).EQ.10)HVENT3 YDOT(1)=YDOT(1)+VFOR
    FOPC=P3*(A3-AVENT) - P1*(A1-AVENT)
    FOPD=PSR5*(A1-AVENT)
225 IF(TVENT(1).EQ.10)HVENT3 FOPC=P3*(A3-AHULE)-P1*(A1-AHULE)
    IF(TVENT(1).EQ.10)HVENT3 FOPD=PSR5*(A1-AHULE)
    IF(FOPC.GE.FOPD)YDOT(2)=(G0/P54T)*(FOPC-FOPD)
    IF(FOPC.LT.FOPD)YDOT(2)=0.0

```

```
IF (F00C.LT.0.0) YDOT(2) = (G0/PS*Y) * F00C
```

```
YDOT(3) = VPS
```

```
IF (SPS.LT.0.0) AND (YDOT(2).LT.0.0) YDOT(2) = 0.0
```

```
IF (SPS.LT.0.0) AND (YDOT(3).LT.0.0) YDOT(3) = 0.0
```

```
YDOT(4) = -RM1*YDOT(1)/V1 - RMD13/V1
```

```
YDOT(5) = CL1*CL1*YDOT(4)/G0
```

```
YDOT(4) = VPS*Y3
```

```
IF (TVENT(1).EQ.10HVE*IT3) YDOT(6) = YDOT(4) - VCOR
```

```
YDOT(7) = -RM3*YDOT(6)/V3 + RMD13/V3 - RMD34/V3
```

```
YDOT(8) = (RM3*YDOT(6)/G0) * (-YDOT(6)/V3 +
```

```
+ RMD13/(RML3*V3) + (RMD3/(RMD3*V3)) *
```

```
+ (1.0 - RMG3/RML3 + G0*(H13-H3)*(GAM-1.0)/
```

```
+ (CG3*CG3*(1.0-COV*RMG3)) - RMD34/RM3)
```

```
YDOT(9) = VPS*Y4
```

```
IF (PR.GE.PJRS) YDOT(10) = (PR-PJRS)*A4*G0/PJRT
```

```
IF (PR.LT.PJRS) YDOT(10) = 0.0
```

```
APJ = YDOT(10)/(1.098145*1.0F7)
```

```
YDOT(11) = VPS
```

```
YDOT(12) = -RM4*YDOT(9)/V4 + RMD34/V4
```

```
YDOT(13) = (RM4*YDOT(9)/G0*V4) * (-YDOT(9) +
```

```
+ (RMD4/RM4) * (1.0 - RMG4/RML4 +
```

```
+ G0*(H14-H4)*(GAM-1.0)/(CG4*CG4*(1.0-COV*RMG4))) *
```

```
+ (RMD34/(RMD34*V3)) + (PML3*RMG4/RML4 + RMG3 +
```

```
+ G0*RMG3*(H3-H4)*(GAM-1.0)/(CG4*CG4*(1.0-COV*RMG4))) )
```

```
YDOT(14) = G0*YDOT(8)/(CL3*CL3)
```

```
YDOT(15) = RMD13 - RML3*YDOT(13)/(CL4*CL4)
```

```
YDOT(16) = G0*YDOT(13)/(CL4*CL4)
```

```
YDOT(17) = RML3*YDOT(13)/(CL4*CL4)
```

```
YDOT(18) = RMD13 - PML3(1)*RMD34/RM3 - RMD3(1) -
```

```
+ PML3(1)*OD3/DINC
```

```
DO 135 I=2,9
```

```
IM=I-1
```

```
INDT=I+17
```

```
YDOT(INDT) = -PML3(I)*RMD34/RM3 - RMD3(I) +
```

```
+ (PML3(I)*PML3(I))*OD3/DINC
```

```
135 CONTINUE
```

```
YDOT(27) = -PML3(10)*RMD34/RM3 - RMD3(10) +
```

```
+ PML3(9)*OD3/DINC
```

```
YDOT(28) = PML3(1)*RMD34/RM3 - PML3(1) -
```

```
+ PML4(1)*OD4/DINC
```

```
DO 145 I=2,9
```

```
IM=I-1
```

```
INDT=I+27
```

```
YDOT(INDT) = PML3(I)*RMD34/RM3 - PML4(I) +
```

```
+ (PML4(I)*PML4(I))*OD4/DINC
```

```
145 CONTINUE
```

```
YDOT(37) = PML3(10)*RMD34/RM3 - PML4(10) +
```

```
+ PML4(9)*OD4/DINC
```

```
RETURN
```

```
140 CONTINUE
```

```
C REGION 1 IS OPEN.
```

```
C REGION 4 IS CLOSED.
```

```
C VIEW REGION 3 AND REGION 4 AS ONE REGION.
```

```
YDOT(11) = VPS*Y4
```

```
IF (TVENT(1).EQ.10HVE*IT3) YDOT(11) = YDOT(1) - VCOR
```

```
FORCEP3 = (A3-AVMT) - P1*(A1-AVMT)
```

```
FORCEP3 = (A1-AVMT)
```

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```

IF (TVENT(1) .EQ. 10HVENT3) IFORC=0.3*(A3-AMOLE)-PI*(A1-AMOLE)
IF (TVEIT(1) .EQ. 10HVENT3) IFORC=PS*(A1-AMOLE)
IF (FORC-GE.FORR) YDOT(2) = (GR/PSWT) * (FDR-FCORR)
IF (FORC-LE.FORR) YDOT(2) = 0.0
IF (FORC-LE.FORR) YDOT(2) = (GR/PSWT) * FORC
YDOT(3) = VPS
IF (SPS-LE.0.0-AND-YDOT(2) .LT.0.0) YDOT(2) = 0.0
IF (SPS-LE.0.0-AND-YDOT(3) .LT.0.0) YDOT(3) = 0.0
YDOT(4) = -RM1*YDOT(1)/V1 - RMD13/V1
YDOT(5) = CL1*YDOT(4)/G0
YDOT(6) = VPS*A3
IF (TVENT(1) .EQ. 10HVENT3) YDOT(6) = YDOT(6) - VCOR
YDOT(9) = VPS*A4
V34 = V3 + V4
PM34 = PM3 + PM4
YDOT(7) = -RM3*(YDOT(6) + YDOT(9))/V34 + RMD13/V34
YDOT(8) = (RM3*CG3/CG0) * (-YDOT(6) + YDOT(9))/V34 +
* (PM13/RML3*V34) + ((RMD3-RMD4)/(RMD3+V34)) *
* (1.0 - CG3/RML3 + G0*(HL3-M3)/(GAM-1.0))/
* (CG3*CG3*(1.0-CGV+MG3))
IF (PR-GE.PJRS) YDOT(10) = (PR-PJRS) * A4*G0/PJWT
APJ = YDOT(10)/(1.09A1*6*1.0E7)
YDOT(11) = VPSJ
YDOT(12) = YDOT(7)
YDOT(13) = YDOT(8)
YDOT(14) = G0*YDOT(8)/(CL3*CL3)
YDOT(15) = (RMD13-RMD3-RMD4)*V3/V34
YDOT(16) = YDOT(14)
YDOT(17) = YDOT(15)*V4/V3
YDOT(18) = (PM13 - PMD3(1) - PMD4(1) -
* (PML3(1) + PML4(1)) * DD3/DINC) * V3/V34
DO 155 I=2,9
IM=I-1
IDOT=I+17
YDOT(IDOT) = (-PMD3(I) - PMD4(I) +
* (PML3(IM) + PML4(IM) - PML3(I) - PML4(I)) * DD3/DINC) * V3/V34
155 CONTINUE
YDOT(27) = (-PMD3(10) - PMD4(10) +
* (PML3(9) + PML4(9)) * DD4/DINC) * V3/V34
DO 158 I=18,27
IP=I+10
158 YDOT(IP) = YDOT(I) * V4/V3
RETURN
150 CONTINUE
IF (MOD4.EQ.1) GO TO 160
C REGION 1 IS CLOSED.
C REGION 4 IS CLOSED.
YDOT(1) = 0.0
YDOT(2) = 0.0
YDOT(3) = 0.0
YDOT(4) = 0.0
YDOT(5) = 0.0
YDOT(6) = 0.0
V34 = V3 + V4
YDOT(9) = VPS*A4
YDOT(7) = -RM3*(YDOT(6) + YDOT(9))/V34

```

```

345 YDOT(9)=(RM3*CG3/G0)*(-YDOT(6)+YDOT(9)/V3 +
    * (RMD3-RMD4)/(RM3*V34))* (1.0 - RMG3/RHL3 +
    * G0*(HML3-H3)*(GAM-1.0)/(CG3*CG3*(1.0-COV*RMG3)))
    IF (PR-GE,PJRS)YDOT(10)=(PR-PJRS)*G0/PJMT
    IF (PR-LT,PJRS)YDOT(10)=0.0
    APJ=YDOT(10)/(1.098146*1.0E7)
    YDOT(11)=VPJ
350 YDOT(12)=YDOT(7)
    YDOT(13)=YDOT(8)
    YDOT(14)=G0*YDOT(8)/(CL3*CL3)
    YDOT(15)=(-RMD3-RMD4)*V3/V34
    YDOT(16)=YDOT(14)
    YDOT(17)=YDOT(15)*V4/V3
355 YDOT(18)=(-PM3(1) - PM04(1) -
    * (PML3(1)+PML4(1))*UD3/DINC)*V3/V34
    DO 145 I=2,9
    IM=I-1
    IDOT=I+17
360 YDOT(IDOT)= (-PM03(I) - PM04(I) +
    * (PML3(IM)+PML4(IM)-PML3(I)-PML4(I))*DD3/DINC)*V3/V34
    165 CONTINUE
365 YDOT(27)= (-PM03(10) - PM04(10) +
    * (PML3(9)+PML4(9))*DD3/DINC)*V3/V34
    DO 168 I=18,27
    IP=I-10
370 168 YDOT(IP)=YDOT(I)*V4/V3
    RETURN
    160 CONTINUE
    C REGION 1 IS CLOSED.
    C REGION 4 IS OPEN.
375 YDOT(1)=0.0
    YDOT(2)=0.0
    YDOT(3)=0.0
    YDOT(4)=0.0
    YDOT(5)=0.0
    YDOT(6)=0.0
380 YDOT(7)=RM3*YDOT(6)/V3 -RMD34/V3
    YDOT(8)=(RM3*CG3/G0)*(-YDOT(6)/V3 +
    * (PMD3/(RMG3*V3))* (1.0 - RMG/RHL3 +
    * G0*(HML3-H3)*(GAM-1.0)/(CG3*CG3*(1.0-COV*RMG3))) -
    * RMD34/RM3)
    YDOT(9)=VPJ*AA
385 IF (PR-GE,PJRS)YDOT(10)=(PR-PJRS)*G0/PJMT
    IF (PR-LT,PJRS)YDOT(10)=0.0
    APJ=YDOT(10)/(1.098146*1.0E7)
    YDOT(11)=VPJ
390 YDOT(12)=RMA*YDOT(9)/V4 + RMD34/V4
    YDOT(13)=(-RMA*CG4/G0*V4) + (-YDOT(9) +
    * (RMD4/RMG4) + (1.0-RMG4/RHL4 +
    * G0*(HML4-H4)*(GAM-1.0)/(CG4*CG4*(1.0-COV*RMG4))) +
    * (PMD34/(RMG4*V3)) + (PML3*RMG4/RHL4 + RMG3 +
    * G0*RMG3*(H3-H4)*(GAM-1.0)/(CG4*CG4*(1.0-COV*RMG4))))
395 YDOT(14)=G0*YDOT(9)/(CL3*CL3)
    YDOT(15)=RML3+RMD34/V4 - RM03
    YDOT(16)=G0*YDOT(13)/(CL4*CL4)
    YDOT(17)=RML3+RMD34/V4 - PM04
    YDOT(18)=PML3(1)+PML4(1)+UD3/DINC

```

02/27/95 13.15.44

FTN 4.8.601

SUBROUTINE FPROP3 76/76 OPT=1 ROUND=0/ TRACE

```

400      * PML3(1)*DD3/DINC
      DO 175 I=2,9
      IM=I-1
      IDOT=I*17
      YDOT(IDOT)=PML3(1)*RMD34/RM3 - PWD3(I) *
      * (PML3(IM)-PML3(1))*DD3/DINC
      175 CONTINUE
405      YDOT(27)=PML3(10)*RMD34/RM3 - PWD3(10) *
      * PML3(9)*DD3/DINC
      YDOT(28)=PML3(1)*RMD34/RM3-PWD4(1)-
      * PML4(1)*DD4/DINC
      DO 178 I=2,9
      IM=I-1
      IDOT=I*27
      YDOT(IDOT)=PML3(1)*RMD34/RM3 - PWD4(I) *
      * (PML4(IM)-PML4(1))*DD4/DINC
      178 CONTINUE
      YDOT(37)=PML3(10)*RMD34/RM3 - PWD4(10) *
      * PML4(9)*DD4/DINC
      RETURN
      END
410
415
420

```

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018890
018900
018910
018920

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02/22/85 13.15.44

FTN 4.8.401

74/75 OPT=1 ROUND=4-0/ TRACE

SUBROUTINE PERERV

018930 -
018940 -
018950

SUBROUTINE PERERV (N, T, Y, PD, MD)
RETURN
END

1

```

1      SURROUTINE DRIVE(N,T0,H0,Y0,TOUT,EPS,IFROR,PF,INDEX)
C THIS IS THE JUNE 24, 1975 VERSION OF
C EPISODE.. EXPERIMENTAL PACKAGE FOR INTEGRATION OF
C SYSTEMS OF ORDINARY DIFFERENTIAL EQUATIONS.
C   DY/DX = F(Y,X), Y = (Y(1),Y(2),...,Y(N)) TRANSPOSE,
C   GIVEN THE INITIAL VALUE OF Y.
C THIS CODE IS FOR THE IBM 370/195 AT ARGONNE NATIONAL LABORATORY
C AND IS A MODIFICATION OF EARLIER VERSIONS BY G.D. RYNE
C AND A.C. HINDMARSH.
C
10     REFERENCES
C 1. G. D. RYNE AND A. C. HINDMARSH, A POLYALGORITHM FOR THE
C    NUMERICAL SOLUTION OF ORDINARY DIFFERENTIAL EQUATIONS,
C    UCRL-75652, LAWRENCE LIVERMORE LABORATORY, P. O. BOX 808,
C    LIVERMORE, CA 94550, APRIL 1974. ALSO IN ACM TRANSACTIONS
C    ON MATHEMATICAL SOFTWARE, 1 (1975), PP. 71-96.
C
15     C 2. A. C. HINDMARSH AND G. D. RYNE, EPISODE.. AN EXPERIMENTAL
C        PACKAGE FOR THE INTEGRATION OF SYSTEMS OF ORDINARY
C        DIFFERENTIAL EQUATIONS, UCID-30112, L.L.L., MAY, 1975.
C
20     C 3. A. C. HINDMARSH, GEAR.. ORDINARY DIFFERENTIAL EQUATION
C        SYSTEM SOLVER, UCID-30001, REV. 3, L.L.L., DECEMBER, 1974.
C
25     -----
C DRIVE IS A DRIVER SUBROUTINE FOR THE EPISODE PACKAGE.
C DRIVE IS TO BE CALLED ONCE FOR EACH OUTPUT VALUE OF T.
C IT THEN MAKES REPEATED CALLS TO THE CODE INTEGRATOR
C SUBROUTINE, TSTEP.
C
30     C THE INPUT PARAMETERS ARE AS FOLLOWS.
C   N = THE NUMBER OF DIFFERENTIAL EQUATIONS (USED ONLY ON
C       FIRST CALL, UNLESS INDEX = -1). N MUST NEVER BE
C       INCREASED DURING A GIVEN PROBLEM.
C   T0 = THE INITIAL VALUE OF T, THE INDEPENDENT VARIABLE
C       USED FOR INPUT ONLY ON FIRST CALL.
C   H0 = THE STEP SIZE IN T (USED FOR INPUT ONLY ON THE
C       FIRST CALL, UNLESS INDEX = 3 ON INPUT). WHEN
C       INDEX = 3, H0 IS THE MAXIMUM ABSOLUTE VALUE OF
C       THE STEP SIZE TO BE USED.
C   Y0 = A VECTOR OF LENGTH N CONTAINING THE INITIAL VALUES OF
C       Y (USED FOR INPUT ONLY ON FIRST CALL).
C   TOUT = THE VALUE OF T AT WHICH OUTPUT IS DESIRED NEXT.
C          INTEGRATION WILL NORMALLY GO BEYOND TOUT AND
C          INTERPOLATE TO T = TOUT. (USED ONLY FOR INPUT.)
C   EPS = THE RELATIVE ERROR BOUND (USED ONLY ON FIRST CALL,
C          UNLESS INDEX = -1). THIS BOUND IS USED AS FOLLOWS.
C          LET R(I) DENOTE THE ESTIMATED RELATIVE LOCAL ERROR
C          IN Y(I), I.E. THE ERROR RELATIVE TO YMAX(I). AS
C          MEASURED PER STEP (OF SIZE H) OR PER 55 UNITS OF T.
C          THEN EPS IS A BOUND ON THE ROOT-MEAN-SQUARE NORM
C          OF THE VECTOR R, I.E.
C
40     N
C      SORT ( SUM ( R(I)**2 ), N ) .LT. EPS.
C      I=1
C
45     THE VECTOR YMAX IS COMPUTED IN DRIVE AS DESCRIBED
C      UNDER IERROR BELOW.
C
50     IF EROOP CONTROL PER 55 UNITS OF T IS DESIRED, SET 55
55

