AD-786 616

CONCEPT FOR ATTENUATION OF THE BACK BLAST REGION OF A 105 mm RECOILLESS RIFLE

Hugo J. Nielsen

IIT Research Institute

Prepared for:

Watervliet Arsenal

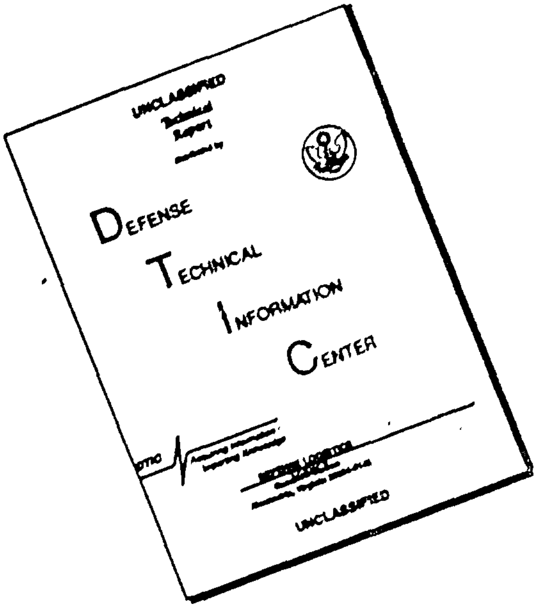
July 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: WVT-CR-74026	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: AD-786616	
4. TITLE (and Subtitle): Concept for Attenuation of the Back Blast Region of a 105 mm Recoilless Rifle	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER: J6293 (Sep 1973)
7. AUTHOR(s): Hugo J. Nielsen	8. CONTRACT OR GRANT NUMBER(s): Contract No. DAAF07-73-C-0155
9. PERFORMING ORGANIZATION NAME AND ADDRESS: IIT Research Institute, 10 West 35th St., Chicago, Illirois 60616	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AMCMS No. 513F.12.05014.02; DA Project No. 1F163206D050; Pron No. EJ-2-50139-(01)-M7-M7
11. CONTROLLING OFFICE NAME AND ADDRESS: Benet Weapons Laboratory, Watervliet Arsenal, Watervliet, N.Y. 12189	12. REPORT DATE: July 1974
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Recoilless Rifles
Air Blast
Blast Attenuation
Two-Phase Flow
Interior Ballistics
Fluid Dynamics
Breech Blast
Davis Gun

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

A concept for attenuating the back blast field of a recoilless rifle by the ejection of liquid or solid particles was investigated with respect to feasibility. The concept involves attaching a cylinder partially filled with liquid or solid particles to the nozzle. In this way the propellant gas is forced to expend some of its energy in driving the particles out of the cylinder and the duration of the flow of propellant gas into the blast field is altered.

SEE REVERSE SIDE

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ABSTRACT (Continued)

Block No. 20

The feasibility of the concept was investigated computationally. Computer programs were prepared to solve the gas dynamics of the blast field which included traveling particles. Computational procedures were used that are analogous to current single phase gas dynamics methods, but which are also based on the conservation relations for mass, momentum and energy in multiphase systems. The velocity and temperature of the gas and particles are allowed to be different in this computational procedure.

The results of the investigation, are that attenuation of the blast field is possible if the attached cylinder is long and the total weight of the expelled particles approaches the weight of the projectile. For shorter cylinders and smaller weights of particles, the blast field is not attenuated. Thus, the blast attenuation concept studied is feasible only in a rifle which is encumbered with an attachment which is so heavy the rifle is no longer a practical weapon.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

WVT-CR-74026

AD

CONCEPT FOR ATTENUATION OF THE BACK BLAST REGION OF A 105 MM RECOILLESS RIFLE

PREPARED BY

HUGO J. NIELSEN
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

PREPARED FOR

U.S. ARMY ARMAMENT COMMAND

BENET WEAPONS LABORATORY
WATERVLIET ARSENAL
WATERVLIET, N.Y. 12189

JULY 1974

TECHNICAL REPORT

AMCMS No. 513F.12.0?014.02

DA Project No. 1F163206D050

Pron No. EJ-2-50139-(01)-M7-M7

Contract No. DAAF07-73-C-0155

APPROVED FOR PUBLIC RELEASE. DISTRIBUTION UNLIMITED

FOREWORD

This is the final report on Contract DAAF07-73-C-0155 for Watervliet Arsenal, IIT Research Institute Project J6293. Charles C. Andrade was project monitor. A significant contribution to the effort described in this report was made by Arnold Wiedermann in the area of mechanisms that would influence the blast field and assistance in the programing effort.

