MR-7008
Project 6910

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

Harold S. Schechter

and

Samuel Z. Burstein

Final Report

to

National Aeronautics and Space Administration

Contract NAS7-752

August 31, 1970

TABLE OF CONTENTS

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.

NOTICE

This report was prepared as an account of Government-sponsored work. Neither the United States, nor the National Aeronautics and Space Administration (NASA), nor any person acting on behalf of NASA:

a) Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or

b) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

As used above, "person acting on behalf of NASA" includes any employee or contractor of NASA, or employee of such contractor, to the extent that such employee or contractor of NASA or employee of such contractor prepares, disseminates, or provides access to any information pursuant to his employment or contract with NASA, or his employment with such contractor.

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, θ, (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-θ-t can be given by the vector form

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

The vector W has four components which are the mass, momentum in the z and θ 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-θ 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 ψ.

The exact form of the vectors are:

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

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

$$p = (\gamma-1)\rho e \tag{3}$$

The total energy of the system per unit volume is

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

The area is approximated by a quadratic function

$$A/A_c=1-\alpha(z-L_c)+\beta(z-L_c)^2 \quad L_c\le z\le L; \quad A/A_c=1 \quad z\le L_c \tag{5}$$

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 α and β are determined from the position L_t and area ratio A_t/A_c at the throat

$$\alpha = 2(1-A_t/A_c)/(L_t-L_c) \qquad \beta = \frac{1}{2}a/(L_t-L_c) \tag{6}$$

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

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

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_o psia, a_{p_o}, can be expressed as

$$a_{p_o} = 3.73\times10^{-5}T+1.855 \qquad (8)$$

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

$$a_p/a_{p_o} = (p/p_o)^{\lambda} \qquad (9)$$

where p_o is the steady state pressure. The drop temperature, T_ℓ, which is the boiling temperature at the chamber pressure, can be obtained from the integrated Clausius-Clapeyron equation

$$\ell n(p/2131) = 8.7\times10^3\ (1/1176-1/T_\ell) \qquad (10)$$

$$T_\ell = 1176^{\circ}R \quad p\geq2131 \text{ psia}$$

The thermal conductivity, k, is given by

$$k = (8.33\times10^{-5}(460-T_\ell)+0.2107)/3600 \text{ Btu/ft-sec-}R^{\circ} \qquad (11)$$

and the specific heat, c_p, is obtained from

$$c_p = 0.138+0.527\times10^{-3}T_\ell-0.120\times10^{-6}T_\ell^{\,2} \text{ Btu/lbm-}^{\circ}R \qquad (12)$$

The burning rate in stationary surroundings is obtained from

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

where d_ℓ is the drop diameter.

The viscosity is given by

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

while the Reynold's number is

$$Re = \rho d_{\ell}|u-v|/\mu \tag{15}$$

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

$$\dot{m}_F/\dot{m}_F^o = 1+0.276Re^{\frac{1}{2}}Pr^{1/3} \tag{16}$$

where Pr is the Prandtl number.

The components of the ψ vector are then

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

where ϕ 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:

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

$L_F=540$ Btu/lbm $L_O=178.2$ 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

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

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

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

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

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

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

and the drop density is obtained from

$$\rho_\ell = 14.4+86.82(1-T_\ell/1176)+6.343(1-T_\ell/1176)^{\frac{1}{2}}$$

$$+ 17.716(1-T_\ell/1176)^{1/3}-60.654(1-T_\ell/1176)^2 \ \text{lbm/ft}^3$$

where T_ℓ 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

$$p=p_s+p_b=p_s+A\sin\ (a_1\theta+a_2)\sin(b_1 z+b_2) \qquad \begin{matrix}\theta_1\le\theta\le\theta_2\\ z_1\le z\le z_2\end{matrix} \tag{19}$$

$$\rho=\rho_s+\rho_b=\rho_s+p_b^{1/\gamma} \qquad e_b=p_b^{(\gamma-1)/\gamma}/(\gamma-1)$$

where p_s and ρ_s are the steady-state values and hence are functions of z only, and p_b, ρ_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, α, of the total energy E_T in the chamber.

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

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-θ plane from the motor axis. An arbitrary pressure, p_o, and temperature, T_o, are assigned and are usually taken approximately equal to the conditions in the chamber at steady state. Using p_o, T_o, and the molecular weight of the gas, M, the reference density, ρ_o, is calculated from the equation of state. A reference sound speed, a_o, calculated from the specific heat ratio, γ, and the values of p_o and ρ_o is used to normalize the velocities. The other reference values used for normalization are γp_o for the pressure and $t_o = r/a_o$ for the time.

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

$$\begin{array}{lll} z_i = i\Delta z & \theta_j = j\Delta\theta & t_n = n\theta t \\ i=0,1,\ldots,I & j=0,1,\ldots,J & n=0,1,2,\ldots \end{array} \qquad (21)$$

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

$$W(z_i,\theta_j,t_n) \approx V(z_i,\theta_j,t_n) = V^n_{i,j} \qquad (22)$$

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 $B = \psi - H^* \frac{\partial LnA}{\partial z}$ and $L = H^* \frac{\partial LnA}{\partial z}$ the finite difference equations are:

$$\begin{aligned} \tilde{V}^n_{i+\frac{1}{2},j+\frac{1}{2}} &= \tfrac{1}{4}(V^{n-1}_{i+1,j+1} + V^{n-1}_{i+1,j} + V^{n-1}_{i,j+1} + V^{n-1}_{i,j}) \\ &- \frac{\Delta t}{2\Delta\theta}(G^{n-1}_{i+1,j+1} + G^{n-1}_{i,j+1} - G^{n-1}_{i+1,j} - G^{n-1}_{i,j}) \\ &- \frac{\Delta t}{2\Delta z}(H^{n-1}_{i+1,j+1} + H^{n-1}_{i+1,j} - H^{n-1}_{i,j+1} - H^{n-1}_{i,j}) \\ &+ \frac{\Delta t}{4}(B^{n-1}_{i+1,j+1} + B^{n-1}_{i+1,j} + B^{n-1}_{i,j+1} + B^{n-1}_{i,j}) \end{aligned} \qquad (23)$$

$$V^n_{i,j}=V^{n-1}_{i,j}-\frac{\Delta t}{4\Delta\theta}(G^{n-1}_{i,j+1}-G^{n-1}_{i,j+1}+\tilde{G}^n_{i+\frac{1}{2},j+\frac{1}{2}}+\tilde{G}^n_{i-\frac{1}{2},j+\frac{1}{2}}-\tilde{G}^n_{i+\frac{1}{2},j-\frac{1}{2}}-\tilde{G}^n_{i-\frac{1}{2},j-\frac{1}{2}})$$

$$-\frac{\Delta t}{4\Delta z}(H^{n-1}_{i+1,j}-H^{n-1}_{i-1,j}+\tilde{H}^n_{i+\frac{1}{2},j+\frac{1}{2}}+\tilde{H}^n_{i+\frac{1}{2},j-\frac{1}{2}}-\tilde{H}^n_{i-\frac{1}{2},j+\frac{1}{2}}-\tilde{H}^n_{i-\frac{1}{2},j-\frac{1}{2}})$$

$$-\frac{\Delta t}{4}(C^{n-1}_{i+1,j}+C^{n-1}_{i-1,j}+\tfrac{1}{2}(\tilde{C}^n_{i+\frac{1}{2},j+\frac{1}{2}}+\tilde{C}^n_{i+\frac{1}{2},j-\frac{1}{2}}+\tilde{C}^n_{i-\frac{1}{2},j+\frac{1}{2}}+\tilde{C}^n_{i-\frac{1}{2},j-\frac{1}{2}}))$$

$$+\Delta t\psi^{n-1}_{i,j} \qquad (24)$$

The boundary conditions are:

$$\rho^n_{-1,j}=\rho^n_{1,j} \quad u^n_{-1,j}=-u^n_{1,j} \quad v^n_{-1,j}=v^n_{1,j} \quad p^n_{-1,j}=p^n_{1,j}$$

$$v^n_{i,J+1}=v^n_{i,o} \quad v^n_{i,-1}=v^n_{i,J} \quad v^n_{I,j}=2v^n_{I-1,j}-v^n_{I-2,j} \qquad (25)$$

and the baffles are represented by the conditions

$$\rho^n_{i,j_B\pm 1}=\rho^n_{i,j_B\mp 1} \quad u^n_{i,j_B\pm 1}=u^n_{i,j_B\mp 1} \quad v^n_{i,j_B\pm 1}=-v^n_{i,j_B\mp 1}$$

$$p^n_{i,j_B\pm 1}=p^n_{i,j_B\mp 1} \qquad i=1,2,\ldots,i_B \qquad (26)$$

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

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

where Δ is either Δz 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

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

where u is the velocity in the m direction, Δm 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 (θ,z), two fractional steps for the numerical solution of the diffusion equation

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

where the nonlinear operator, $\overline{\nabla}^2$, is defined in terms of the velocity components u and v by $\overline{\nabla}^2 W = (|u_\theta|W_\theta)_\theta + (|v_z|W_z)_z$ 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 perserved 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.