```

```

C      TO A POSITIVE NUMBER AFTER STATEMENT 10 (WHERE IT IS
C      NOW SET TO ZERO) AND UPDATE IT AFTER STATEMENT 60.
C      SEE ALSO THE COMMENTS ON SS AND YMAX BELOW.
C      THE ERROR FLAG WITH VALUES AND MEANINGS AS FOLLOW.
C      1 ABSOLUTE ERROR IS CONTROLLED. YMAX(1) = 1.0.
C      2 ERROR RELATIVE TO ABS(Y) IS CONTROLLED. IF Y(1) = 0.0
C      A DIVIDE ERROR WILL OCCUR. YMAX(1) = ABS(Y(1)).
C      3 ERROR RELATIVE TO THE LARGEST VALUE OF ABS(Y(I)) SEEN
C      SO FAR IS CONTROLLED. IF THE INITIAL VALUE OF Y(1) IS
C      0.0, THEN YMAX(1) IS SET TO 1.0 INITIALLY AND REMAINS
C      AT LEAST 1.0.
C      MF = THE METHOD FLAG (USED ONLY ON FIRST CALL, UNLESS
C      INDEX = -1). ALLOWED VALUES ARE 10, 11, 12, 13,
C      20, 21, 22, 23. MF IS AN INTEGER WITH TWO DECIMAL
C      DIGITS. METH AND MITER (MF = 10*METH + MITER). (MF
C      CAN BE THOUGHT OF AS THE ORDERED PAIR (METH,MITER).)
C      METH IS THE BASIC METHOD INDICATOR.
C      METH = 1 INDICATES VARIABLE-STEP SIZE, VARIABLE-
C      ORDER ADAMS METHOD, SUITABLE FOR NON-
C      STIFF PROBLEMS.
C      METH = 2 INDICATES VARIABLE-STEP SIZE, VARIABLE-
C      ORDER BACKWARD DIFFERENTIATION METHOD.
C      SUITABLE FOR STIFF PROBLEMS.
C      MITER INDICATES THE METHOD OF ITERATIVE CORRECTION
C      (NONLINEAR SYSTEM SOLUTION).
C      MITER = 0 INDICATES FUNCTIONAL ITERATION (NO
C      PARTIAL DERIVATIVES NEEDED).
C      MITER = 1 INDICATES A CHORD OR SEMI-STATIONARY
C      NEWTON METHOD WITH CLOSED FORM (EXACT)
C      JACOBIAN, WHICH IS COMPUTED IN THE
C      USER SUPPLIED SUBROUTINE
C      PEDERVIN,T,Y,PD,N0) DESCRIBED BELOW.
C      MITER = 2 INDICATES A CHORD OR SEMI-STATIONARY
C      NEWTON METHOD WITH AN INTERNALLY
C      COMPUTED FINITE DIFFERENCE APPROXIMATION
C      TO THE JACOBIAN.
C      MITER = 3 INDICATES A CHORD OR SEMI-STATIONARY
C      NEWTON METHOD WITH AN INTERNALLY
C      COMPUTED DIAGONAL MATRIX APPROXIMATION
C      TO THE JACOBIAN, BASED ON A DIAGONAL
C      DERIVATIVE.
C      INDEX = INTEGER USED ON INPUT TO INDICATE TYPE OF CALL.
C      WITH THE FOLLOWING VALUES AND MEANINGS..
C      1 THIS IS THE FIRST CALL FOR THIS PROBLEM.
C      0 THIS IS NOT THE FIRST CALL FOR THIS PROBLEM,
C      AND INTEGRATION IS TO CONTINUE.
C      -1 THIS IS NOT THE FIRST CALL FOR THE PROBLEM,
C      AND THE USER HAS RESET N, EPS, AND/OR MF.
C      2 SAME AS 0 EXCEPT THAT TOUT IS TO BE HIT
C      EXACTLY (NO INTERPOLATION IS DONE).
C      ASSUMES TOUT .GE. THE CURRENT T.
C      3 SAME AS 0 EXCEPT CONTROL RETURNS TO CALLING
C      PROGRAM AFTER ONE STEP. TOUT IS IGNORED.
C      SINCE THE NORMAL OUTPUT VALUE OF INDEX IS 0,
C      IT NEED NOT BE RESET FOR NORMAL CONTINUATION.
C      C AFTER THE INITIAL CALL. IF A NORMAL RETURN OCCURRED AND A NORMAL

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02/22/85 13.15.44

FTN 4.8+401

76/76 OPT=1 ROUNDO=--e/ TRACE

```

115 C CONTINUATION IS DESIRED, SIMPLY RESET TOUT AND CALL AGAIN.
116 C ALL OTHER PARAMETERS WILL BE READY FOR THE NEXT CALL.
117 C A CHANGE OF PARAMETERS WITH INDEX = -1 CAN BE MADE AFTER
118 C EITHER A SUCCESSFUL OR AN UNSUCCESSFUL RETURN.
119
120 C THE OUTPUT PARAMETERS ARE AS FOLLOWS.
121 C T0 = THE OUTPUT VALUE OF T. IF INTEGRATION WAS SUCCESSFUL,
122 C T0 = TOUT. OTHERWISE, T0 IS THE LAST VALUE OF T
123 C REACHED SUCCESSFULLY.
124 C M0 = THE STEP SIZE H USED LAST, WHETHER SUCCESSFULLY OR NOT.
125 C Y0 = THE COMPUTED VALUES OF Y AT T = T0.
126 C INDEX = INTEGER USED ON OUTPUT TO INDICATE RESULTS.
127 C WITH THE FOLLOWING VALUES AND MEANINGS..
128 C 0 INTEGRATION WAS COMPLETED TO TOUT OR BEYOND.
129 C -1 THE INTEGRATION WAS HALTED AFTER FAILING TO PASS THE
130 C ERROR TEST EVEN AFTER REDUCING H BY A FACTOR OF
131 C 1.E10 FROM ITS INITIAL VALUE.
132 C -2 AFTER SOME INITIAL SUCCESS, THE INTEGRATION WAS
133 C HALTED EITHER BY REPEATED ERROR TEST FAILURES OR
134 C BY A TEST ON EPS. POSSIBLY TOO MUCH ACCURACY WAS
135 C BEEN REQUESTED, OR A BAD CHOICE OF MF WAS MADE.
136 C -3 THE INTEGRATION WAS HALTED AFTER FAILING TO ACHIEVE
137 C CORRECTOR CONVERGENCE EVEN AFTER REDUCING H BY A
138 C FACTOR OF 1.E10 FROM ITS INITIAL VALUE.
139 C -4 IMMEDIATE HALT BECAUSE OF ILLEGAL VALUES OF INPUT
140 C PARAMETERS. SEE PRINTED MESSAGE.
141 C -5 INDEX WAS -1 ON INPUT, BUT THE DESIRED CHANGES OF
142 C PARAMETERS WERE NOT IMPLEMENTED BECAUSE TOUT WAS
143 C NOT BEYOND T. INTERPOLATION TO T = TOUT WAS
144 C PERFORMED AS ON A NORMAL RETURN. TO CONTINUE,
145 C SIMPLY CALL AGAIN WITH INDEX = -1 AND A NEW TOUT.
146 C INDEX WAS 2 ON INPUT, BUT TOUT WAS NOT BEYOND T.
147 C NO ACTION WAS TAKEN.
148
149 C IN ADDITION TO DRIVE, THE FOLLOWING SUBROUTINES ARE USED BY AND
150 C PROVIDED IN THIS PACKAGE
151 C INTERP(TOUT,Y,N0,Y0) INTERPOLATES TO GIVE OUTPUT VALUES AT
152 C T = TOUT BY USING DATA IN THE Y ARRAY.
153 C TSTEP(Y,N0) IS THE CORE INTEGRATION SUBROUTINE, WHICH INTEGRATES
154 C OVER A SINGLE STEP AND DOES ASSOCIATED ERROR
155 C CONTROL.
156 C COSET SETS COEFFICIENTS FOR USE IN TSTEP.
157 C ADJUST(Y,N0) ADJUSTS THE HISTORY ARRAY Y ON REDUCTION OF ORDER.
158 C PSET(Y,N0,CON,MITER,IER) COMPUTES AND PROCESSES THE JACOBIAN
159 C MATRIX, J = DF/DY.
160 C DECIN(N0,A,IP,IER) PERFORMS THE LU DECOMPOSITION OF A MATRIX.
161 C SOL(N,N0,A,R,IP) SOLVES A LINEAR SYSTEM A*X = R, AFTER DEC
162 C HAS BEEN CALLED FOR THE MATRIX A.
163 C NOTE PSET, DEC, AND SOL ARE CALLED IF AND ONLY IF MITER = 1
164 C OR MITER = 2.
165
166 C THE USER MUST FURNISH THE FOLLOWING SUBROUTINES
167 C DIFFFUN(N,T,Y,YDOT) COMPUTES THE FUNCTION YDOT = F(Y,T).
168 C THE RIGHT HAND SIDE OF THE ORDINARY
169 C DIFFERENTIAL EQUATION SYSTEM, WHERE Y
170 C AND YDOT ARE VECTORS OF LENGTH N.
171 C PEDERFV(N,T,Y,P0,N0) COMPUTES THE N BY N JACOBIAN MATRIX OF

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108

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FTN 4.8x401

TRACE

76/76

SUBROUTINE DRIVE

OPT=1 HOUND=0-0/

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230      IF (INDEX.EQ. 3) GO TO 40
      IF (INDEX.NE. 1) GO TO 430
      IF (FPS.LE. 7E0) GO TO 400
      IF (4.LE. 0) GO TO 410
      IF ((T0-TOUT)*H0.GE. 2E0) GO TO 420
-----
235      C IF INITIAL VALUES FOR YMAX OTHER THAN THOSE BELOW ARE DESIRED,
      C THEY SHOULD BE SET HERE. ALL YMAX(I) MUST BE POSITIVE. IF
      C VALUES FOR HMIN OR HMAX, THE ROUNDS ON THE ABSOLUTE VALUE OF H,
      C OTHER THAN THOSE BELOW, ARE DESIRED, THEY ALSO SHOULD BE SET HERE.
      C IF ERROR PER SS UNITS OF T IS TO BE CONTROLLED, SS SHOULD BE SET
      C TO A POSITIVE VALUE BELOW. ERROR PER UNIT STEP IS CONTROLLED
      C WHEN SS = 1. THE DEFAULT VALUE FOR SS IS 0 AND YIELDS CONTROL
      C OF ERROR PER STEP.
-----
240      C SET URROUND, THE MACHINE ROUNDOFF CONSTANT, HERE.
      C USE STATEMENT BELOW FOR SHORT PRECISION ON IBM 360 OR 370.
      C URROUND = 9.53674E-7
      C USE STATEMENT BELOW FOR SINGLE PRECISION ON CDC 7600 OR 6600.
      C URROUND = 7.105427406E-15
      C USE STATEMENT BELOW FOR LONG PRECISION ON IBM 360 OR 370.
-----
245      URROUND=7.105427406E-15
      DO 10 I = 1,N
      GO TO (5, 6, 7), IERROR
      C IERRORP = 1, 2, 3 -----
      5      YMAX(I) = ONE
      GO TO 10
      C
      6      YMAX(I)=AMAX1(Y0(I),SPEC)
      GO TO 10
      7      YMAX(I)=ABS(Y0(I))
      IF (YMAX(I).EQ. ZERO) YMAX(I) = ONE
      10      Y(I,1) = Y0(I)
      NC = N
      T = T0
      H = H0
      IF ((T+H).EQ. T) WRITE(6,15) T
      C
      15 FORMAT(/46H--- MESSAGE FROM SUBROUTINE DRIVE IN EPISODE..
      1 24H THE O.D.E. SOLVER. ---/22H WARNING.. T + H = T =,
      2E18.8,14H IN THE NEXT STEP./)
      HMIN=ABS(H0)
      HMAX=ABS(T0-TOUT)*TEN
      EPSC = EPS
      HFC = HF
      JSTART = 0
      SS = ZERO
      N0 = N
      NSQ = 40*N0
      FPSJ=SQRT(1/URROUND)
      NCUT = 0
      GO TO 50
      C TOP IS THE PREVIOUS OUTPUT VALUE OF T0 FOR USE IN HMAX. -----
      20      HMAX=ABS(TOUT-TOP)*TEN
      GO TO 40
      25      HMAX=ABS(TOUT-TOP)*TEN

```

```

      C
      30 IF ((T-TOUT)*H .GE. ZFPO) GO TO 450
      GO TO 45
      205 C
      40 HMAX = H0
      C
      45 IF ((T+H) .EQ. T) WRITE(6,15) T
      C
      50 CALL TSTEP(N0,NS0,Y,YMAX,ERROR,SAVE1,SAVE2,SAVE3,PV,PTV)
      C
      KGO = 1 - KFLAG
      GO TO (60, 100, 200, 300), KGO
      C KFLAG = 0, -1, -2, -3
      C
      60 CONTINUE
      C
      C NORMAL RETURN FROM TSTEP.
      C
      C THE WEIGHTS YMAX(1) ARE UPDATED. IF DIFFERENT VALUES ARE DESIRED,
      C THEY SHOULD BE SET HERE. IF SS IS TO BE UPDATED FOR CONTROL OF
      C ERROR PER SS UNITS OF T, IT SHOULD ALSO BE DONE HERE. A TEST IS
      C MADE TO DETERMINE IF EPS IS TOO SMALL FOR MACHINE PRECISION.
      C
      C ANY OTHER TESTS OR CALCULATIONS THAT ARE REQUIRED AFTER EACH STEP
      C SHOULD BE INSERTED HERE.
      C
      C IF INDEX = 3, Y0 IS SET TO THE CURRENT Y VALUES ON RETURN.
      C IF INDEX = 2, H IS CONTROLLED TO HIT TOUT (WITHIN ROUNDOFF
      C ERROR), AND THEN THE CURRENT Y VALUES ARE PUT IN Y0 ON
      C RETURN. FOR ANY OTHER VALUE OF INDEX, CONTROL RETURNS TO
      C THE INTEGRATOR UNLESS TOUT HAS BEEN REACHED. THEN
      C INTERPOLATED VALUES OF Y ARE COMPUTED AND STORED IN Y0 ON
      C RETURN.
      C IF INTERPOLATION IS NOT DESIRED, THE CALL TO INTERP SHOULD
      C BE DELETED AND CONTROL TRANSFERRED TO STATEMENT 500 INSTEAD
      C OF 520.
      C
      D = ZERO
      DO 70 I = 1,N
      AYI=ABS(Y(I,1))
      GO TO (70, 66, 67), IERROR
      C IERROR = 1, 2, 3
      66 YMAX(I)=AMAX1(AYI,SHC)
      GO TO 70
      67 YMAX(I)=AMAX1(YMAX(I),AYI)
      70 D=0.(AYI/YMAX(I))**2
      D=D+(UPRND/EPS)**2
      IF (D.GT.FLOAT(N)) GO TO 250
      IF (INDEX .EQ. 3) GO TO 500
      IF (INDEX .EQ. 2) GO TO 45

```