Respectfully submitted,
IIT Research Institute

Hugo J. Nielsen
Senior Research Engineer
Safety Research

Approved by

K. E. McKee
Director or Research
Engineering Mechanics Division

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The army is currently investigating methods for arming helicopters with weapons of greater firepower. A major difficulty stems from the relatively weak helicopter structure which cannot sustain the recoil of most large caliber weapons. Although recoilless rifles obviate one problem, the blast field created by propellant gases discharged through the rifle nozzle creates other problems. Damaging peak overpressures of several pounds per square inch would be produced on some parts of the helicopter fuselage.

Constraints which arise from considerations of loading, firing, etc., prevent mounting the rifle so that the blast field does not affect the helicopter's structure. Moreover, severe weight penalties are involved in shielding the fuselage or employing ducts to carry away the nozzle blast gases. The net effect of these constraints is to make the feasibility of arming helicopters with recoilless rifles depend on finding a means for attenuating the intensity of the blast field.

A particular concept for attenuating the blast field was investigated. The concept involves attaching a short cylinder filled with water or solid particles to the rifle nozzle to delay the emergence of propellant gas. The flowing propellant gas would be slowed by driving the particles* out of the cylinder, thereby reducing the blast pressure, if the expelled liquid or solid does not give up its acquired momentum to the atmosphere too rapidly after it emerges from the cylinder.

The approach taken in this investigation is to develop a computational method and program for describing the blast field produced by the particles expelled from the cylinder. This is accomplished by extending the numerical methods presently used for solving unsteady compressible single component flows to a multiphase flow where the velocity and temperature of the particles can be different from that of the gas in which they are suspended.

*The word "particles" as used herein refers to solid or liquid particles.

2. BLAST ATTENUATION

a. Basic Mechanism

The blast field behind a recoilless rifle depends mainly upon two factors, the total energy of the propellant gas flowing through the nozzle and the duration of the flow. Since the comparative importance of these factors varies with the distance from the nozzle, it is desirable to have an assessment of the distances in which one or the other has a predominant influence.

The distribution of pressure, density, energy or velocity in the blast field can be regarded as a system of traveling waves in which the local wave speed is the speed of sound. As the propellant gas flows into the blast field and raises the temperature by the effect of compression or by the convection of gases of higher temperature, the wave speed increases. A consequence of this is that a profile of pressure versus time that formerly rose gradually to the peak pressure in the vicinity of the nozzle, changes so that it rises more rapidly at greater distances. As one considers increasing distances from the nozzle the pressure profile eventually steepens to form a shock wave. The process takes place as illustrated in Figs. 1a and 1b. For distances large enough for the profile to steepen up to a shock wave the pressure is independent of the duration of the nozzle flow and only depends on the total energy of the gas and the distance from the nozzle. If the shock pressure were still strong compared to the ambient pressure at these distances it would approach the Taylor's result for a point source explosion (Ref. 1),