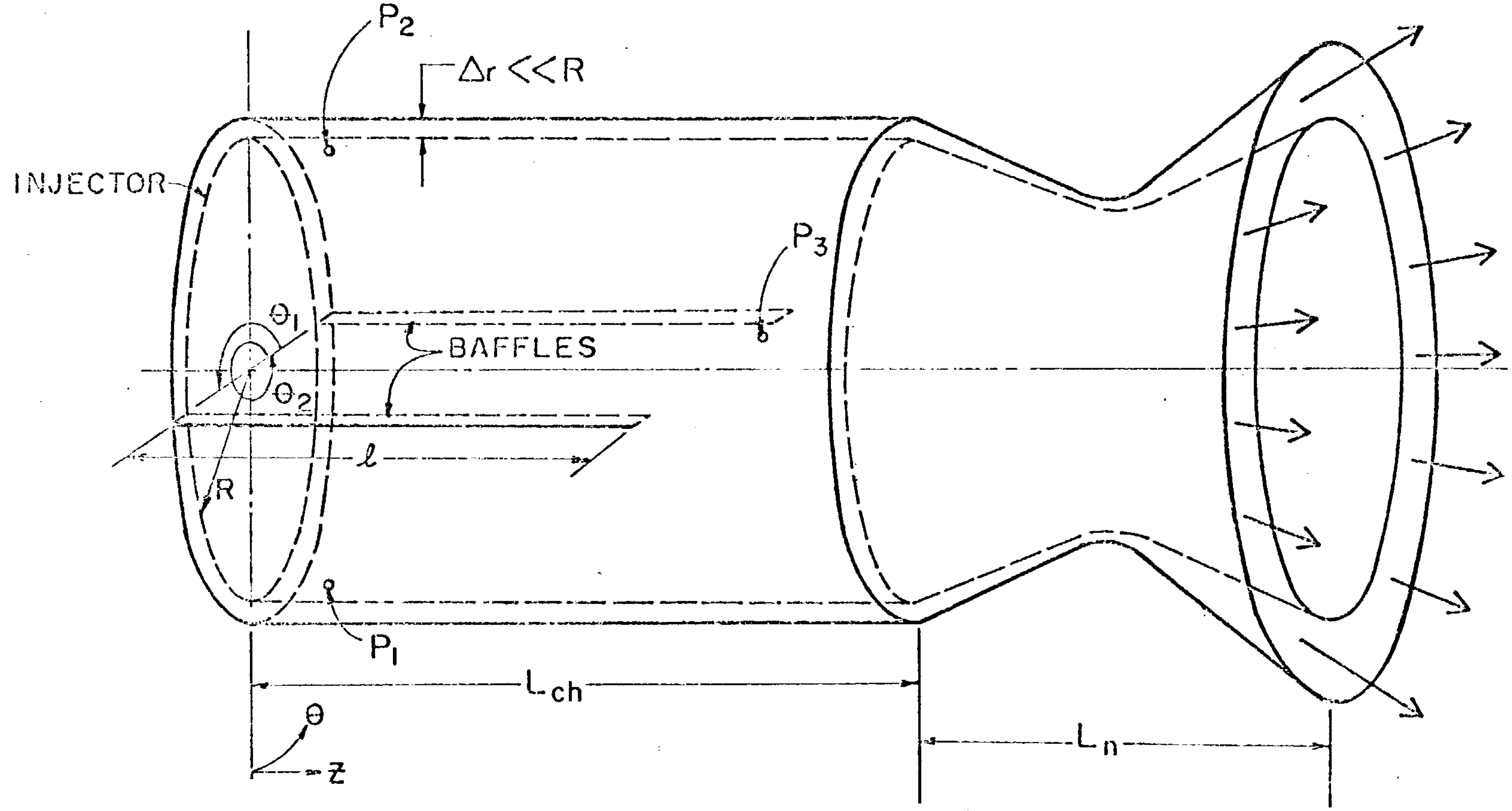


FIGURE 1 2 - BAFFLE ENGINE GEOMETRY

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 stop, Δt, is determined in subroutine CONVRG. The vectors G, H, and $H*\frac{\partial LnA}{\partial z}$ 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 $H*\frac{\partial LnA}{\partial z}$ 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 θ equal to 0, $\pi/2$, π and $3\pi/2$ are printed by subroutine PRTOUT. The function subroutine FZ determines $\frac{\partial LnA}{\partial z}$.

The forcing function ψ 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 PPLOT 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 PPLOT 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 PPLOT. 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 θ, 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 emperical initial value is used, which serves as a maximum possible time step.

VECTR evaluates the vectors, G, H, and $H*\frac{\partial LnA}{\partial z}$ in a rather straightforward manner and places the values in OVRLAY. 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 $\theta_{baffle}+\varepsilon$ and $\theta_{baffle}-\varepsilon$, 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 θ of 0, 90, 180 and 270 degrees.

FZ evaluates $\frac{\partial LnA}{\partial z}$ 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 θ. 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 subrotuine 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.

PPLOT 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±n. The ±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:

Card	Columns	Type	Description
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

Card	Columns	Type	Description
	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_o (psi)
	21-30	Decimal	Reference temperature T_o (^{o}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^3)

Card	Columns	Type	Description
5	41-50	Decimal	Drop diameter d_ℓ (microns)
	51-60	Decimal	Injected axial drop velocity u_d (ft/sec)
	61-70	Decimal	Burning rate power λ
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.

Card	Columns	Type	Description
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.

Card	Columns	Type	Description
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.

Card	Columns	Type	Description
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.

Card	Columns	Type	Description
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       E7100,0    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,                3,98257099E+00
 9,20661429E-01 7,70952308E-02 0,                3,90777001E+00
 9,12286283E-01 1,33143325E-01 0,                3,87536989E+00
 8,85190692E-01 1,87751091E-01 0,                3,76660893E+00
 8,67082711E-01 2,27059427E-01 0,                3,68457560E+00
 8,42145342E-01 2,56628046E-01 0,                3,59303298E+00
 8,30998125E-01 2,77719019E-01 0,                3,53141730E+00
 8,13992929E-01 2,88762844E-01 0,                3,48177862E+00
 8,15015423E-01 2,97242853E-01 0,                3,45953576E+00
 8,05779716E-01 2,94154030E-01 0,                3,45367429E+00
 8,18275071E-01 2,99276904E-01 0,                3,46685587E+00
 8,01678287E-01 2,90397224E-01 0,                3,44405962E+00
 8,25202504E-01 3,06843603E-01 0,                3,48870004E+00
 8,11002738E-01 3,52743360E-01 0,                3,35722585E+00
 8,16184347E-01 4,18502663E-01 0,                3,28522045E+00
 7,61420373E-01 4,92420835E-01 0,                3,00024088E+00
 7,11292029E-01 5,39317497E-01 0,                2,77313695E+00
 5,99268859E-01 5,54922440E-01 0,                2,34136874E+00
 4,71536477E-01 5,24862450E-01 0,                1,87164971E+00
 3,76626248E-01 4,64644911E-01 0,                1,52793650E+00
 2,81716019E-01 4,04427372E-01 0,                1,18422330E+00
 9,20545407E-10 1,00000000E+02 0,                0,
 4,93112723E-10 1,53147758E+02 0,                0,
 2,62132725E-10 2,51416505E+02 0,                0,
 1,38947556E-10 3,86092461E+02 0,                0,
 7,15351536E-11 5,36483867E+02 0,                0,
 3,42793193E-11 6,99723040E+02 0,                0,
 1,41346226E-11 8,63650011E+02 0,                0,
 4,15748906E-12 1,01967811E+03 0,                0,
 1,15994331E-12 1,15948313E+03 0,                0,
 9,20545407E-13 1,17540979E+03 0,                0,
 9,20545407E-13 1,17765943E+03 0,                0,
 9,20545407E-13 1,16778393E+03 0,                0,
-1
```

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     E7100,0     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,             3,90777001E+00
 9,12286283E-01 1,33143325E-01 0,             3,87536989E+00
 8,85190692E-01 1,87751091E-01 0,             3,76660893E+00
 8,67082711E-01 2,27059427E-01 0,             3,68457560E+00
 8,42145342E-01 2,56628046E-01 0,             3,59303298E+00
 8,30998125E-01 2,77719019E-01 0,             3,53141730E+00
 8,13992929E-01 2,88762844E-01 0,             3,48177362E+00
 8,15015423E-01 2,97242853E-01 0,             3,45953576E+00
 8,05779716E-01 2,94154030E-01 0,             3,45367429E+00
 8,18275071E-01 2,99276904E-01 0,             3,46685587E+00
 8,01678287E-01 2,90397224E-01 0,             3,44405962E+00
 8,25202504E-01 3,06843603E-01 0,             3,48870004E+00
 8,11002738E-01 3,52743360E-01 0,             3,35722585E+00
 8,16184347E-01 4,18502663E-01 0,             3,28522045E+00
 7,61420373E-01 4,92420835E-01 0,             3,00024088E+00
 7,11292029E-01 5,39317497E-01 0,             2,77313695E+00
 5,99268859E-01 5,54922440E-01 0,             2,34136874E+00
 4,71536477E-01 5,24862450E-01 0,             1,87164971E+00
 3,76626248E-01 4,64644911E-01 0,             1,52793650E+00
 2,81716019E-01 4,04427372E-01 0,             1,18422330E+00
 9,20545407E-10 1,00000000E+02 0,             0,
 4,93112723E-10 1,53147758E+02 0,             0,
 2,62132725E-10 2,51416505E+02 0,             0,
 1,38947556E-10 3,86092461E+02 0,             0,
 7,15351536E-11 5,36483867E+02 0,             0,
 3,42793193E-11 6,99723040E+02 0,             0,
 1,41346226E-11 8,63650011E+02 0,             0,
 4,15748906E-12 1,01967811E+03 0,             0,
 1,15994331E-12 1,15948313E+03 0,             0,
 9,20545407E-13 1,17540979E+03 0,             0,
 9,20545407E-13 1,17765943E+03 0,             0,
 9,20545407E-13 1,16778393E+03 0,             0,
-1
```