```

145      A0 IF ((T-TOUT)*4 .LT. ZERO) GO TO 45
        CALL INTERP (TOUT, Y, NO, Y0)
        TO = TOUT
        GO TO 520
146      A5 IF ((T-H)-TOUT)*4 .LT. ZERO) GO TO 45
        IF (ABS(T-TOUT).LT.HUNDRED*UPROUND*HMAX) GO TO 500
        IF ((T-TOUT)*4 .GE. ZERO) GO TO 500
        H = (TOUT - T)*(ONE - FOUR*URROUND)
        JSTART = -1
        GO TO 45
147      C-----
        C ON AN ERROR RETURN FROM TSTEP, AN IMMEDIATE RETURN OCCURS IF
        C MFLAG = -2, AND RECOVERY ATTEMPTS ARE MADE OTHERWISE.
        C TO RECOVER, H AND HMIN ARE REDUCED BY A FACTOR OF .1 UP TO 10
        C TIMES BEFORE GIVING UP.
        C-----
148      100 WRITE (6,101)
149      101 FORMAT ('//46M--- MESSAGE FROM SUBROUTINE DRIVE IN EPISODE..
150      1 24M THE O.D.E. SOLVER. ---//')
151      WRITE (6,4400) J1
152      4400 FORMAT (5X, 'J1 =', I5)
153      WRITE (6,105) T, HMIN
154      105 FORMAT ('//35M KFLAG = -1 FROM INTEGRATOR AT T =', E10.8, /
155      140M ERROR TEST FAILED WITH ABS(H) = HMIN =', E10.8, /
156      110 IF (HNCUT .EQ. 10) GO TO 150
157      HNCUT = HNCUT + 1
158      HMIN = HNCUT*HMIN
159      H = HNCUT*H
160      WRITE (6,115) H
161      115 FORMAT (24H 'H HAS BEEN REDUCED TO', E10.8,
162      1 24M AND STEP WILL BE RETRIED//')
163      JSTART = -1
164      GO TO 45
165      C
166      150 WRITE (6,155)
167      155 FORMAT ('//46M PROBLEM APPEARS UNSOLVABLE WITH GIVEN INPUT//')
168      GO TO 500
169      C
170      200 WRITE (6,101)
171      WRITE (6,205) T, H, EPS
172      205 FORMAT ('//16M KFLAG = -2 T =', E10.8, 4H 'H =', E10.8, 6H 'EPS =', E10.8, /
173      1 50M THE REQUESTED ERROR IS TOO SMALL FOR INTEGRATOR.//')
174      GO TO 500
175      C
176      250 WRITE (6,101)
177      WRITE (6,255) T, EPS
178      C
179      255 FORMAT ('//46M INTEGRATION HALTED BY SUBROUTINE DRIVE AT T =',
180      1 E10.8, 43M 'EPS IS TOO SMALL FOR MACHINE PRECISION AND/
181      2 29M PROBLEM BEING SOLVED. EPS =', E10.8, //')
182      KFLAG = -2
183      GO TO 500
184      C
185      300 WRITE (6,101)
186      WRITE (6,305) T
187      305 FORMAT ('//34M KFLAG = -3 FROM INTEGRATOR AT T =', E10.8, /
188      1 46M CORRECTING CONVERGENCE COULD NOT BE ACHIEVED//')

```

```

400      GO TO 110
      C
400      WRITE (6,101)
401      WRITE (6,405) EPS
405      FORMAT(/35H ILLEGAL INPUT.. EPS .EE. 0. EPS = .E18.R//)
      INDEX = -4
      RETURN
      C
410      WRITE (6,101)
411      WRITE (6,415) N
415      FORMAT(/31H ILLEGAL INPUT.. N .LE. 0. N = .I9//)
      INDEX = -4
      RETURN
      C
420      WRITE (6,101)
421      WRITE (6,425) T0,TOUT,MH
425      FORMAT(/39H ILLEGAL INPUT.. (T0 - TOUT)*MH .GE. 0./
      1 5H T0 =.E18.R.7H TOUT =.E18.R.5H MH =.E18.R//)
      INDEX = -4
      RETURN
      C
430      WRITE (6,101)
431      WRITE (6,435) INDEX
435      FORMAT(/24H ILLEGAL INPUT.. INDEX =.I8//)
      INDEX = -4
      RETURN
      C
440      WRITE (6,101)
441      WRITE (6,445) N
445      FORMAT (/39H ILLEGAL INPUT.. THE NUMBER OF ORDINARY/
      1 43H DIFFERENTIAL EQUATIONS BEING SOLVED IS N =. I6/
      2 42H STORAGE ALLOCATION IN SUBROUTINE DRIVE IS/
      3 46H TOO SMALL. SEE COMMENTS IN SUBROUTINE DRIVE../)
      INDEX = -4
      RETURN
      C
450      WRITE (6,101)
451      WRITE (6,455) T,TOUT,MH
455      FORMAT(/46H INDEX = -1 ON INPUT WITH (T - TOUT)*MH .GE. 0./
      1 44H INTERPOLATION HAS DONE AS ON NORMAL RETURN./
      2 41H DESIRED PARAMETER CHANGES WERE NOT MADE./
      3 44H T =.E18.R.7H TOUT =.E18.R.4H MH =.E18.R//)
      CALL INTERP (TOUT, Y, N0, Y0)
      T0 = TOUT
      INDEX = -5
      RETURN
      C
460      WRITE (6,101)
461      WRITE (6,465) T,TOUT,MH
465      FORMAT(/45H INDEX = 2 ON INPUT WITH (T - TOUT)*MH .GE. 0./
      1 44H T =.E18.R.7H TOUT =.E18.R.4H MH =.E18.R//)
      INDEX = -4
      RETURN
      C
470      T0 = T

```

02/22/85 13.15.44

FTN 4.9.601

TRACE

OPT=1 ROUND=0.0/

76/76

SUBROUTINE DRIVE

023520 -
023530
023540
023550
023560
023570
023580
023590
023600

DO 510 I = 1,N
510 Y0(I) = Y(I,1)
520 INDFX = KFLAG
TOP = T0
M0 = MUSED
IF (KFLAG .NE. 0) M0 = M
RETURN
C----- END OF SUBROUTINE DRIVE -----
END

460
465

CARD NR. SEVERITY DETAILS DIAGNOSIS OF PROBLEM

253 I AN IF STATEMENT MAY BE MORE EFFICIENT THAN A 2 OR 3 BRANCH COMPUTED GO TO STATEMENT.
313 I AN IF STATEMENT MAY BE MORE EFFICIENT THAN A 2 OR 3 BRANCH COMPUTED GO TO STATEMENT.

```

1      SUBROUTINE INTERP (TOUT, Y, N0, Y0)
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23910

5      C-----
6      C SUBROUTINE INTERP COMPUTES INTERPOLATED VALUES OF THE DEPENDENT
7      C VARIABLE Y AND STORES THEM IN Y0. THE INTERPOLATION IS TO THE
8      C POINT T = TOUT AND USES THE NORDSIECK HISTORY ARRAY Y AS FOLLOWS..
9      C
10     C NO
11     C      Y0(I) = SUM Y(I,J)*S**J ,
12     C      J=0
13     C WHERE S = -(T-TOUT)/H.
14     C-----
15     C CAUTION NOT ALL MEMBERS OF EPCOM1 ARE USED IN THIS SUBROUTINE.
16     C-----
17     C DIMENSION Y0(N0),Y(N0,13)
18     C COMMON /EPCOM1/ T,H,MMIN,HMAX,EPS,SS,URUND,N,MF,KFLAG,JSTART
19     C ONE=1.0
20     C DO 10 I = 1,N
21     C      Y0(I) = Y(I,1)
22     C      L = JSTART + 1
23     C      S = (TOUT - T)/H
24     C      S1 = ONE
25     C      DO 30 J = 2,L
26     C        S1 = S1*S
27     C        DO 20 I = 1,N
28     C          Y0(I) = Y0(I) + S1*Y(I,J)
29     C        CONTINUE
30     C      RETURN
31     C-----
32     C END OF SUBROUTINE INTERP
33     C-----
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02/22/85 13.15.44

FTN 4.0.401

74/76 OPT=1 ROUNDO=.../ TRACE

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1  SUBROUTINE TSTEP(M0,NSD,Y,VMAX,FDPDR,SAVE,I,SAVE2,SAVE3,
   * PW,PIV)
5  C TSTEP PERFORMS ONE STEP OF THE INTEGRATION OF AN INITIAL VALUE
   C PROBLEM FOR A SYSTEM OF ORDINARY DIFFERENTIAL EQUATIONS.
   C COMMUNICATION WITH TSTEP IS VIA THE FOLLOWING VARIABLES..
10  C Y AN M0 BY LMAX ARRAY CONTAINING THE DEPENDENT VARIABLES
   C AND THEIR SCALED DERIVATIVES. LMAX IS CURRENTLY 6 FOR
   C THE VARIABLE STEP BACKWARD DIFFERENTIATION FORMULAS.
   C AND 13 FOR THE VARIABLE STEP ADAMS FORMULAS.
   C (LMAX -1) = MAXDER. THE MAXIMUM ORDER USED.
   C SEE SUBROUTINE COSET. Y(I,J+1) CONTAINS THE
   C J-TH DERIVATIVE OF Y(I), SCALED BY M0/J*FACTORIAL(J)
   C FOR J = 0,1,...,NQ. WHERE NQ IS THE CURRENT ORDER.
15  C M0 A CONSTANT INTEGER .GE. N. USED FOR DIMENSIONING
   C PURPOSES.
   C T THE INDEPENDENT VARIABLE, UPDATED ON EACH STEP TAKEN.
   C H THE STEP SIZE TO BE ATTEMPTED ON THE NEXT STEP.
   C M IS ALTERED BY THE ERROR CONTROL ALGORITHM DURING
   C THE SOLUTION OF THE PROBLEM. M CAN BE EITHER POSITIVE
   C OR NEGATIVE, BUT ITS SIGN MUST REMAIN CONSTANT
   C THROUGHOUT THE PROBLEM RUN.
   C HMIN, HMAX THE MINIMUM AND MAXIMUM ABSOLUTE VALUES OF THE STEP
   C SIZE TO BE USED FOR THE STEP. THESE MAY BE CHANGED AT
   C ANY TIME. BUT THE CHANGE WILL NOT TAKE EFFECT UNTIL THE
   C NEXT CHANGE IN M IS MADE.
20  C EPS THE RELATIVE ERROR BOUND. SEE DESCRIPTION IN
   C SUBROUTINE DRIVE.
   C SS THE SIZE OF THE TIME INTERVAL TO BE USED FOR ERROR
   C CONTROL. A DEFAULT VALUE OF 0 IS USED TO PRODUCE
   C CONTROL OF ERROR PER STEP. SEE SUBROUTINE DRIVE.
   C UROUND THE UNIT OF ROUNDOFF FOR THE COMPUTER BEING USED.
   C N THE NUMBER OF FIRST ORDER ORDINARY DIFFERENTIAL
   C EQUATIONS BEING SOLVED.
30  C MF THE METHOD FLAG. SEE DESCRIPTION IN SUBROUTINE DRIVE.
   C KFLAG A COMPLETION CODE WITH THE FOLLOWING MEANINGS..
   C 0 THE STEP WAS SUCCESSFUL.
   C -1 THE REQUESTED ERROR COULD NOT BE ACHIEVED
   C WITH ABS(H) = HMIN.
   C -2 THE REQUESTED ERROR IS SMALLER THAN CAN
   C BE HANDLED FOR THIS PROBLEM.
   C -3 CORRECTOR CONVERGENCE COULD NOT BE
   C ACHIEVED FOR ABS(H) = HMIN.
   C ON A RETURN WITH KFLAG NEGATIVE, THE VALUES OF T AND
   C THE Y ARRAY ARE AS OF THE BEGINNING OF THE LAST
   C STEP AND M IS THE LAST STEP SIZE ATTEMPTED.
35  C JSTART AN INTEGER USED ON INPUT AND OUTPUT.
   C ON INPUT, IT HAS THE FOLLOWING VALUES AND MEANINGS..
   C 0 PERFORM THE FIRST STEP.
   C .GT.0 TAKE A NEW STEP CONTINUING FROM THE LAST.
   C .LT.0 TAKE THE NEXT STEP WITH A NEW VALUE OF
   C M AND/OR MF.
   C ON EXIT, JSTART IS SET TO NQ. THE CURRENT ORDER OF THE
   C METHOD.
   C Y-1AY AN ARRAY OF N ELEMENTS WITH WHICH THE ESTIMATED LOCAL
   C ERRORS IN Y ARE COMPARED.

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C      EPOOR      AM ARRAY OF N ELEMENTS. FPROP(1)/TO(2) IS THE
C      ESTIMATED LOCAL ERROR IN Y(I) PER SS UNITS OF
C      Y OR PER STEP (OF SIZE H).
C      SAVE1.      TWO ARRAYS FOR WORKING STORAGE.
C      SAVE2      EACH OF LENGTH N.
C      PW         A BLOCK OF LOCATIONS USED FOR THE PARTIAL DERIVATIVES
C      OF F WITH RESPECT TO Y. IF MITER IS NOT 0. SEE
C      DESCRIPTION IN SUBROUTINE DRIVE.
C      IPIV       AN INTEGER ARRAY OF LENGTH N, WHICH IS USED FOR PIVOT
C      INFORMATION FOR THE LINEAR ALGEBRAIC SYSTEM IN THE
C      CORRECTION PROCFS, WHEN MITER = 1 OR 2.
C
C THE COMMON BLOCK EPCMI0, DECLARED BELOW, IS PRIMARILY INTENDED
C FOR INTERNAL USE, BUT IT CAN BE ACCESSED EXTERNALLY.
C-----
C
C      DIMENSION Y(N0,13)
C      DIMENSION YMAX(N0),ERROR(N0),SAVE1(N0),SAVE2(N0),PW(N0),IPIV(N0)
C      DIMENSION SAVE3(N0)
C
C      COMMON /EPCMI0/ T,H,MMIN,MMAX,EPS,SS,UPOUND,N,MF,KFLAG,JSTART
C      COMMON/EPCMI0/NUSED,NSTEP,MFE,NJE,NMI
C      COMMON/TARINT/PWRITE,KOUTO,SPEC,TITLE(M),TVENT(8),TOPRO(8),TDSIS(8)
C      COMMON /EPCMI0/ TAU(13),EL(13),TQ(5),LMAX,METH,N0,L,NQINDX
C      COMMON/TAB1/G0,GAM,COV,ENER,OFFSET
C      COMMON/TAB2/RK1,RK2,RM1,VII,VPER
C      COMMON/TAB3/OC,AVENT,A1,A3,A4,AHOLE,VCOR
C      COMMON/TAB4/PSWT,PSTRAV,M001,NSACK,M004
C      COMMON/TAB5/C3,C4,RMD13,RMD34,RMD3,RMD4,RM1,RM3,RM4,RMSUM,RMINT
C      COMMON/TAB6/V1,VPS,SPS,RM1,P1,V3,RM3,P3,V4,VPJ,SPJ,APJ,RH4,P4
C      COMMON/TAB7/PJMT,TRAVEL
C      COMMON/TAB8/PSRS,PJRS,PL,PR,DC34
C      COMMON/TAB9/ELL,E03,EG4,EKPS,EKPJ,FKG4,ESUM,EINT
C      COMMON/TAB10/R1,NG,RS,CP,CV,TEMP3,TEMP4,HL1,HL3,HL4,H3,H4
C      COMMON/TAB11/LSKIP,LPAGE,TMS,RMAX(10)
C      COMMON/TAB12/NVENT,NVENT,AVMIN,AVMAX,AK,ACS
C      COMMON/TAB13/PI
C      COMMON/TAB14/DDP,ADR,RDR
C      COMMON/TAB15/CL1,CL3,CG3,CL4,CG4,RMG3,RML3,RMG4,RML4
C      COMMON/TAB16/RHG3,RML3,RMG4,RHL4,EL3,EL4,EK4
C      COMMON/TAB17/VG3,VL3,V64,VL4,EP53,EPS4
C      COMMON/TAB18/DINC,PDDR(10),PML3(10),PMD3(10),PML4(10),PMD4(10)
C      COMMON/TAB19/SIGMA,U13,WE
C      DATA ISTEPJ/20,KFC/-3,KFH/-7,MAXCOP/3/
C
C      DATA ANDON/1.0E-6,BIAS1/2.5E1/BIAS2/2.5E1/BIAS3/1.0E2/,
C      ICRDOWN/0.1E0,DELC/0.3E0,ETACF/0.25E0,ETAMIN/0.1E0/,
C      ZETAPF/0.2E0,ETAMX1/1.0E4,ETAMX2/1.0E1,ETAMX3/1.5E0/,
C      ZONEPSN/1.0001E0,SHORT/0.1E0,THRESH/1.3E0/
C      DATA ONE/1.0E0,PT5/0.5E0/ZERO/0.0E0/
C      KFLAG = 0
C      TOLD = T
C      FLOTN=FLOAT(N)
C      IF (JSTART .GT. 0) GO TO 200
C      IF (JSTART .NE. 0) GO TO 150
C-----
C ON THE FIRST CALL, THE ORDER IS SET TO 1 AND THE INITIAL