$$p \propto E_t/R^3 \tag{1}$$

1. Taylor, G., "The Formation of a Blast Wave by a Very Intense Explosion," Vol. 201.

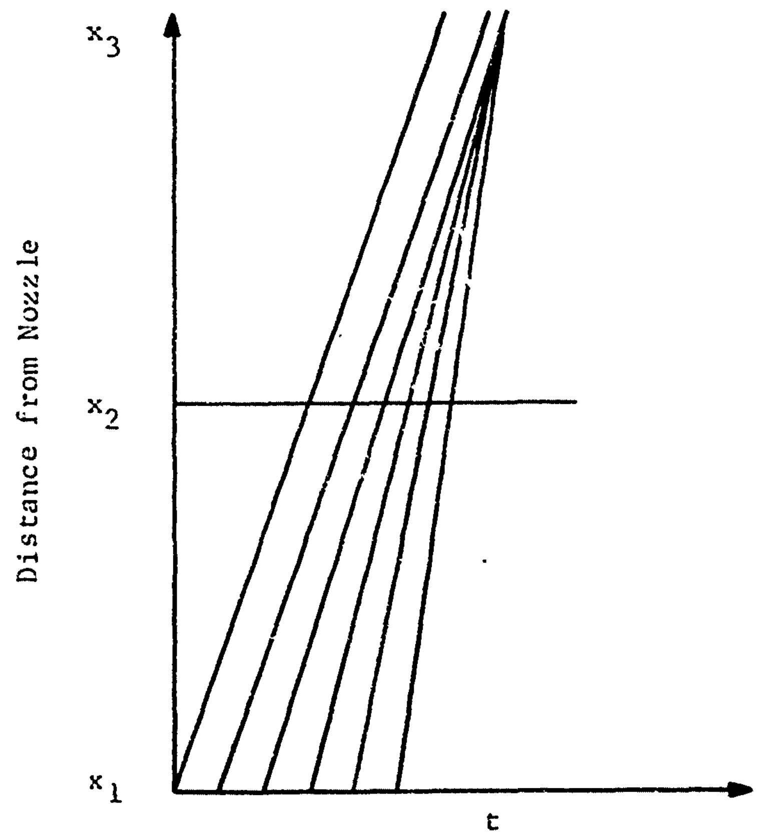


Figure 1a. DISTANCE OF WAVE PROPAGATION

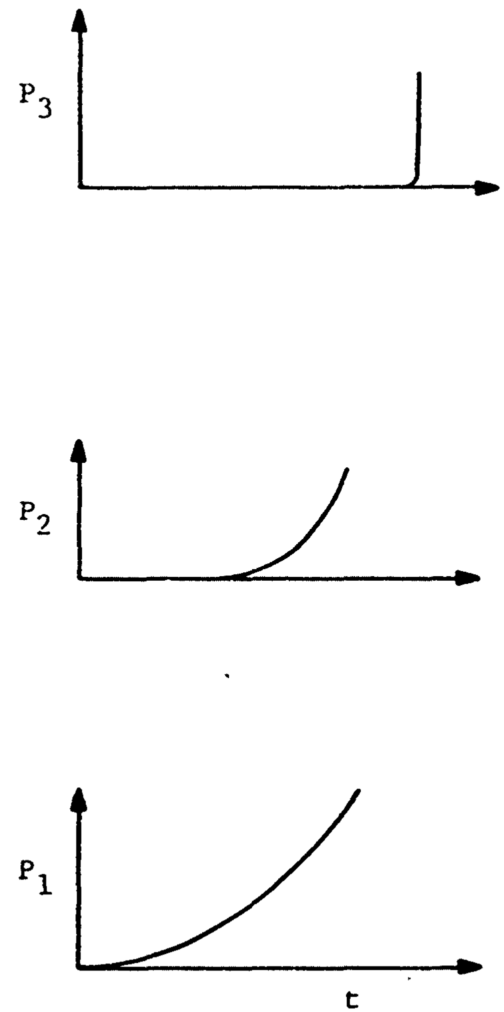


Figure 1b. PRESSURE PROFILE AT VARIOUS DISTANCES FROM NOZZLE

where

E_t = total energy released by explosion or in propellant gases

p = pressure

R = realistic distance from source

Although Taylor's result may not be useful for a quantitative estimate of the blast pressure in the problem of concern, the indicated linear dependence of the pressure on the total gas energy is probably a good guide.

These preliminary considerations of the propagation of the blast wave show that for positions in the blast field beyond the distance where a shock wave forms, the only means for attenuating blast intensity is to reduce the total energy in the propellant gas. At lesser distances, nozzle flow duration is a factor and prolonging it would result in reduced peak pressure. An approximation of the distance required for the formation of the shock wave can be made as follows. The temperature of the propellant gas increases the speed of sound two to three times over that which exists in ambient air. The peak chamber pressure is reached about 6 msec after ignition. Equating the travel distances for waves emitted at the initial and peak pressure conditions and assuming that the waves at the peak condition travel at a speed three times greater than the others, yields a distance of 10 ft.