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 $\theta=0$, π, $\pi/2$ 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/CUB 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+00	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+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	3,64203E-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/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	1,43559E+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	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

TOTAL TIME= 4,5030199E+00 NUMBER OF CYCLES= 100

TOTAL TIME= 4.50302E+00 NUMBER OF CYCLES= 100 TIME STEP= 4.74558E-02 REAL TIME= 83.751 MAX PRESS= 1.26503E+00

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	4.26243E+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	5.70785E-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	8.40304E-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	1.70960E-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	3.24118E-01	1.90007E-01	4.53700E+00	1.05835E+00	3.60047E-01
1.19013E+00	3.53168E-01	1.94298E-01	4.44840E+00	1.05884E+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	9.64006E-01	5.96020E-01
1.04040E+00	7.04259E-01	1.86043E-01	4.11013E+00	8.55238E-01	7.33411E-01
9.46981E-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	3.72450E+00	4.47174E-01	1.25871E+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	7.98418E-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	8.77395E-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	8.51526E-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	4.25313E+00	8.06831E-01	3.33876E-01
9.18165E-01	3.35307E-01	1.89683E-01	4.16575E+00	7.64969E-01	3.85283E-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	6.68880E-01	2.04339E-01	3.77904E+00	6.23209E-01	7.34391E-01
6.99980E-01	8.59284E-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	1.19586E+00	2.28110E-01	3.49287E+00	3.20608E-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	9.84336E-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	4.34060E+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	3.31318E-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	6.92188E-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= [illegible]

SMOOTH EVERY 1 CYCLES UNTIL 50 CYCLES,THEN SMOOTH EVERY 5 CYCLES

GAMMA	1.200000E+00	CHAMBER RADIUS(FT)	6.091700E-01	SMOOTHING COEFFICIENT	[illegible]
MOLECULAR WEIGHT	2.300000E+01	CHAMBER LENGTH(FT)	1.321670E+00	PERCENT BOMB ENERGY	[illegible]
REF PRESSURE(PSI)	1.050000E+02	THROAT LOCATION(FT)	1.851670E+00	DROP DENSITY(DROPS/CUB FT)	[illegible]
REF TEMPERATURE(DEG R)	4.000000E+03	AREA RATIO	5.025000E-01	DROP DIAMETER(MICRONS)	[illegible]
REF SOUND SPEED(FT/SEC)	3.220672E+03	AXIAL STEPSIZE	1.808020E-01	DROP VELOCITY(FT/SEC)	[illegible]
REF DENSITY(LBM/CUB FT)	5.359223E-02	TANGENTIAL STEPSIZE	3.141593E-01	BURNING RATE POWER	[illegible]
REF TIME SCALE(MILLISEC)	1.891436E-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	19[illegible]
	0.00	0.00	8.72	0.00	1[illegible].38	[illegible]0

THERE ARE 4 BAFFLES 5.33 INCHES LONG AT THETA = 81.00 153.00 243.00 31[illegible]

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

** END OF INITILIZATION PHASE **

TOTAL TIME= 0.   NUMBER OF CYCLES= 0   TIME STEP= 5.11845E-02   REAL TIME= .609   MAX PRESS= [illegible]

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	7.60908E-01	8.30[illegible]E-02
9,12286E-01	1.45945E-01	0.	4.23733E+00	7.73131E-01	1.44[illegible]E-01
8,85191E-01	2.12102E-01	0.	4.23264E+00	7.49340E-01	2.10443E-[illegible]
8,67083E-01	2.61866E-01	0.	4.21511E+00	7.30969E-01	2.60[illegible]E-[illegible]
8,42145E-01	3.04731E-01	0.	4.22009E+00	7.10786E-01	3.02796E-[illegible]
8,30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33[illegible]18E-[illegible]
8,13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.527[illegible]E-[illegible]
8,15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64[illegible]E-[illegible]
8,05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.62763E-[illegible]
8,18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65[illegible]E-01
8,01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-[illegible]
8,25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.722[illegible]E-[illegible]
8,11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-[illegible]
8,16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-[illegible]
7,61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.83[illegible]E-[illegible]
7,11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.144[illegible]E-[illegible]
5,99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01[illegible]E+[illegible]
4,71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+[illegible]
3,76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.387[illegible]E+[illegible]
2,81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.645[illegible]E+[illegible]

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	1.17168E-[illegible]
6,47224E+00	2.12102E-01	0.	6.64831E+00	8.60588E+00	1.679[illegible]3E-[illegible]
5,82927E+00	2.61866E-01	0.	6.46139E+00	7.53304E+00	2.10296E-[illegible]
3,99265E+00	3.04731E-01	0.	5.81672E+00	4.64482E+00	2.57[illegible]3E-[illegible]
8,30998E-01	3.34199E-01	0.	4.19376E+00	6.97002E-01	3.33[illegible]8E-[illegible]
8,13993E-01	3.54749E-01	0.	4.21448E+00	6.86112E-01	3.527[illegible]E-[illegible]
8,15015E-01	3.64708E-01	0.	4.17824E+00	6.81066E-01	3.64[illegible]3E-[illegible]
8,05780E-01	3.65055E-01	0.	4.21949E+00	6.79997E-01	3.627[illegible]E-[illegible]
8,18275E-01	3.65741E-01	0.	4.16990E+00	6.82425E-01	3.65[illegible]E-[illegible]
8,01678E-01	3.62237E-01	0.	4.23045E+00	6.78293E-01	3.59[illegible]5E-[illegible]
8,25203E-01	3.71840E-01	0.	4.15856E+00	6.86330E-01	3.72[illegible]3E-[illegible]
8,11003E-01	4.34947E-01	0.	4.04501E+00	6.56103E-01	4.41439E-[illegible]
8,16184E-01	5.12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-[illegible]
7,61420E-01	6.46714E-01	0.	3.73120E+00	5.68203E-01	6.834[illegible]E-[illegible]
7,11292E-01	7.58222E-01	0.	3.61128E+00	5.13735E-01	8.1444[illegible]E-[illegible]
5,99269E-01	9.25999E-01	0.	3.47831E+00	4.16888E-01	1.01349E+[illegible]
4,71536E-01	1.11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+[illegible]
3,76626E-01	1.23370E+00	0.	3.29589E+00	2.48264E-01	1.387[illegible]3E+[illegible]
2,81716E-01	1.43559E+00	0.	3.17315E+00	1.78786E-01	1.645[illegible]5E+[illegible]

SOLUTION ALONG THE RAY THETA = 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	8.3[illegible]
9,12286E-01	1,45945E-01	0.	4.23733E+00	7.73131E-01	1.447[illegible]
8,85191E-01	2,12102E-01	0.	4.23264E+00	7.49340E-01	2.10443E-[illegible]
8,67083E-01	2,61866E-01	0.	4.21511E+00	7.30969E-01	2.6035[illegible]
8,42145E-01	3,04731E-01	0.	4.22009E+00	7.10786E-01	3.02[illegible]
8,30998E-01	3,34199E-01	0.	4.19376E+00	6.97002E-01	3.33[illegible]
8,13993E-01	3,54749E-01	0.	4.21448E+00	6.86112E-01	3.527[illegible]
8,15015E-01	3,64708E-01	0.	4.17824E+00	6.81066E-01	3.64[illegible]
8,05780E-01	3,65055E-01	0.	4.21949E+00	6.79997E-01	3.62[illegible]
8,18275E-01	3,65741E-01	0.	4.16990E+00	6.82425E-01	3.65[illegible]
8,01678E-01	3,62237E-01	0.	4.23045E+00	6.78293E-01	3.594[illegible]
8,25203E-01	3,71840E-01	0.	4.15856E+00	6.86330E-01	3.722[illegible]
8,11003E-01	4,34947E-01	0.	4.04501E+00	6.56103E-01	4.41[illegible]
8,16184E-01	5,12755E-01	0.	3.89364E+00	6.35585E-01	5.30[illegible]
7,61420E-01	6,46714E-01	0.	3.73120E+00	5.68203E-01	6.834[illegible]
7,11292E-01	7,58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-[illegible]
5,99269E-01	9,25999E-01	0.	3.47831E+00	4.16888E-01	1.01[illegible]
4,71536E-01	1,11309E+00	0.	3.34977E+00	3.15908E-01	1.24[illegible]
3,76626E-01	1,23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+[illegible]
2,81716E-01	1,43559E+00	0.	3.17315E+00	1.78786E-01	1.645[illegible]

