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A Study of High Frequency Nonlinear Combustion Instability  
in Baffled Annular Liquid Propellant Rocket Motors

Volume II

A User Manual For  
Computer Programs TRDL and TRDPLT

by

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## FOREWORD

This is the final report on Contract NAS7-752 for the National Aeronautics and Space Administration. The work was performed in the period from August 25, 1969 to September 25, 1970. The NASA program manager was Dr. Robert Levine, of the Office of Advanced Research and Technology, and the technical manager was Dr. Raymond Kushida, of the Jet Propulsion Laboratory.

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## ABSTRACT

A computer program for a nonlinear evaporation rate controlling combustion instability model is described herein. All of the equations used in the model are listed. The methods used for the numerical solution of the equations are described. A complete description of the logic of the computer program is given together with its utilization. The format required for the input to the program is explained with a description of the output. Sample cases are also provided. The utilization of a second program for plotting the results of the calculations is fully described together with samples of the various plots that may be produced.

## I. Introduction

This volume of the report describes a computer program for a nonlinear evaporation rate controlling combustion instability model. Volume I describes the results of using the computer program for experiments on the effects of baffles on the damping of bomb-like disturbances in liquid rocket engines. The numerical model has been constructed so as to approximate the gross features of a baffled liquid propellant rocket motor which has a radial measurement significantly smaller than the axial or circumferential dimensions, i.e., an annular motor. Hence, the radial coordinate,  $r$ , is neglected and the relevant coordinates are the axial length,  $z$ , circumferential distance,  $\theta$ , (actually  $r\theta$  but  $r$  is normalized to unity) and the time,  $t$ .

The numerical methods used in the model calculate the three regimes of gas dynamic flow: the subsonic chamber including the droplet spray region, which induces a combustion zone adjacent to the injector face, the transonic region in the converging-diverging nozzle and the supersonic outflow region in the diverging section of the nozzle. Up to six baffled compartments are allowed in the combustion chamber each of which may have a length ranging up to and including the combustor length and whose boundaries may be specified at arbitrary angular positions around the circumference of the chamber.

Interacting with the gas dynamic flow in the subsonic combustor is a droplet field approximating a dilute spray. The drops experience aerodynamic forces through a difference in velocities between gas and droplet. The force field resulting from the velocity field is, of course, time dependent and hence, motion of the droplet field is also time dependent. Droplets of prescribed radius are injected into the chamber and they are allowed to evaporate and accelerate in the dynamic gas field. The droplet field equations are solved for in a Lagrangian frame. The solution of the droplet evaporation and dynamic equations provides the source term for the gas dynamic equations. The reinforcement of an initial pressure disturbance present in the combustor is then possible; dependence on the phase of the wave with respect to the time dependent combustion field partially determines success or failure of the amplification process. The energy supplied to the wave versus energy outflow by advection is another important criterion.

It is hoped that the method developed in this research effort for nonlinear rocket modeling in two space dimensions will prove useful for the analysis of stability limits in rocket motors yet to be designed and built.

## II. Nonlinear Differential and Difference Equations for an Annular Motor

The differential equations describing the motion of a compressible fluid in the coordinates  $z-\theta-t$  can be given by the vector form

$$\frac{\partial W}{\partial t} + \frac{1}{r} \frac{\partial G}{\partial \theta} + \frac{\partial H}{\partial z} + H^* \frac{\partial \ln A}{\partial z} = \psi \quad (1)$$

The vector  $W$  has four components which are the mass, momentum in the  $z$  and  $\theta$  directions and the total energy, all per unit volume. The vectors  $G$  and  $H$  represent the flux of these quantities in the tangential and axial directions respectively. The term containing the logarithmic derivative corresponds to an approximate way of treating small radial variations of the annular geometry. It is analogous to the treatment of one-dimensional time dependent flows with an attempt to include area variations. This term can also be considered as a source term of flux proportional to the derivative of the logarithmic variation of area, the proportionality constant being the flux  $H^*$ . This term allows us to treat, in a simple way, an annular subsonic-supersonic nozzle. The term,  $r$ , represents the radial distance of the  $z-\theta$  plane under consideration from the axis of the motor. When the equations are put in a non-dimensional form,  $r$  is used as the characteristic distance so that this term reduces to unity. The droplet combustion source term is denoted by  $\psi$ .



The exact form of the vectors are:

$$W = \begin{pmatrix} \rho \\ \rho u \\ \rho v \\ E \end{pmatrix} \quad G = \begin{pmatrix} \rho v \\ \rho uv \\ \rho v^2 + p \\ (E+p)v \end{pmatrix} \quad H = \begin{pmatrix} \rho u \\ \rho u^2 + p \\ \rho uv \\ (E+p)u \end{pmatrix} \quad H^* = \begin{pmatrix} \rho u \\ \rho u^2 \\ \rho uv \\ Eu \end{pmatrix} \quad \psi = \begin{pmatrix} \psi_\rho \\ 0 \\ 0 \\ \psi_E \end{pmatrix} \quad (2)$$

The pressure  $p$  is a function of the density  $\rho$  and specific internal energy  $e$  through the equation of state

$$p = (\gamma - 1) \rho e \quad (3)$$

The total energy of the system per unit volume is

$$E = \rho (e + 1/2(u^2 + v^2)) \quad (4)$$

The area is approximated by a quadratic function

$$A/A_C = 1 - \alpha(z - L_C) + \beta(z - L_C)^2 \quad L_C \leq z \leq L; \quad A/A_C = 1 \quad z \leq L_C \quad (5)$$

where  $A_C$  is the area of the chamber and  $L_C$  and  $L$  are the length of the chamber and motor respectively. The constants  $\alpha$  and  $\beta$  are determined from the position  $L_t$  and area ratio  $A_t/A_C$  at the throat

$$\alpha = 2(1 - A_t/A_C)/(L_t - L_C) \quad \beta = \frac{1}{2} \frac{A_t/A_C}{(L_t - L_C)} \quad (6)$$

The boundary conditions required are that  $W$  be periodic in  $\theta$ , the axial component of velocity vanish on the injector face and that the outflow be supersonic

$$W(z, \theta, t) = W(z, \theta + 2\pi, t); \quad u(0, \theta, t) = 0; \quad M(z, \theta, t) > 1 \quad z > z_t \quad (7)$$

Baffles are simply described by the condition that the tangential velocity vanish along their length, i.e.  $v = 0$ .

The source terms are obtained from a simplified Godsave analysis. The weak, almost linear, dependence on the temperature,  $T^{\circ}R$  of the dimensionless mass burning rate at a reference pressure of  $p_0$  psia,  $a_{p_0}$ , can be expressed as

$$a_{p_0} = 3.73 \times 10^{-5} T + 1.855 \quad (8)$$

The mass burning rate,  $a_p$ , is then given as a function of the pressure by

$$a_p/a_{p_0} = (p/p_0)^{\lambda} \quad (9)$$

where  $p_0$  is the steady state pressure. The drop temperature,  $T_{\ell}$ , which is the boiling temperature at the chamber pressure, can be obtained from the integrated Clausius-Clapeyron equation

$$\ln(p/2131) = 8.7 \times 10^3 (1/1176 - 1/T_{\ell}) \quad (10)$$

$$T_{\ell} = 1176^{\circ}R \quad p \geq 2131 \text{ psia}$$

The thermal conductivity,  $k$ , is given by

$$k = (8.33 \times 10^{-5} (460 - T_{\ell}) + 0.2107) / 3600 \text{ Btu/ft-sec- } R^{\circ} \quad (11)$$

and the specific heat,  $c_p$ , is obtained from

$$c_p = 0.138 + 0.527 \times 10^{-3} T_{\ell} - 0.120 \times 10^{-6} T_{\ell}^2 \text{ Btu/lbm-}^{\circ}R \quad (12)$$

The burning rate in stationary surroundings is obtained from

$$\dot{m}_F^{\circ} = \frac{2\pi k}{c_p} d_{\ell} a_p \quad (13)$$

where  $d_{\ell}$  is the drop diameter.

The viscosity is given by

$$\mu = 2.5 \times 10^{-5} (T/560)^{1/2} \text{ lbm/ft-sec.} \quad (14)$$

while the Reynold's number is

$$\text{Re} = \rho d_g |u-v| / \mu \quad (15)$$

where  $|u-v|$  is the magnitude of the velocity difference between the drop and the gas. The burning rate in the convective environment,  $\dot{m}_f$ , is then obtained from

$$\dot{m}_f / \dot{m}_f^0 = 1 + 0.276 \text{Re}^{1/2} \text{Pr}^{1/3} \quad (16)$$

where Pr is the Prandtl number.

The components of the  $\psi$  vector are then

$$\begin{aligned} \psi_\rho &= \dot{m}_f \left(1 + \frac{1}{\phi f_s}\right) N \\ \psi_E &= \dot{m}_f \left(Q - L_F - \frac{L_O}{\phi f_s}\right) N \end{aligned} \quad (17)$$

where  $\phi$  is the fuel-oxidant equivalence ratio,  $f_s$  is the stoichiometric fuel oxidant ratio,  $Q$  is the heat of reaction per unit mass of fuel,  $L_F$  is the latent heat of the fuel and  $L_O$  is the latent heat of the oxidizer. The significance of  $N$ , the number of drops per unit volume, is explained in Volume I. Under the engine conditions of interest, the following constant values are used:

$$\text{Pr}^{1/3} = 0.591 \quad \phi = 1.0 \quad f_s = 16/23$$

$$L_F = 540 \text{ Btu/lbm} \quad L_O = 178.2 \text{ Btu/lbm}$$

while  $Q$  is obtained by interpolating from a table of values of  $Q$  as a function of temperature.

The equations used to describe the droplet motion are

$$dm_{\ell}/dt = -\dot{m}_F$$

$$du_{\ell}/dt = \frac{3}{8}C_D(\rho/\rho_{\ell})(u-u_{\ell})|u-u_{\ell}|/r_{\ell} \quad (18)$$

$$dv_{\ell}/dt = \frac{3}{8}C_D(\rho/\rho_{\ell})(v-v_{\ell})|v-v_{\ell}|/r_{\ell}$$

where  $m_{\ell} = \frac{4}{3}\pi\rho_{\ell}r_{\ell}^3$  is the mass of the drop,  $\rho_{\ell}$  is the drop density and the axial and tangential components of the drop velocity are  $u_{\ell}$  and  $v_{\ell}$ . The drag coefficient,  $C_D$ , is related to the Reynolds number through

$$C_D = 27.0Re^{-0.84} \quad 0 \leq Re \leq 62.9; \quad C_D = 0.271Re^{0.271} \quad 62.9 \leq Re \leq 10^4;$$

$$C_D = 0.271(10^4)^{0.271} \quad 10^4 \leq Re$$

and the drop density is obtained from

$$\rho_{\ell} = 14.4 + 86.82(1 - T_{\ell}/1176) + 6.343(1 - T_{\ell}/1176)^{\frac{1}{2}} \\ + 17.716(1 - T_{\ell}/1176)^{1/3} - 60.654(1 - T_{\ell}/1176)^2 \quad \text{lbm/ft}^3$$

where  $T_{\ell}$  is taken as the drop boiling temperature at the steady-state pressure at the injector. The drop density is thus kept constant throughout a run.

The initial conditions are obtained by perturbing a given steady state to simulate a bomb. The perturbed equations in the region of the bomb are

$$\begin{aligned}
p &= p_s + p_b = p_s + A \sin(a_1 \theta + a_2) \sin(b_1 z + b_2) & \theta_1 \leq \theta \leq \theta_2 & \quad (19) \\
\rho &= \rho_s + \rho_b = \rho_s + p_b^{1/\gamma} & z_1 \leq z \leq z_2 & \\
e_b &= p_b^{(\gamma-1)/\gamma} / (\gamma-1) & &
\end{aligned}$$

where  $p_s$  and  $\rho_s$  are the steady-state values and hence are functions of  $z$  only, and  $p_b$ ,  $\rho_b$ , and  $e_b$  are the pressure, density and energy due to the bomb. The constant  $A$  is evaluated by assigning the bomb a percentage,  $\alpha$ , of the total energy  $E_T$  in the chamber.

$$\alpha E_T = \int_{\theta_1}^{\theta_2} \int_{z_1}^{z_2} \frac{p_b^{(\gamma-1)/\gamma}}{\gamma-1} d\theta dz = \frac{A^{(\gamma-1)/\gamma}}{\gamma-1} \int_{\theta_1}^{\theta_2} \int_{z_1}^{z_2} \sin(a_1 \theta + a_2) \sin(b_1 z + b_2) d\theta dz \quad (20)$$

The equations are solved in a non-dimensional form. In order that the non-dimensional equations remain consistent, certain variables may be assigned arbitrary reference values. Then the corresponding reference values for the remaining variables are solved for using the equation of state, the equation defining the speed of sound and a reference length. The reference distance used is  $r$ , the radial distance of the  $z$ - $\theta$  plane from the motor axis. An arbitrary pressure,  $p_0$ , and temperature,  $T_0$ , are assigned and are usually taken approximately equal to the conditions in the chamber at steady state. Using  $p_0$ ,  $T_0$ , and the molecular weight of the gas,  $M$ , the reference density,  $\rho_0$ , is calculated from the equation of state. A reference sound speed,  $a_0$ ,

calculated from the specific heat ratio,  $\gamma$ , and the values of  $p_0$  and  $\rho_0$  is used to normalize the velocities. The other reference values used for normalization are  $\gamma p_0$  for the pressure and  $t_0=r/a_0$  for the time.