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02/22/85 13.15.66

FTN 4.8.401

76/76 OPT=1 ROUNDO=***/ TSPACE

SUBROUTINE TSTEP

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115 C DERIVATIVES ARE CALCULATED. ETAMAX IS THE MAXIMUM RATIO BY
C WHICH H CAN BE INCREASED IN A SINGLE STEP. IT IS 1.E04 FOR THE
C FIRST STEP TO COMPENSATE FOR THE SMALL INITIAL H, THEN 10 FOR
C THE NEXT 10 STEPS, AND THEN 1.5 THEREAFTER. IF A FAILURE
C OCCURS (IN CORRECTOR CONVERGENCE OR ERROR TEST), ETAMAX IS SET AT 1
C FOR THE NEXT INCREASE. ETAMIN = .1 IS THE MINIMUM RATIO BY WHICH
C H CAN BE REDUCED ON ANY RETRY OF A STEP.
C-----
      CALL DIFFIN(N,T,Y,SAVE1)
      DO 110 I = 1,N
110      Y(I,2) = H*SAVE1(I)
      METH = MF/10
      MITER = MF - 10*METH
      MITER1 = MITER + 1
      MFOLD = MF
      NO = 1
      L = 2
      TAU(I) = H
      PRL1 = ONE
      PC = ZERO
      ETAMAX = ETAMX1
      NOINH = 2
      NSTEP = 0
      NSTEPJ = 0
      NFE = 1
      NJE = 0
      TPRINT=.00005
      GO TO 200
C-----
125 C IF THE USER HAS CHANGED H, THEN Y MUST BE RESCALED. IF THE
C USER HAS CHANGED MITER, THEN NEWJ IS SET TO MITER TO FORCE
C THE PARTIAL DERIVATIVES TO BE UPDATED. IF THEY ARE BEING USED.
C-----
150 IF (MF.EQ. MFOLD) GO TO 170
      MIO = MITER
      METH = MF/10
      MITER = MF - 10*METH
      MFOLD = MF
      IF (MITER.EQ. MIO) GO TO 170
      NEWJ = MITER
      MITER1 = MITER + 1
170 IF (H.EQ. HOLD) GO TO 200
      ETA = H/HOLD
      H = HOLD
      IREDO = 3
      GO TO 185
180 ETAMAX1(ETA,HMIN/ABS(H),ETAMIN)
185 ETAMIN1(ETA,HMAX/ABS(H),ETAMAX)
      R1 = ONE
      DO 190 J = 2,L
          R1 = PI*ETA
190      Y(I,J) = Y(I,J)*R1
      H = H*ETA
      QC = QC*ETA
      IF (10*NO.EQ. 0) GO TO 400
C-----

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175 C THIS SECTION COMPUTES THE PREDICTED VALUES BY EFFECTIVELY
180 C MULTIPLYING THE Y ARRAY BY THE PASCAL TRIANGLE MATRIX. THEN
185 C COSET IS CALLED TO OBTAIN EL. THE VECTOR OF COEFFICIENTS OF
190 C LENGTH NO * 1. RC IS THE RATIO OF NEW TO OLD VALUES OF THE
195 C COEFFICIENT H/EL(2). WHEN RC DIFFERS FROM 1 BY MORE THAN
200 C DELPC, NEWJ IS SET TO MITER TO FORCE THE PARTIAL DERIVATIVES
205 C TO BE UPDATED. IF USED, DELPC IS 0.3. IN ANY CASE, THE PARTIAL
210 C DERIVATIVES ARE UPDATED AT LEAST EVERY 20-TH STEP.
215 DO 210 J1 = 1,NO
220 DO 210 J2 = J1,NO
225 J = (NO + J1) - J2
230 DO 210 I = 1,N
235 Y(I,J) = Y(I,J) + Y(I,J+1)
240 CALL COSET
245 BND = FLOTN*(TN(4)*EPS)**2
250 RL1 = ONE/EL(2)
255 RC = PC*(RL1/PP1)
260 PP1 = RL1
265 IF (NSTEP*GE. NSTEPJ+1STEPJ) NEWJ = MITER
270 DRC=ABS(RC-ONE)
275 IF (DRC.LE. DELPC) GO TO 215
280 NEWJ = MITER
285 CRATE = ONE
290 RC = ONE
295 GO TO 220
300 215 IF ((MITER.NE. 0) .AND. (DPC.NE. ZERO)) CRATE = ONE
305 C UP TO 3 CORRECTOR ITERATIONS ARE TAKEN. A CONVERGENCE TEST IS MADE
310 C ON THE ROOT MEAN SQUARE NORM OF EACH CORRECTION. USING BND, WHICH
315 C IS DEPENDENT ON EPS. THE SUM OF THE CORRECTIONS IS ACCUMULATED IN
320 C THE VECTOR ERROR. THE Y ARRAY IS NOT ALTERED IN THE CORRECTOR
325 C LOOP. THE UPDATED Y VECTOR IS STORED TEMPORARILY IN SAVE1.
330 DO 230 I = 1,N
335 FPROR(I) = ZERO
340 M = 0
345 CALL DIFFUN(M,T,Y,SAVE2)
350 NFE = NFE + 1
355 IF (NEWJ.LE. 0) GO TO 290
360 C IF INDICATED, THE MATRIX P = I - H*QL1*J IS REEVALUATED BEFORE
365 C STARTING THE CORRECTOR ITERATION. NEWJ IS SET TO 0 AS AN
370 C INDICATOR THAT THIS HAS BEEN DONE. IF MITER = 1 OR 2, P IS
375 C COMPUTED AND PROCESSED IN PSET. IF MITER = 3, THE MATRIX IS
380 C P = I - H*QL1*O, WHERE O IS A DIAGONAL MATRIX. RL1 IS 1/EL(2).
385 NEWJ = 0
390 RC = ONE
395 NJF = NJE + 1
400 NSTEPJ = NSTEP
405 GO TO (250, 240, 260), MITER
410 240 NFF = NFE + N
415 250 CON = -H*O*LI
420 CALL PSFT(Y,NO,CON,MITER,TER,NSO,YMAX,SAVE1,SAVE2,SAVE3,
425 * OM,IPIV)

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02/22/85 13.15.44

FTN 4.8.401

76/76 OPT=1 DDJND=**/ TRACE

SUBROUTINE TSIEP

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230      IF (IER.NE. 0) GO TO 420
        GO TO 350
240      R = RL1*SHORT
        DO 270 I = 1,N
          PW(I) = Y(I,1) + R*(H*SAVE2(I) - Y(I,2))
        CALL DIFFUN(N,T,PW,SAVE1)
235      NFE = NFE + 1
        HRL1 = H*RL1
        DO 240 I = 1,N
          R0 = H*SAVE2(I) - Y(I,2)
          PW(I) = ONE
          D = SHORT*R0 - H*(SAVE1(I) - SAVE2(I))
          SAVE1(I) = ZERO
          IF (ABS(R0).LT.URROUND*YMAX(I)) GO TO 240
          IF (ABS(D).EQ.ZERO) GO TO 420
          PW(I) = SHORT*R0/D
          SAVE1(I) = PW(I)*RL1*R0
245      CONTINUE
        GO TO 370
290      GO TO (295, 350, 350, 310), MITER1
C-----
250      C IN THE CASE OF FUNCTIONAL ITERATION, Y IS UPDATED DIRECTLY FROM
        C THE RESULT OF THE LAST DIFFUN CALL.
C-----
295      D = ZERO
        DO 300 I = 1,N
          P = RL1*(H*SAVE2(I) - Y(I,2))
          D = D + ((R - ERROR(I))/YMAX(I))*2
          SAVE1(I) = Y(I,1) + R
          ERROR(I) = R
        GO TO 400
300      C-----
        C IN THE CASE OF A CHORD METHOD, THE RESIDUAL -GIV SUB N(M)
        C IS COMPUTED AND THE LINEAR SYSTEM WITH THAT AS RIGHT-HAND SIDE
        C AND P AS COEFFICIENT MATRIX IS SOLVED, USING THE LU DECOMPOSITION
        C OF P IF MITER = 1 OR 2. IF MITER = 3 THE SCALAR H*RL1 IS UPDATED.
C-----
310      PHRL1 = HRL1
        HRL1 = H*RL1
        IF (HRL1.EQ. PHRL1) GO TO 330
        R = HRL1/PHRL1
        DO 320 I = 1,N
          D = ONE - R*(ONE - ONE/PW(I))
          IF (ABS(D).EQ.ZERO) GO TO 440
          PW(I) = ONE/D
        DO 340 I = 1,N
          SAVE1(I) = PW(I)*(RL1*H*SAVE2(I) - (RL1*Y(I,2) + ERROR(I)))
        GO TO 370
350      DO 360 I = 1,N
          SAVE3(I) = RL1*H*SAVE2(I) - (RL1*Y(I,2) + ERROR(I))
360      CALL SOLVE(N,M,N,PW,IPV,SAVE3,SAVE1)
        D = ZERO
        DO 380 I = 1,N
          ERROR(I) = ERROR(I) + SAVE1(I)
          D = D + (SAVE1(I)/YMAX(I))*2
          SAVE1(I) = Y(I,1) + ERROR(I)
380      C-----

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290      C TEST FOR CONVERGENCE. IF M.GT. 0. AN ESTIMATE OF THE SHAPE OF
      C THE CONVERGENCE RATE CONSTANT IS STORED IN CRATE, AND THIS IS USED
      C IN THE TEST.
      C-----
      400 IF (M.NE.0) CRATE=MAX1(CRDOWN*CRATE,D/01)
      IF (D*AMT1)(ONE,CRATE).LE.RND) GO TO 450
      D1 = 0
      M = M + 1
      IF (D.GE.1000.0*HND) M=MAXCOR
      IF (M.EQ. MAXCOR) GO TO 410
      CALL DIFFUN(NAT,SAVE1,SAVE2)
      GO TO (295, 350, 350, 310), MITER1
      C-----
      300      C THE CORRECTOR ITERATION FAILED TO CONVERGE IN 3 TRIES. IF PARTIAL
      C DERIVATIVES ARE INVOLVED BUT ARE NOT UP TO DATE, THEY ARE
      C REEVALUATED FOR THE NEXT TRY. OTHERWISE THE Y ARRAY IS RESTORED
      C TO ITS VALUES BEFORE PREDICTION, AND H IS REDUCED.
      C IF POSSIBLE. IF NOT, A NO-CONVERGENCE EXIT IS TAKEN.
      C-----
      410 NFE = NFE + MAXCOR - 1
      IF (NEWJ.EQ. -1) GO TO 440
      420 T = TOLD
      ETAMAX = ONE
      DO 430 J1 = 1,NQ
      DO 430 J2 = J1,NQ
      J = (NQ + J1) - J2
      DO 430 I = 1,N
      Y(I,J) = Y(I,J) - Y(I,J+1)
      430 IF (ABS(H).LE.HMIN*ONESM) GO TO 600
      ETA = ETACF
      IPED0 = 1
      GO TO 180
      440 NEWJ = MITER
      GO TO 220
      C-----
      320      C THE CORRECTOR HAS CONVERGED. NEWJ IS SET TO -1 IF PARTIAL
      C DERIVATIVES WERE USED, TO SIGNAL THAT THEY MAY NEED UPDATING ON
      C SUBSEQUENT STEPS. THE ERROR TEST IS MADE AND CONTROL PASSES TO
      C STATEMENT 500 IF IT FAILS.
      C-----
      450 IF (MITER.NE. 0) NEWJ = -1
      NFE = NFE + M
      D = ZERO
      DO 460 I = 1,N
      D = D + (ERROR(I)/YMAX(I))**2
      460 E = FLOTH(TQ(2)*EPS)**2
      C IF V1 IS NEGATIVE, WE HAVE GONE TOO FAR.
      C CUT BACK THE TIME STEP.
      IF (V1.LE.0.0) GO TO 500
      IF (D.GT. E) GO TO 500
      C-----
      335      C AFTER A SUCCESSFUL STEP, THE Y ARRAY, TAU, NSTEP, AND NOUNDX ARE
      C UPDATED, AND A NEW VALUE OF H AT ORDER NQ IS COMPUTED.
      C THE VECTOR TAU CONTAINS THE NQ + 1 MOST RECENT VALUES OF H.
      C A CHANGE IN NQ UP OR DOWN BY 1 IS CONSIDERED IF NOUNDX = 0.
      C IF NOUNDX = 1 AND NQ.LT. MAXNDR, THEN ERROR IS SAVED
      C FOR USE IN A POSSIBLE ORDER INCREASE ON THE NEXT STEP.
      C-----
      340

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345 C A CHANGE IN H OR NQ IS MADE ONLY OF THE INCREASE IN H
C IS BY A FACTOR OF AT LEAST 1.3.
C IF NOT, NQINDX IS SET TO 2 TO PREVENT TESTING FOR THAT MANY
C STEPS. IF NQ IS CHANGED, NQINDX IS SET TO NQ + 1 (NEW VALUE).
C-----
      KFLAG = 0
      IREDO = 0
      NSTEP = NSTEP + 1
      HUSED = H
      NGUSED = NO
      DO 470 IRACK = 1, NQ
        I = L - IRACK
        TAU(I+1) = TAU(I)
      470 TAU(I) = H
      DO 480 J = 1, L
        DO 480 I = 1, N
          Y(I,J) = Y(I,J) + ERROR(I)*EL(J)
      480 NQINDX = NQINDX - 1
      IF (L.EQ. LMAX) .OR. (NQINDX.NE. 1) GO TO 495
      DO 490 I = 1, N
        Y(I,LMAX) = ERROR(I)
      490 COMP = TQ(5)
      495 IF (ETAMAX.NE. ONE) GO TO 520
      IF (NQINDX.LT. 2) NQINDX = 2
      GO TO 690
C-----
370 C THE ERROR TEST FAILED. KFLAG KEEPS TRACK OF MULTIPLE FAILURES.
C T AND THE Y ARRAY ARE RESTORED TO THEIR PREVIOUS VALUES. A NEW
C H FOR A RETRY OF THE STEP IS COMPUTED. THE ORDER IS KEPT FIXED.
C-----
      500 KFLAG = KFLAG + 1
      T = TOLD
      DO 510 J1 = 1, NQ
        DO 510 J2 = J1, NQ
          J = (NQ + J1) - J2
          DO 510 I = 1, N
            Y(I,J) = Y(I,J) - Y(I,J+1)
      510 NEWJ = MITEP
      ETAMAX = ONE
      IF (ABS(H).LE. HMIN*ONEPSM) GO TO 660
      IF (KFLAG.LE. KFC) GO TO 630
      IREDO = 2
      FLOTL=FLOAT(L)
      520 ETAO = ONE/((RIAS2*O/E)**(PT5/FLOTL) + ADDON)
      IF (NQINDX.NE. 0) .OR. (KFLAG.NE. 0) GO TO 540
      ETAO1 = ZERO
      IF (NO.F3. 1) GO TO 540
      C COMPUTE RATIO OF NEW H TO CURRENT H AT THE CURRENT ORDER LESS ONE. -
      D = ZERO
      DO 530 I = 1, N
        D = D + (Y(I,L)/YMAX(I))**2
      530 EDN = FLOTL*(D**FDS)**2
      ETAO1 = ONE/((RIAS1*O/FDN)**(PT5/(FLOTL - ONE)) + ADDON1)
      540 ETAO1 = ZERO
      IF (L.EQ. LMAX) GO TO 560
      C COMPUTE RATIO OF NEW H TO CURRENT H AT CURRENT ORDER PLUS ONE. -----
      CNOUOT = (TQ(5)/COMP)*(H/TAU(2))**1

```