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	8.3[illegible]
9,12286E-01	1,45945E-01	0.	4.23733E+00	7.73131E-01	1.44[illegible]
8,85191E-01	2,12102E-01	0.	4.23264E+00	7.49340E-01	2.1[illegible]
8,67083E-01	2,61866E-01	0.	4.21511E+00	7.30969E-01	2.60[illegible]
8,42145E-01	3,04731E-01	0.	4.22009E+00	7.10786E-01	3.02[illegible]
8,30998E-01	3,34199E-01	0.	4.19376E+00	6.97002E-01	3.33[illegible]
8,13993E-01	3,54749E-01	0.	4.21448E+00	6.86112E-01	3.527[illegible]
8,15015E-01	3,64708E-01	0.	4.17824E+00	6.81066E-01	3.64[illegible]
8,05780E-01	3,65055E-01	0.	4.21949E+00	6.79997E-01	3.62[illegible]
8,18275E-01	3,65741E-01	0.	4.16990E+00	6.82425E-01	3.655[illegible]
8,01678E-01	3,62237E-01	0.	4.23045E+00	6.78293E-01	3.59495E-[illegible]
8,25203E-01	3,71840E-01	0.	4.15856E+00	6.86330E-01	3.72203E-[illegible]
8,11003E-01	4,34947E-01	0.	4.04501E+00	6.56103E-01	4.41459E-[illegible]
8,16184E-01	5,12755E-01	0.	3.89364E+00	6.35585E-01	5.30428E-[illegible]
7,61420E-01	6,46714E-01	0.	3.73120E+00	5.68203E-01	6.83411E-[illegible]
7,11292E-01	7,58222E-01	0.	3.61128E+00	5.13735E-01	8.14442E-[illegible]
5,99269E-01	9,25999E-01	0.	3.47831E+00	4.16888E-01	1.01[illegible]
4,71536E-01	1,11309E+00	0.	3.34977E+00	3.15908E-01	1.24141E+[illegible]
3,76626E-01	1,23370E+00	0.	3.29589E+00	2.48264E-01	1.38713E+[illegible]
2,81716E-01	1,43559E+00	0.	3.17315E+00	1.78786E-01	1.645[illegible]

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

TOTAL TIME= 4.4674[illegible]E+00 NUMBER OF CYCLES= 100 TIME STEP= 4.71972E-02 REAL TIME= 74.3[illegible]7 MAX [illegible]

SOLUTION ALONG THE RAY THETA = 0

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

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
1.25911E+00	0.	3.04740E-03	4.33677E+00	[illegible].09209E+00	2.98[illegible]
1.22542E+00	6.35270E-02	8.08195E-03	4.35085E+00	[illegible].06632E+00	6.26[illegible]
1.23019E+00	9.13883E-02	4.57013E-03	4.37321E+00	[illegible].07597E+00	8.93[illegible]
1.20329E+00	1.30347E-01	1.14650E-02	4.37966E+00	[illegible].15400E+00	1.27[illegible]
1.16943E+00	1.43824E-01	9.00321E-03	4.37101E+00	[illegible].02232E+00	1.4[illegible]
1.12250E+00	1.63134E-01	6.05561E-03	4.36990E+00	9.81046E-01	1.59[illegible]
1.08588E+00	1.66234E-01	-9.27162E-05	4.35552E+00	9.45918E-01	1.6[illegible]
1.03361E+00	1.64444E-01	8.97134E-03	4.37171E+00	[illegible].03727E-01	1.6[illegible]
1.00356E+00	1.54059E-01	1.76247E-02	4.33368E+00	[illegible].69922E-01	1.52[illegible]
9.50692E-01	1.49564E-01	3.64972E-02	4.36280E+00	[illegible].29537E-01	1.5[illegible]
9.40500E-01	1.43028E-01	5.37978E-02	4.27462E+00	[illegible]4056E-01	1.5[illegible]
8.80311E-01	1.49587E-01	7.06743E-02	4.35592E+00	[illegible].66914E-01	1.61[illegible]
8.88927E-01	1.66704E-01	8.04297E-02	4.22005E+00	[illegible].50264E-01	1.8[illegible]
8.76941E-01	2.21700E-01	9.28547E-02	4.10022E+00	[illegible].19131E-01	2.42[illegible]
8.77152E-01	3.02756E-01	1.10322E-01	3.94668E+00	[illegible].92368E-01	3.31[illegible]
8.44365E-01	4.23444E-01	1.24120E-01	3.80395E+00	[illegible].42384E-01	4.61[illegible]
7.88974E-01	5.62940E-01	1.35697E-01	3.68152E+00	[illegible].80925E-01	6.160[illegible]
6.82279E-01	7.41703E-01	1.44689E-01	3.57078E+00	[illegible].87254E-01	8.163[illegible]
5.66923E-01	9.25152E-01	1.55350E-01	3.47271E+00	[illegible].93752E-01	1.02[illegible]
4.73291E-01	1.04823E+00	1.60803E-01	3.44754E+00	[illegible].26338E-01	1.16[illegible]
3.79659E-01	1.23203E+00	1.68945E-01	3.38171E+00	[illegible].56779E-01	1.38[illegible]

SOLUTION ALONG THE RAY THETA = PI

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

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
8.32143E-01	0.	-3.40800E-02	4.09431E+00	[illegible].81410E-01	3.43[illegible]
8.31364E-01	1.02720E-01	-3.93776E-02	4.06686E+00	[illegible].76209E-01	1.11[illegible]
8.23723E-01	1.90078E-01	-4.51096E-02	4.05935E+00	[illegible].68755E-01	1.979[illegible]
8.00408E-01	2.89148E-01	-3.81524E-02	4.04131E+00	[illegible].46940E-01	2.96[illegible]
7.72881E-01	3.54627E-01	-3.13596E-02	4.00640E+00	[illegible].19295E-01	3.[illegible]
7.67335E-01	4.24745E-01	1.31723E-03	4.01729E+00	[illegible].16521E-01	4.3[illegible]
7.79531E-01	4.61755E-01	1.86891E-02	4.02380E+00	[illegible].27335E-01	4.7[illegible]
8.29661E-01	4.62937E-01	6.60625E-02	4.07398E+00	[illegible].76005E-01	4.72[illegible]
9.85611E-01	3.66323E-01	7.58533E-02	4.21318E+00	[illegible].30512E-01	3.72[illegible]
1.18458E+00	2.54774E-01	4.75258E-02	4.36462E+00	[illegible].03405E+00	2.[illegible]
1.21860E+00	3.01065E-01	7.00864E-03	4.33820E+00	[illegible].05730E+00	2.[illegible]

1.07634E+00	4.49792E-01	-1.42930E-02	4.27334E+00	[illegible].19916E-01	4.44[illegible]
1.05468E+00	5.46044E-01	-2.39762E-02	4.13642E+00	[illegible].72517E-01	5.48[illegible]
1.07185E+00	5.91285E-01	-5.68729E-02	4.04069E+00	[illegible].06202E-01	6.[illegible]
1.11362E+00	6.38078E-01	-7.72360E-02	3.90907E+00	[illegible].70641E-01	6.6[illegible]
9.77952E-01	8.11566E-01	-9.33354E-02	3.71561E+00	[illegible].26739E-01	8.6[illegible]
8.72122E-01	9.41293E-01	-1.01819E-01	3.59218E+00	[illegible].26564E-01	1[illegible]
7.36884E-01	1.07545E+00	-1.06643E-01	3.48625E+00	[illegible].13792E-01	1.1[illegible]
5.53690E-01	1.26667E+00	-1.08609E-01	3.35900E+00	[illegible].71969E-01	1.4[illegible]
4.24476E-01	1.38857E+00	-1.07921E-01	3.30313E+00	[illegible].00419E-01	1.5[illegible]
2.95261E-01	1.61716E+00	-1.06631E-01	3.15829E+00	[illegible].86504E-01	1[illegible]

SOLUTION ALONG THE RAY THETA = PI/2

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

RHO	U	V	INT ENERGY	PRESSURE	MACH 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	8.60140E-01	9.16265E-02
1.00617E+00	9.80005E-02	1.67713E-02	4.27656E+00	8.60590E-01	9.81394E-02
1.02562E+00	1.10849E-01	1.33566E-02	4.29828E+00	8.81682E-01	1.09928E-01
9.85169E-01	9.72211E-02	1.59482E-01	4.27493E+00	8.42306E-01	1.84297E-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	3.37901E-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	6.66062E-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	1.14619E+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(LBM/SEC-SQ IN)

RHO	U	V	INT ENERGY	PRESSURE	MACH NO.
9.67697E-01	0.	9.37929E-03	4.20746E+00	8.14310E-01	9.33341E-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	1.43869E-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	2.39316E-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	4.45619E-01	-4.00715E-01	4.23824E+00	7.17512E-01	5.96423E-01
8.41568E-01	4.46286E-01	-3.56575E-01	4.27713E+00	7.19899E-01	5.63818E-01
8.12159E-01	4.26273E-01	-3.69073E-01	4.44069E+00	7.21309E-01	5.46173E-01
8.15862E-01	4.34630E-01	-2.06796E-01	4.45961E+00	7.27685E-01	4.65242E-01
8.14523E-01	5.08063E-01	-2.75095E-02	4.31100E+00	7.02283E-01	5.00257E-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	8.64272E-01
7.47755E-01	8.86282E-01	3.39894E-01	3.65226E+00	5.46199E-01	1.01377E+00
6.36930E-01	1.02494E+00	3.75872E-01	3.50546E+00	4.46546E-01	1.19020E+00
4.82328E-01	1.20885E+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	2.46259E-01	1.55353E+00
2.65146E-01	1.53135E+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
Δt	time stepsize
$\Delta\theta$	tangential stepsize
Δz	axial stepsize
E	total energy per unit volume of gas
f_s	stoichiometric fuel-oxidant ratio
ϕ	fuel-oxidant equivalence ratio
G	tangential flux vector
γ	specific heat ratio
H	axial flux vector
H^*	area variation flux vector
k	termal 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
λ	burning rate power
M	Mach number
M	molecular weight of gas
m_ℓ	mass of drop
$\dot{m}_F$	mass burning rate
μ	viscosity
N	drop density
Pr	Prandtl number
p	pressure of gas
p_o	reference pressure
ψ	source vector
ψ_ρ	density component of source vector
ψ_E	energy component of source vector
Q	heat of reaction per unit mass of fuel
Re	Reynolds number
r	radius of chamber
r_ℓ	radius of drop
ρ	density of gas
ρ_o	reference density
T	temperature of gas
T_ℓ	temperature of drop
T_o	reference temperature
t	time
t_o	reference time
θ	tangential coordinate

u	axial velocity of gas
u_ℓ	axial velocity of drop
v	tangential velocity of gas
v_ℓ	tangential velocity of drop
$V_{i,j}^{n}$	approximation to fluid properties vector at (z_i, θ_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_o
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 Δz
DLN	diameter of drop d_ℓ
DROP	array of drop properties, DROP(K,J,I) for K=1,...,5 contains the drop mass, axial velocity and tangential velocity and the density and energy components of the source vector at point z_i,θ_j
DT	time stepsize Δt
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 γ
HT	array of tangential mesh points θ_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 θ_j,θ_{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
NNPCMX	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,θ_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 λ
PHI	fuel-oxidant equivalence ratio ϕ
PO	reference pressure p_o
PROPTY	array of fluid properties, PROPTY(I,J,K) contains the kth component of V at the point z_i,θ_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 ρ_o
SMK	smoothing coefficient K
T	time t
TO	reference time t_o
T0	reference temperature T_o
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	calculatesfluid 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 $\frac{\partial LnA}{\partial z}$
PHIDOTV	calculates forcing function and drop field
MSHVL	interpolates for drop field at mesh points
SMOOTH	smooths the solution
PPLOT	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^3 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