Equation (1) is solved by the method of finite differences. Step sizes  $\Delta z$ ,  $\Delta \theta$  and  $\Delta t$  are determined and a mesh is introduced with points

$$\begin{aligned} z_i &= i\Delta z & \theta_j &= j\Delta \theta & t_n &= n\Delta t \\ i &= 0, 1, \dots, I & j &= 0, 1, \dots, J & n &= 0, 1, 2, \dots \end{aligned} \quad (21)$$

The vector  $W$  is then approximated by a vector  $V$  defined on the mesh points

$$W(z_i, \theta_j, t_n) \approx V(z_i, \theta_j, t_n) = V_{i,j}^n \quad (22)$$

The approximate solution is written as a two step difference equation. Predicted values  $\tilde{V}$  are first obtained at the center points of the mesh and these values are then used to obtain second order accurate values at the mesh points. Letting  $B = \psi - H * \frac{\partial \ln A}{\partial z}$  and  $L = H * \frac{\partial \ln A}{\partial z}$  the finite difference equations are:

$$\begin{aligned} \tilde{V}_{i+\frac{1}{2}, j+\frac{1}{2}}^n &= \frac{1}{4} (V_{i+1, j+1}^{n-1} + V_{i+1, j}^{n-1} + V_{i, j+1}^{n-1} + V_{i, j}^{n-1}) \\ &- \frac{\Delta t}{2\Delta \theta} (G_{i+1, j+1}^{n-1} + G_{i, j+1}^{n-1} - G_{i+1, j}^{n-1} - G_{i, j}^{n-1}) \\ &- \frac{\Delta t}{2\Delta z} (H_{i+1, j+1}^{n-1} + H_{i+1, j}^{n-1} - H_{i, j+1}^{n-1} - H_{i, j}^{n-1}) \\ &+ \frac{\Delta t}{4} (B_{i+1, j+1}^{n-1} + B_{i+1, j}^{n-1} + B_{i, j+1}^{n-1} + B_{i, j}^{n-1}) \end{aligned} \quad (23)$$

$$\begin{aligned}
V_{i,j}^n = & V_{i,j}^{n-1} - \frac{\Delta t}{4\Delta\theta} (G_{i,j+1}^{n-1} - G_{i,j+1}^{n-1} + \tilde{G}_{i+\frac{1}{2},j+\frac{1}{2}}^n + \tilde{G}_{i-\frac{1}{2},j+\frac{1}{2}}^n - \tilde{G}_{i+\frac{1}{2},j-\frac{1}{2}}^n - \tilde{G}_{i-\frac{1}{2},j-\frac{1}{2}}^n) \\
& - \frac{\Delta t}{4\Delta z} (H_{i+1,j}^{n-1} - H_{i-1,j}^{n-1} + \tilde{H}_{i+\frac{1}{2},j+\frac{1}{2}}^n + \tilde{H}_{i+\frac{1}{2},j-\frac{1}{2}}^n - \tilde{H}_{i-\frac{1}{2},j+\frac{1}{2}}^n - \tilde{H}_{i-\frac{1}{2},j-\frac{1}{2}}^n) \\
& - \frac{\Delta t}{4} (C_{i+1,j}^{n-1} + C_{i-1,j}^{n-1} + \frac{1}{2}(\tilde{C}_{i+\frac{1}{2},j+\frac{1}{2}}^n + \tilde{C}_{i+\frac{1}{2},j-\frac{1}{2}}^n + \tilde{C}_{i-\frac{1}{2},j+\frac{1}{2}}^n + \tilde{C}_{i-\frac{1}{2},j-\frac{1}{2}}^n)) \\
& + \Delta t \psi_{i,j}^{n-1}
\end{aligned} \tag{24}$$

The boundary conditions are:

$$\begin{aligned}
\rho_{-1,j}^n = \rho_{1,j}^n \quad u_{-1,j}^n = -u_{1,j}^n \quad v_{-1,j}^n = v_{1,j}^n \quad p_{-1,j}^n = p_{1,j}^n \\
v_{i,J+1}^n = v_{i,0}^n \quad v_{i,-1}^n = v_{i,J}^n \quad v_{I,j}^n = 2v_{I-1,j}^n - v_{I-2,j}^n
\end{aligned} \tag{25}$$

and the baffles are represented by the conditions

$$\begin{aligned}
\rho_{i,j_B\pm 1}^n = \rho_{i,j_B\mp 1}^n \quad u_{i,j_B\pm 1}^n = u_{i,j_B\mp 1}^n \quad v_{i,j_B\pm 1}^n = -v_{i,j_B\mp 1}^n \\
p_{i,j_B\pm 1}^n = p_{i,j_B\mp 1}^n \quad i=1,2,\dots,i_B
\end{aligned} \tag{26}$$

where a baffle at mesh points  $j=j_B$  extends to mesh point  $i=i_B$ .

The time step is obtained from the Richtmyer stability condition

$$\Delta t < \Delta(1/\sqrt{2})/(|u|+a) \tag{27}$$

where  $\Delta$  is either  $\Delta z$  or  $\Delta \theta$ ;  $|u|$  is the magnitude of the velocity and  $a$  is the sound speed.

The time step is set to a fraction of the minimum of the right side of inequality (27) taken over all mesh points.

The smoothing operator is a two step operator in the same way that the difference equations are two step schemes. Let  $D_-^m$  denote the following backward difference operator

$$D_-^m W_{m+1} = W_{m+1} - W_m$$

Then define

$$\tilde{W}_m = W_m + K(\Delta t / \Delta m) D_-^m (|D_-^m u_{m+1}| |D_-^m W_{m+1}|) \quad (28)$$

where  $u$  is the velocity in the  $m$  direction,  $\Delta m$  is the space step in that direction and  $K$  is a constant.

Equation (28) is first applied in one coordinate direction and then in the other. Each time that smoothing takes place, the order in which it is applied is changed.

Equation (28) defines, for  $m=1,2$  ( $\theta, z$ ), two fractional steps for the numerical solution of the diffusion equation

$$W_t = \lambda K \bar{\nabla}^2 W \quad (29)$$

where the nonlinear operator,  $\bar{\nabla}^2$ , is defined in terms of the velocity components  $u$  and  $v$  by  $\bar{\nabla}^2 W = (|u_\theta| W_\theta)_\theta + (|v_z| W_z)_z$  and where  $\lambda = \Delta t / \Delta m$ . The constant  $K = (\Delta m)^3 K'$  with  $K'$  a pure number usually between one and two. This difference operator is added to the



fundamental difference operator, and as a result, we note that second order accuracy is preserved because the smoothing operator is third order. The addition of such a term to the equations of motion is in the same spirit as the von Neumann-Richtmyer artificial viscosity used in hydrodynamic calculations in 1952.

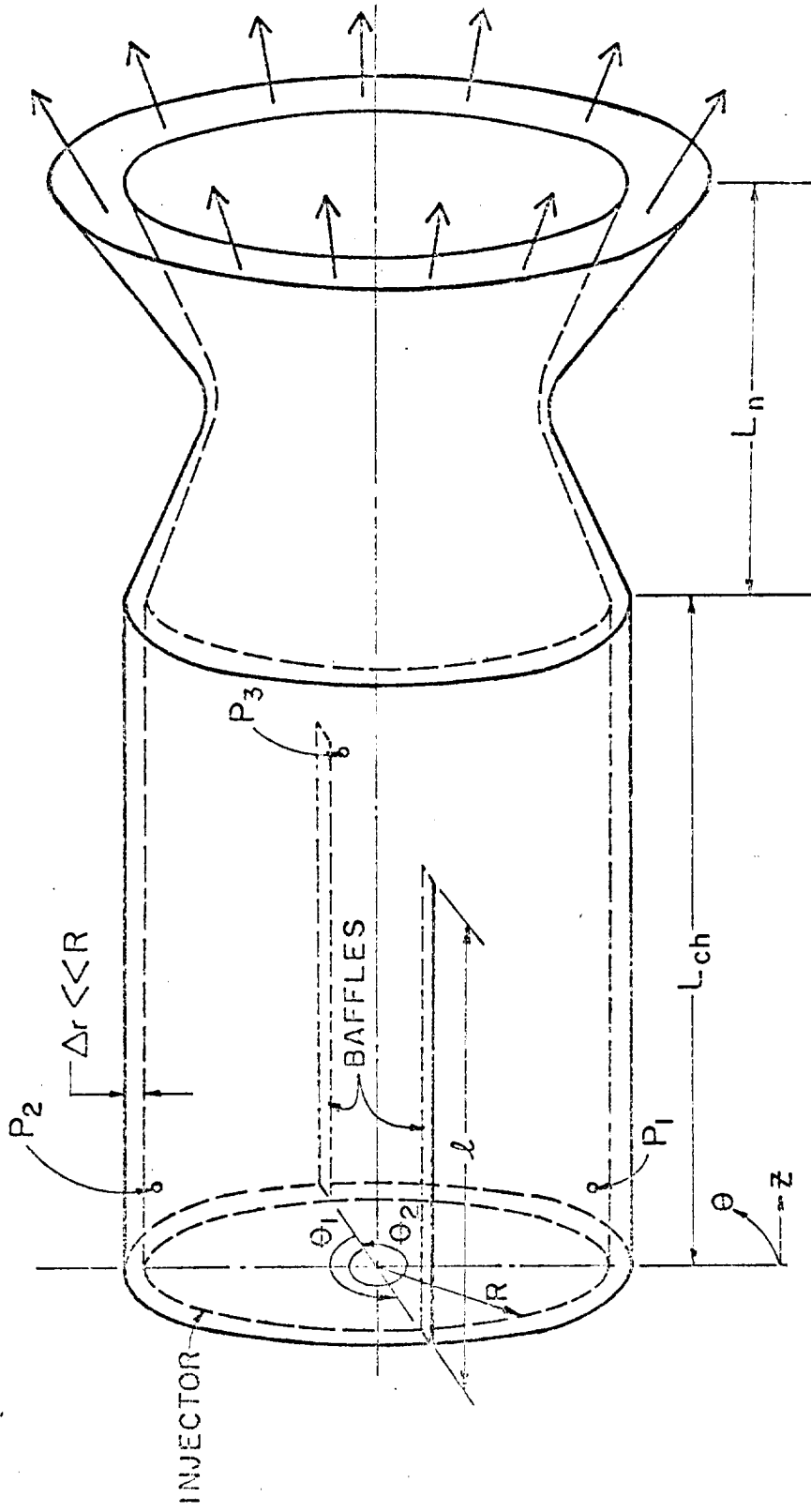


FIGURE 1 2 - BAFFLE ENGINE GEOMETRY

### III. Program TRDL

#### Description of Computer Program (TRDL)

The computer program consists of a main program and fourteen subroutines. It is written in FORTRAN IV for the CDC 6600 computer, but can be converted for use on any computer that has a FORTRAN IV compiler. The main program is called TRDL. It reads some input, writes information on tape for future plotting and to allow a run to be restarted, and mainly controls the general flow of the program logic. Subroutine INITAL reads most of the input, calculates various quantities needed throughout the run and either calculates the initial conditions, or if the run is a continuation of a previous run, reads the starting conditions from tape. Subroutine CHARGE calculates the fluid properties at the injector and nozzle exit plane. The stable time step,  $\Delta t$ , is determined in subroutine CONVRG. The vectors  $G$ ,  $H$ , and  $H^* \frac{\partial \text{LnA}}{\partial z}$  are evaluated at time,  $t$ , in subroutine VECTR and subroutine QUAD calculates the predicted fluid properties at  $t+\Delta t$ . Subroutine TMPVCT evaluates the predicted vectors  $G$ ,  $H$ , and  $H^* \frac{\partial \text{LnA}}{\partial z}$  at  $t+\Delta t$  and the corrected fluid properties at  $t+\Delta t$  are calculated in subroutine GENPT. The fluid properties along the rays with  $\theta$  equal to  $0$ ,  $\pi/2$ ,  $\pi$  and  $3\pi/2$  are printed by subroutine PRTOU. The function subroutine FZ determines  $\frac{\partial \text{LnA}}{\partial z}$ .

The forcing function  $\psi$  at time  $t$ , and the drop field at time  $t+\Delta t$  are calculated in subroutine PHIDOTV. In subroutine MSHVL, the drop mass and velocities are interpolated at the mesh points.

The smoothing is accomplished in subroutine SMOOTH while subroutine P PLOT is used to find the minimum and maximum pressure in the chamber and the value of pressure at the pressure sensors. Subroutine SEEK is a binary search routine.

TRDL starts by reading some input and initializing counters. INITAL and then CONVRG are called after which the library subroutine SECOND is called to obtain the elapsed real time which is then passed to PRTOUT. If the run is not a restart, the initial values are written onto tape 4 for the plotting program and P PLOT is called. The main loop is then started by increasing the cycle counters and the time. If the run includes energy addition PHIDOTV is called. Calls are then made in order to VECTR, QUAD, TMPVCT, GENPT, CHARGE and if it is a cycle where smoothing is to occur a call is made to SMOOTH. Next the fluid properties are tested for negative density which means an error has occurred or an instability has arisen, in which case the run is terminated. Very small momenta are also set to zero. CONVRG is called and if a point on the pressure plots is wanted a call is made to P PLOT. If the run is finished values are written on tape 4, PRTOUT is called; if information is to be saved for restarting the run it is written on tape 3 and data cards are read for a possible new run. If the run is not finished and this cycle is a plot cycle the information is written on tape 4. PRTOUT is called if it is a print cycle and if restart information is to be saved the values are written onto tape 3. The next cycle is then started.

INITAL reads all of the input that was not read in TRDL. Factors for transforming dimensions and for changing from dimensional to non-dimensional variables and back are then computed. Values of other constants that are used throughout the run are also computed at this time. If a run is being restarted, the necessary information is read from tape 1 and control leaves the subroutine. For a new run, the proper initial field for either steady state or a bomb blast is computed and placed in array PROPTY. In either case, these fields are obtained from an inputted steady-state field. A steady-state droplet field is also read at this time into the first part of array DROP. Since the steady state is independent of  $\theta$ , values along only one axial line are input.

CHARGE solves the special equations at the injector and nozzle exit planes. Logic is also included to take account of the special conditions that are introduced due to baffles.

CONVRG calculates the stable time step from the stability criteria. An empirical initial value is used, which serves as a maximum possible time step.

VECTR evaluates the vectors, G, H, and  $H \cdot \frac{\partial \ln A}{\partial z}$  in a rather straightforward manner and places the values in OVLAY. An attempt is made to avoid evaluating repeated expressions more than once.