The area of interest on the helicopter extends from about 3 to 10 ft from the fuselage. For much of this area it is apparent that both of the factors discussed will influence the blast pressure, but at the extremity the peak pressure is determined by the total energy in the propellant gases.

b. Approaches for Implementing the Blast Attenuating Mechanism

Two recoilless rifle configurations were considered in which particles are expelled. Each epitomizes a different blast attenuation mechanism: (1) reduction of total energy, and (2) prolongation of flow duration.

(1) Davis Gas

A rifle based on this principle would consist of a straight tube in which particles are expelled from one end and the projectile from the other. Since the momentum of the particles must equal that of the projectile to fulfill the requirements for cancellation of recoil, the tube length required is large unless the weight of the particles is much larger than that of the projectile. For particles of weight equal to the projectile, the tube length would be twice that of a conventional rifle and, therefore, impractical. The blast pressure is reduced because the gas does not escape from the rifle freely until the particles are expelled from the tube. An estimate of the energy removed from the propellant gas by accelerating the projectile and particles may be obtained by assuming that the expansion is isentropic,

$$\frac{e_2}{e_1} = (\text{volume ratio})^{\nu-1} = 0.66 \quad (2)$$

where

e_1 = initial internal energy

e_2 = internal energy when propellant gas emerges

ν = ratio of specific heat, 1.21 for propellant gas volume ratio = 1/7, chamber-to-chamber plus barrel volume

About one-third of the energy in the propellant gas is removed and the approximate effect on the blast field is proportional to the value given for the ratio of the emergent to the initial internal energy.

This concept provides a means for reducing the blast intensity and shows that it is feasible to attenuate the blast pressure by expelling particles. The question remaining is, do the expelled particles release their acquired momentum to the air after exiting? If the particles remain as a coherent mass, they would not; if they expand rapidly, the drag forces acting on the particles would cause them to transmit their momentum to the air again and produce a blast field. This problem is dealt with by means of the two-dimensional blast field code discussed in the following section. A listing of one- and two-dimensional codes is provided in Appendices A and B.

(2) Short Cylinder Concept

This concept was developed in an attempt to achieve blast attenuation without the excessive length of the Davis gun. The cylinder from which particles are expelled is shorter and a nozzle is used between the cylinder and rifle chamber to permit the chamber pressure to build up properly. With the shorter cylinder, the amount of energy that can be removed from the propellant gas is less than with the Davis Gas concept. To have a significant reduction in the intensity of the blast field, the effect of flow duration has to be exploited. In this study, the particles are not compacted and the propellent gas is permitted to leak through void spaces, thus prolonging the flow period. Since the particles are not attached to the cylinder and do not transmit an axial load to it, the recoilless properties of the rifle are not affected significantly by the cylinder.

3. MATHEMATICAL MODELING

The physical problem to be modeled involves the motion of liquid droplets or solid particles through a gas in which strong compressible effects take place that include the formation of shock waves. Because the temperature and velocity of the particles are not usually the same as of the gas at the same location, various interactions take place between the gas and the suspended particles. The effects of drag and heat transfer cause momentum and energy to be transferred between the gas and the particles. The motion and temperature of the gas therefore, are different than in an analogous flow case without particles.

A numerical method is developed for the solution of this problem that is patterned after the same techniques used for the numerical solution of single component flows. Conservation relations for the mass, momentum and energy are developed for the gas and particle phases and these relations are then expressed in finite difference form for solution by numerical methods. Approaches to the development of the conservation relations and some solution for particular flow cases are summarized by Soo (Ref. 2) and Marble (Ref. 3).

a. Conservation Relations

The conservation relations are developed for an elemental cell as indicated in Fig. 2. Particle sizes and mean separation distances are assumed to be small relative to the size of the cell. This limits the applicability of the method to problems in which the mean particle separation distance is small relative to the system size and the scale of the phenomena of interest.