Card	Columns	Type	Description
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

Card	Columns	Type	Description
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^3 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.

Card	Columns	Type	Description
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.

Card	Columns	Type	Description
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.

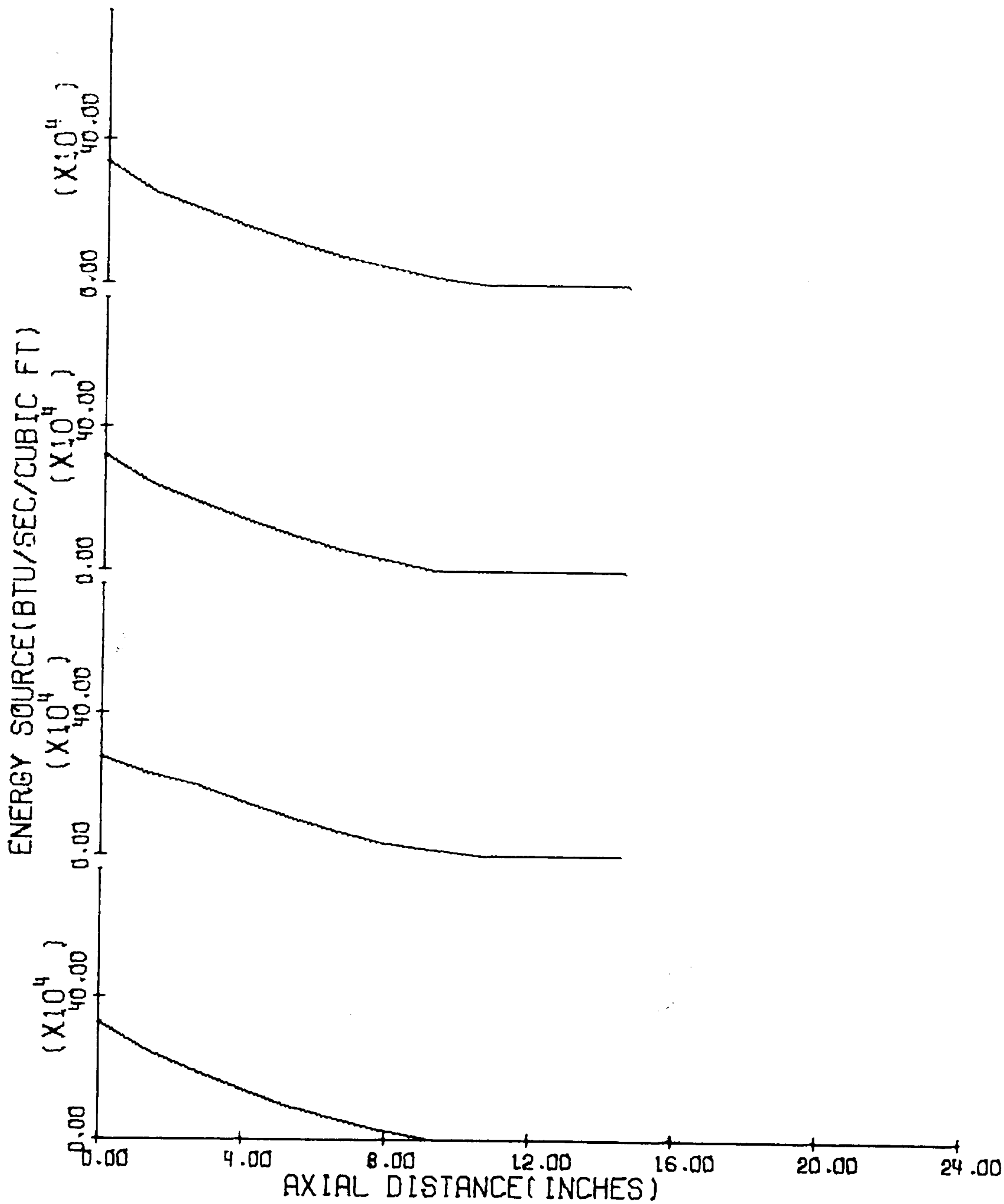
The use which can be made of various combinations of the plot program input options is illustrated by the sample input. Suppose that four runs were made and the plot output for each was placed as a separate file on tape 4. Each file has information for every 100 cycles from 0 to 600 cycles. The pressure 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       8.95      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       8.95      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       8.95      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       8.95      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