QUAD solves the finite difference equations for the predicted fluid properties at time  $t + \Delta t$ . The first part of array OVRPRM is used for these values. For points along a baffle the special baffle equations are solved. There are separate solutions for above and below the baffle. The solution above the baffle is included in OVRPRM, while a separate array, BFL, is used for the

solution below the baffle. (Above and below the baffle are defined as  $\theta_{\text{baffle}}^{+\epsilon}$  and  $\theta_{\text{baffle}}^{-\epsilon}$ , respectively.)

TMPVCT has identical logic to that of VECTR except that the two arrays OVRPRM and BFL which contain the fluxes are treated separately.

GENPT evaluates the finite difference equations for the corrected fluid properties at time  $t+\Delta t$  and places the values in PROPTY. This includes regular points, and points on either side of a baffle.

PRTOUT evaluates and prints the density, velocities, internal energy, pressure, and Mach number along the rays with  $\theta$  of 0, 90, 180 and 270 degrees.

FZ evaluates  $\frac{\partial \text{LnA}}{\partial z}$  at a given value of  $z$ .

PHIDOTV calculates the forcing function and the droplet field. If the mass of a drop falls below one-thousandth of the initial mass, it is assumed that the drop has completely burned. In this case, the drop is assigned this minimum mass and is given the velocity of the surrounding fluid. The forcing function in this case is set to zero. The second part of array DROP contains the forcing function values.

MSHVL takes the droplet field produced in PHIDOTV, where the drops are not necessarily located at the mesh points, and produces a droplet field located at the mesh points by using successive linear interpolation. These new values are then placed in the first part of array DROP.

Interpolation is first accomplished in the axial direction so that values are obtained along the rays of constant  $\theta$ . It is assumed that the drops always have a positive axial velocity. In the tangential direction it is first determined which way the drop has moved from a mesh point. The proper values are then selected to interpolate at the point. Adjustments are made to take the periodicity condition into account. It is also determined whether a baffle exists between two points. In this case, interpolation across the baffle is not valid and values at the mesh point are determined by extrapolating from values on the same side of the baffle as the mesh point.

SMOOTH applies the smoothing equations to the solution. The order in which the smoothing takes place is alternated between calls to the subroutine to avoid bias in any direction. The location of the baffles is also determined so that smoothing does not occur across a baffle. The formulas are altered to take the conditions at a baffle into account.

PLOT determines the minimum and maximum pressure in the chamber at a given time. It also determines the value of the pressure at given sensor locations by the use of two-dimensional linear interpolation. It is assumed that the sensors are not located near a baffle so that the baffles need not be taken into account.

SEEK is a binary search routine. Given a table and a value, it determines the interval in the table where the value lies.

## Input Preparation for Program TRDL

There are basically two types of input data, integer and decimal. An integer is a number without a decimal point, which must be right adjusted in its field. A decimal is a number with a decimal point which may be followed by an exponent of the form  $E \pm n$ . The  $\pm n$  represents the power of 10 by which the number is to be multiplied and  $n$  may consist of up to three digits. The  $+$  may be omitted if  $n$  is positive and the  $E$  need not appear if either  $+$  or  $-$  is present. If an exponent is present it must be right justified in the field. A description of the necessary input data for program TRDL follows:

<u>Card</u>	<u>Columns</u>	<u>Type</u>	<u>Description</u>
1	1-5	Integer	<0 end of input deck =0 find starting condition on tape 1 >0 generate starting conditions
	6-10	Integer	=0 do not save conditions on tape 3 =n>0 save every nth cycle on tape 3
	11-15	Integer	Total number of axial mesh points
	16-20	Integer	Total number of tangential mesh points
	21-25	Integer	Number of axial mesh points in chamber
	26-30	Integer	Maximum number of mesh points with droplets in axial direction
2	1-40	Alpha-numeric	Any alphanumeric information to be printed on output and plots.
3	1-5	Integer	Total number of cycles for this run
	6-10	Integer	Number of cycles between edited printouts



<u>Card</u>	<u>Columns</u>	<u>Type</u>	<u>Description</u>
	11-15	Integer	Number of cycles between output of plot information on tape 4.
	16-20	Integer	=0 no printout of entire flow field ≠0 printout of entire flow field whenever edited printout appears
	21-25	Integer	Number of cycles between points on pressure tap plots.
	26-30	Integer	Initial number of cycles between applications of smoothing operator.
	31-35	Integer	Final number of cycles between applications of smoothing operator.
	36-40	Integer	Cycle at which number of applications of smoothing operator changed.
	41-45	Integer	Number of pressure taps
	46-50	Integer	Number of baffles
4	1-10	Decimal	Specific heat ratio
	11-20	Decimal	Reference pressure $p_0$ (psi)
	21-30	Decimal	Reference temperature $T_0$ ( $^{\circ}R$ )
	31-40	Decimal	Molecular weight of gas
	41-50	Decimal	Chamber radius $r$ (ft)
	51-60	Decimal	Chamber length $L_C$ (ft)
	61-70	Decimal	Length at throat $L_t$ (ft)
	71-80	Decimal	Minimum area ratio $A_t/A_C$
5	1-10	Decimal	Time step safety factor
	11-20	Decimal	Smoothing coefficient $K$
	21-30	Decimal	Percent of total energy in bomb
	31-40	Decimal	Drop density $N$ (drops/ft <sup>3</sup> )

<u>Card</u>	<u>Columns</u>	<u>Type</u>	<u>Description</u>
5	41-50	Decimal	Drop diameter $d_d$ (microns)
	51-60	Decimal	Injected axial drop velocity $u_d$ (ft/sec)
	61-70	Decimal	Burning rate power $\lambda$
6	1-10	Decimal	Axial position of first pressure tap (inches)
	11-20	Decimal	Tangential position of first pressure tap (deg)
	21-30	Decimal	Axial position of second pressure tap
	31-40	Decimal	Tangential position of second pressure tap

This is repeated for all taps with a maximum of four taps on a card.

7	1-10	Decimal	Length of baffles (inches)
	21-30	Decimal	Tangential position of first baffle (deg)
	31-40	Decimal	Tangential position of second baffle

This pattern is repeated for all baffles.

Card 7 is omitted if there are no baffles, i.e. 0 is punched in columns 46-50 of card 3.

8	1-10	Decimal	Axial coordinate of bomb center (inches)
	11-20	Decimal	Tangential coordinate of bomb center (deg)
	21-30	Decimal	Length of blast in axial direction (inches)
	31-40	Decimal	Length of blast in tangential direction (deg)

Card 8 is omitted if there is no bomb, i.e. bomb given 0 energy in columns 21-30 of card 5.

9	1-15	Decimal	Steady state density at first mesh point
	16-30	Decimal	Steady state axial momentum at first mesh point
	31-45	Decimal	Steady state tangential momentum at first mesh point
	46-60	Decimal	Steady state total energy at first mesh point

Card 9 is repeated for each mesh point. The values on these cards are the non-dimensional values used in the program.

<u>Card</u>	<u>Columns</u>	<u>Type</u>	<u>Description</u>
10	1-15	Decimal	Steady state mass of drop at first mesh point (lbm)
	16-30	Decimal	Steady state axial velocity of drop at first mesh point (ft/sec)
	31-45	Decimal	Steady state tangential velocity of drop at first mesh point (ft/sec)

Card 10 is repeated for each mesh point. There must be a card for each drop. Drops to be neglected should be given the minimum mass (0.1% of initial mass) and the velocity of the gas.

Cards 9 and 10 are omitted if the starting conditions are on tape 1.

The entire sequence of cards may be repeated in order to run several different cases. However, no more than one case should use starting conditions from tape 1 and only the last case should save conditions on tape 3. The last input card should have a negative integer in columns 1-5.

To obtain a new steady state, an old steady state should be input. The percent of energy in the bomb should be set to zero. Since there are no tangential velocities, there is no need to use more than two tangential mesh points. The values needed for cards 9 and 10 in the proper dimensions will be printed if the option for printing the entire flow field is used. Alternatively, the new steady state could be saved on tape 3 and a special program written to punch the values in the proper format.

SAMPLE INPUT FOR PROGRAM TRDL

NON-BAFFLED CASE

COLUMN															
1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76
1	100	21	20	13	12										
CLAYTON MOTOR-1															
600	100	100	0	2	1	5	50	6	0						
1,2	100.0		4000.0		23.0			0,60917		1,32167		1,85167		0,5025	
0,85	1,0		0,1		7,0			67100,0		100,0		0,5			
3,95	0,0		3,95		135,0			3,95		198,0		0,0		0,0	
8,02	0,0		13,38		0,0										
3,97	198,0		3,97		36,0										
9,37120427E-01	0,		0,		0,					3,98257099E+00					
9,20661429E-01	7,70952308E-02		0,		0,					3,90777001E+00					
9,12286283E-01	1,33143325E-01		0,		0,					3,87536989E+00					
8,85190692E-01	1,87751091E-01		0,		0,					3,76660893E+00					
8,67082711E-01	2,27059427E-01		0,		0,					3,68457560E+00					
8,42145342E-01	2,56628046E-01		0,		0,					3,59303298E+00					
8,30998125E-01	2,77719019E-01		0,		0,					3,53141730E+00					
8,13992929E-01	2,88762844E-01		0,		0,					3,48177862E+00					
8,15015423E-01	2,97242853E-01		0,		0,					3,45953576E+00					
8,05779716E-01	2,94154030E-01		0,		0,					3,45367429E+00					
8,18275071E-01	2,99276904E-01		0,		0,					3,46685587E+00					
8,01678287E-01	2,90397224E-01		0,		0,					3,44405962E+00					
8,25202504E-01	3,06843603E-01		0,		0,					3,48870004E+00					
8,11002738E-01	3,52743360E-01		0,		0,					3,35722585E+00					
8,16184347E-01	4,18502663E-01		0,		0,					3,28522045E+00					
7,61420373E-01	4,92420835E-01		0,		0,					3,00024088E+00					
7,11292029E-01	5,39317497E-01		0,		0,					2,77313595E+00					
5,99268859E-01	5,54922440E-01		0,		0,					2,34136874E+00					
4,71536477E-01	5,24862450E-01		0,		0,					1,87164971E+00					
3,76626248E-01	4,64644911E-01		0,		0,					1,52793650E+00					
2,81716019E-01	4,04427372E-01		0,		0,					1,18422330E+00					
9,20545407E-10	1,00000000E+02		0,		0,					0,					
4,93112723E-10	1,53147758E+02		0,		0,					0,					
2,62132725E-10	2,51416505E+02		0,		0,					0,					
1,38947556E-10	3,86092461E+02		0,		0,					0,					
7,15351536E-11	5,36483867E+02		0,		0,					0,					
3,42793193E-11	6,99723040E+02		0,		0,					0,					
1,41346226E-11	8,63650011E+02		0,		0,					0,					
4,15748906E-12	1,01967811E+03		0,		0,					0,					
1,15994331E-12	1,15948313E+03		0,		0,					0,					
9,20545407E-13	1,17540979E+03		0,		0,					0,					
9,20545407E-13	1,17765943E+03		0,		0,					0,					
9,20545407E-13	1,16778393E+03		0,		0,					0,					

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SAMPLE INPUT FOR PROGRAM TRD\_

BAFFLED CASE

COLUMN															
1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76
-----															
1	100	21	20	13	12										
CLAYTON MOTOR-5															
600	100	100	0	2	1	5	50	6	4						
1,2	100.0		4000.0		23.0			0,60917		1,32167		1,85167		0,5025	
0,85	1,0		0,1		7,0			7100,0		100,0		0,5			
3,95	0,0		3,95		135,0			3,95		198,0		0,0		0,0	
8,02	0,0		13,38		0,0										
5,375	81,0		153,0		243,0			315,0							
3,97	198,0		3,97		36,0										
9,37120427E-01	0,				0,					3,98257099E+00					
9,20661429E-01	7,70952308E-02		0,		0,					3,90777001E+00					
9,12286283E-01	1,33143325E-01		0,		0,					3,87536989E+00					
8,85190692E-01	1,87751091E-01		0,		0,					3,76660893E+00					
8,67082711E-01	2,27059427E-01		0,		0,					3,68457360E+00					
8,42145342E-01	2,56628046E-01		0,		0,					3,59303298E+00					
8,30998125E-01	2,77719019E-01		0,		0,					3,53141730E+00					
8,13992929E-01	2,88762844E-01		0,		0,					3,48177362E+00					
8,15015423E-01	2,97242853E-01		0,		0,					3,45953576E+00					
8,05779716E-01	2,94154030E-01		0,		0,					3,45367429E+00					
8,18275071E-01	2,99276904E-01		0,		0,					3,46685587E+00					
8,01678287E-01	2,90397224E-01		0,		0,					3,44405962E+00					
8,25202504E-01	3,06843603E-01		0,		0,					3,48870004E+00					
8,11002738E-01	3,52743336E-01		0,		0,					3,35722585E+00					
8,16184347E-01	4,18502663E-01		0,		0,					3,28522045E+00					
7,61420373E-01	4,92420835E-01		0,		0,					3,00024088E+00					
7,11292029E-01	5,39317497E-01		0,		0,					2,77313695E+00					
5,99268859E-01	5,54922440E-01		0,		0,					2,34136874E+00					
4,71536477E-01	5,24862450E-01		0,		0,					1,97164971E+00					
3,76626248E-01	4,64644911E-01		0,		0,					1,52793650E+00					
2,81716019E-01	4,04427372E-01		0,		0,					1,18422330E+00					
9,20545407E-10	1,00000000E+02		0,		0,					0,					
4,93112723E-10	1,53147758E+02		0,		0,					0,					
2,62132725E-10	2,51416505E+02		0,		0,					0,					
1,38947556E-10	3,86092461E+02		0,		0,					0,					
7,15351536E-11	5,36483867E+02		0,		0,					0,					
3,42793193E-11	6,99723040E+02		0,		0,					0,					
1,41346226E-11	8,63650011E+02		0,		0,					0,					
4,15748906E-12	1,01967811E+03		0,		0,					0,					
1,15994331E-12	1,15948313E+03		0,		0,					0,					
9,20545407E-13	1,17540979E+03		0,		0,					0,					
9,20545407E-13	1,17765943E+03		0,		0,					0,					
9,20545407E-13	1,16778393E+03		0,		0,					0,					

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## Description of Output for Program TRDL

The printed output consists first of various input and calculated values that remain constant throughout the program. At the desired cycles the non-dimensional time and time step are printed as is the maximum non-dimensional pressure in the chamber and the elapsed computer time in seconds from the beginning of the run. Properties of the flow field in non-dimensional form are printed along the lines  $\theta=0$ ,  $\pi$ ,  $\pi/2$  and  $3\pi/2$ . These are the density, axial velocity, tangential velocity, internal energy per unit mass, pressure and Mach number. If a printout of the entire flow field is requested it is printed next. First the non-dimensional density, axial momentum, tangential momentum and total energy per unit volume appear. These are printed by tangential coordinate for each axial coordinate. The dimensional mass (lbm), axial velocity (ft/sec) and tangential velocity (ft/sec) of the drops are printed next. They also appear by tangential coordinate for each axial coordinate.