(1) Mass Conservation

Equating the accumulation of gas or particles to the net flux of gas or particles into the cell and the contributions due to evaporation and other effects, gives the following expressions for the gaseous and particle phases:

---

2. Soo, S. L., Fluid Dynamics of Multiphase System, Blaudell Publishing Co., (1967).

3. Marble, F. E., "Dynamics of Dusty Gases," Annual Rev. Fluid Mech., Vol. 2, (1970).

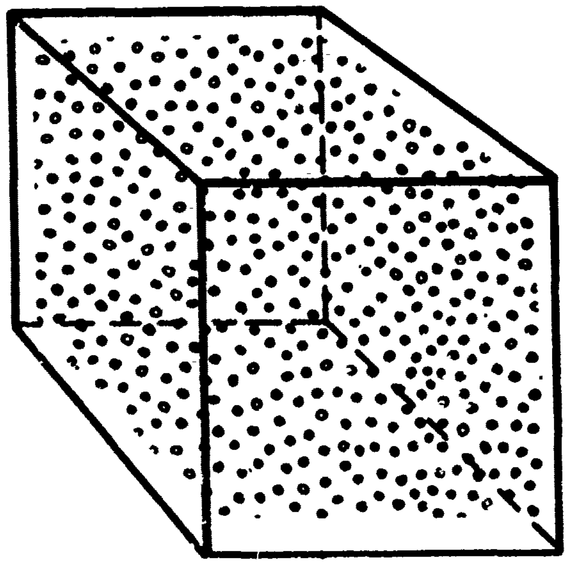


Figure 2 ELEMENTAL CELL

$$\frac{\partial c_g}{\partial t} = - \nabla \cdot \vec{u}_g c_g + N W_e + W_{pb} \tag{3}$$

$$\frac{\partial c_d}{\partial t} = - \nabla \cdot \vec{u}_d c_d - N W_e \tag{4}$$

$$\frac{\partial N}{\partial t} = - \nabla \cdot \vec{u}_d N \tag{5}$$

where

c_g = concentration of gas

c_d = concentration of matter present as particles

N = number of particles per unit volume

t = time

$\vec{u}_d$ = velocity of particles

$\vec{u}_g$ = velocity of gas

W_e = mass loss of a single particle by vaporization

W_{pb} = mass addition by propellant burning

(2) Momentum Conservation

When one considers the motion of a single particle the governing equation is obtained by equating the Lagrangian acceleration to the drag force and the pressure difference across the particle.

$$m \frac{D\vec{u}_d}{Dt} = - \vec{D} - V \nabla p \tag{6}$$

where

$\vec{D}$ = drag force vector

m = mass of the particle

p = pressure

V = volume of the particle

For the purpose of the computational method to be developed, a Eulerian expression (i.e., at a fixed point for the derivative), is required and can be obtained if the number of particles within the cell indicated in Fig. 2 is large enough so that the mean velocity is reasonably well defined and can be assumed to be continuous.

$$m \frac{\partial \vec{u}_d}{\partial t} = - m \vec{u}_d \cdot \nabla \vec{u}_d - \vec{D} - V \nabla p \tag{7}$$

Multiplying through by the number of particles and using Eq. (4) gives the following for the momentum of the particle phase.

$$\frac{\partial c_d \vec{u}_d}{\partial t} = - \nabla \cdot c_d \vec{u}_d ; \vec{u}_d - ND - \frac{c_d}{\rho_d} \nabla \rho \tag{8}$$

where ρ_d is the density of the material of which the particles are composed.

Although the dyadic notation used ($\nabla \cdot cu; u$) is inconvenient, it permits the development of a conservative computational scheme, i.e., one in which the accumulation of momentum in the computational grid is exactly consistent with the fluxes of momentum over the grid boundaries. The alternative and more common expression for acceleration ($\vec{u} \cdot \nabla \vec{u}$), does not permit this.

The momentum equation for the gas phase may be obtained by subtracting the equation for the particle momentum derived here from the equations for total momentum of both the gas and the particles. However, the experience obtained with various different computation procedures with this problem, showed that a more stable program is obtained if the computational procedure is based on the equations for the total momentum of both the gas and particles and the momentum of the particles alone rather than on the equations for the momentum of the gas and particle phases.

Equating the accumulation of the momentum to the fluxes across the cell boundaries and the effects of pressure, gives the following expression for the total momentum of both phases,

$$\frac{\partial}{\partial t} (c_g \vec{u}_g + c_d \vec{u}_d) = - \nabla\cdot(c_g \vec{u}_g ; \vec{u}_g + c_d \vec{u}_d ; \vec{u}_d) - \nabla p \qquad (9)$$

Terms relating to particle drag do not appear in this equation since they control only the transfer of momentum between the gas and particle phases and thus do not add to or substract from the momentum sum.