```

400      D = 7EPO
      NO 550 I = 1,N
      550      D = 0 * (IERPOR(I) - CNDQOT*Y(I,LMAX))/YMAX(I)**2
      EUP = FLOTN*(TQI3)*EPS**2
      ETAOP1 = ONE/(RIAS3*D/EUP)**(PTS/(FLOTL * ONE)) * ADDON
405      NOINDX = 2
      IF (ETAQ .GE. ETAOP1) GO TO 570
      IF (ETAOP1 .GT. ETAQMI) GO TO 600
      GO TO 590
410      570 IF (ETAQ .LT. ETAQMI) GO TO 590
      580 IF ((ETAQ .LT. THRESH) .AND. (KFLAG .EQ. 0)) GO TO 690
      ETA = ETAQ
      IF ((KFLAG .LE. -2) .AND. (ETA .GT. ETAMXF)) ETA = ETAMXF
      GO TO 180
415      590 IF (ETAQMI .LT. THRESH) GO TO 690
      CALL ADJUST (Y, NO)
      L = NO
      NO = NO - 1
      ETA = ETAQMI
      NOINDX = L
420      GO TO 180
      600 IF (ETAOP1 .LT. THRESH) GO TO 690
      NO = L
      ETA = ETAOP1
      L = L + 1
425      DO 610 I = 1,N
      610      Y(I,L) = ZERO
      NOINDX = L
      GO TO 180
430      C-----
      C CONTROL REACHES THIS SECTION IF 3 OR MORE CONSECUTIVE FAILURES
      C HAVE OCCURRED. IT IS ASSUMED THAT THE ELEMENTS OF THE Y ARRAY
      C HAVE ACCUMULATED ERRORS OF THE WRONG ORDER. THE ORDER IS REDUCED
      C BY ONE. IF POSSIBLE. THEN M IS REDUCED BY A FACTOR OF 0.1 AND
      C THE STEP IS RETRIED. AFTER A TOTAL OF 7 CONSECUTIVE FAILURES,
      C AN EXIT IS TAKEN WITH KFLAG = -2.
      C-----
435      630 IF (KFLAG .EQ. KFM) GO TO 670
      IF (NO .EQ. 1) GO TO 640
      ETA = ETAMIN
      CALL ADJUST (Y, NO)
      L = NO
      NO = NO - 1
      NOINDX = L
      GO TO 180
440      640 ETA=AMAX1(ETAMIN,MMIN/ARS(M))
      M = M*ETA
      CALL DIFFUN(N,T,Y,SAVE1)
      NFE = NFE + 1
      NO 650 I = 1,N
      650      Y(I,2) = M*SAVE1(I)
      NOINDX = 10
      GO TO 200
445      C-----
      C ALL RETIPTS ARE MADE THROUGH THIS SECTION. M IS SAVED IN HOLD
      C TO ALLOW THE CALLED TO CHANGE M ON THE NEXT STEP.
      C-----

```

07/27/65 13.15.44

FTN 4.R.401

76/76 OPT=1 FOUND=---/ TRAPE

SURROUTINE TSTEP

```

460      KFLAG = -1
        GO TO 700
470      KFLAG = -2
        GO TO 700
480      KFLAG = -3
        GO TO 700
490      ETAMAX = ETAMX3
        IF (NSTEP .LE. 10) ETAMAX = ETAMX2
        HOLD = H
        JSTART = NO
C      IF V1 IS SMALL ENOUGH, COLLAPSE REGION 1.
        IF (V1.LT.VPERV(1))MOD1=0
C      IF THE PROJECTILE TRAVEL IS LARGE ENOUGH, OPEN REGION 4.
        IF ((OFFSET*SPJ).GE.0.01)MOD4=1
        IF (MVENT.NE.1)GO TO 800
        IF (PR.LT.PJRS)GO TO 800
C      ADJUST THE VENT OPENING.
C      FIND THE DESIRED GASE PRESSURE.
        PRASE=PJRT*0.09146*ACS/A4 - PJRS
        RATIO=(PRASE-PR)/PRASE
        AVENT=AVENT*(1.0+AK*RATIO)
        IF (AVENT.LT.AVMIN)AVENT=AVMIN
        IF (AVENT.GT.AVMAX)AVENT=AVMAX
495      CONTINUE
        IF (KWRITF.NE.1)RETURN
        WRITE(6,1000)NSTEP,NQ,T,H,MOD1,MOD4
1000      FORMAT(/2X,21A,1P2E12.4,6X,21A)
        TMS=T+1800.
        CALL DIFFUN(N,T,Y,SAVE2)
        WRITE(6,1010)TMS,P1,P3,PL,P4,PR,SPS,VPS,SPJ,VPJ,APJ
        WRITE(6,1010)TMS,RH1,RHL3,RMG3,RH3,RHL4,RMG4,RH4
        WRITE(6,1010)TMS,V1,VL3,VG3,V3,VL4,VG4,V4,EPS3,EPS4,AVENT
        WRITE(6,1010)TMS,RM1,RML3,RMG3,RM3,RML4,RMG4,RM4,RMSUM
        WRITE(6,1010)TMS,RMD13,RMD3,RMD34,RMD4,HL1,HL3,H3,HL4,H4
        WRITE(6,1010)TMS,CL1,CL3,CG3,C3,CL4,CG4,C4,TEMP3,TEMP4
        WRITE(6,1010)TMS,EL1,EL3,EG3,EL4,EG4,EKPS,EKPJ,EKL4,EKG4,FCIJM
        WRITE(6,1010)TMS,(PML3(I),I=1,10)
        WRITE(6,1010)TMS,(PMD3(I),I=1,10)
        WRITE(6,1010)TMS,(PML4(I),I=1,10)
        WRITE(6,1010)TMS,(PMD4(I),I=1,10)
        FORMAT(1P11E11.4)
1010      WRITE(6,1020)(Y(I,1),I=1,N)
        WRITE(6,1020)(SAVE2(I),I=1,N)
1020      FORMAT(1P10E12.4)
        RETURN
C----- END OF SUBROUTINE TSTEP -----
        END

```

CARD NR. SEVERITY DETAILS DIAGNOSIS OF PROBLEM

224 1 AM IF STATEMENT MAY BE MORE EFFICIENT THAN A 2 OR 3 BRANCH COMPUTED GO TO STATEMENT.

02/22/85 13.15.44

FTN 4.8.601

76/76 OPT=1 ROUND=0.0/ TRACE

```

1      SUBROUTINE COSFT
2      C-----
3      C COSFT IS CALLED BY TSTEP AND SETS COEFFICIENTS FOR USE THERE.
4      C
5      C FOR EACH ORDER NO, THE COEFFICIENTS IN EL ARE CALCULATED BY USE OF
6      C THE GENERATING POLYNOMIAL LAMBDA(X). WITH COEFFICIENTS EL(I)
7      C LAMBDA(X) = EL(1) + EL(2)*X + ... + FL(NQ+1)*(X**NQ).
8      C FOR THE BACKWARD DIFFERENTIATION FORMULAS.
9      C
10     C NO
11     C LAMRDA(X) = PRODUCT (1 + X/XI(I) ) .
12     C I = 1
13     C FOR THE ADAMS FORMULAS,
14     C NO-1
15     C (D/DX) LAMBDA(X) = C * PRODUCT (1 + X/XI(I) ) ,
16     C I = 1
17     C LAMRDA(-1) = 0. LAMRDA(0) = 1.
18     C WHERE C IS A NORMALIZATION CONSTANT.
19     C IN BOTH CASES, YI(I) IS DEFINED BY
20     C H*YI(I) = Y SUB N - T SUB (N-I)
21     C = M + TAU(1) + TAU(2) + ... TAU(I-1).
22     C
23     C COSFT ALSO SETS MAXDER, THE MAXIMUM ORDER OF THE FORMULAS
24     C AVAILABLE. CURRENTLY THIS IS 5 FOR THE BACKWARD DIFFERENTIATION
25     C FORMULAS, AND 12 FOR THE ADAMS FORMULAS. TO USE DIFFERENT
26     C VALUES (I.E. 13), CHANGE THE NUMBERS IN STATEMENTS 1 AND 2 BELOW.
27     C
28     C IN ADDITION TO VARIABLES DESCRIBED PREVIOUSLY, COMMUNICATION
29     C WITH COSFT USES THE FOLLOWING..
30     C TAU = A VECTOR OF LENGTH 13 CONTAINING THE PAST NQ VALUES
31     C OF M.
32     C EL = A VECTOR OF LENGTH 13 IN WHICH COSFT STORES THE
33     C COEFFICIENTS FOR THE CORRECTOR FORMULA.
34     C TO = A VECTOR OF LENGTH 5 IN WHICH COSFT STORES CONSTANTS
35     C USED FOR THE CONVERGENCE TEST, THE ERROR TEST, AND
36     C SELECTION OF M AT A NEW ORDER.
37     C LMAX = MAXDER + 1, WHERE MAXDER IS THE MAXIMUM ORDER
38     C AVAILABLE. LMAX IS THE MAXIMUM NUMBER OF COLUMNS
39     C OF THE Y ARRAY TO BE USED.
40     C METH = THE BASIC METHOD INDICATOR.
41     C NO = THE CURRENT ORDER.
42     C L = NQ + 1, THE LENGTH OF THE VECTOR STORED IN EL, AND
43     C THE NUMBER OF COLUMNS OF THE Y ARRAY BEING USED.
44     C NQINDX = A COUNTER CONTROLLING THE FREQUENCY OF ORDER CHANGES.
45     C AN ORDER CHANGE IS ABOUT TO BE CONSIDERED IF
46     C NQINDX = 1.
47     C-----
48     C CAUTION NOT ALL MEMBERS OF EPCOM1 ARE USED IN THIS SUBROUTINE.
49     C DIMENSION E*(13)
50     C
51     C COMMON /EPCOM1/ T,M,MMIN,MMAX,EPS,SS,UPROUND,N,MF,MFLAG,JUSTART
52     C DATA CORTES/0.1E0/
53     C DATA CORTES/0.1E0/
54     C DATA ONE/1.0E0/,SIX/6.0E0/,TWO/2.0E0/,ZERO/0.0E0/
55     C AMNDS=ONE
56     C IF(SS.NF.ZERO)AMNDS=ABS(H)/SS
57     C FLOTL=FLOAT(L)

```

02/22/85 13.15.44

FTN 4.0.4.01

TRACE

74/76

SURROUTINE C0SET

OPT=1 ROUNDO=0.0/

```

60      NQM1 = NO - 1
        GO TO (1, 2), METH
        MAXDER = 12
        GO TO 100
C
        MAXDER = 5
        GO TO 200
C
100     IF (NQ.NE. 1) GO TO 110
        EL(1) = ONE
        EL(2) = ONE
        TQ(1) = ONE
        TQ(2) = TWO*AMDS
        TQ(3) = SIX*TQ(2)
        TQ(5) = ONE
        GO TO 300
110     MSUM = 4
        EM(1) = ONE
        FLOTNO = FLOTL - ONE
        DO 115 I = 2, L
            EM(I) = ZERO
        DO 120 J = 1, NQM1
            IF ((J.NE. NQM1).OR. (NINDEX.NE. 1)) GO TO 130
            S = ONE
            CSUM = ZERO
            DO 120 I = 1, NQM1
                CSUM = CSUM + S*EM(I)/FLOT(I+1)
            S = -S
            TQ(1) = AMDS*EM(NQM1)/(FLOTNO*CSUM)
            PXI = W/MSUM
            DO 140 IACK = 1, J
                I = (J + 2) - IACK
                EM(I) = EM(I) + EM(I-1)*PXI
            MSUM = MSUM + TAU(J)
120     S = ONE
        C COMPUTE INTEGRAL FROM -1 TO 0 OF POLYNOMIAL AND OF X TIMES IT. -----
        EM0 = ZERO
        CSUM = ZERO
        DO 160 I = 1, NQ
            FLOTI = FLOT(I)
            EM0 = EM0 + S*EM(I)/FLOTI
            CSUM = CSUM + S*EM(I)/(FLOTI+1)
            S = -S
        C IN EL, FORM COEFFICIENTS OF NORMALIZED INTEGRATED POLYNOMIAL. -----
        S = ONE/EM0
        EL(1) = ONE
        DO 170 I = 1, NQ
            EL(I+1) = S*EM(I)/FLOT(I)
            XI = MSUM/W
            TQ(2) = AMDS*XI*EM0/CSUM
            TQ(5) = XI/EL(1)
            IF (NINDEX.NE. 1) GO TO 300
        C FOR HIGHER ORDER CONTROL CONSTANT, MULTIPLY POLYNOMIAL BY 1+X/XI(0).
        PXI = ONE/XI
        DO 190 IACK = 1, NQ
            I = (L + 1) - IACK
            EM(I) = F(I) + F(I-1)*PXI
190

```

02/22/85 13.15.44

FTN 4.9.601

76/76 OPT=1 ROUND=0.0/ TRACE

SURROUTINE COSFT

```

115 C COMPUTE INTEGRAL OF POLYNOMIAL. -----
      S = ONE
      CSUM = ZERO
      DO 190 I = 1,L
      CSUM=CSUM+S*EM(I)/FLOAT(I+1)
      S = -S
120 TQ(3) = AMOSS*FLOTL*EM0/CSUM
      GO TO 300
C
200 DO 210 I = 3,L
210 EL(I) = ZERO
      EL(1) = ONE
      EL(2) = ONE
      MSUM = H
      MSUM1 = ZERO
      PROD = ONE
      RXI = ONE
      IF (NO.EQ. 1) GO TO 240
      DO 230 J = 1,NOM1
230 JPI = J + 1
      DO 220 IBACK=1,JPI
      I = (J + 3) - IBACK
      EL(I)=EL(I) + EL(I-1)*RXI
220 CONTINUE
      TQ(2) = AMOSS*EL(2)*(ONE + PROD)
      TQ(5) = (ONE + PROD)/EL(1)
      IF (NOINDEX.NE. 1) GO TO 300
      CNOM1 = RXI/EL(L)
      TQ(1) = AMOSS*ELP/CNOM1
      MSUM = MSUM + TAU(NQ)
      RXI = H/MSUM
      ELP = EL(2) + RXI
      TQ(3) = AMOSS*ELP*RXI*(ONE + PROD)*(FLOTL + ONE)
      TQ(4) = CORTES*TQ(2)
300 LMAX = MAXDER + 1
      RETURN
C----- END OF SUBROUTINE COSFT -----
      END
030090
030100
030110
030120
030130
030140
030150
030160
030170
030180
030190
030200
030210
030220
030230
030240
030250
030260
030270
030280
030290
030300
030310
030320
030330
030340
030350
030360
030370
030380
030390
030400
030410
030420
030430
030440
030450
030460
030470
030480
030490
030500
030510
030520

```

CARD NO. SEVERITY DETAILS DIAGNOSIS OF PROBLEM

54 1 AN IF STATEMENT MAY BE MORE EFFICIENT THAN A 2 OR 3 BRANCH COMPUTED GO TO STATEMENT.

```

1      SURROUTINE ADJUST (Y, NO)
C-----
C THIS SUBROUTINE ADJUSTS THE Y ARRAY ON REDUCTION OF ORDER.
C SEE REFERENCE 1 FOR DETAILS.
C-----
5      C CAUTION NOT ALL MEMBERS OF EPCOM1 ARE USED IN THIS SUBROUTINE.
C-----
      DIMENSION Y(N0,13)

C
      COMMON /EPCOM1/ T,MMIN,MMAX,EPS,SS,URROUND,N,MF,KFLAG,JSTART
      COMMON /EPCOM10/ TAU(13),EL(13),TO(S),LMAX,METH,N0,L,NQ1,CX
      DATA ONE/1.0E0/,ZERO/0.0E0/
      IF (N0.EQ. 2) RETURN
      NQM1 = N0 - 1
      NQM2 = N0 - 2
      GO TO (100, 200), METH

C
100  DO 110 J = 1,LMAX
110  EL(J) = ZERO
      EL(2) = ONE
      MSUM = ZERO
      DO 130 J = 1,NQM2
C CONSTRUCT COEFFICIENTS OF  $X \cdot (X \cdot XI(1)) \cdot \dots \cdot (X \cdot XI(J))$ .
      MSUM = MSUM + TAU(J)
      XI = MSUM/H
      JPI = J + 1
      DO 120 IBACK = 1,JPI
120  FL(I) = EL(I)*XI + EL(I-1)
130  CONTINUE
C CONSTRUCT COEFFICIENTS OF INTEGRATED POLYNOMIAL.
140  EL(J+1)=FLOAT(N0)*EL(J)/FLOAT(J)
      GO TO 300

C
200  DO 210 J = 1,LMAX
210  FL(J) = ZERO
      EL(3) = ONE
      MSUM = ZERO
      DO 230 J = 1,NQM2
C CONSTRUCT COEFFICIENTS OF  $X \cdot X \cdot (X \cdot XI(1)) \cdot \dots \cdot (X \cdot XI(J))$ .
      MSUM = MSUM + TAU(J)
      XI = MSUM/H
      JPI = J + 1
      DO 220 IBACK = 1,JPI
220  FL(I) = EL(I)*XI + EL(I-1)
230  CONTINUE

C
300  DO 320 J = 3,N0
320  Y(I,J) = Y(I,J) - Y(I,L)*EL(J)
      CONTINUE
      PFTIME=1
C-----
      END OF SUBROUTINE ADJUST
      FTH

```

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FIN 4.8.401

74/76 OPT=1 POINT=000/ TRACE

SUMMARY OF ADJUST

CARD NO. SECURITY DETAILS DIAGNOSIS OF PROBLEM

14 I AN IF STATEMENT MAY BE MORE EFFICIENT THAN A 2 OR 3 BRANCH COMPUTED GO TO STATEMENT.