CLAYTON MOTOR-1

TOTAL NUMBER OF CYCLES = 600    NUMBER OF CYCLES BETWEEN PRINTOUTS = 100    NUMBER OF CYCLES BETWEEN PLOTS = 100  
SMOOTH EVERY 1 CYCLES UNTIL 50 CYCLES, THEN SMOOTH EVERY 5 CYCLES

GAMMA	1.200000E+00	CHAMBER RADIUS(FT)	6.091700E-01	SMOOTHING COEFFICIENT	1.000000E+00
MOLECULAR WEIGHT	2.300000E+01	CHAMBER LENGTH(FT)	1.321670E+00	PERCENT BOMB ENERGY	1.000000E+01
REF PRESSURE(PSI)	1.000000E+02	THROAT LOCATION(FT)	1.851670E+00	DROP DENSITY(DROPS/CMH FT)	7.000000E+07
REF TEMPERATURE( DEG R)	4.000000E+03	AREA RATIO	5.025000E+01	DROP DIAMETER(MICRONS)	1.000000E+02
REF SOUND SPEED(FT/SEC)	3.220672E+03	AXIAL STEPSIZE	1.808020E-01	DROP VELOCITY(FT/SEC)	1.000000E+02
REF DENSITY(LBM/CUB FT)	5.359223E-02	TANGENTIAL STEPSIZE	3.141593E-01	BURNING RATE POWER	5.000000E+01
REF TIME SCALE(MILLISEC)	1.891438E-01	SAFETY FACTOR	8.500000E-01		

PRESSURE SENSOR LOCATIONS	Z	THETA	Z	THETA	Z	THETA
	3.95	0.00	3.95	135.00	3.95	198.00
	0.00	0.00	8.02	0.00	13.38	0.00

BOMB CENTER AT Z = 3.97, THETA=198.00 WITH DELTA Z = 3.97 AND DELTA THETA = 36.00

\*\*\*\*\* END OF INITIALIZATION PHASE \*\*\*\*\*

TOTAL TIME= 0. NUMBER OF CYCLES= 0 TIME STEP= 5.11845E-02 REAL TIME= 10.198 MAX PRESS= 1.18622E+01

SOLUTION ALONG THE RAY THETA = 0

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
9.20661E-01	8.37390E-02	0.	4.24102E+00	7.80908E-01	8.30017E-02
9.12286E-01	1.45945E-01	0.	4.23733E+00	7.73131E-01	1.44723E-01
8.85191E-01	2.12102E-01	0.	4.23264E+00	7.49340E-01	2.10443E-01
8.67083E-01	2.61866E-01	0.	4.21511E+00	7.30969E-01	2.60357E-01
8.42145E-01	3.04731E-01	0.	4.22009E+00	7.10786E-01	3.02796E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33118E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52730E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64203E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62763E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65599E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72203E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.83411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-01
5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01349E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+00
2.81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

SOLUTION ALONG THE RAY THETA = PI

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
4.05331E+00	8.37390E-02	0.	5.81631E+00	4.71507E+00	7.08758E-02
5.86507E+00	1.45945E-01	0.	6.46465E-01	7.58314E+00	1.17168E-01
6.47224E+00	2.12102E-01	0.	6.64831E+00	8.60588E+00	1.67913E-01
5.82927E+00	2.61866E-01	0.	6.46139E+00	7.53304E+00	2.10286E-01
3.99265E+00	3.04731E-01	0.	5.81672E-01	4.64482E+00	2.57913E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33118E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52730E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64203E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62763E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65599E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72203E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.83411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-01

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5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01349E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+00
2.81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

SOLUTION ALONG THE RAY THETA = PI/2

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RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
9.20661E-01	8.37390E-02	0.	4.24102E+00	7.80908E-01	8.30017E-02
9.12286E-01	1.45945E-01	0.	4.23733E+00	7.73131E-01	1.44723E-01
8.85191E-01	2.12102E-01	0.	4.23264E+00	7.49340E-01	2.10443E-01
8.67083E-01	2.61866E-01	0.	4.21511E+00	7.30969E-01	2.60357E-01
8.42145E-01	3.04731E-01	0.	4.22009E+00	7.10786E-01	3.02796E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33118E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52730E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64203E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62763E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65599E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72203E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.83411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-01
5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01349E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+00
2.81716E-01	1.43549E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

SOLUTION ALONG THE RAY THETA = 3\*PI/2

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
9.20661E-01	8.37390E-02	0.	4.24102E+00	7.80908E-01	8.30017E-02
9.12286E-01	1.45945E-01	0.	4.23733E+00	7.73131E-01	1.44723E-01
8.85191E-01	2.12102E-01	0.	4.23264E+00	7.49340E-01	2.10443E-01
8.67083E-01	2.61866E-01	0.	4.21511E+00	7.30969E-01	2.60357E-01
8.42145E-01	3.04731E-01	0.	4.22009E+00	7.10786E-01	3.02796E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33118E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52730E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64203E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62763E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65599E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72203E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.83411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-01
5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01349E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+00
2.81716E-01	1.43549E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

TOTAL TIME= 4.5030199E+00 NUMBER OF CYCLES= 100

SOLUTION ALONG THE RAY THETA = 0

STEADY STATE FLOW RATE= .22159(NON-DIMENSIONAL)= .2656(LBM/SEC-SQ IN)

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
8.84734E-01	0.	-1.74435E-02	3.98792E+00	7.05650E-01	1.78302E-02
8.68342E-01	1.23221E-01	-3.47394E-02	3.96246E+00	6.88155E-01	1.31282E-01
8.55140E-01	2.15347E-01	-3.04006E-02	3.94456E+00	6.74631E-01	2.23521E-01
8.47523E-01	2.80636E-01	-3.63135E-02	3.93600E+00	6.67170E-01	2.91150E-01
8.74584E-01	2.93449E-01	-3.71484E-02	3.93590E+00	6.88455E-01	3.04339E-01
9.26535E-01	2.65423E-01	-3.88287E-02	3.98765E+00	7.38939E-01	2.74203E-01
9.85431E-01	2.20839E-01	-4.11165E-02	4.03338E+00	7.94924E-01	2.28315E-01
9.92352E-01	1.99221E-01	-4.62545E-02	4.10799E+00	8.15315E-01	2.05976E-01
9.65167E-01	2.09294E-01	-4.50332E-02	4.12502E+00	7.96266E-01	2.15163E-01
9.02168E-01	2.25133E-01	-4.55394E-02	4.20423E+00	7.58584E-01	2.28664E-01
8.77381E-01	2.38479E-01	-4.27742E-02	4.15549E+00	7.29190E-01	2.42610E-01
8.25318E-01	2.40463E-01	-3.42749E-02	4.12502E+00	7.03572E-01	2.40149E-01
8.27601E-01	2.58924E-01	-2.64781E-02	4.17729E+00	6.91426E-01	2.59943E-01
8.06345E-01	3.26754E-01	-3.27266E-02	4.06741E+00	6.55947E-01	3.32372E-01
8.00268E-01	4.15340E-01	-3.35976E-02	3.92201E+00	6.27731E-01	4.29497E-01
7.57028E-01	5.44403E-01	-3.22340E-02	3.76991E+00	5.70789E-01	5.73336E-01
7.22917E-01	6.51036E-01	-2.63882E-02	3.66141E+00	5.29379E-01	6.95075E-01
6.06816E-01	8.40394E-01	-2.30856E-02	3.52215E+00	4.27459E-01	9.14305E-01
4.83250E-01	1.03885E+00	-2.06393E-02	3.39445E+00	3.28074E-01	1.15120E+00
3.95124E-01	1.15936E+00	-2.02618E-02	3.35298E+00	2.64968E-01	1.29260E+00
3.06998E-01	1.34905E+00	-1.96676E-02	3.25827E+00	2.00057E-01	1.52571E+00

SOLUTION ALONG THE RAY THETA = PI

STEADY STATE FLOW RATE= .55782(NON-DIMENSIONAL)= .6686(LBM/SEC-SQ IN)

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
1.20518E+00	0.	1.29873E-01	4.44035E+00	1.07028E+00	1.25807E-01
1.20144E+00	4.89753E-02	1.35298E-01	4.45653E+00	1.07085E+00	1.39131E-01
1.25308E+00	4.91418E-02	1.27812E-01	4.50860E+00	1.12992E+00	1.31639E-01
1.31072E+00	4.01640E-02	1.15298E-01	4.56396E+00	1.19641E+00	1.16658E-01
1.33190E+00	5.92279E-02	1.08967E-01	4.58809E+00	1.22217E+00	1.18190E-01
1.27610E+00	1.32983E-01	1.19749E-01	4.56541E+00	1.16519E+00	1.70900E-01
1.20322E+00	2.20267E-01	1.45625E-01	4.52208E+00	1.08821E+00	2.53464E-01
1.16663E+00	2.77173E-01	1.74503E-01	4.50882E+00	1.05202E+00	3.14857E-01
1.16995E+00	3.02203E-01	1.83465E-01	4.50487E+00	1.05409E+00	3.40004E-01
1.16635E+00	3.24114E-01	1.90007E-01	4.53700E+00	1.05835E+00	3.60047E-01
1.19013E+00	3.53188E-01	1.94298E-01	4.44840E+00	1.05984E+00	3.90114E-01
1.17116E+00	3.71679E-01	2.08556E-01	4.48968E+00	1.05163E+00	4.10576E-01
1.18756E+00	4.03932E-01	2.11695E-01	4.45149E+00	1.05729E+00	4.41212E-01
1.15084E+00	4.81896E-01	2.11733E-01	4.37468E+00	1.00692E+00	5.13693E-01
1.13319E+00	5.69076E-01	1.96967E-01	4.25350E+00	9.64004E-01	5.96020E-01
1.04040E+00	7.04259E-01	1.86043E-01	4.11013E+00	8.55238E-01	7.33411E-01
7.46981E-01	8.20647E-01	1.75449E-01	3.99533E+00	7.56701E-01	8.56997E-01
7.81829E-01	9.87767E-01	1.65836E-01	3.86044E+00	6.03640E-01	1.04056E+00
6.00314E-01	1.17928E+00	1.59706E-01	3.77450E+00	4.47174E-01	1.25807E+00
4.70687E-01	1.30053E+00	1.55531E-01	3.66518E+00	3.45031E-01	1.39653E+00
3.41061E-01	1.51394E+00	1.48182E-01	3.52501E+00	2.40449E-01	1.65384E+00

SOLUTION ALONG THE RAY THETA = PI/2

STEADY STATE FLOW RATE = .26798(NON-DIMENSIONAL) = .3211(LBM/SEC-SQ IN)

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.69938E-01	0.	2.98704E+02	4.09057E+00	7.93520E-01	3.01470E-02
9.51283E-01	1.34240E-01	6.87617E+02	4.04752E+00	7.70066E-01	1.53030E-01
9.65501E-01	1.97320E-01	1.07734E+01	4.04902E+00	7.81866E-01	2.28058E-01
9.49033E-01	2.62910E-01	1.26426E+01	4.03361E+00	7.65606E-01	2.96501E-01
9.86381E-01	2.64477E-01	1.47889E+01	4.04721E+00	7.98419E-01	3.07456E-01
1.02674E+00	2.51424E-01	1.71299E+01	4.07577E+00	8.36953E-01	3.07606E-01
1.07183E+00	2.39688E-01	2.01377E+01	4.09258E+00	8.77309E-01	3.15875E-01
1.06629E+00	2.56695E-01	2.39112E+01	4.11423E+00	8.77399E-01	3.53038E-01
1.04812E+00	2.77239E-01	2.61314E+01	4.11057E+00	8.61671E-01	3.83572E-01
1.01521E+00	2.72141E-01	2.69736E+01	4.19385E+00	8.51524E-01	3.81925E-01
1.01387E+00	2.58825E-01	2.50066E+01	4.17667E+00	8.46922E-01	3.59463E-01
9.59997E-01	2.50334E-01	2.29209E+01	4.29686E+00	8.24994E-01	3.34236E-01
9.48515E-01	2.71179E-01	2.00621E+01	4.29313E+00	8.06831E-01	3.33876E-01
9.18165E-01	3.35307E-01	1.89683E+01	4.16575E+00	7.64969E-01	3.85243E-01
9.18128E-01	4.17321E-01	1.90663E+01	4.03027E+00	7.40061E-01	4.66512E-01
8.67311E-01	5.51826E-01	1.92093E+01	3.87991E+00	6.73018E-01	6.05511E-01
8.24561E-01	6.68840E-01	2.04339E+01	3.77904E+00	6.23209E-01	7.34361E-01
6.99980E-01	8.59244E-01	2.14534E+01	3.65333E+00	5.11452E-01	9.45839E-01
5.60239E-01	1.06623E+00	2.21539E+01	3.53007E+00	3.95536E-01	1.18312E+00
4.58946E-01	1.19546E+00	2.28110E+01	3.49287E+00	3.20408E-01	1.32967E+00
3.57652E-01	1.39893E+00	2.38402E+01	3.40074E+00	2.43257E-01	1.57079E+00