(3) Energy Conservation

Considering again a single particle, the following equation is obtained for the temperature by equating the rate of change of stored sensible heat to the losses by convection and evaporative cooling.

$$m\, c_{pd} \frac{DT_d}{Dt} = - (Q_c + Q_e) \qquad (10)$$

where

c_{pd} = specific heat of the particle

Q_c = cooling rate of particle by convection

Q_e = cooling rate of particle by evaporation

An Eulerian representation for the rate of temperature change can be obtained when the number of particles within the cell is large enough to permit a reasonable definition of a mean particle temperature.

$$c_{pd} \frac{\partial c_d T_d}{\partial t} + \nabla\cdot c_d \vec{u}_d T_d = - N(Q_c + Q_e) \qquad (11)$$

An expression for the total energy in both phases is obtained by equating the rate of accumulation of energy to the fluxes and the work done by pressure effects at the cell boundaries.

$$\frac{\partial}{\partial t}\ c_g(e_g + \frac{1}{2}\vec{u}_g\cdot\vec{u}_g) + c_d\ (c_{pd}T_d + \frac{1}{2}\vec{u}_d\cdot\vec{u}_d)$$

$$= - \nabla\cdot\vec{u}_g\ \ c_g(e_g + \frac{1}{2}\vec{u}_g\cdot\vec{u}_g) + VFp$$

$$- \nabla\cdot\vec{u}_d\ \ c_d(cT_d + \frac{1}{2}\vec{u}_d\cdot\vec{u}_d) + (1 - VF)p \qquad (12)$$

where

e_g = internal energy of the gas phase

VF = void fraction

As in the case of the momentum equation, the computation scheme is more stable if the computations are based on the total energy and the energy in the particle stream. The gas phase energy is then obtained by calculating the difference in these quantities rather than by calculating the gas energy from an equation for the energy of the gas phase.

b. Subsidiary Relations

To obtain solutions for the above set of equations, it is necessary to connect the concentration, pressure and density with an equation of state, to evaluate the drag forces and particle heat transfer rates that transfer momentum and energy between the gas and particle phases. A propellant burning law is also required to predict the rate at which mass and energy is added to the propellant gases.

Equation of State

Tabulated values for the thermodynamic properties of the propellant gas from 23 different military propellants are given in Ref. 4. For computational purposes a polynomial representation was used to fit the equation of state data. The following nine term polynomial was fitted by least squares to the data for M8 propellant with a maximum discrepancy of only 0.3 of 1 percent:

4. Baer, P. G. and Bryson, K. R., Tables of Computed Thermodynamics Properties of Military Gun Propellants, BRL Memo. Rept. No. 1338 (Mar. 1961).

$$pR = \sum_{i=1}^{3} \sum_{j=o}^{2} A_{ij} \rho_g^i e_g^j \qquad (13)$$

where

ρ_g = density

e_g = internal energy, including energy of formation as defined for e in Ref. 4

Numerical values for the coefficients A_{ij} are given in Appendix A in the subroutine entitled EQSTAT of the one-dimensional code.

The gas density to be used in this equation of state is determined from the amount of gas existing in a unit volume and the void fraction.

$$VF = 1 - \frac{c_d}{pd} \qquad (14)$$

$$\rho_g = c_g/V \qquad (15)$$

- Drag Forces

Drag forces acting on the drops are calculated from the drag coefficient and the dynamic pressure as follows:

$$D = C_d \frac{\pi}{4} a^2 \rho_g \frac{|\vec{u}_d - \vec{u}_g| \quad (\vec{u}_d - \vec{u}_g)}{2} \qquad (16)$$

where

a = particle diameter

C_d = drag coefficient

ρ_g = gas density

Absolute values of the velocity difference are used in the manner shown to preserve the proper sign and direction of the drag force irrespective of the sign of the velocity difference.

---

4. Baer, P. G. and Bryson, K. R., Tables of Computed Thermodynamics Properties of Military Gun Propellants, BRL Memo. Rept. No. 1338 (Mar. 1961).