```

1  SUBROUTINE PSET(Y,N0,CON,MITER,IFP,NS0,YMAX,SAVE1,SAVE2,
   * SAVE3,PV,IPV)
5  C-----
   C PSET IS CALLED BY TSTEP TO COMPUTE AND TO PROCESS THE MATRIX
   C P = I - (M/EL(2))J, WHERE J IS AN APPROXIMATION TO THE
   C JACOBIAN. J IS COMPUTED BY EITHER THE USER SUPPLIED
   C SUBROUTINE PEDERV, WHEN MITER = 1, OR BY FINITE DIFFERENCES,
   C WHEN MITER = 2. J IS STORED IN PW AND REPLACED BY P, USING
   C CON = -M/EL(2). THEN P IS SUBJECTED TO AN LU DECOMPOSITION
   C FOR LATP SOLUTION OF LINEAR ALGEBRAIC SYSTEMS WITH P AS THE
   C COEFFICIENT MATRIX.
10  C IN ADDITION TO VARIABLES DESCRIBED PREVIOUSLY, COMMUNICATION
   C WITH PSET USES THE FOLLOWING..
15  C EPSJ = SORT(ROUND), USED IN THE NUMERICAL JACOBIAN INCREMENTS.
   C NS0 = N0**2.
   C-----
   C CAUTION NOT ALL EPCOM1 VARIABLES ARE USED IN THIS SUBROUTINE.
20  C-----
   DIMENSION Y(N0,13)
   DIMENSION YMAX(N0),SAVE1(N0),SAVE2(N0),PW(NS0),IPV(N0)
   DIMENSION SAVE3(N0)
   C
25  COMMON /EPCOM1/ T,M,MMIN,HMAX,EPS,SS,UPOUND,N,MF,KFLAG,JSTART
   COMMON /EPCOM2/ FPSJ,NSOR
   COMMON /EPCOM3/ HUSED,NOUSED,NSTEP,MFE,NJE,NMI
   DATA ONE/1.0E0/,PEP/1.0E-3/,ZERO/0.0E0/
   IF (MITER.EQ. 2) GO TO 20
30  C IF MITER = 1, CALL PEDERV AND MULTIPLY BY A SCALAR. -----
   CALL PEDERV (N, T, Y, PW, N0)
   DO 10 I = 1,NS0
     PW(I) = PW(I)*CON
   10 GO TO 40
   C IF MITER = 2, MAKE N CALLS TO DIFFJN TO APPROXIMATE J. -----
35  DO 30 I = 1,N
     D = ZERO
     DO 30 J = 1,N
       U = 0
       SAVE2(I)**2
       R0=ARS(H)*SORT(D)*UPOUND/PEP
       J1 = 0
       DO 50 J = 1,N
         YJ = Y(J,I)
         P = EPSJ*YMAX(J)
         P=MAX1(P,P0)
         Y(J,I) = Y(J,I) + R
         D = CON/R
       CALL DIFFJN(T,Y,SAVE1)
       DO 40 I = 1,N
         PW(I+J1) = (SAVE1(I) - SAVE2(I))*N
       40 Y(J,I) = YJ
         J1 = J1 + N0
       50 CONTINUE
   C ADD ON THE IDENTITY MATRIX. -----
   DO 70 I = 1,N
     DO 70 J = 1,N
       PW(I,J) = PW(I,J) + ONE
     70 J = J + (N0 + 1)

```

SUBROUTINE PSET 74/74 OPT=1 ROUNDO=00/ TRACE FTA 4,0,401 02/22/85 13.15.44 PAGE 70

```

C GET LU DECOMPOSITION OF P. ----- 031470
CALL DECOMP('H0.P4.SAVE3.PIV) ----- 031480
NMI=NMI+1 ----- 031490
RETURN ----- 031700
C----- END OF SUBROUTINE PSET ----- 031710
END ----- 031720

```

```

1  SUBROUTINE DECOMP(N,NDIM,UL,SCALES,IPS)
   DIMENSION UL(NDIM,NDIM),SCALES(NDIM),IPS(NDIM)
   C THIS IS A STANDARD ALGORITHM FOR SOLVING A SET OF LINEAR
   C ALGEBRAIC EQUATIONS USING AN LU DECOMPOSITION AND
   C BACK SUBSTITUTION.
   C REFERENCE.
   C FORSYTHE AND WOLFE. COMPUTER SOLUTION OF LINEAR ALGEBRAIC SYSTEMS.
   DO 5 I=1,N
     IPS(I)=1
     POWNRM=0.0
     DO 2 J=1,N
       IF (ROWNRM-ABS(UL(I,J)))1.2,2
       POWNRM=ABS(UL(I,J))
     CONTINUE
     IF (POWRM=)3.4,3
     SCALES(I)=1.0/POWRM
     GO TO 5
   CALL SING(1)
   SCALES(I)=0.0
   CONTINUE
   N1=N-1
   DO 17 K=1,NM1
     BIG=0.0
     DO 11 I=K,N
       IP=IPS(I)
       SIZE=ABS(UL(IP,K))*SCALES(IP)
       IF (SIZE-RIG)11.11,10
       RIG=SIZE
       IDXPIV=I
     CONTINUE
     IF (RIG)13,12,13
     CALL SING(2)
     GO TO 17
   IF (IDXPIV-K)14,15,14
   J=IPS(K)
   IPS(K)=IPS(IDXPIV)
   IPS(IDXPIV)=J
   KP=IPS(K)
   PIVOT=UL(KP,K)
   KP1=K+1
   DO 16 I=KP1,N
     IP=IPS(I)
     EM=-UL(IP,K)/PIVOT
     UL(IP,K)=EM
   DO 16 J=KP1,N
     UL(IP,J)=UL(IP,J)+EM*UL(KP,J)
   CONTINUE
   CONTINUE
   KP=IPS(N)
   IF (UL(KP,N)-NE,0.0)GO TO 19
   CALL SING(2)
   RETURN
   END

```

```

1 SUBROUTINE SOLVE (N,NDIM,UL,IPS,R,X)
  DIMENSION UL(NDIM),IP(NDIM),IPS(NDIM),X(NDIM)
  NPT=N+1
  IP=IPS(1)
  X(1)=R(IP)
  DO 2 I=2,N
    IP=IPS(I)
    IMI=I-1
    SUM=0.0
    DO 1 J=1,IMI
      SUM=SUM+UL(IP,J)*X(J)
      X(I)=X(IP)-SUM
    1 IP=IPS(N)
    X(N)=X(N)/UL(IP,N)
    I=NP1-TRACK
    IP=IPS(I)
    IMI=I-1
    SUM=0.0
    DO 3 J=IP1,N
      SUM=SUM+UL(IP,J)*X(J)
      X(I)=X(I)-SUM/UL(IP,I)
    3
  4 RETURN
  END

```

```

1  SUBROUTINE SING(I4MY)
   NOUT=6
   IF(I4MY.EQ.1)WRITE(NOUT,11)
   IF(I4MY.EQ.2)WRITE(NOUT,12)
5  11 FORMAT(1H0,'MATRIX WITH ZERO ROW IN DECOMPOSE.')
   12 FORMAT(1H0,'SING MATRIX IN DECOMPOSE. ZERO DIVIDE IN SOLVE.')
   RETURN
   END
032500 -
032510
032520
032530
032540
032550
032560
032570

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APPENDIX B

Below is a listing of the job stream for the above test problem (initial gas pressure = 10 MPa). Following is a listing of the output. Since there are many variables to keep track of, the output is on multiple files. Only the ones of interest for a particular problem need to be printed out. Additional files contain the values of interest for a problem with a droplet option.

COEFFE-25MM-ROUND 4-077011-I-USTAN-P3=10-DC=5.5

OFFSET = 1.2700E+00 TRAVEL = 2.1334E+02

TUBE DIAM = 2.5000E+00 TUBE AREA = 4.9087E+00

TUBE ENTRANCE COEFF = 9.5000E-01

PJNT = 1.9440E+02 PSWT = 4.8092E+02

WACK = 0 NO BACK FLOW

V1 IN = 9.6000E+01 V3 IN = 3.5396E+01 VOL = 1.3140E+02

VPER = 1.0000E-03

AREA FUEL = 1.3000E+01 AREA COMB = 1.5490E+01

VENT1 VENT AREA TABLE

NVENT = 2

PIS TRAV = 0. VENT AREA = 2.4900E+00 HYDROLIC DIFF = 1.2140E+00
PIS TRAV = 1.0000E+00 VENT AREA = 2.4900E+00 HYDROLIC DIFF = 1.2140E+00

MAX PISTON TRAVEL = 7.3846E+00

RORE = 4.4394E+00 BORE/STROKE = 6.0119E-01

COMRUSTOR LENGTH = 3.4502E+01

NPIS = 2

FRAC PIS TRAV = 0. PIS TRAV = 0. PIS RESISTANCE = 0.
FRAC PIS TRAV = 1.0000E+00 PIS TRAV = 7.3846E+00 PIS RESISTANCE = 0.

DIS1 DIS COEFF VS. PISTON TRAVEL

NDC = 2

FRAC PIS TRAV = 0. PIS TRAV = 0. DIS COEFF = 5.0000E-01
FRAC PIS TRAV = 1.0000E+00 PIS TRAV = 7.3846E+00 DIS COEFF = 5.0000E-01

NPROJ = 3

TRAVEL = 0. RESISTIVE PRESS = 3.6200E+01
TRAVEL = 1.0000E-02 RESISTIVE PRESS = 1.0000E-01
TRAVEL = 2.1336E+02 RESISTIVE PRESS = 1.0000E-01

DEMS LIQUID = 1.2300E+00 M1 = 2.4131E+03 K2 = 0.

CHEM ENERGY = 3.3300E+03 GAM = 1.2400E+00

SURFACE TENSION = 3.6300E+01

MOL WT GAS = 1.9010E+01 CONVOLUME = 1.2570E+00

POES LIQUID = 9.0000E+00 POES GAS = 1.0000E+01

SPECIFIC GAS CONSTANT = 4.3756E-01

CV = 1.6820E+00 CP = 2.1205E+00

PROP1 INSTAN BURNING

PRIM1 NO PRIMER

NPRTM = 1

TTC = 1.0000E-04

MF = 22 EPS = 1.0000E-04 SPEC = 1.0000E-06

CHARGE = 1.1852E+02 PRIMER = 4.7392E-01 C/M = 6.1211E-01

LOADING DENSITY = 9.0562E-01

T (MS)	P1	P3	PL	P4	PR	S PS	V PS	S PJ	V PJ	ACC K-R
0.000	9.000	10.000	10.000	10.000	10.000	0.000	0.000	0.000	0.000	0.000
.100	10.061	10.056	10.055	10.055	10.055	.001	64.957	0.000	0.000	0.000
.200	11.587	11.569	11.567	11.567	11.567	.013	120.111	0.000	0.000	0.000
.300	14.104	14.062	14.059	14.058	14.058	.029	185.139	0.000	0.000	0.000
.400	17.818	17.732	17.725	17.725	17.725	.050	265.226	0.000	0.000	0.000
.500	23.031	22.864	22.854	22.854	22.854	.082	366.537	0.000	0.000	0.000
.600	30.157	29.847	29.834	29.834	29.834	.124	496.527	0.000	0.000	0.000
.700	39.754	39.188	39.171	39.170	39.169	.182	664.130	.000	11.356	.862
.800	52.490	51.450	51.418	51.405	51.378	.259	876.583	.020	618.044	13.193
.900	68.844	66.882	66.791	66.767	66.718	.360	1151.575	.152	2099.807	17.139
1.000	89.230	85.576	85.334	85.286	85.190	.491	1493.680	.454	4008.717	21.892
1.100	113.874	107.269	106.685	106.587	106.391	.658	1870.332	.971	6419.787	27.346
1.200	142.580	131.107	129.925	129.728	129.336	.866	2291.759	1.757	9390.959	33.250
1.300	174.500	156.107	153.622	153.250	152.504	1.117	2711.592	2.869	12947.889	39.210
1.400	207.989	180.446	176.078	175.417	174.096	1.407	3082.054	4.365	17073.857	44.765
1.500	240.595	202.600	195.442	194.556	192.383	1.730	3357.041	6.300	21707.026	49.470
1.600	269.353	221.159	211.009	209.354	206.045	2.074	3508.652	8.719	26746.263	52.985
1.700	291.449	234.592	221.384	219.038	214.346	2.428	3538.719	11.658	32063.738	55.121
1.800	305.121	243.489	226.541	223.428	217.501	2.779	3477.485	15.137	37521.750	55.955
1.900	310.189	246.637	226.812	222.916	215.125	3.122	3368.925	19.163	42987.796	55.321
2.000	308.012	245.070	222.986	218.352	209.043	3.453	3251.968	23.731	48348.681	53.767
2.100	300.742	239.875	216.110	210.825	200.254	3.773	3148.899	28.426	53518.995	51.495
2.200	290.497	232.286	207.327	201.497	189.937	4.083	3065.765	34.427	58443.631	48.815
2.300	278.859	223.419	197.770	191.494	178.942	4.386	2999.678	40.506	63096.886	46.012
2.400	266.929	214.174	188.311	181.665	168.373	4.684	2946.237	47.037	67477.579	43.293
2.500	255.456	205.167	179.133	172.190	158.303	4.974	2901.867	53.993	71597.777	40.702
2.600	244.627	196.442	169.950	162.801	148.504	5.254	2862.020	61.349	75466.806	38.181
2.700	234.225	188.080	161.556	154.241	139.012	5.548	2822.498	69.079	79100.247	35.893
2.800	224.537	180.288	153.780	146.341	131.445	5.829	2784.503	77.162	82518.623	33.797
2.900	215.578	173.063	146.627	139.097	124.038	6.105	2747.540	85.576	85740.410	31.886
3.000	207.294	166.392	140.063	132.468	117.277	6.378	2711.329	94.304	88783.075	30.147
3.100	199.647	160.241	134.046	126.405	111.124	6.648	2675.960	103.328	91642.732	28.564
3.200	192.629	154.576	128.528	120.859	105.520	6.913	2641.261	112.632	94394.026	27.122
3.300	186.094	149.347	123.463	115.778	100.407	7.174	2607.606	122.203	96990.121	25.807
3.400	0.000	137.859	118.649	110.973	95.620	7.380	0.000	132.026	99442.692	24.575
3.500	0.000	115.898	110.948	103.609	88.930	7.380	0.000	142.091	101793.875	22.854
3.600	0.000	104.673	102.248	95.404	81.716	7.380	0.000	152.379	103944.691	20.998
3.700	0.000	96.917	94.286	87.917	73.886	7.380	0.000	162.874	105921.085	19.316
3.800	0.000	88.944	87.226	81.286	69.406	7.380	0.000	173.558	107742.458	17.831
3.900	0.000	82.497	80.966	75.412	64.304	7.380	0.000	184.418	109426.745	16.518
4.000	0.000	76.757	75.395	70.188	59.776	7.380	0.000	195.440	110989.640	15.353
4.100	0.000	71.629	70.415	65.523	55.739	7.380	0.000	206.612	112444.407	14.315
4.140	0.000	68.813	67.445	62.959	53.509	7.380	0.000	213.384	113700.409	13.767

MUZZLE VFL (M/SEC) 1132.7

MAX P1 (MPA)

310.2

MAX P3 (MPA)

244.6

MAX PL (MPA)

226.8

MAX PR (MPA)

217.2

MAX ACC (K-G)

55.9

MAX MASS ERROR

.07

MAX ENERGY ERROR

2.20

PIIN TIME = 2.5 NSTEP = 689
13.10.11.UCLP, FA, TM1602C. 0.501KLS.