SOLUTION ALONG THE RAY THETA = 3+PI/2

STEADY STATE FLOW RATE = .37603(NON-DIMENSIONAL) = .4507(LBM/SEC-SQ IN)

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
1.15852E+00	0.	-1.34305E+01	4.26518E+00	9.88259E-01	1.32745E-01
1.11591E+00	1.16674E-01	-1.66109E+01	4.24606E+00	9.47642E-01	2.01084E-01
1.13638E+00	1.57693E-01	-1.95583E+01	4.27171E+00	9.70857E-01	2.48128E-01
1.14684E+00	1.92975E-01	-2.02417E+01	4.29152E+00	9.84334E-01	2.75567E-01
1.20800E+00	1.80369E-01	-2.08348E+01	4.33944E+00	1.04841E+00	2.70034E-01
1.25182E+00	1.79665E-01	-2.17987E+01	4.37196E+00	1.09459E+00	2.75773E-01
1.26259E+00	2.05492E-01	-2.41887E+01	4.36635E+00	1.10258E+00	3.10047E-01
1.23554E+00	2.51295E-01	-2.82992E+01	4.35122E+00	1.07522E+00	3.70349E-01
1.22823E+00	2.89620E-01	-3.17978E+01	4.31321E+00	1.05953E+00	4.22734E-01
1.21920E+00	3.05316E-01	-3.47409E+01	4.34040E+00	1.05841E+00	4.53143E-01
1.24227E+00	3.10966E-01	-3.42113E+01	4.30005E+00	1.06837E+00	4.55095E-01
1.20046E+00	3.11894E-01	-3.40589E+01	4.41144E+00	1.05915E+00	4.48826E-01
1.19673E+00	3.31319E-01	-3.17893E+01	4.42642E+00	1.05945E+00	4.45484E-01
1.16104E+00	3.93917E-01	-3.07318E+01	4.38206E+00	1.01755E+00	4.87181E-01
1.16343E+00	4.77089E-01	-3.04874E+01	4.27334E+00	9.94346E-01	5.59071E-01
1.10128E+00	6.13511E-01	-3.09951E+01	4.14076E+00	9.12031E-01	6.89508E-01
1.03733E+00	7.41358E-01	-3.21655E+01	4.03733E+00	8.37613E-01	8.20972E-01
8.84757E-01	9.29528E-01	-3.32457E+01	3.91174E+00	6.92189E-01	1.01885E+00
7.09134E-01	1.13443E+00	-3.42852E+01	3.78759E+00	5.37182E-01	1.24300E+00
5.75241E-01	1.26616E+00	-3.51770E+01	3.74267E+00	4.30588E-01	1.38655E+00
4.41347E-01	1.47781E+00	-3.66100E+01	3.63400E+00	3.20771E-01	1.63025E+00

TOTAL TIME = 9.3439880E+00 NUMBER OF CYCLES = 200

CLAYTON MOTOR-5

TOTAL NUMBER OF CYCLES = 600    NUMBER OF CYCLES BETWEEN PRINTOUTS= 100    NUMBER OF CYCLES BETWEEN PLOTS= 100  
 SMOOTH EVERY 1 CYCLES UNTIL 50 CYCLES, THEN SMOOTH EVERY 5 CYCLES

GAMMA	1.200000E+00	CHAMFER RADIUS(FT)	6.091700E-01	SMOOTHING COEFFICIENT	0.100000E+00
MOLECULAR WEIGHT	2.300000E+01	CHAMFER LENGTH(FT)	1.321670E+00	PERCENT BOMB ENERGY	0.000000E+00
REF PRESSURE(PSI)	1.000000E+02	THROAT LOCATION(FT)	1.851670E+00	DROP DENSITY(DROPS/GR OF B)	0.000000E+00
REF TEMPERATURE(DEG R)	4.000000E+03	AREA RATIO	5.025000E-01	DROP DIAMETER(MICRONS)	1.000000E+02
REF SOUND SPEED(FT/SFC)	3.220672E+03	AXIAL STEPSIZE	1.800020E-01	DROP VELOCITY(FT/SFC)	1.000000E+02
REF DENSITY(LBM/CUB FT)	5.359223E-02	TANGENTIAL STEPSIZE	3.141593E-01	BURNING RATE POWER	0.000000E+00
REF TIME SCALE(MILLISEC)	1.851436E-01	SAFETY FACTOR	8.500000E-01		

PRESSURE SENSOR LOCATIONS	Z	THETA	Z	THETA	Z	THETA
	3.95	0.00	3.95	135.00	3.95	195.00
	0.00	0.00	8.72	0.00	15.38	0.00

THERE ARE 4 BAFFLES 5.33 INCHES LONG AT THETA = 81.00 153.00 243.00 315.00

BOMB CENTER AT Z= 3.97, THETA=198.00 WITH DELTA Z= 3.97 AND DELTA THETA= 36.00

\*\*\*\*\* END OF INITIALIZATION PHASE \*\*\*\*\*

TOTAL TIME= 0. NUMBER OF CYCLES= 0 TIME STEP= 5.11845E-02 REAL TIME= .619 MAX PRESS= 1.11E+01

SOLUTION ALONG THE RAY THETA = 0

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
9.20661E-01	8.37390E-02	0.	4.24102E+00	7.80904E-01	8.30002E-02
9.12286E-01	1.45945E-01	0.	4.23733E+00	7.73131E-01	1.44223E-01
8.85191E-01	2.12102E-01	0.	4.23264E+00	7.49340E-01	2.10443E-01
8.67083E-01	2.61866E-01	0.	4.21511E+00	7.30969E-01	2.60055E-01
8.42145E-01	3.04731E-01	0.	4.22009E+00	7.10786E-01	3.02796E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33118E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52730E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64208E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62708E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65095E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72203E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.43411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-01
5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16880E-01	1.01349E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+00
2.81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

SOLUTION ALONG THE RAY THETA = PI

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
4.05331E+00	8.37390E-02	0.	5.81631E+00	4.71507E+00	7.08758E-02
5.86507E+00	1.45945E-01	0.	6.46465E+00	7.58314E+00	1.17108E-01
6.47224E+00	2.12102E-01	0.	6.64831E+00	8.60580E+00	1.67933E-01
5.82927E+00	2.61866E-01	0.	6.46139E+00	7.53304E+00	2.10246E-01
3.99265E+00	3.04731E-01	0.	5.81672E+00	4.64482E+00	2.57913E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33118E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52730E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64208E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62708E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65095E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72203E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.43411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-01
5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16880E-01	1.01349E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+00
2.81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

SOLUTION ALONG THE RAY THETA = PI/2

RHO	U	V	INT ENERGY	PRESSURE	MACRO NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
9.20661E-01	8.37390E-02	0.	4.24102E+00	7.60908E-01	8.38003E-01
9.12286E-01	1.45945E-01	0.	4.23733E+00	7.73131E-01	1.44203E-01
8.85191E-01	2.12102E-01	0.	4.23264E+00	7.49340E-01	2.10000E-01
8.67083E-01	2.61866E-01	0.	4.21511E+00	7.30969E-01	2.60000E-01
8.42145E-01	3.04731E-01	0.	4.22009E+00	7.10786E-01	3.02000E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33000E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52700E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64000E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62000E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65000E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59000E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72200E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41400E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30400E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	6.68203E-01	6.83411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	6.13735E-01	8.14402E-01
5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01049E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24161E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38428E+00
2.81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

SOLUTION ALONG THE RAY THETA = 3\*PI/2

RHO	U	V	INT ENERGY	PRESSURE	MACRO NO.
9.37120E-01	0.	0.	4.24980E+00	7.96514E-01	0.
9.20661E-01	8.37390E-02	0.	4.24102E+00	7.60908E-01	8.38003E-01
9.12286E-01	1.45945E-01	0.	4.23733E+00	7.73131E-01	1.44203E-01
8.85191E-01	2.12102E-01	0.	4.23264E+00	7.49340E-01	2.10000E-01
8.67083E-01	2.61866E-01	0.	4.21511E+00	7.30969E-01	2.60000E-01
8.42145E-01	3.04731E-01	0.	4.22009E+00	7.10786E-01	3.02000E-01
8.30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33000E-01
8.13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.52700E-01
8.15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64000E-01
8.05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62000E-01
8.18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65000E-01
8.01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59000E-01
8.25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72200E-01
8.11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41400E-01
8.16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30400E-01
7.61420E-01	6.46714E-01	0.	3.73120E+00	6.68203E-01	6.83411E-01
7.11292E-01	7.58222E-01	0.	3.61128E+00	6.13735E-01	8.14402E-01
5.99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01049E+00
4.71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24161E+00
3.76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.38428E+00
2.81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.64505E+00

TOTAL TIME= 4.4674407E+00 NUMBER OF CYCLES= 100

TOTAL TIME= 4.4674E+00 NUMBER OF CYCLES= 100 TIME STEP= 4.71972E-02 REAL TIME= 74.307 FAX EXPENSE= 1.1000E+00

SOLUTION ALONG THE RAY THETA = 0

STEADY STATE FLOW RATE= .27949(NON-DIMENSIONAL)= .3350(LBM/SEC\*IN)

RHO	U	V	INT ENERGY	PRESSURE	MASS FLOW
1.25911E+00	0.	3.04740E-03	4.33677E+00	1.49209E+00	2.98733E-01
1.22542E+00	6.35270E-02	8.08195E-03	4.35085E+00	1.46632E+00	6.26638E-01
1.23019E+00	9.13893E-02	4.57013E-03	4.37321E+00	1.47897E+00	3.93136E-01
1.20329E+00	1.30347E-01	1.14650E-02	4.37966E+00	1.45400E+00	1.27569E-01
1.16943E+00	1.43824E-01	9.00321E-03	4.37101E+00	1.42232E+00	1.46097E-01
1.12250E+00	1.63134E-01	6.05561E-03	4.36990E+00	1.41046E+00	1.59016E-01
1.08588E+00	1.66234E-01	-9.27162E-05	4.35552E+00	1.45918E-01	1.82097E-01
1.03361E+00	1.64444E-01	8.97134E-03	4.37171E+00	1.43727E-01	1.60736E-01
1.00356E+00	1.54059E-01	1.76247E-02	4.33368E+00	1.40922E-01	1.52247E-01
9.50692E-01	1.49564E-01	3.64972E-02	4.36280E+00	1.42953E-01	1.50042E-01
9.40500E-01	1.43028E-01	5.37978E-02	4.27462E+00	1.40456E-01	1.50009E-01
8.80311E-01	1.49587E-01	7.06743E-02	4.35592E+00	1.466914E-01	1.61319E-01
8.88927E-01	1.66704E-01	8.04297E-02	4.22005E+00	1.40004E-01	1.83538E-01
8.76941E-01	2.21700E-01	9.28547E-02	4.10022E+00	1.41913E-01	2.42499E-01
8.77152E-01	3.02756E-01	1.10322E-01	3.94668E+00	1.42368E-01	3.31099E-01
8.44365E-01	4.23444E-01	1.24120E-01	3.80395E+00	1.42384E-01	4.61019E-01
7.88974E-01	5.62940E-01	1.35697E-01	3.68152E+00	1.40025E-01	6.16038E-01
6.82279E-01	7.41703E-01	1.44689E-01	3.57078E+00	1.40729E-01	8.16366E-01
5.66923E-01	9.25152E-01	1.55350E-01	3.47271E+00	1.43752E-01	1.02757E+00
4.73291E-01	1.04823E+00	1.60803E-01	3.44754E+00	1.42633E-01	1.16397E+00
3.79659E-01	1.23203E+00	1.68945E-01	3.39171E+00	1.456779E-01	1.38036E+00

SOLUTION ALONG THE RAY THETA = P1

STEADY STATE FLOW RATE= .36907(NON-DIMENSIONAL)= .4424(LBM/SEC\*IN)

RHO	U	V	INT ENERGY	PRESSURE	MASS FLOW
8.32143E-01	0.	-3.40800E-02	4.09431E+00	1.481410E-01	3.43798E-01
8.31364E-01	1.02720E-01	-3.93776E-02	4.06686E+00	1.476209E-01	1.11351E-01
8.23723E-01	1.90078E-01	-4.51096E-02	4.05935E+00	1.468755E-01	1.97923E-01
8.00408E-01	2.89148E-01	-3.81524E-02	4.04131E+00	1.46970E-01	2.96036E-01
7.72881E-01	3.54627E-01	-3.13596E-02	4.00640E+00	1.49295E-01	3.63001E-01
7.67335E-01	4.24745E-01	1.31723E-01	4.01729E+00	1.416521E-01	4.32507E-01
7.79531E-01	4.61755E-01	1.86891E-02	4.02380E+00	1.427335E-01	4.76466E-01
8.29661E-01	4.62937E-01	6.70625E-02	4.07398E+00	1.476005E-01	4.72911E-01
9.85611E-01	3.66323E-01	7.58533E-02	4.21318E+00	1.430512E-01	3.72003E-01
1.18458E+00	2.54774E-01	4.75258E-02	4.36462E+00	1.403405E+00	2.53201E-01
1.21860E+00	3.01065E-01	7.00864E-03	4.33820E+00	1.45730E+00	2.95146E-01
1.07634E+00	4.49792E-01	-1.42930E-02	4.27334E+00	1.419016E-01	4.44066E-01
1.05468E+00	5.46044E-01	-2.39762E-02	4.13642E+00	1.472517E-01	5.48064E-01
1.07185E+00	5.91205E-01	-5.68729E-02	4.04069E+00	1.466202E-01	6.15003E-01
1.11362E+00	6.38078E-01	-7.72360E-02	3.90907E+00	1.470641E-01	6.63075E-01
9.77952E-01	8.11566E-01	-9.33354E-02	3.71561E+00	1.426739E-01	8.65000E-01
8.72122E-01	9.41293E-01	-1.01819E-01	3.59218E+00	1.426564E-01	1.01066E+00
7.36884E-01	1.07545E+00	-1.06643E-01	3.48625E+00	1.43792E-01	1.18109E+00
5.53690E-01	1.26667E+00	-1.08609E-01	3.35900E+00	1.471969E-01	1.41500E+00
4.24476E-01	1.38857E+00	-1.07921E-01	3.30313E+00	1.400419E-01	1.56408E+00
2.95261E-01	1.61716E+00	-1.06631E-01	3.15829E+00	1.486504E-01	1.86450E+00