Coefficients of drag C_d are obtained from the particle Reynolds number Re as shown, Ref. 5

$$C_d = \frac{24}{Re} \qquad Re < 2.05 \tag{17}$$

$$C_d = \frac{18}{Re} 0.6 \qquad 2.05 < Re < 486 \tag{18}$$

$$C_d = 0.44 \qquad 486 < Re \tag{19}$$

where

$$Re = \frac{\rho_g a \left| \vec{u}_d - \vec{u}_g \right|}{u_g}$$

μ_g = gas viscosity

- Heat Exchange

The rate at which heat is transferred from the gas to the particulate phase is obtained from correlations for the heat transfer coefficient on a single particle (Ref. 6),

$$\frac{ha}{k_g} = 2 + 0.34 \, Re^{0.6} \, P_r^{\;1/3} \tag{20}$$

where

h = heat transfer coefficient

k_g = thermal conductivity of the gas

P_r = Prandtl number of the gas

The heat transfer rate, Q, is given by

$$Q = \pi a^2 \, h(T_g - T_d) \tag{21}$$

---

5. Perry, J. H., Chemical Engineering Handbook, McGraw-Hill Publishing Co. (1950).

6. McAdams, Heat Transmission, McGraw-Hill Publishing Co. (1954).

where

T_g = the gas temperature.

- Propellant Burning Law

The rate at which gas and energy is added to the propellant gas will be computed from surface regression rate of the burning propellant. Watervliet Arsenal provided the following correlation for the propellant to be considered.

$$R = 0.00186\ p^{0.83} \tag{22}$$

where p is the pressure in pounds per square inch and R is the regression rate of the propellant surface in inches per second.

c. Computational Procedure

For the purpose of presenting the numerical method by which solutions to the preceeding equation may be obtained, it is useful to use a more compact notation. Each of the differential Eqs. (3), (4), (5), (8), (9), (11) and (12) can be expressed in the following form.

$$\frac{\partial r\alpha_n}{\partial t} + \frac{\partial r(u\alpha_n + \beta_n)}{\partial r} + r\,\frac{\partial \gamma_n}{\partial r} + \frac{\partial r(w\delta_n + \varepsilon_n)}{\partial z} = r\xi_n \tag{23}$$

where r is the radial distance from the axis and z is the distance along the axis. Each of the variables α to ξ are defined in Table I. The velocity components, u and w, are of the phase considered.

The numerical procedure is based on a finite difference form for each of the equations represented by Eq. 23. Conceptually, the field of interest is divided into descrete cells and the finite difference equations describe the rate of accumulation of mass, number of particles, momentum, energy, etc. in terms of the fluxes of these quantities across the cell boundaries and the other quantities appearing in Eq. 23. In the particular grid system used in this study, velocity is defined at the cell boundaries

Table I DEFINITION OF TERMS IN EQUATION

Conservation of	α	β	ν	δ	ξ
Gas	c_g	o	o	o	$NW_e + W_{pg}$
Particle Mass	c_d	o	o	o	$-NW_e$
Number of Particles	N	o	o	o	o
Radial Momentum of Particles	$c_d u_d$	o	o	o	$-ND_r - \frac{c_d}{\rho_d}\frac{\partial p}{\partial r}$
Radial Momentum of Gas and Particles	$c_g u_g + c_d u_d$	o	p	o	o
Axial Momentum of Particles	$c_d w_d$	o	o	o	$-ND_z - \frac{c_d}{\rho_d}\frac{\partial p}{\partial z}$
Axial Momentum of Gas and Particles	$c_g w_g + c_d w_d$	o	o	p	o
Energy of Particles	$c_{pd}\, c_d\, T_d$	o	o	o	$-N(Q_c + Q_e)$
Energy of Gas and Particles	$c_g(e_g + \frac{1}{2} u_g \cdot u_g) + c_d(c_{pd}T_d + \frac{1}{2} u_d \cdot u_d)$	$VF \cdot p \cdot u_g + (1-VF) \cdot p \cdot u_d$	o	$VF \cdot p \cdot w_g + (1-VF) \cdot p \cdot w_d$	o

and particle number, concentration, pressure energy and temperature are defined at the cell centers as indicated in Fig. 3. The fluxes across the cell boundaries are computed in accordance with the donor cell concept described by Gentry and Martin (Ref. 7). That is, the flux of particles for example, is calculated from the particle density in the cell which donates the particles.