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

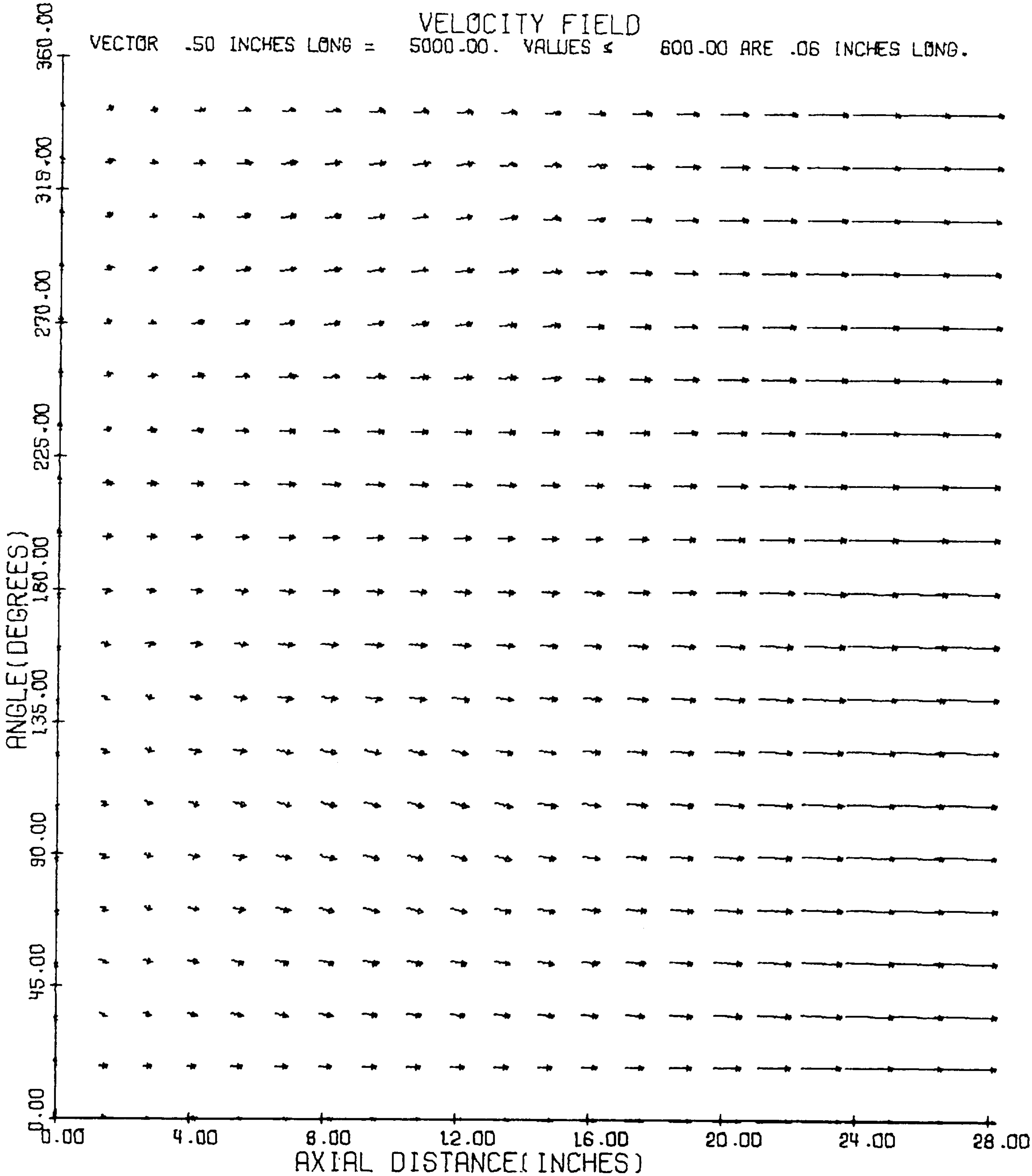
CLAYTON MOTOR-1

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

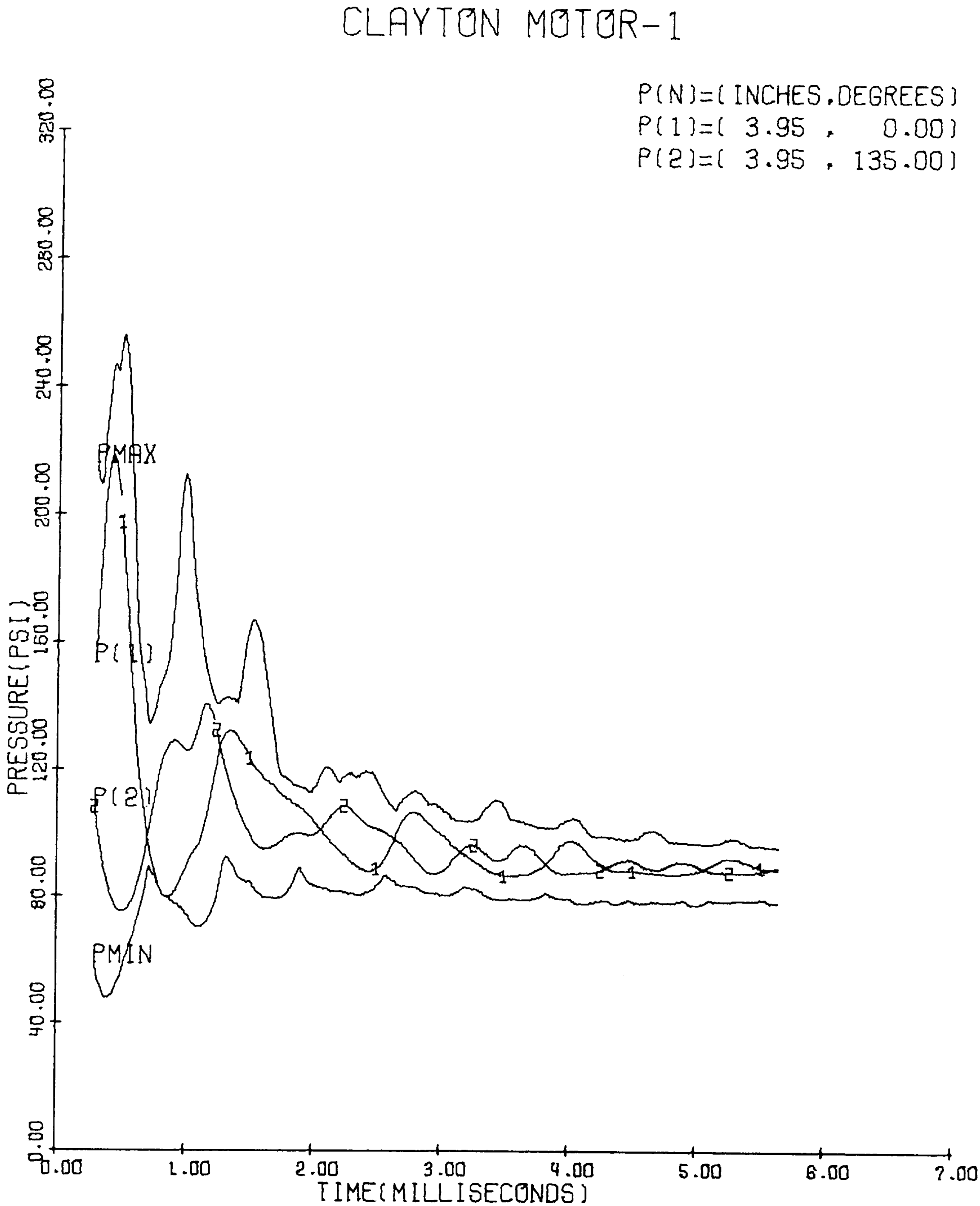
T/TREF= 14,47133

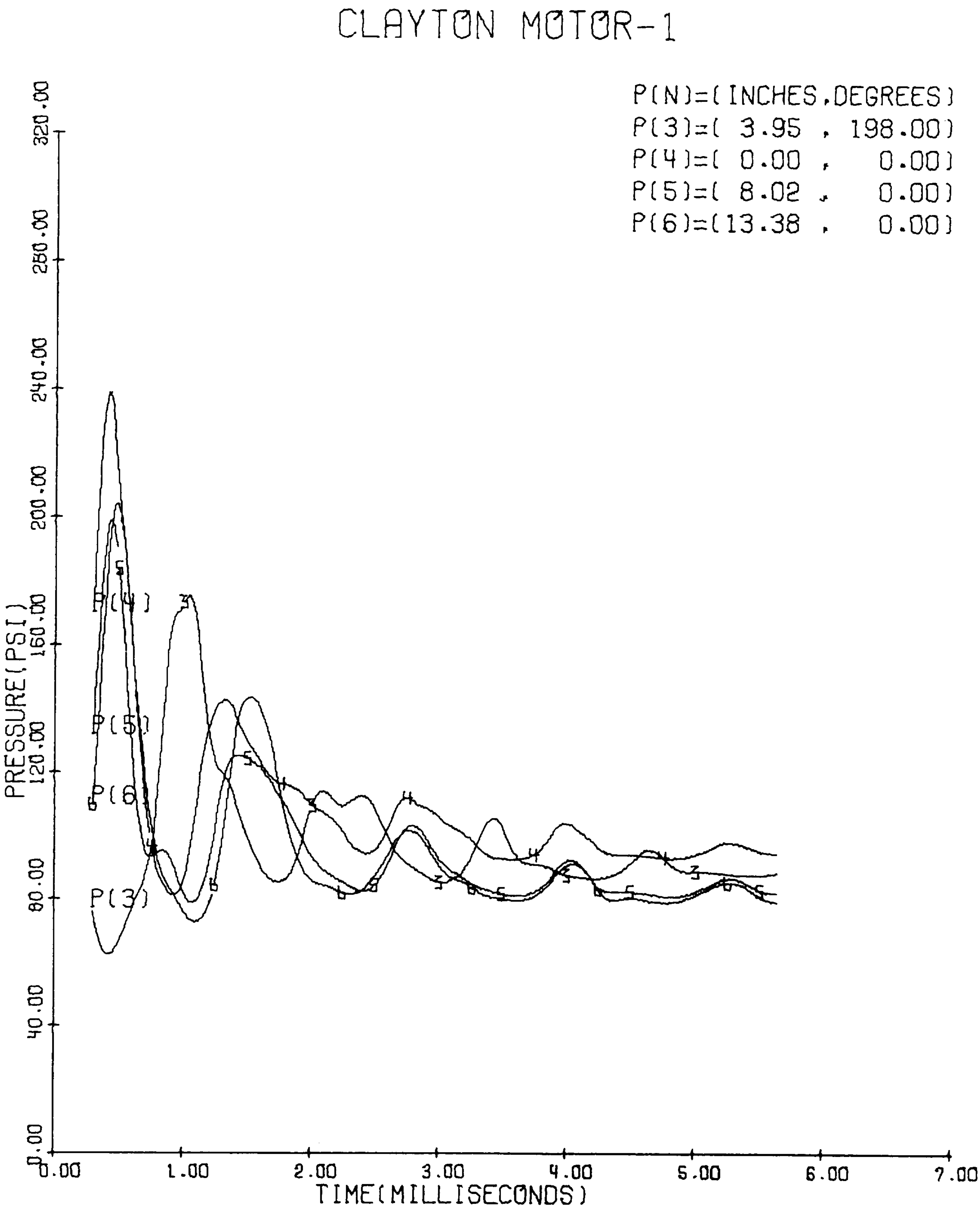
ISOBAR	PRESSURE/PREF
1	,219
2	,283
3	,347
4	,411
5	,476
6	,540
7	,604
8	,668
9	,733
10	,797
11	,861
12	,925
13	,990
14	1,054
15	1,118