SOLUTION ALONG THE RAY THETA = P1/2

STEADY STATE FLOW RATE= .24862(NON-DIMENSIONAL)= .2980(LHM/SEC-SQ IN)

RWO	U	V	INT ENERGY	PRESSURE	TRACH NO.
1.00993E+00	0.	-1.48412E-02	4.26583E+00	8.61635E-01	1.46677E-02
9.92004E-01	6.72438E-02	-6.18495E-03	4.25481E+00	8.44157E-01	6.68246E-02
1.00686E+00	9.25795E-02	5.95767E-03	4.27141E+00	8.60014E-01	9.16265E-02
1.00617E+00	9.80005E-02	1.67713E-02	4.27656E+00	8.60590E-01	9.81364E-02
1.02562E+00	1.10849E-01	1.33566E-02	4.29828E+00	8.81682E-01	1.09928E-01
9.85169E-01	9.70211E-02	1.59482E-01	4.27493E+00	8.42306E-01	1.84247E-01
9.63658E-01	1.96663E-01	2.65611E-01	4.25320E+00	8.19725E-01	3.27113E-01
9.70202E-01	2.02480E-01	3.06991E-01	4.27778E+00	8.30062E-01	3.62944E-01
9.42987E-01	2.10018E-01	3.00807E-01	4.29021E+00	8.09123E-01	3.61547E-01
9.01395E-01	1.93150E-01	2.97552E-01	4.36214E+00	7.86402E-01	3.46706E-01
8.65913E-01	1.96708E-01	2.66029E-01	4.33774E+00	7.51221E-01	3.24266E-01
8.12512E-01	1.63190E-01	2.52199E-01	4.48556E+00	7.28915E-01	2.89517E-01
8.26572E-01	1.57441E-01	1.38984E-01	4.42799E+00	7.32010E-01	2.03719E-01
8.33588E-01	2.22494E-01	4.83246E-02	4.35319E+00	7.25753E-01	2.22750E-01
8.63307E-01	3.33901E-01	-5.54530E-02	4.24315E+00	7.32628E-01	3.40299E-01
8.49378E-01	5.02715E-01	-1.14286E-01	4.11683E+00	6.99348E-01	5.18654E-01
8.08190E-01	6.65062E-01	-1.56952E-01	4.00399E+00	6.47198E-01	6.98067E-01
7.01387E-01	8.61576E-01	-1.84693E-01	3.88295E+00	5.44690E-01	9.12774E-01
5.64934E-01	1.07151E+00	-1.91704E-01	3.75799E+00	4.24603E-01	1.14819E+00
4.60255E-01	1.20232E+00	-1.85329E-01	3.71459E+00	3.41931E-01	1.28842E+00
3.55575E-01	1.41014E+00	-1.75200E-01	3.61037E+00	2.56751E-01	1.52653E+00

SOLUTION ALONG THE RAY THETA = 3\*PI/2

STEADY STATE FLOW RATE= .27295(NON-DIMENSIONAL)= .3272(LHM/SEC-SQ IN)

RWO	U	V	INT ENERGY	PRESSURE	TRACH NO.
9.67697E-01	0.	9.37929E-03	4.20746E+00	8.14310E-01	9.33311E-02
9.37414E-01	8.65563E-02	6.85546E-03	4.18179E+00	7.84014E-01	8.66702E-02
9.50351E-01	1.44442E-01	-1.14399E-03	4.20023E+00	7.98338E-01	1.43849E-01
9.30693E-01	1.91258E-01	-3.59228E-02	4.18967E+00	7.79859E-01	1.94067E-01
9.46882E-01	2.33410E-01	-5.93292E-02	4.21984E+00	7.99139E-01	2.39310E-01
9.25747E-01	2.72006E-01	-1.23592E-01	4.20713E+00	7.78947E-01	2.97328E-01
9.19865E-01	3.24272E-01	-1.78281E-01	4.20173E+00	7.73004E-01	3.68502E-01
8.95415E-01	3.93867E-01	-2.74080E-01	4.18301E+00	7.49106E-01	4.78907E-01
8.82104E-01	4.35923E-01	-3.45366E-01	4.14482E+00	7.31232E-01	5.57617E-01
8.46473E-01	4.48619E-01	-4.00715E-01	4.23824E+00	7.17512E-01	5.96428E-01
8.41568E-01	4.46286E-01	-3.56575E-01	4.27713E+00	7.19899E-01	5.63818E-01
8.12159E-01	4.28273E-01	-3.69073E-01	4.44069E+00	7.21309E-01	5.46127E-01
8.15862E-01	4.34630E-01	-2.06796E-01	4.45961E+00	7.27685E-01	4.65242E-01
8.14923E-01	5.00063E-01	-2.75095E-02	4.31100E+00	7.02283E-01	5.00207E-01
8.43911E-01	6.12937E-01	1.64007E-01	4.07300E+00	6.87449E-01	6.41754E-01
7.94324E-01	7.78627E-01	2.80466E-01	3.82058E+00	6.06955E-01	8.64722E-01
7.47755E-01	8.86282E-01	3.39894E-01	3.65226E+00	5.46199E-01	1.01317E+00
6.36930E-01	1.02494E+00	3.75872E-01	3.50546E+00	4.46546E-01	1.19020E+00
4.82328E-01	1.20805E+00	3.93736E-01	3.35539E+00	3.23680E-01	1.41674E+00
3.73737E-01	1.32342E+00	3.96039E-01	3.29455E+00	2.46299E-01	1.55353E+00
2.65146E-01	1.53195E+00	4.00227E-01	3.15021E+00	1.67053E-01	1.82087E+00
TOTAL	TIME= 9.3178051E+00	NUMBER OF CYCLES= 200			



## Nomenclature

A	cross-sectional area of motor
$A_C$	cross-sectional area of chamber
$A_t$	cross-sectional area of throat
$a_p$	dimensionless mass burning rate at pressure p
$a_o$	reference sound speed
$C_D$	drag coefficient
$c_p$	specific heat
$d_l$	diameter of drop
$\Delta t$	time stepsize
$\Delta \theta$	tangential stepsize
$\Delta z$	axial stepsize
E	total energy per unit volume of gas
$f_s$	stoichiometric fuel-oxidant ratio
$\phi$	fuel-oxidant equivalence ratio
G	tangential flux vector
$\gamma$	specific heat ratio
H	axial flux vector
$H^*$	area variation flux vector
k	thermal conductivity
K	smoothing constant
L	length of motor
$L_C$	length of chamber
$L_F$	latent heat of fuel
$L_O$	latent heat of oxidizer

$L_t$	length of motor at throat
$\lambda$	burning rate power
$M$	Mach number
$M$	molecular weight of gas
$m_\ell$	mass of drop
$\dot{m}_F$	mass burning rate
$\mu$	viscosity
$N$	drop density
$Pr$	Prandtl number
$p$	pressure of gas
$p_0$	reference pressure
$\psi$	source vector
$\psi_\rho$	density component of source vector
$\psi_E$	energy component of source vector
$Q$	heat of reaction per unit mass of fuel
$Re$	Reynolds number
$r$	radius of chamber
$r_\ell$	radius of drop
$\rho$	density of gas
$\rho_0$	reference density
$T$	temperature of gas
$T_\ell$	temperature of drop
$T_0$	reference temperature
$t$	time
$t_0$	reference time
$\theta$	tangential coordinate

$u$	axial velocity of gas
$u_{\ell}$	axial velocity of drop
$v$	tangential velocity of gas
$v_{\ell}$	tangential velocity of drop
$V_{i,j}^n$	approximation to fluid properties vector at $(z_i, \theta_j, t_n)$
$\tilde{V}_{i+\frac{1}{2}, j+\frac{1}{2}}^n$	predicted approximation vector at $(z_i + \frac{1}{2}\Delta z, \theta_j + \frac{1}{2}\Delta\theta, t_n)$
$W$	vector of fluid properties
$z$	axial coordinate

## Definition of Major Program Variables

AO	reference sound speed $a_0$
AR	area ratio at throat $A_t/A_c$
BFL	array of fluid properties and fluxes behind baffles, similar to array OVRPRM with BFL(K,J,I) containing properties behind jth baffle
DELO	tangential stepsize $\Delta\theta$
DELR	axial stepsize $\Delta z$
DLN	diameter of drop $d_d$
DROP	array of drop properties, DROP(K,J,I) for $K=1,\dots,5$ contains the drop mass, axial velocity and tangential velocity and the density and energy components of the source vector at point $z_i, \theta_j$
DT	time stepsize $\Delta t$
DTDO	stepsize ratio $\Delta t/\Delta\theta$
DTDR	stepsize ratio $\Delta t/\Delta z$
ELBFL	baffle length
EN	drop density $N$
FS	stoichiometric fuel-oxidant ratio $f_s$
FUDG	time stepsize safety factor
GAMMA	specific heat ratio $\gamma$
HT	array of tangential mesh points $\theta_j$
IJP	array of pressure tap locations, if $I=IJP(K,1)$ and $J=IJP(K,2)$ then kth pressure tap is between $z_i, z_{i+1}$ and $\theta_j, \theta_{j+1}$ .
IM	number of droplets in axial direction
IMAX	total number of axial mesh points
IM3	number of axial mesh points in chamber

INTPNT option for printing full flow field

IPR number of points in array containing pressure at taps PRSS

IPRMX maximum number of points in array containing pressure at taps PRSS

ISAVE option to save information on tape 3 for restarting run

ISMTH number of cycles between applications of smoothing operator

ISMTH1 initial number of cycles between applications of smoothing operator

ISMTH2 final number of cycles between applications of smoothing operator

ISTART option for generating starting conditions or using conditions on tape 1 for restart of a previous run

ITITLE array of title information

JBFL array of baffle locations, if  $J=JBFL(K)$  then kth baffle located at  $\theta_j + \frac{1}{2}\Delta\theta$

JMAX number of tangential mesh points

KALKOM number of cycles between placing of information on tape 4 for future plotting

L number of cycles between points in array containing pressure at taps PRSS

LBFL number of last axial mesh point in baffle

NBFL number of baffles

NCYCLE cycle count for a run

NCYCMX total number of cycles for a run

NCYSM cycle at which number of cycles between applications of smoothing operator changes

NNPCM number of cycles between printouts

NPP number of pressures in array PRSS, i.e. maximum and minimum pressure and pressure at taps.

NPS            number of pressure taps  
 NTCYCL        cycle count for an entire case  
 OVRLAY        array of flux values, OVRLAY(K,J,I), OVRLAY(K+4,J,I)  
                  and OVRLAY(K+8,J,I) contain the kth components of H,  
                  G and H\* at the point  $z_i, \theta_j$   
 OVRPRM        array of predicted fluid properties and flux values,  
                  OVRPRM(K,J,I), OVRPRM(K+4,J,I), OVRPRM(K+8,J,I) and  
                  OVRPRM(K+12,J,I) contain the kth components of  $\tilde{V}$ ,  $\tilde{H}$ ,  
                   $\tilde{G}$  and  $\tilde{H}^*$  at the point  $z_i - \frac{1}{2}\Delta z, \theta_j + \frac{1}{2}\Delta\theta$   
 PCF            array of coefficients of interpolating polynomials for  
                  pressure at taps  
 PEX            burning rate power  $\lambda$   
 PHI            fuel-oxidant equivalence ratio  $\phi$   
 PO            reference pressure  $p_0$   
 PROPTY        array of fluid properties, PROPTY(I,J,K) contains the  
                  kth component of V at the point  $z_i, \theta_j$   
 PRSS          array of minimum and maximum pressures in chamber and  
                  pressure at pressure taps  
 PSPT          array of pressure tap locations  
 RAD            array of axial mesh points  $z_i$   
 RMAX          radius of chamber r  
 ROO            reference density  $\rho_0$   
 SMK            smoothing coefficient K  
 T              time t  
 TO            reference time  $t_0$   
 T0            reference temperature  $T_0$   
 TPRS          array of time for points in pressure array PRSS  
 UD            injected axial velocity of drops

VFACT      percent of total energy given to bomb  
XM          molecular weight of gas M  
ZCH        length of chamber  $L_c$   
ZTH        length of motor at throat  $L_t$

## Program and Subprogram Functions

TRDL	reads some input and controls flow of program
INITAL	reads some input and reads or generates initial conditions
CHARGE	calculates fluid properties at injector and nozzle exit planes
CONVRG	calculates stable time step
VECTR	calculates flux vectors
QUAD	calculates predicted fluid properties
TMPVCT	calculates predicted flux vectors
GENPT	calculates corrected fluid properties
PRTOUT	produces edited printout
FZ	calculates $\frac{\partial \text{LnA}}{\partial z}$
PHIDOTV	calculates forcing function and drop field
MSHVL	interpolates for drop field at mesh points
SMOOTH	smooths the solution
PLOT	finds minimum and maximum pressure in chamber and pressure at taps
SEEK	binary search routine



#### IV. Program TRDPLT - The Plot Package

##### Description of Plot Program (TRDPLT)

The plot program produces plots of the information on tape 4 using a CALCOMP type digital incremental plotter. It uses a standard subroutine package to generate the actual plots (or a tape to be used with the plotter). A set of subroutines for producing contour and vector plots is also used. These subroutines, in turn, use the standard plot package. The program is written in FORTRAN IV for the CDC 6600 computer. While the basic program can be converted for use on any computer with a FORTRAN IV compiler difficulties may be encountered because of differences in the plot package in use at various installations.