T (MS)	QW1	QW3	QW53	RM3	QHL4	RMG4	RM4
0.0000	1.2366	0.0000	0.0000	.0114	0.0000	0.0000	.0114
1.0000	1.2351	0.0000	0.0000	.0115	0.0000	0.0000	.0114
2.0000	1.2350	0.0000	0.0000	.0132	0.0000	0.0000	.0128
3.0000	1.2377	0.0000	0.0000	.0141	0.0000	0.0000	.0150
4.0000	1.2391	0.0000	0.0000	.0203	0.0000	0.0000	.0183
5.0000	1.2418	0.0000	0.0000	.0261	0.0000	0.0000	.0224
6.0000	1.2455	0.0000	0.0000	.0339	0.0000	0.0000	.0269
7.0000	1.2504	0.0000	0.0000	.0441	0.0000	0.0000	.0369
8.0000	1.2570	0.0000	0.0000	.0571	0.0000	0.0000	.0473
9.0000	1.2656	0.0000	0.0000	.0731	0.0000	0.0000	.0609
1.0000	1.2763	0.0000	0.0000	.0920	0.0000	0.0000	.0780
1.1000	1.2894	0.0000	0.0000	.1134	0.0000	0.0000	.0978
1.2000	1.3049	0.0000	0.0000	.1364	0.0000	0.0000	.1191
1.3000	1.3222	0.0000	0.0000	.1595	0.0000	0.0000	.1404
1.4000	1.3407	0.0000	0.0000	.1814	0.0000	0.0000	.1601
1.5000	1.3590	0.0000	0.0000	.2012	0.0000	0.0000	.1773
1.6000	1.3752	0.0000	0.0000	.2176	0.0000	0.0000	.1911
1.7000	1.3879	0.0000	0.0000	.2301	0.0000	0.0000	.2013
1.8000	1.3958	0.0000	0.0000	.2386	0.0000	0.0000	.2077
1.9000	1.3987	0.0000	0.0000	.2432	0.0000	0.0000	.2107
2.0000	1.3975	0.0000	0.0000	.2445	0.0000	0.0000	.2108
2.1000	1.3933	0.0000	0.0000	.2420	0.0000	0.0000	.2085
2.2000	1.3874	0.0000	0.0000	.2394	0.0000	0.0000	.2045
2.3000	1.3807	0.0000	0.0000	.2345	0.0000	0.0000	.1994
2.4000	1.3739	0.0000	0.0000	.2289	0.0000	0.0000	.1943
2.5000	1.3674	0.0000	0.0000	.2229	0.0000	0.0000	.1887
2.6000	1.3612	0.0000	0.0000	.2168	0.0000	0.0000	.1824
2.7000	1.3554	0.0000	0.0000	.2107	0.0000	0.0000	.1771
2.8000	1.3499	0.0000	0.0000	.2046	0.0000	0.0000	.1715
2.9000	1.3449	0.0000	0.0000	.1984	0.0000	0.0000	.1662
3.0000	1.3403	0.0000	0.0000	.1932	0.0000	0.0000	.1612
3.1000	1.3341	0.0000	0.0000	.1879	0.0000	0.0000	.1563
3.2000	1.3322	0.0000	0.0000	.1824	0.0000	0.0000	.1518
3.3000	1.3286	0.0000	0.0000	.1740	0.0000	0.0000	.1475
3.4000	1.3260	0.0000	0.0000	.1687	0.0000	0.0000	.1433
3.5000	1.3240	0.0000	0.0000	.1511	0.0000	0.0000	.1369
3.6000	1.3260	0.0000	0.0000	.1415	0.0000	0.0000	.1297
3.7000	1.3260	0.0000	0.0000	.1339	0.0000	0.0000	.1228
3.8000	1.3260	0.0000	0.0000	.1271	0.0000	0.0000	.1165
3.9000	1.3260	0.0000	0.0000	.1208	0.0000	0.0000	.1117
4.0000	1.3260	0.0000	0.0000	.1151	0.0000	0.0000	.1054
4.1000	1.3260	0.0000	0.0000	.1094	0.0000	0.0000	.1005
4.1500	1.3260	0.0000	0.0000	.1068	0.0000	0.0000	.0978

13.14.54.UCLP. FA, TM1602C. 0.233ML/S.

T (°C)	V1	VL3	V63	V3	VL4	V64	V4	EPS3	EPS4	AVENT
0.000	96.000	0.000	0.000	35.396	0.000	0.000	6.234	0.000	0.000	2.490
.100	95.955	0.000	0.000	35.450	0.000	0.000	6.234	0.000	0.000	2.490
.200	95.836	0.000	0.000	35.592	0.000	0.000	6.234	0.000	0.000	2.490
.300	95.638	0.000	0.000	35.927	0.000	0.000	6.234	0.000	0.000	2.490
.400	95.348	0.000	0.000	36.173	0.000	0.000	6.234	0.000	0.000	2.490
.500	94.940	0.000	0.000	36.659	0.000	0.000	6.234	0.000	0.000	2.490
.600	94.382	0.000	0.000	37.323	0.000	0.000	6.234	0.000	0.000	2.490
.700	93.632	0.000	0.000	38.215	0.000	0.000	6.235	0.000	0.000	2.490
.800	92.635	0.000	0.000	39.403	0.000	0.000	6.330	0.000	0.000	2.490
.900	91.321	0.000	0.000	40.968	0.000	0.000	6.941	0.000	0.000	2.490
1.000	89.614	0.000	0.000	43.000	0.000	0.000	8.462	0.000	0.000	2.490
1.100	87.440	0.000	0.000	45.589	0.000	0.000	11.000	0.000	0.000	2.490
1.200	84.737	0.000	0.000	48.808	0.000	0.000	14.867	0.000	0.000	2.490
1.300	81.482	0.000	0.000	52.683	0.000	0.000	20.315	0.000	0.000	2.490
1.400	77.709	0.000	0.000	57.176	0.000	0.000	27.460	0.000	0.000	2.490
1.500	73.511	0.000	0.000	62.176	0.000	0.000	37.158	0.000	0.000	2.490
1.600	69.032	0.000	0.000	67.508	0.000	0.000	49.035	0.000	0.000	2.490
1.700	64.438	0.000	0.000	72.980	0.000	0.000	63.460	0.000	0.000	2.490
1.800	59.867	0.000	0.000	78.421	0.000	0.000	80.536	0.000	0.000	2.490
1.900	55.414	0.000	0.000	83.725	0.000	0.000	100.299	0.000	0.000	2.490
2.000	51.112	0.000	0.000	88.848	0.000	0.000	122.723	0.000	0.000	2.490
2.100	46.955	0.000	0.000	93.798	0.000	0.000	147.735	0.000	0.000	2.490
2.200	42.918	0.000	0.000	98.604	0.000	0.000	175.226	0.000	0.000	2.490
2.300	38.978	0.000	0.000	103.296	0.000	0.000	205.069	0.000	0.000	2.490
2.400	35.114	0.000	0.000	107.897	0.000	0.000	237.128	0.000	0.000	2.490
2.500	31.313	0.000	0.000	112.423	0.000	0.000	271.273	0.000	0.000	2.490
2.600	27.567	0.000	0.000	116.884	0.000	0.000	307.378	0.000	0.000	2.490
2.700	23.872	0.000	0.000	121.283	0.000	0.000	345.324	0.000	0.000	2.490
2.800	20.228	0.000	0.000	125.623	0.000	0.000	385.000	0.000	0.000	2.490
2.900	16.632	0.000	0.000	129.905	0.000	0.000	426.305	0.000	0.000	2.490
3.000	13.084	0.000	0.000	134.130	0.000	0.000	469.148	0.000	0.000	2.490
3.100	9.582	0.000	0.000	138.299	0.000	0.000	513.443	0.000	0.000	2.490
3.200	6.126	0.000	0.000	142.415	0.000	0.000	559.116	0.000	0.000	2.490
3.300	2.715	0.000	0.000	146.477	0.000	0.000	606.095	0.000	0.000	2.490
3.400	.055	0.000	0.000	149.644	0.000	0.000	654.317	0.000	0.000	2.490
3.500	.055	0.000	0.000	149.644	0.000	0.000	703.720	0.000	0.000	2.490
3.600	.055	0.000	0.000	149.644	0.000	0.000	754.224	0.000	0.000	2.490
3.700	.055	0.000	0.000	149.644	0.000	0.000	805.739	0.000	0.000	2.490
3.800	.055	0.000	0.000	149.644	0.000	0.000	858.186	0.000	0.000	2.490
3.900	.055	0.000	0.000	149.644	0.000	0.000	911.493	0.000	0.000	2.490
4.000	.055	0.000	0.000	149.644	0.000	0.000	965.596	0.000	0.000	2.490
4.100	.055	0.000	0.000	149.644	0.000	0.000	1020.440	0.000	0.000	2.490
4.150	.055	0.000	0.000	149.644	0.000	0.000	1053.681	0.000	0.000	2.490

13.15.25.UCLP, FA, TM1402C, 0.233KLS.

T (MS)	PM1	PM1.3	PM1.3	PM3	PM4	PM4	RMSUM
0.000	118.521	0.000	0.000	.403	0.000	0.000	118.995
.100	118.519	0.000	0.000	.406	0.000	0.000	118.995
.200	118.445	0.000	0.000	.470	0.000	0.000	118.995
.300	118.325	0.000	0.000	.577	0.000	0.000	118.995
.400	118.147	0.000	0.000	.734	0.000	0.000	118.995
.500	117.896	0.000	0.000	.957	0.000	0.000	118.995
.600	117.550	0.000	0.000	1.265	0.000	0.000	118.995
.700	117.081	0.000	0.000	1.684	0.000	0.000	118.995
.800	116.446	0.000	0.000	2.249	0.000	0.000	118.995
.900	115.575	0.000	0.000	2.994	0.000	0.000	118.995
1.000	114.378	0.000	0.000	3.957	0.000	0.000	118.995
1.100	112.748	0.000	0.000	5.171	0.000	0.000	118.994
1.200	110.570	0.000	0.000	6.655	0.000	0.000	118.995
1.300	107.739	0.000	0.000	8.405	0.000	0.000	118.996
1.400	104.186	0.000	0.000	10.382	0.000	0.000	118.997
1.500	99.898	0.000	0.000	12.511	0.000	0.000	118.997
1.600	94.937	0.000	0.000	14.687	0.000	0.000	118.996
1.700	89.431	0.000	0.000	16.791	0.000	0.000	118.995
1.800	83.562	0.000	0.000	18.710	0.000	0.000	118.998
1.900	77.509	0.000	0.000	20.364	0.000	0.000	119.005
2.000	71.427	0.000	0.000	21.719	0.000	0.000	119.011
2.100	65.420	0.000	0.000	22.787	0.000	0.000	119.008
2.200	59.543	0.000	0.000	23.607	0.000	0.000	118.990
2.300	53.816	0.000	0.000	24.226	0.000	0.000	118.974
2.400	49.242	0.000	0.000	24.697	0.000	0.000	119.006
2.500	42.817	0.000	0.000	25.064	0.000	0.000	119.073
2.600	37.525	0.000	0.000	25.344	0.000	0.000	119.056
2.700	32.356	0.000	0.000	25.549	0.000	0.000	119.057
2.800	27.307	0.000	0.000	25.705	0.000	0.000	119.056
2.900	22.369	0.000	0.000	25.823	0.000	0.000	119.055
3.000	17.537	0.000	0.000	25.913	0.000	0.000	119.054
3.100	12.803	0.000	0.000	25.981	0.000	0.000	119.053
3.200	8.162	0.000	0.000	26.035	0.000	0.000	119.053
3.300	3.607	0.000	0.000	26.075	0.000	0.000	119.052
3.400	.073	0.000	0.000	25.240	0.000	0.000	119.052
3.500	.073	0.000	0.000	22.610	0.000	0.000	119.053
3.600	.073	0.000	0.000	21.171	0.000	0.000	119.055
3.700	.073	0.000	0.000	20.037	0.000	0.000	119.057
3.800	.073	0.000	0.000	19.017	0.000	0.000	119.058
3.900	.073	0.000	0.000	18.082	0.000	0.000	119.058
4.000	.073	0.000	0.000	17.222	0.000	0.000	119.059
4.100	.073	0.000	0.000	16.429	0.000	0.000	119.059
4.160	.073	0.000	0.000	15.983	0.000	0.000	119.061

13.14.5A.11CLP. FA. TM1602C. 0.233KLS.

T (MS)	RMD13	PMN3	RMD34	RMD4	HL1	HL3	M3	HL4	M4
0.000	0.000	0.000	0.000	0.000	3338.190	0.000	4209.504	0.000	4209.504
.100	513.707	0.000	59.270	0.000	3339.046	0.000	4207.164	0.000	4214.330
.200	951.249	0.000	109.784	0.000	3340.275	0.000	4197.497	0.000	4190.794
.300	1470.662	0.000	168.843	0.000	3342.300	0.000	4185.684	0.000	4473.914
.400	2114.147	0.000	240.351	0.000	3345.290	0.000	4146.583	0.000	4617.923
.500	2940.291	0.000	328.263	0.000	3349.446	0.000	4132.393	0.000	4747.532
.600	4011.742	0.000	476.563	0.000	3355.113	0.000	4123.586	0.000	4858.119
.700	5431.907	0.000	570.812	0.000	3362.692	0.000	4120.000	0.000	4950.600
.800	7385.699	0.000	895.947	0.000	3372.657	0.000	4119.348	0.000	5013.826
.900	10178.117	0.000	1699.733	0.000	3385.297	0.000	4111.269	0.000	5086.929
1.000	13948.401	0.000	3109.937	0.000	3400.811	0.000	4092.874	0.000	4887.967
1.100	18448.774	0.000	5368.770	0.000	3419.213	0.000	4094.645	0.000	4766.108
1.200	24890.881	0.000	8488.087	0.000	3440.164	0.000	4028.492	0.000	4651.139
1.300	31850.490	0.000	13130.572	0.000	3462.873	0.000	3987.185	0.000	4550.359
1.400	39287.295	0.000	18573.790	0.000	3486.032	0.000	3943.762	0.000	4460.526
1.500	46404.063	0.000	24692.860	0.000	3507.944	0.000	3900.227	0.000	4376.986
1.600	52581.334	0.000	30949.996	0.000	3526.759	0.000	3857.079	0.000	4296.146
1.700	57171.732	0.000	36901.371	0.000	3548.893	0.000	3813.574	0.000	4215.415
1.800	59903.786	0.000	41935.720	0.000	3569.501	0.000	3768.680	0.000	4133.333
1.900	60893.478	0.000	45794.958	0.000	3582.665	0.000	3721.838	0.000	4049.557
2.000	60573.637	0.000	48455.109	0.000	3591.309	0.000	3673.575	0.000	3964.957
2.100	59477.172	0.000	50110.169	0.000	3546.756	0.000	3625.310	0.000	3881.129
2.200	58041.599	0.000	50978.294	0.000	3540.290	0.000	3578.960	0.000	3799.958
2.300	56507.129	0.000	51148.883	0.000	3532.873	0.000	3536.430	0.000	3723.435
2.400	54983.352	0.000	50745.310	0.000	3525.190	0.000	3499.212	0.000	3653.374
2.500	53557.822	0.000	50243.243	0.000	3517.725	0.000	3467.744	0.000	3589.466
2.600	52307.341	0.000	49983.994	0.000	3510.610	0.000	3440.707	0.000	3529.855
2.700	51078.006	0.000	49297.065	0.000	3503.712	0.000	3417.504	0.000	3475.289
2.800	49917.501	0.000	48570.424	0.000	3497.230	0.000	3398.276	0.000	3426.649
2.900	48839.252	0.000	47807.717	0.000	3491.188	0.000	3382.408	0.000	3382.747
3.000	47822.374	0.000	47034.921	0.000	3485.560	0.000	3369.434	0.000	3343.110
3.100	46864.705	0.000	46263.553	0.000	3480.326	0.000	3358.878	0.000	3307.293
3.200	45985.871	0.000	45508.192	0.000	3475.493	0.000	3350.377	0.000	3274.950
3.300	45129.986	0.000	44766.810	0.000	3470.968	0.000	3343.525	0.000	3245.422
3.400	0.000	0.000	37537.645	0.000	3330.900	0.000	3294.504	0.000	3217.366
3.500	0.000	0.000	18035.815	0.000	3330.900	0.000	3156.951	0.000	3165.638
3.600	0.000	0.000	12215.956	0.000	3330.900	0.000	3079.401	0.000	3103.924
3.700	0.000	0.000	10632.194	0.000	3330.900	0.000	3017.613	0.000	3044.410
3.800	0.000	0.000	9745.169	0.000	3330.900	0.000	2961.726	0.000	2988.718
3.900	0.000	0.000	8967.546	0.000	3330.900	0.000	2909.699	0.000	2936.755
4.000	0.000	0.000	8257.115	0.000	3330.900	0.000	2861.023	0.000	2888.183
4.100	0.000	0.000	7613.606	0.000	3330.900	0.000	2815.435	0.000	2842.674
4.160	0.000	0.000	7238.210	0.000	3330.900	0.000	2759.447	0.000	2816.755

13.1E+55.HCLP, FA, TM1402C, 0.233KINS.