CLAYTON MOTOR-1

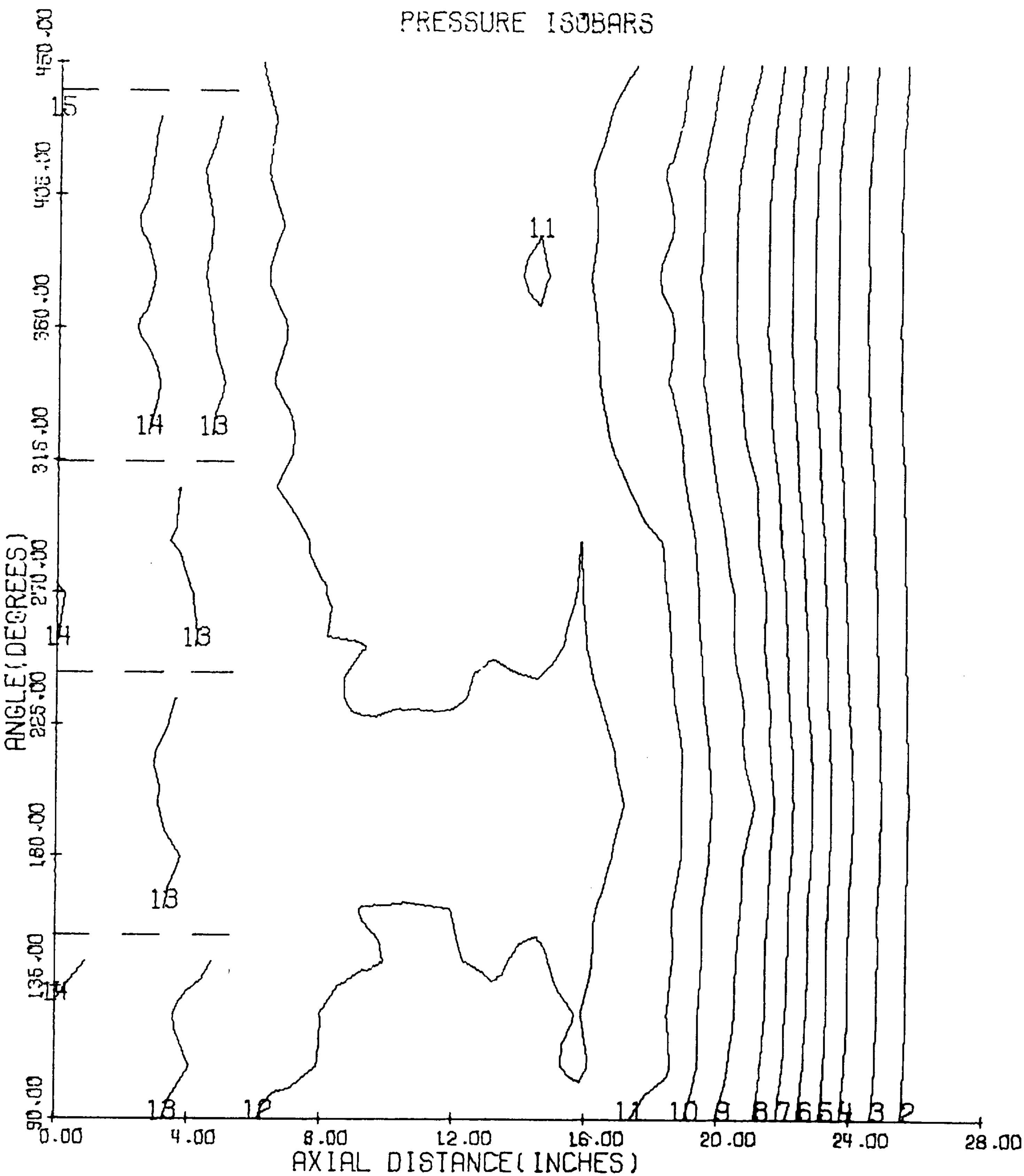


T= 2.737 MILLISECONDS


CLAYTON MOTOR-1
P(N)=(INCHES,DEGREES)
P(1)=(3.95 , 0.00)
P(2)=(3.95 , 135.00)
PMAX
P(1)
P(2)
PMIN
PRESSURE(PSI)
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
TIME(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)
PRESSURE(PSI)
TIME(MILLISECONDS)
P(3)
P(4)
P(5)
P(6)

CLAYTON MOTOR-5



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

BIBLIOGRAPHY

Burstein, S. Z., Nonlinear Combustion Instability in Liquid Propellant Rocket Engines: The Transverse Mode 1. The Hydrodynamic Differential and Difference Equations and Computer Algorithm, NASA TR32-1111, September 15, 1967.

Burstein, S.Z., Chinitz, W., and Schechter, H. S., Nonlinear Combustion Instability in Liquid Propellant Rocket Motors, MAGI Final Report to J.P.L., Contract No. 951946, July 1970.

Burstein, S.Z. and Schechter, H., Nonlinear Combustion Instability: Computer Experiments Using Codes COMB and TRDL, MAGI Final Report to J.P.L., Contract No. 952505, July 1969.

Burstein, S.Z. and Schechter, H. S., A Study of High Frequency Nonlinear Combustion Instability in Baffled Annular Liquid Propellant Rocket Motors, Volume I, MAGI Final Report to N.A.S.A., Contract NAS7-752, August 1970.

Clayton, R.M., Resonant Combustion, J.P.L. Space Program Summary 37-55, Vol. 3, February 28, 1969.

DISTRIBUTION LIST

CONTRACT NAS 7 752

COPIES	RECIPIENT	DESIGNEE
	NASA HEADQUARTERS WASHINGTON, D.C. 20546	
1	CONTRACTING OFFICER	%X"
1	PATENT OFFICE	%X"
	NASA LEWIS RESEARCH CENTER 21000 BROOKPARK RD. CLEVELAND, OHIO 44135	
1	OFFICE OF TECHNICAL INFORMATION	%X"
1	DR. R. J. PRIEM	%X"
	NASA MANNED SPACECRAFT CENTER HOUSTON, TEXAS 77001	
1	OFFICE OF TECHNICAL INFORMATION	%X"
	NASA MARSHALL SPACE FLIGHT CENTER HUNTSVILLE, ALABAMA 35812	
1	TECHNICAL LIBRARY	%X"
1	DALE BURROWS, S+E, ATTN-PJ BLDG 4666	%X"
	NASA PASADENA OFFICE 4800 OAK GROVE DRIVE PASADENA, CALIFORNIA 91103	
1	PATENTS AND CONTRACTS MANAGEMENT	%X"
	JET PROPULSION LABORATORY 4800 OAK GROVE DR. PASADENA, CALIF. 91103	
2	JACK H. RUPE	%X"
3	CHIEF, LIQUID PROPULSION TECHNOLOGY RPL OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY NASA HEADQUARTERS WASHINGTON, D.C., 20546	%X"
1	DIRECTOR, TECHNOLOGY UTILIZATION DIVISION OFFICE OF TECHNOLOGY UTILIZATION NASA HEADQUARTERS WASHINGTON, D.C., 20546	%X"

COPIES	RECIPIENT	DESIGNEE
25	NASA SCIENTIFIC AND TECHNICAL INFORMATION FACILITY P.O.BOX 33 COLLEGE PARK, MARYLAND 20740	%X"
1	DIRECTOR, LAUNCH VEHICLES AND PROPULSION, SV OFFICE OF SPACE SCIENCE AND APPLICATIONS NASA HEADQUARTERS WASHINGTON, D.C., 20546	%X"
1	DIRECTOR, ADVANCED MANNED MISSIONS, MT OFFICE OF MANNED SPACE FLIGHT NASA HEADQUARTERS WASHINGTON, D.C., 20546	%X"
1	MISSION ANALYSIS DIVISION NASA AMES RESEARCH CENTER MOFFETT FIELD, CALIFORNIA 24035	%X"

NASA FIELD CENTERS

1	AMES RESEARCH CENTER MOFFETT FIELD, CALIF. 94035	ALBERTA ALKSNE N-203-9
2	LEWIS RESEARCH CENTER 21000 BROOKPARK ROAD CLEVELAND, OHIO 44135	E. W. CONRAD ALLEN J. METZLER
1	GODDARD SPACE FLIGHT CENTER GREENBELT, MARYLAND 20771	MERLAND L. MOSESON CODE 620
2	JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY 4800 OAK GROVE DRIVE PASADENA, CALIFORNIA 91103	HENRY BURLAGE, JR PROPULSION DIV. 38
2	LANGLEY RESEARCH CENTER LANGLEY STATION HAMPTON, VIRGINIA 23365	ED CORTWRIGHT DIRECTOR
2	LEWIS RESEARCH CENTER 21000 BROOKPARK ROAD CLEVELAND, OHIO 44135	DR. ABE SILVERSTEIN DIRECTOR

COPIES	RECIPIENT	DESIGNEE
2	MANNED SPACECRAFT CENTER HOUSTON, TEXAS 77001	J.G. THIBODAUX, JR. CHIEF, PROP. + POWER
2	JOHN F. KENNEDY SPACE CENTER, NASA COCOA BEACH, FLORIDA 32931	DR. KURT H. DEBUS

GOVERNMENT INSTALLATIONS

1	AERONAUTICAL SYSTEMS DIVISION AIR FORCE SYSTEMS COMMAND WRIGHT-PATTERSON AIR FORCE BASE DAYTON, OHIO 45433	D.L. SCHMIDT CODE ASRCNC-2
1	ARNOLD ENGINEERING DEVELOPMENT CENTER ARNOLD AIR FORCE STATION TULLAHOMA, TENNESSEE 37388	DR. H. K. DOETSCH
1	BUREAU OF NAVAL WEAPONS DEPARTMENT OF THE NAVY WASHINGTON, D.C., 20546	J. KAY RIMS-41
1	DEFENSE DOCUMENTATION CENTER HEADQUARTERS CAMERON STATION, BUILDING 5 5010 DUKE STREET ALEXANDRIA, VIRGINIA 22314 ATTN: TISIA	
1	PICATINNY ARSENAL DOVER, NEW JERSEY 07801	I. FORSTEN, CHIEF LIQUID PROPULSION LABORATORY,
2	AIR FORCE ROCKET PROPULSION LABORATORY RESEARCH AND TECHNOLOGY DIVISION AIR FORCE SYSTEMS COMMAND EDWARDS, CALIFORNIA 93523	RPRPD/MR. H. MAIN
1	U. S. ARMY MISSILE COMMAND REDSTONE ARSENAL ALABAMA 35809	MR. WALTER WHARTON
1	U. S. BUREAU OF MINES 4800 FORBES AVE. PITTSBURGH, PENN. 15213	MR. HENRY PERLEE

COPIES	RECIPIENT	DESIGNEE
1	U. S. NAVAL ORDNANCE TEST STATION CHINA LAKE CALIFORNIA 93557	D. COUCH
1	AIR FORCE OFFICE OF SCIENTIFIC RESEARCH 1400 WILSON BLVD. ARLINGTON, VIRGINIA 22209	B. T. WOLFSON