Four basic type of plots are produced. The first is a plot of pressure isobars which is produced by using subroutine CONTOUR. The pressure levels may be equally spaced values between the minimum and maximum pressure, or they may be input values. The isobars are plotted as axial distance in inches against tangential angle in degrees. Each isobar is marked with a number which increases with increasing pressure. The program produces a printed page which shows the pressure corresponding to each isobar number. Both dimensional and non-dimensional values are given. If baffles are present, their positions and lengths are plotted as dashed lines.

The second type of plot is of the velocity vector field. The foot of the vector is located at the point of given axial distance in inches and tangential angle in degrees. The length of the vector is proportional to the speed at that point. The scale of vector length in inches to speed in ft/sec. is printed at the top of the plot.

The third type of plot is of the energy source in BTU/sec/ft<sup>3</sup> as a function of axial distance in inches. There are four graphs on each plot at given tangential positions.

The fourth type of plot is of pressure in psi against time in milleseconds. Several graphs appear on each plot. These graphs are of the minimum and maximum pressure and of the pressure at the pressure taps. The graphs of pressure at the taps are numbered and the axial and tangential positions of each numbered tap are printed at the upper right hand portion of the graph.

All of the plots have the title associated with each run printed across the top. The time of occurrence in milleseconds is printed at the bottom of the contour, vector and energy source plots.

#### Input Preparation for Program TRDPLT

<u>Card</u>	<u>Columns</u>	<u>Type</u>	<u>Description</u>
1	1-5	Integer	<0 end of input deck  =n>0 number of pressure isobars to be plotted except if columns 6-10≠0
	6-10	Integer	=0 plot number of isobars specified in columns 1-5 of equally spaced values between the minimum and maximum pressure  =n>0 number of isobars of given pressure values, these are plotted in addition to minimum and maximum pressure
	11-15	Integer	cycle number on tape 4 at which plot of pressure at taps is wanted. If number is negative, a new set of input will be read after this plot is generated.
	16-20	Integer	number of point in array of pressures at taps at which to start the plot

<u>Card</u>	<u>Columns</u>	<u>Type</u>	<u>Description</u>
1	21-25	Integer	=0 do not plot energy source ≠0 plot energy source
	26-30	Integer	number of pressure taps, if negative, only plots produced by this data set will be pressure vs. time plots
	31-35	Integer	number of baffles
2	1-5	Integer	number of cycle numbers at which plots are desired
	6-10	Integer	first cycle number at which plot is desired
	11-15	Integer	second cycle number, repeated each five columns for number of entries specified in columns 1-5
3	1-10	Decimal	axial distance in inches corresponding to 7 inches of plot
	11-20	Decimal	speed in ft/sec corresponding to 0.5 inches of plot for vector plots
	21-30	Decimal	value of pressure in psi at origin of pressure plot
	31-40	Decimal	value of pressure in psi corresponding to 8 inches for pressure plot
	41-50	Decimal	time in milliseconds corresponding to 7 inches of plot
	51-60	Decimal	energy source in BTU/sec/ft <sup>3</sup> corresponding to 2 inches of plot
4	1-10	Decimal	axial position of first pressure tap
	11-20	Decimal	tangential position of first pressure tap

Repeated for all pressure taps, four to a card.

5	1-10	Decimal	length of baffles
	11-20	Decimal	tangential position of first baffle

Repeated for all baffles. Card 5 should not appear if there are no baffles.

<u>Card</u>	<u>Columns</u>	<u>Type</u>	<u>Description</u>
6	1-10	Decimal	tangential position of first energy source graph
	11-20	Decimal	tangential position of second energy source graph
	21-30	Decimal	tangential position of third energy source graph
	31-40	Decimal	tangential position of fourth energy source graph

Card 6 should not appear if energy source is not plotted.

7	1-10	Decimal	pressure level of first isobar
	11-20	Decimal	pressure level of second isobar

Repeated for all isobars. Card 7 should not appear if equally spaced isobar levels are calculated.

The entire set of input cards may be repeated for each file on tape 4. It is also repeated after pressure plot if the integer in columns 11-15 of card 1 is negative. The last card of the input deck should have a negative integer in columns 1-5.

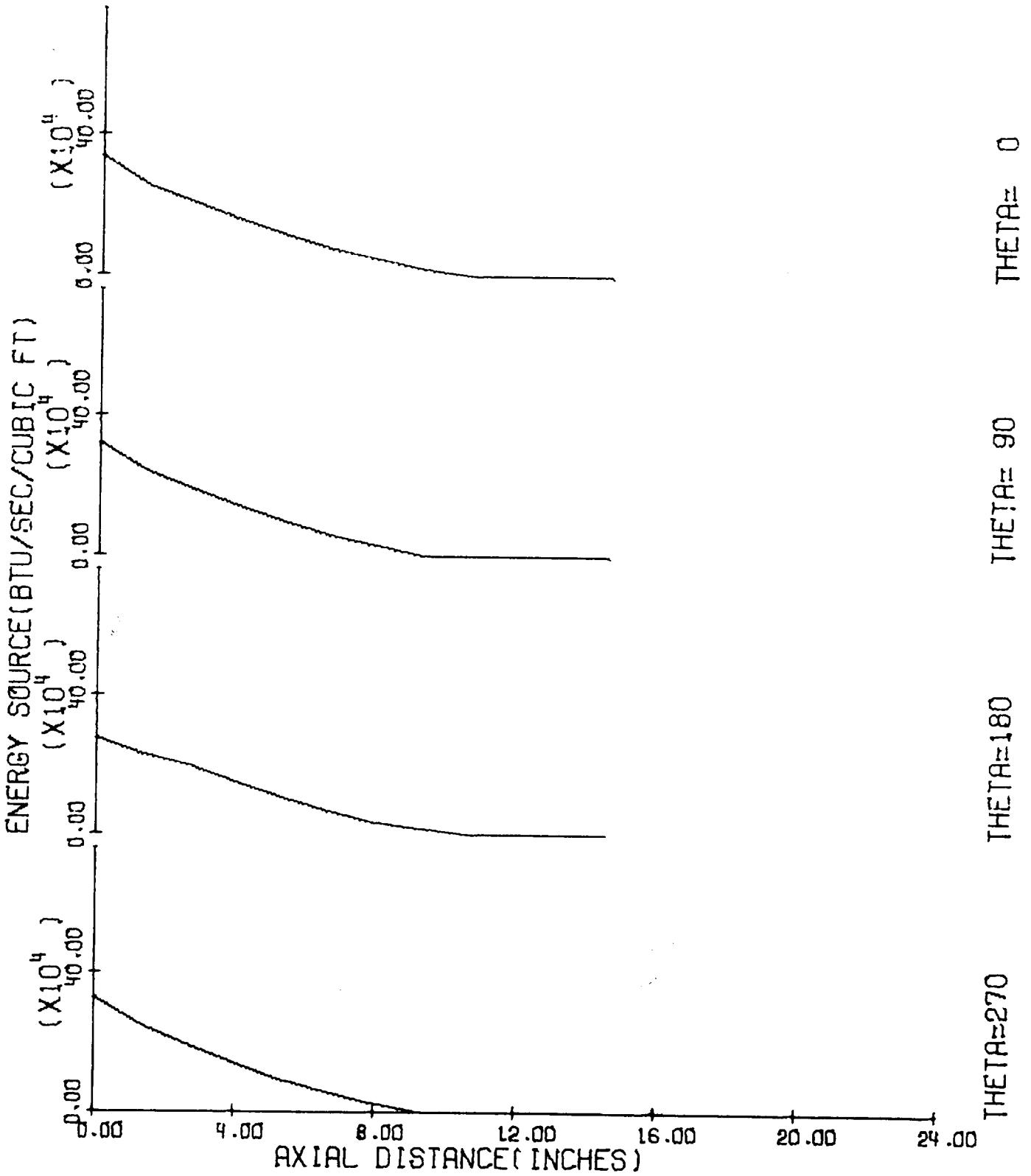
The use which can be made of various combinations of the plot program input options is illustrated by the sample input. Suppose that four runs were made and the plot output for each was placed as a separate file on tape 4. Each file has information for every 100 cycles from 0 to 600 cycles. The pressure at the taps was retained for every other cycle. The bomb caused a high initial transient pressure which subsided by the end of 40 cycles. All plots are desired for run 1. Since scaling for the initial transient would not give sufficient detail to the latter part of

the plots of pressure at the taps, the initial part is plotted separately. New scaling is then input for the second part, which is plotted from point 21 which corresponds to cycle 40. Run 2 was a baffled run and plots only at cycles 300 and 600 are required. Run 3 was also a baffled run but only plots at cycle 600 are wanted without any energy source plot. The only plot desired from Run 4 is that of the pressure at the taps.

SAMPLE INPUT FOR PROGRAM TRDPLT

								COLUMN							
1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76
15	0	-100		1	1	6	0								
2	0	100													
28,0		6000,0		0,0		1600,0		7,00			0,8E6				
3,95		0,0		3,95		135,0		3,95		198,0		0,0			0,0
8,02		0,0		13,38		0,0									
15	0	600		21	1	6	0								
5	200	300		400	500	600									
28,0		6000,0		0,0		320,0		7,00			0,8E6				
3,95		0,0		3,95		135,0		3,95		198,0		0,0			0,0
8,02		0,0		13,38		0,0									
15	0	600		21	1	6	4								
2	300	600													
28,0		6000,0		0,0		320,0		7,00			0,8E6				
3,95		0,0		3,95		135,0		3,95		198,0		0,0			0,0
8,02		0,0		13,38		0,0									
5,375		81,0		153,0		243,0		315,0							
15	0	600		21	0	6	4								
1	600														
28,0		6000,0		0,0		320,0		7,00			0,8E6				
3,95		0,0		3,95		135,0		3,95		198,0		0,0			0,0
8,02		0,0		13,38		0,0									
4,375		81,0		153,0		243,0		315,0							
15	0	600		21	0	-6	0								
1	600														
28,0		6000,0		0,0		320,0		7,00			0,8E6				
3,95		0,0		3,95		135,0		3,95		198,0		0,0			0,0
8,02		0,0		13,38		0,0									
-1															

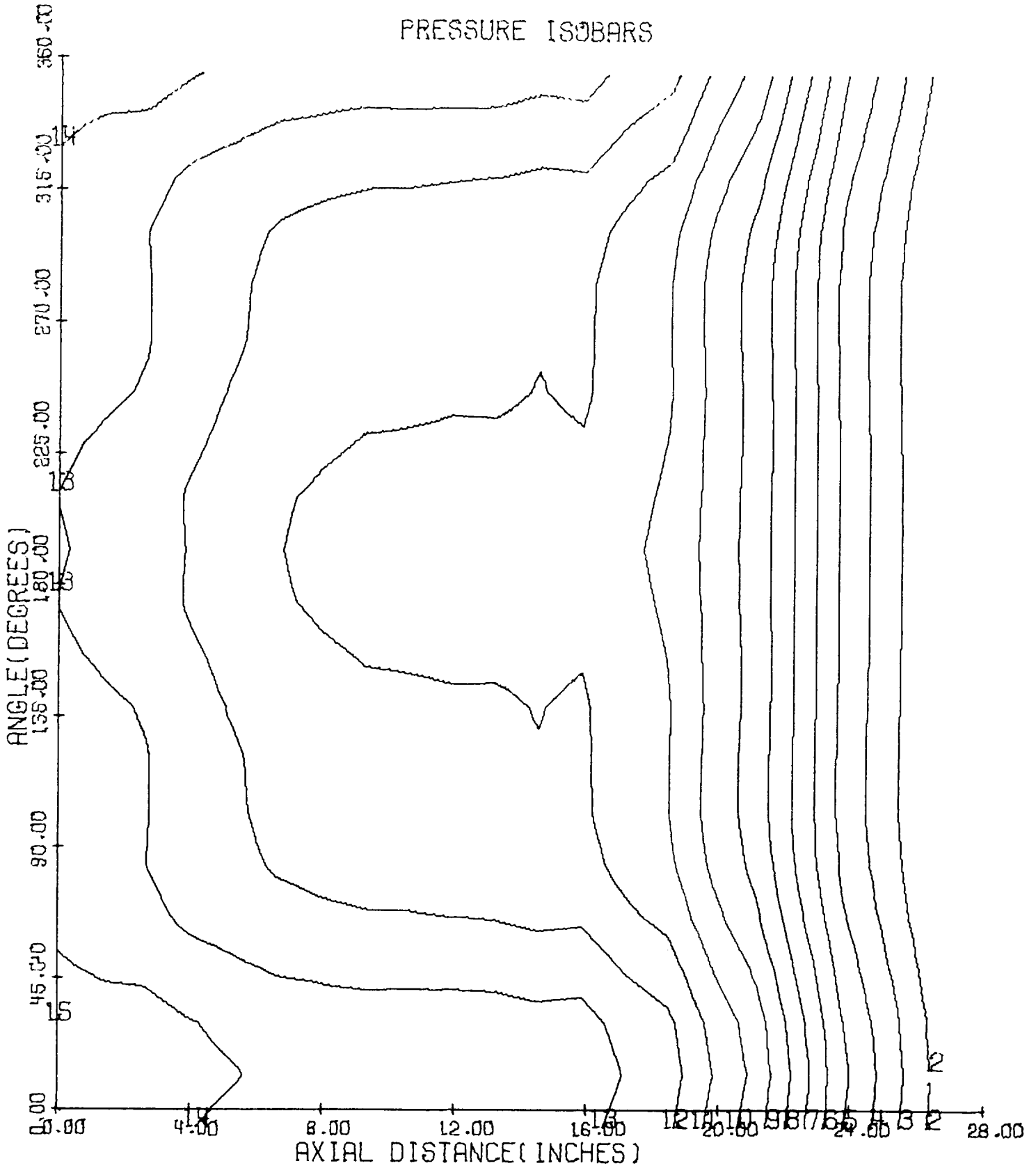
# CLAYTON MOTOR-1



T = 2.737 MILLISECONDS

# CLAYTON MOTOR-1

## PRESSURE ISOBARS



T= 2.737 MILLISECONDS



CLAYTON MOTOR-1

T = 2,737 MILLISECONDS

ISOBAR	PRESSURE (PSI)
1	21,865
2	28,289
3	34,713
4	41,137
5	47,561
6	53,986
7	60,410
8	66,834
9	73,258
10	79,682
11	86,106
12	92,531
13	98,955
14	105,379
15	111,803