T (MS)	CL1	CL3	CG3	C3	CL4	CG4	C4	TE403	TE404
0.000	130805.811	0.000	0.000	105976.943	0.000	0.000	105976.843	1979.239	1979.239
.100	130775.075	0.000	0.000	105955.772	0.000	0.000	106043.541	1978.102	1981.482
.200	130730.895	0.000	0.000	105920.561	0.000	0.000	107664.583	1967.930	2035.510
.300	130658.035	0.000	0.000	105904.607	0.000	0.000	107070.923	1956.145	2101.528
.400	130550.592	0.000	0.000	106264.745	0.000	0.000	111477.054	1944.382	2157.219
.500	130399.952	0.000	0.000	106799.032	0.000	0.000	116032.949	1935.248	2225.348
.600	130194.262	0.000	0.000	107658.104	0.000	0.000	116174.282	1926.955	2273.362
.700	130917.757	0.000	0.000	108911.217	0.000	0.000	118383.912	1919.727	2311.484
.800	130551.622	0.000	0.000	110611.467	0.000	0.000	120614.139	1912.151	2334.006
.900	130882.924	0.000	0.000	112678.577	0.000	0.000	122272.072	1899.193	2312.215
1.000	137500.883	0.000	0.000	115107.843	0.000	0.000	127605.579	1879.436	2256.567
1.100	136600.541	0.000	0.000	117889.329	0.000	0.000	125125.704	1853.264	2184.473
1.200	135089.294	0.000	0.000	120958.631	0.000	0.000	127043.681	1822.030	2116.536
1.300	135092.897	0.000	0.000	124183.744	0.000	0.000	129245.689	1787.784	2055.066
1.400	134158.921	0.000	0.000	127377.847	0.000	0.000	131456.590	1752.878	1999.561
1.500	133255.570	0.000	0.000	130317.907	0.000	0.000	133382.420	1719.209	1948.819
1.600	132463.903	0.000	0.000	132776.522	0.000	0.000	134780.847	1687.865	1901.923
1.700	131858.696	0.000	0.000	134556.080	0.000	0.000	134889.404	1659.148	1858.110
1.800	131485.482	0.000	0.000	135527.065	0.000	0.000	135440.125	1632.939	1816.799
1.900	131347.366	0.000	0.000	135659.382	0.000	0.000	136660.343	1608.983	1777.594
2.000	131404.679	0.000	0.000	135037.117	0.000	0.000	133260.313	1587.152	1740.403
2.100	131604.921	0.000	0.000	133829.922	0.000	0.000	131399.975	1567.470	1705.333
2.200	131884.679	0.000	0.000	132241.686	0.000	0.000	129261.521	1550.110	1672.582
2.300	132203.064	0.000	0.000	130464.196	0.000	0.000	127030.659	1535.310	1642.425
2.400	132530.210	0.000	0.000	128456.838	0.000	0.000	124856.696	1523.236	1615.211
2.500	132845.612	0.000	0.000	126924.264	0.000	0.000	122769.219	1513.738	1590.689
2.600	133144.005	0.000	0.000	125268.363	0.000	0.000	120704.758	1506.159	1567.785
2.700	133431.285	0.000	0.000	123698.864	0.000	0.000	118814.777	1500.174	1547.484
2.800	133699.403	0.000	0.000	122253.510	0.000	0.000	117063.109	1495.725	1529.229
2.900	133947.811	0.000	0.000	120928.486	0.000	0.000	115449.291	1492.525	1512.820
3.000	134177.883	0.000	0.000	119719.078	0.000	0.000	113965.858	1490.361	1498.037
3.100	134390.683	0.000	0.000	118616.290	0.000	0.000	112603.394	1489.029	1484.755
3.200	134584.287	0.000	0.000	117612.131	0.000	0.000	111351.948	1488.379	1472.747
3.300	134768.589	0.000	0.000	116695.066	0.000	0.000	110201.338	1488.247	1461.992
3.400	134902.034	0.000	0.000	114321.723	0.000	0.000	109104.143	1471.939	1451.499
3.500	134902.034	0.000	0.000	109228.628	0.000	0.000	107308.911	1420.089	1431.470
3.600	134902.034	0.000	0.000	106482.901	0.000	0.000	105236.580	1390.170	1407.230
3.700	134902.034	0.000	0.000	104344.945	0.000	0.000	103282.245	1366.038	1383.602
3.800	134902.034	0.000	0.000	102445.327	0.000	0.000	101492.375	1343.999	1361.259
3.900	134902.034	0.000	0.000	100711.465	0.000	0.000	99854.671	1323.286	1340.245
4.000	134902.034	0.000	0.000	99120.137	0.000	0.000	98351.195	1303.733	1320.435
4.100	134902.034	0.000	0.000	97855.510	0.000	0.000	96965.956	1285.274	1301.741
4.140	134902.034	0.000	0.000	96832.455	0.000	0.000	94196.412	1274.707	1291.036

13.14.24.UCLP. FA. TM1602C. 0.233KLS.

Y (MS)	EL1	FL3	EG3	EL4	FG4	FPG5	KPJ	FL4	FXG4	FSJM
0.000	304742.327	0.000	1341.908	0.000	236.343	0.000	0.000	0.000	0.000	394340.577
.100	304771.080	0.000	1351.345	0.000	237.635	.101	0.000	0.000	0.000	394340.171
.200	304528.838	0.000	1557.435	0.000	272.495	.347	0.000	0.000	0.000	394359.514
.300	394128.214	0.000	1898.474	0.000	330.718	.824	0.000	0.000	0.000	394358.232
.400	393534.960	0.000	2403.945	0.000	415.245	1.491	0.000	0.000	0.000	394355.890
.500	392498.326	0.000	3117.870	0.000	532.282	3.230	0.000	0.000	0.000	394351.707
.600	391547.039	0.000	4101.997	0.000	689.358	5.927	0.000	0.000	0.000	394344.321
.700	389984.188	0.000	5440.857	0.000	895.671	10.604	.001	0.000	0.000	394331.321
.800	387870.686	0.000	7237.871	0.000	1177.054	18.600	3.713	0.000	.002	394307.926
.900	384969.821	0.000	9570.308	0.000	1655.459	31.981	42.857	0.000	.031	394270.357
1.000	380981.179	0.000	12515.754	0.000	2503.642	52.922	156.199	0.000	.177	394209.871
1.100	375551.547	0.000	16127.343	0.000	3955.065	84.099	400.597	0.000	.739	394119.189
1.200	369297.533	0.000	20407.393	0.000	6303.043	176.267	857.208	0.000	2.601	395094.044
1.300	358968.756	0.000	25288.139	0.000	9861.489	176.767	1629.537	0.000	7.947	395832.654
1.400	347031.901	0.000	30625.095	0.000	14905.247	229.347	2833.541	0.000	21.521	395645.712
1.500	332749.149	0.000	36196.603	0.000	21608.101	270.935	4580.015	0.000	51.741	395454.634
1.600	316224.005	0.000	41719.404	0.000	29987.703	295.940	6953.324	0.000	111.740	395302.228
1.700	297891.877	0.000	46883.908	0.000	39937.449	301.054	9992.970	0.000	218.439	395226.297
1.800	278337.900	0.000	51416.641	0.000	51140.407	290.725	13684.610	0.000	392.472	395262.755
1.900	258174.265	0.000	55140.219	0.000	63218.396	272.857	17962.080	0.000	650.859	395418.675
2.000	237914.997	0.000	58012.622	0.000	75759.436	254.241	27271.423	0.000	1007.724	395670.443
2.100	217906.910	0.000	60111.005	0.000	88398.256	238.380	27840.429	0.000	1470.401	395965.781
2.200	198330.896	0.000	61582.975	0.000	100884.173	225.950	33200.196	0.000	2040.306	396264.505
2.300	179254.799	0.000	62595.229	0.000	113140.876	216.323	38497.430	0.000	2716.034	396620.591
2.400	160889.735	0.000	63309.106	0.000	125223.967	208.683	44257.333	0.000	3495.928	397184.752
2.500	142617.911	0.000	63851.570	0.000	137039.903	202.445	49827.069	0.000	4373.670	397912.569
2.600	124993.008	0.000	64241.222	0.000	148244.160	196.924	55357.722	0.000	5333.273	398366.309
2.700	107774.704	0.000	64503.011	0.000	159257.470	191.523	60816.573	0.000	6376.973	398920.254
2.800	90955.717	0.000	64703.936	0.000	169970.815	186.401	64186.620	0.000	7495.335	399498.824
2.900	74510.370	0.000	64842.054	0.000	180414.078	181.485	71455.783	0.000	8682.398	400106.168
3.000	58414.263	0.000	64993.496	0.000	190607.117	176.733	76617.262	0.000	9932.452	400741.323
3.100	42645.722	0.000	65107.381	0.000	200568.960	172.152	81667.988	0.000	11240.350	401402.553
3.200	27185.454	0.000	65212.487	0.000	210318.113	167.716	86607.456	0.000	12401.514	402092.740
3.300	12013.561	0.000	65310.288	0.000	219869.851	163.469	91436.851	0.000	14011.795	402805.817
3.400	244.517	0.000	62522.538	0.000	228982.311	0.000	96158.280	0.000	15455.778	403363.425
3.500	244.517	0.000	54036.401	0.000	232157.184	0.000	100718.572	0.000	16442.880	403799.555
3.600	244.517	0.000	49531.101	0.000	231638.999	0.000	105019.708	0.000	17413.126	404047.451
3.700	244.517	0.000	46042.684	0.000	230398.402	0.000	109051.366	0.000	18501.995	404258.965
3.800	244.517	0.000	43014.394	0.000	229015.992	0.000	112834.009	0.000	19341.091	404450.005
3.900	244.517	0.000	40269.223	0.000	227598.005	0.000	116389.389	0.000	20137.130	404628.244
4.000	244.517	0.000	37786.790	0.000	226136.455	0.000	119737.767	0.000	20893.133	404798.664
4.100	244.517	0.000	35536.720	0.000	224737.521	0.000	122497.198	0.000	21611.674	404963.630
4.140	244.517	0.000	34287.953	0.000	223707.813	0.000	124709.403	0.000	22026.001	405065.695

13.17.30.11CLP. FA. TM1602C.
0.233WLS.

T (MS)	UL3	WE	OC
0.000	0.000	0.000	.500
.100	167.032	0.000	.500
.200	309.104	0.000	.500
.300	477.387	0.000	.500
.400	685.858	0.000	.500
.500	950.913	0.000	.500
.600	1293.603	0.000	.500
.700	1744.589	0.000	.500
.800	2359.604	0.000	.500
.900	3229.778	0.000	.500
1.000	4388.951	0.000	.500
1.100	5870.622	0.000	.500
1.200	7660.816	0.000	.500
1.300	9674.070	0.000	.500
1.400	11756.378	0.000	.500
1.500	13713.619	0.000	.500
1.600	15355.079	0.000	.500
1.700	16543.380	0.000	.500
1.800	17235.949	0.000	.500
1.900	17483.922	0.000	.500
2.000	17407.799	0.000	.500
2.100	17144.306	0.000	.500
2.200	16801.706	0.000	.500
2.300	16436.586	0.000	.500
2.400	16072.609	0.000	.500
2.500	15730.505	0.000	.500
2.600	15432.319	0.000	.500
2.700	15134.727	0.000	.500
2.800	14850.364	0.000	.500
2.900	14583.628	0.000	.500
3.000	14329.081	0.000	.500
3.100	14086.709	0.000	.500
3.200	13862.813	0.000	.500
3.300	13661.681	0.000	.500
3.400	0.000	0.000	.500
3.500	0.000	0.000	.500
3.600	0.000	0.000	.500
3.700	0.000	0.000	.500
3.800	0.000	0.000	.500
3.900	0.000	0.000	.500
4.000	0.000	0.000	.500
4.100	0.000	0.000	.500
4.160	0.000	0.000	.500

13.18.02.0CLP, FA, TW1602C. 0.233K(LNS.

GLOSSARY

A_1	Cross section area of the liquid reservoir, cm^2 .
A_3	Cross section area of the combustion chamber, cm^2 .
A_4	Cross section area of the gun tube, cm^2 .
A_v	Vent area, cm^2 .
b	Covolume, cm^3/gm .
c_1	Speed of sound in the liquid in the reservoir, cm/s .
c_{L3}	Speed of sound in the liquid in the combustion chamber, cm/s .
c_{L4}	Speed of sound in the liquid in the gun tube, cm/s .
c_{G3}	Speed of sound in the gas in the combustion chamber, cm/s .
c_{G4}	Speed of sound in the gas in the gun tube, cm/s .
c_3	Average speed of sound in the combustion chamber, cm/s .
c_4	Average speed of sound in the gun tube, cm/s .
c_p	Specific heat at constant pressure, joules/gm-K .
c_v	Specific heat at constant volume, joules/gm-K .
C_D	Discharge coefficient for the piston.
C'_D	Discharge coefficient for the gun tube.
e_1	Chemical energy of the liquid, joules/gm .

e_3	Internal energy of the gas in the combustion chamber, joules/gm.
e_4	Internal energy of the gas in the gun tube, joules/gm.
E_1	Total internal energy of the liquid, joules.
E_3	Total internal energy in the gas in the chamber, joules.
E_4	Total internal energy in the gas in the gun tube, joules.
EK_{G4}	Kinetic energy of the gas in the gun tube, joules.
EK_{L4}	Kinetic energy of the liquid in the gun tube, joules.
EK_{pj}	Kinetic energy of the projectile, joules.
EK_{ps}	Kinetic energy of the piston, joules.
g_0	Conversion constant = 10^7 gm/s-cm-MPa.
h_1	Liquid enthalpy in the reservoir, joules/gm.
h_{L3}	Liquid enthalpy in the combustion chamber, joules/gm.
h_{G3}	Gas enthalpy in the combustion chamber, joules/gm.
h_{L4}	Liquid enthalpy in the gun tube, joules/gm.
h_{G4}	Gas enthalpy in the gun tube, joules/gm.
K	Bulk modulus, MPa.
K_1	Bulk modulus at zero pressure, MPa.
K_2	Derivative of the bulk modulus, MPa.

M_{G3}	Gas mass in the combustion chamber, gm.
M_{G4}	Gas mass in the gun tube, gm.
M_1	Liquid mass in the reservoir, gm.
M_{L3}	Liquid mass in the combustion chamber, gm.
M_{L4}	Liquid mass in the gun tube, gm.
M_T	Total propellant mass in the system, gm.
M_{pj}	Projectile mass, gm.
M_{ps}	Piston mass, gm.
$\dot{m}_{13}$	Mass flux into the combustion chamber, gm/s.
$\dot{m}_{34}$	Mass flux into the gun tube, gm/s.
$\dot{m}_3$	Rate of gas formation in the combustion chamber, gm/s.
$\dot{m}_4$	Rate of gas formation in the gun tube, gm/s.
P_1	Pressure in the liquid reservoir, MPa.
P_3	Pressure in the combustion chamber, MPa.
P_4	Average pressure in the gun tube, MPa.
P_L	Pressure at the gun throat, MPa.
P_R	Pressure at the base of the projectile, MPa.
P_{RS}	Projectile resistance pressure, MPa.

R	Universal gas constant = 8.318 joules/mole-K.
S_{pj}	Projectile travel, cm.
S_{ps}	Piston travel, cm.
T_3	Temperature in the combustion chamber, K.
T_4	Average temperature in the gun tube, K.
V_1	Volume of the liquid reservoir, cm^3 .
V_3	Volume of the combustion chamber, cm^3 .
V_4	Volume of the gun tube behind the projectile, cm^3 .
V_{L3}	Liquid volume in the combustion chamber, cm^3 .
V_{G3}	Gas volume in the combustion chamber, cm^3 .
V_{L4}	Liquid volume in the gun tube, cm^3 .
V_{G4}	Gas volume in the gun tube, cm^3 .
V_{pj}	Projectile velocity, cm/s.
V_{ps}	Piston velocity, cm/s.
W	Molecular weight of the gas, gm.
ϵ_3	Porosity of the combustion chamber.
ϵ_4	Porosity of the gun tube.
γ	Ratio of specific heats.

- ρ_1 Liquid density in the reservoir, gm/cm.
- ρ_{L3} Liquid density in the combustion chamber, gm/cm.
- ρ_{L4} Liquid density in the gun tube, gm/cm.
- ρ_{G3} Gas density in the combustion chamber, gm/cm.
- ρ_{G4} Gas density in the gun tube, gm/cm.

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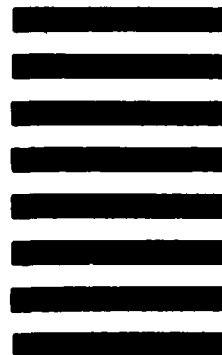


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