CPIA

1	CHEMICAL PROPULSION INFORMATION AGENCY APPLIED PHYSICS LABORATORY 8621 GEORGIA AVENUE SILVER SPRING, MARYLAND 20910	TOM REEDY

INDUSTRY CONTRACTORS

1	AEROJET-GENERAL CORPORATION P.O.BOX 296 AZUSA, CALIFORNIA 91703	W. L. ROGERS
1	SPACE DIVISION AEROJET-GENERAL CORPORATION 9200 EAST FLAIR DR. EL MONTE, CALIFORNIA 91734	S. MACHLAWSKI
1	AEROSPACE CORPORATION 2400 EAST EL SEGUNDO BOULEVARD P.O.BOX 95085 LOS ANGELES, CALIFORNIA 90045	O. W. DYKEMA
1	ATLANTIC RESEARCH CORPORATION EDSALL ROAD AND SHIRLEY HIGHWAY ALEXANDRIA, VIRGINIA 22314	LIBRARIAN
1	BELL AEROSYSTEMS COMPANY P.O.BOX 1 BUFFALO, NEW YORK 14240	W. M. SMITH
1	BOEING COMPANY P.O.BOX 3707 SEATTLE, WASHINGTON 98124	J. D. ALEXANDER

COPIES	RECIPIENT	DESIGNEE
1	WRIGHT AERONAUTICAL DIVISION CURTISS-WRIGHT CORPORATION WOOD-RIDGE, NEW JERSEY 07075	G. KELLEY
1	RESEARCH CENTER FAIRCHILD HILLER CORPORATION GERMANTOWN, MARYLAND	RALPH HALL
1	MISSILE AND SPACE SYSTEMS CENTER GENERAL ELECTRIC COMPANY VALLEY FORGE SPACE TECHNOLOGY CENTER P.O.BOX 8555 PHILADELPHIA, PA.	F. MEZGER F. E. SCHULTZ
1	GRUMMAN AIRCRAFT ENGINEERING CORP. BETHPAGE, LONG ISLAND NEW YORK 11714	JOSEPH GAVIN
1	HONEYWELL, INC. AEROSPACE DIV. 2600 RIDGWAY RD. MINNEAPOLIS, MINN.	MR. GORDON HARMS
1	HUGHES AIRCRAFT CO. AEROSPACE GROUP CENTINELA AND TEALE STREETS CULVER CITY, CALIF. 90230	E. H. MEIER V.P. AND DIV. MGR., RESEARCH + DEV. DIV.
1	ARTHUR D. LITTLE, INC. 20 ACORN PARK CAMBRIDGE, MASSACHUSETTS 02140	LIBRARY
1	LOCKHEED PROPULSION COMPANY P.O.BOX 111 REDLANDS, CALIFORNIA 92374	H. L. THACKWELL
1	THE MARQUARDT CORPORATION 16555 SATICOY STREET VAN NUYS, CALIFORNIA 91409	HOWARD MC FARLAND
1	DENVER DIVISION MARTIN MARIETTA CORPORATION P.O.BOX 179 DENVER, COLORADO 80201	DR. MORGANTHALER A. J. KULLAS
1	ASTROPOWER LABORATORY MC DONNELL-DOUGLAS AIRCRAFT CO. 2121 PAULARINO NEWPORT BEACH, CALIF. 92663	DR. GEORGE MOC DIRECTOR, RESEARCH

COPIES	RECIPIENT	DESIGNEE
1	MISSILE AND SPACE SYSTEMS DIVISION MC DONNELL-DOUGLAS AIRCRAFT CO. 3000 OCEAN PARK BOULEVARD SANTA MONICA, CALIF. 90406	MR. R. W. HALLET CHIEF ENGINEER ADV. SPACE TECH.
1	SPACE + INFORMATION SYSTEMS DIVISION NORTH AMERICAN ROCKWELL 12214 LAKEWOOD BOULEVARD DOWNEY, CALIFORNIA 90241	LIBRARY
1	ROCKETDYNE C/0 LIBRARY 586-306 6633 CANOGA AVENUE CANOGA PARK, CALIF. 91304	DR. R. J. THOMPSON S. F. IACOBELLIS
1	NORTHROP SPACE LABORATORIES 3401 WEST BROADWAY HAWTHORNE, CALIFORNIA 90250	DR. WILLIAM HOWARD
1	STANFORD RESEARCH INSTITUTE 333 RAVENSWOOD AVENUE MENLO PARK, CALIFORNIA 94025	DR. GERALD MARKSMAN
1	TRW SYSTEMS GROUP TRW INCORPORATED ONE SPACE PARK REDONDO BEACH, CALIF. 90278	G. W. ELVERUM
1	REACTION MOTORS DIVISION THIOKOL CHEMICAL CORPORATION DENVILLE, NEW JERSEY 07832	DWIGHT S. SMITH
1	RESEARCH LABORATORIES 400 MAIN ST. EAST HARTFORD, CONN. 06108	ERLE MARTIN
1	UNITED TECHNOLOGY CENTER 587 METHILDA AVENUE P.O.BOX 358 SUNNYVALE, CALIFORNIA 94088	DR. DAVID ALTMAN
1	ROCKETDYNE A DIV. OF NORTH AMERICAN ROCKWELL 6633 CANOGA AVENUE CANOGA PARK, CALIFORNIA 91304	R. B. LAWHEAD

COPIES	RECIPIENT	DESIGNEE
1	PRATT ? WHITNEY AIRCRAFT FLORIDA RESEARCH ? DEVELOPMENT CTR. P.O.BOX 2691 WEST PALM BEACH, FLORIDA 33402	G. D. LEWIS
1	DEFENSE RESEARCH CORPORATION P.O.BOX 3587 SANTA BARBARA, CALIFORNIA 93105	. GRAY
1	AEROJET-GENERAL CORPORATION P.O.BOX 1947 SACRAMENTO, CALIFORNIA 95809	DAVID KORS
1	DYNAMIC SCIENCE 2400 MICHELSON DRIVE IRVINE, CALIF. 92664	THOMAS TYSOM
1	MATHEMATICAL APPLICATIONS GROUP, INC. 180 SO. BROADWAY WHITE PLAINS, NEW YORK 10605	DR. S. Z. BURNSTEIN
	UNIVERSITIES	
1	OHIO STATE UNIVERSITY DEPT. OF AERONAUTICAL ENG. COLUMBUS, OHIO 43210	R. EDSE
1	PENNSYLVANIA STATE UNIV. MECH. ENGINEERING DEPT. 207 MECHANICAL ENGINEERING BLVD. UNIVERSITY PARK, PA. 16802	G. M. FAETH
1	UNIVERSITY OF SOUTHERN CALIF. DEPT. OF MECH ENG UNIVERSITY PARK LOS ANGELES, CALIF. 90007	M. GERSTEIN
1	PRINCETON UNIVERSITY FORRESTAL CAMPUS GUGGENHEIM LABORATORIES PRINCETON, NEW JERSEY 08540	D. HARRJE I. GLASSMAN
1	UNIVERSITY OF WISCONSIN MECHANICAL ENG DEPT 1513 UNIVERSITY AVE. MADISON, WISCONSIN 53705	P. S. MYERS

COPIES	RECIPIENT	DESIGNEE
1	UNIVERSITY OF MICHIGAN AEROSPACE ENGINEERING ANN ARBOR, MICHIGAN 48104	J. A. NICHOLLS
1	UNIVERSITY OF CALIF. DEPT. OF CHEM. ENG. 6161 ETCHEVERRY HALL BERKELEY, CALIF. 94720	A. K. OPPENHIEM R. SAWYER
1	PURDUE UNIV SCHOOL OF MECH ENG LAFAYETTE, INDIANA 47907	J. R. OSBORN
1	SACRAMENTO STATE COLLEGE ENGINEERING DIVISION 60000 J. STREET SACRAMENTO, CALIFORNIA 95818	E. H. REARDON
1	ILLINOIS INSTITUTE OF TECH RM 200 M. H. 3300 S. FEDERAL STREET CHICAGO, ILLINOIS 60616	T. P. TORDA
1	POLYTECHNIC INSTITUTE OF BROOKLYN GRADUATE CENTER ROUTE 110 FARMINGDALE, NEW YORK	V. D. AGOSTA
1	GEORGIA INST OF TECH ATLANTA, GEORGIA 30332	B. T. ZINN
1	UNIVERSITY OF DENVER RESEARCH INSTITUTE DENVER, COLORADO	W. H. MCLAIN
1	NEW YORK UNIVERSITY DEPT. OF CHEM. ENG. UNIVERSITY HEIGHTS NEW YORK 53, NEW YORK	LEONARD DAUERMAN
1	THE JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY 8621 GEORGIA AVE. SILVER SPRINGS, MARYLAND 20910	W. G. BERL

COPIES	RECIPIENT	DESIGNEE
	FOREIGN UNIVERSITIES	
1	THE UNIVERSITY OF SHEFFIELD DEPT. OF FUEL TECHNOLOGY ST. GEORGE'S SQUARE SHEFFIELD 1, YORKS ENGLAND	MR. J. SWITHENBANK
1	MOTORLAR ENSTITUSU PROFESSOR ZUBEYIR DEMIRGUE DIRECTOR OF ENGINE INSTITUTE ISTANBUL - GUMUSSUYU	
1	INSTITUTO NACIONAL DE TECNICA AEROESPACIAL CARLOS SANCHEZ-TARIFA SERRANO 43 MADRID, SPAIN	