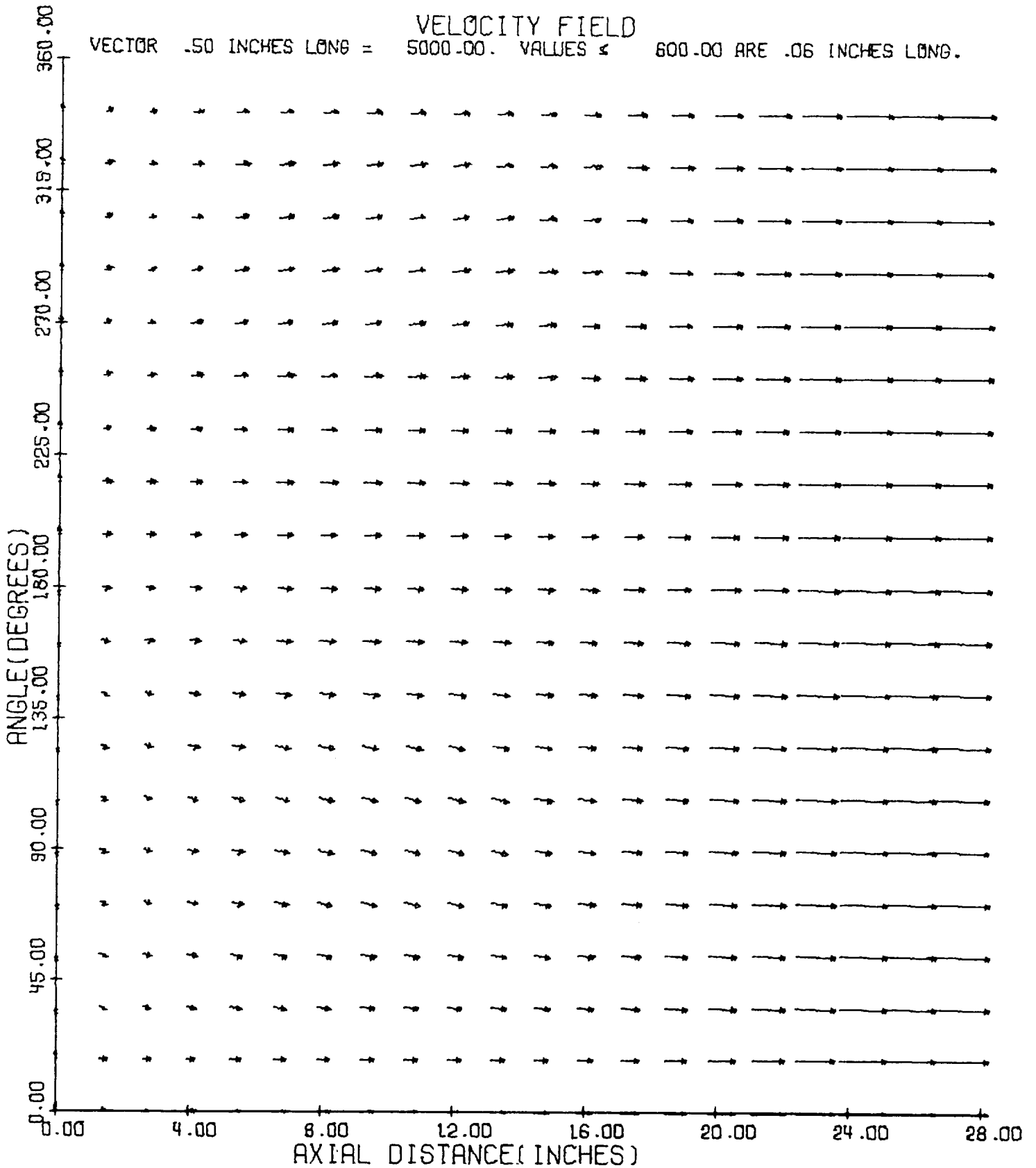
CLAYTON MOTOR-1

PREF=REFERENCE PRESSURE = 100,00 PSI  
 AREF=REFERENCE SOUND SPEED = 3220,7 FT/SEC  
 R =CHAMBER RADIUS = ,60917 FEET  
 TREF=REFERENCE TIME=R/AREF=,0001891 SEC

T/TREF = 14,47133

ISOBAR	PRESSURE/PREF
1	,219
2	,283
3	,347
4	,411
5	,476
6	,540
7	,604
8	,668
9	,733
10	,797
11	,861
12	,925
13	,990
14	1,054
15	1,118

# CLAYTON MOTOR-1



T = 2.737 MILLISECONDS



# CLAYTON MOTOR-1

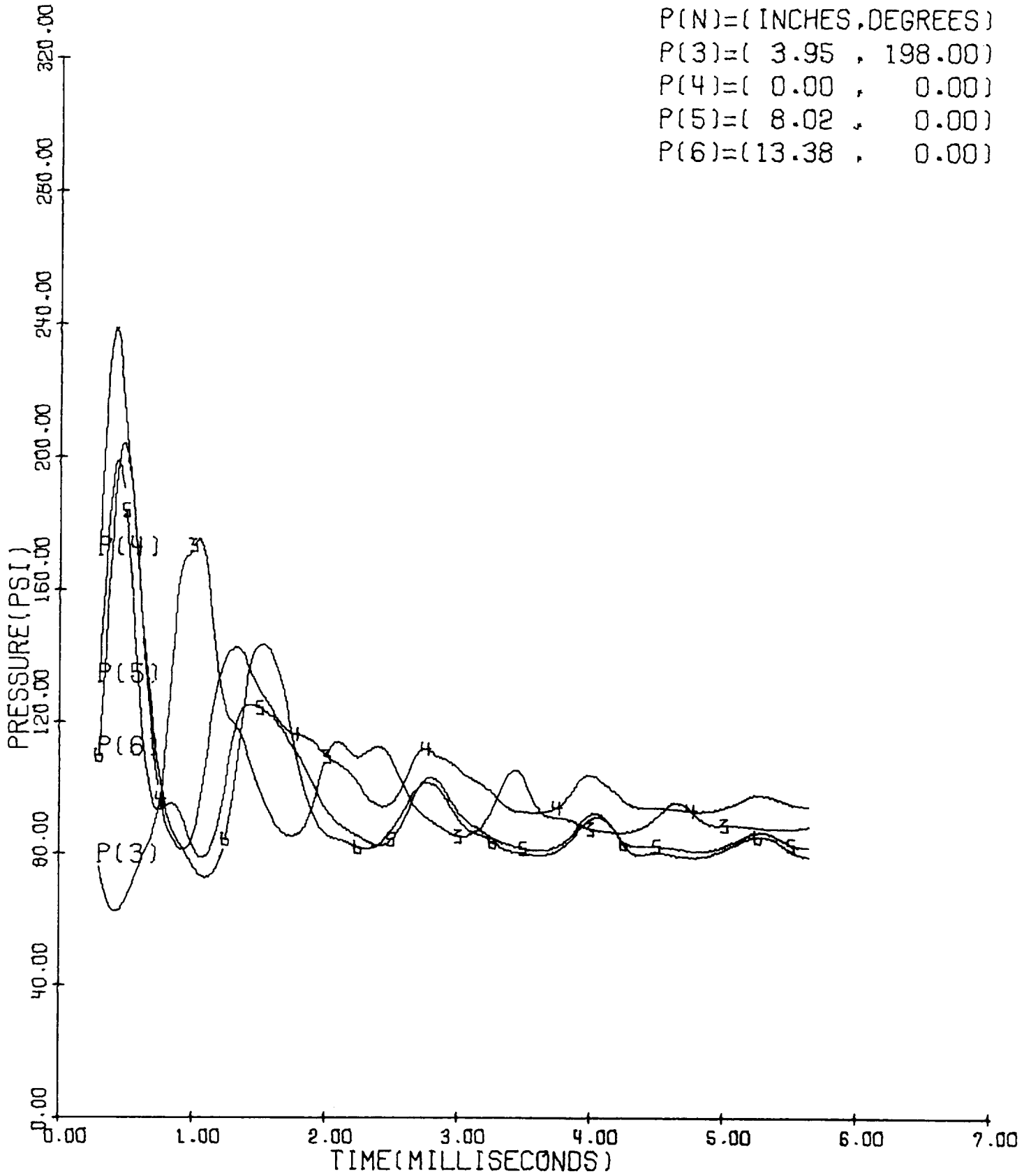
P(N)=(INCHES,DEGREES)

P(3)=( 3.95 , 198.00)

P(4)=( 0.00 , 0.00)

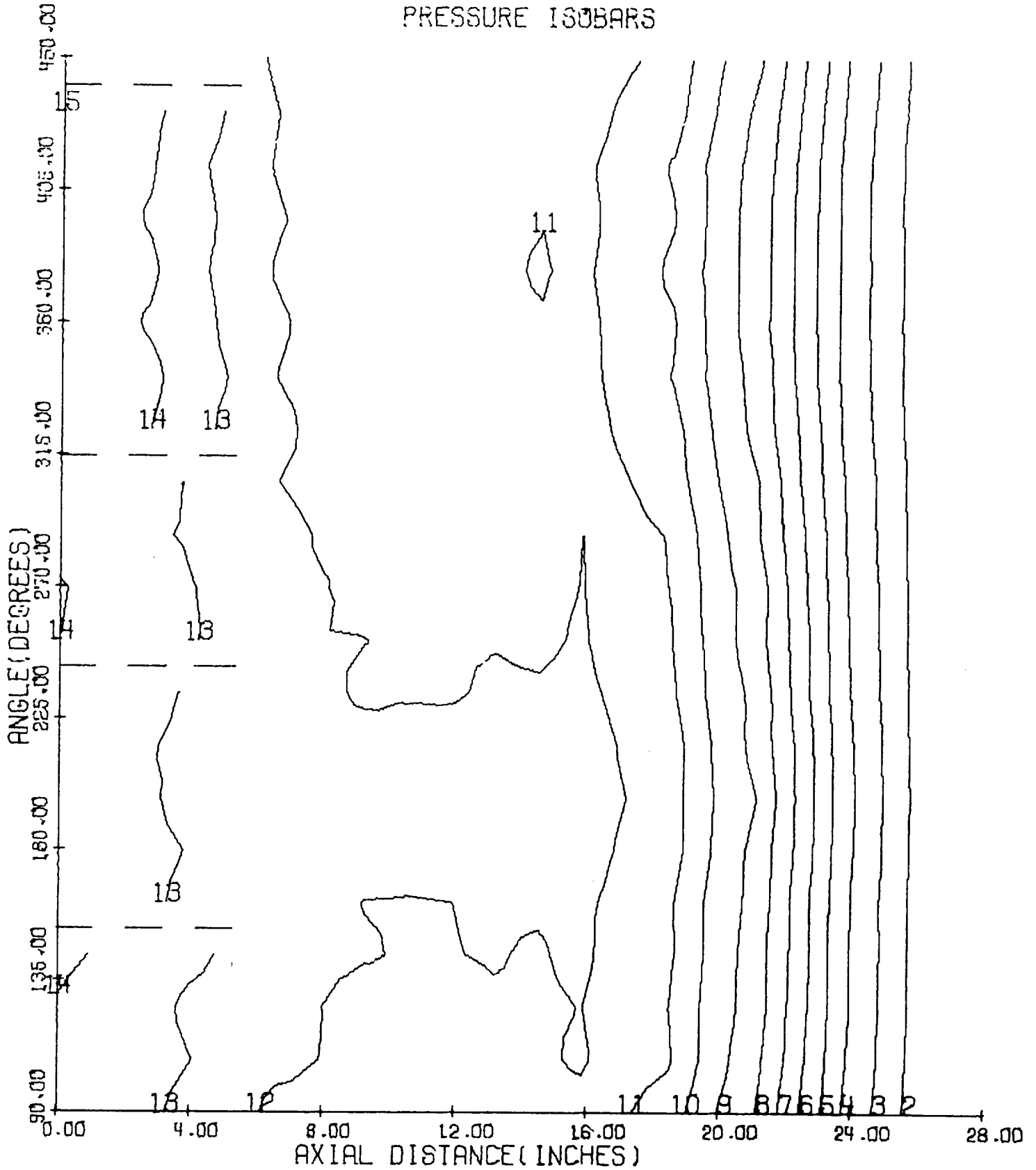
P(5)=( 8.02 , 0.00)

P(6)=(13.38 , 0.00)



# CLAYTON MOTOR-5

## PRESSURE ISOBARS



T = 2.720 MILLISECONDS

CLAYTON MOTOR-5

T = 2,720 MILLISECONDS

ISOBAR	PRESSURE (PSI)
1	21,359
2	27,230
3	33,101
4	38,972
5	44,842
6	50,713
7	56,584
8	62,455
9	68,326
10	74,196
11	80,067
12	85,938
13	91,809
14	97,680
15	103,551

CLAYTON MOTOR-5

PREF = REFERENCE PRESSURE = 100,00 PSI  
 AREF = REFERENCE SOUND SPEED = 3220,7 FT/SEC  
 R = CHAMBER RADIUS = ,60917 FEET  
 TREF = REFERENCE TIME = R/AREF = ,0001891 SEC

T/TREF = 14,37799

ISOBAR	PRESSURE/PREF
1	,214
2	,272
3	,331
4	,390
5	,448
6	,507
7	,566
8	,625
9	,683
10	,742
11	,801
12	,859
13	,918
14	,977
15	1,036

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