Because velocity, in the computational procedure used here, is defined at the cell boundaries, computations for the momentum of the gas and of the particles are based on special cells displaced one half the distance between the grid lines so that it is centered over the points where the velocity is defined. The momentum, ρu, is thus based on the velocity at the special cell centers and an interpolated value for the density at that point. Similarly, the kinetic energy at the center of the cells where internal energy is defined is based on interpolated values for the kinetic energy.

Our experience with this computational procedure is that spurious negative values for the internal energy and pressure are obtained less frequently than with the more usual procedure in which the velocity is calculated for the same positions as the density and energy.

For the study of the blast field behind the weapon, the method would be implemented in a two-dimensional grid as shown in Fig. 4. The grid spacing increases with distance from the nozzle to accommodate a large region without an excessive number of grid points. Two computer programs were prepared for solving the blast field problem: (1) a one-dimensional program which describes the interior ballistics of the rifle and the flow from the cylinder; (2) a two-dimensional program which uses the flow from the cylinder as input and calculates the blast field.

---

7. Gentry, R. A.; Martin, R. E.; and Daly, B. J., "An Eulerian Differencing Method for Unsteady Compressible Flow Problems," Computational Phys., Vol. 1, pp 87-118 (1966).

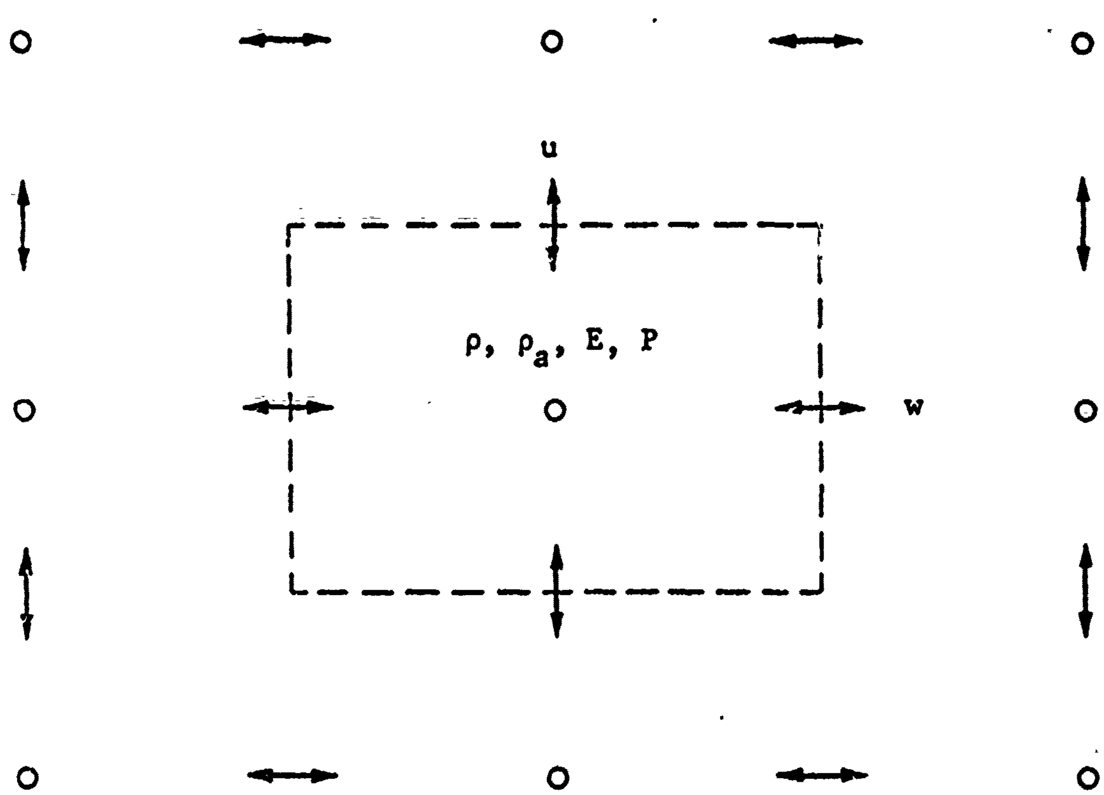


Figure 3 ELEMENT SPATIAL DISTRIBUTION WITH INTERLEAVING OF VELOCITY POINTS BETWEEN POINTS AT WHICH DENSITY, ENERGY, PRESSURE AND COMPOSITION ARE CALCULATED

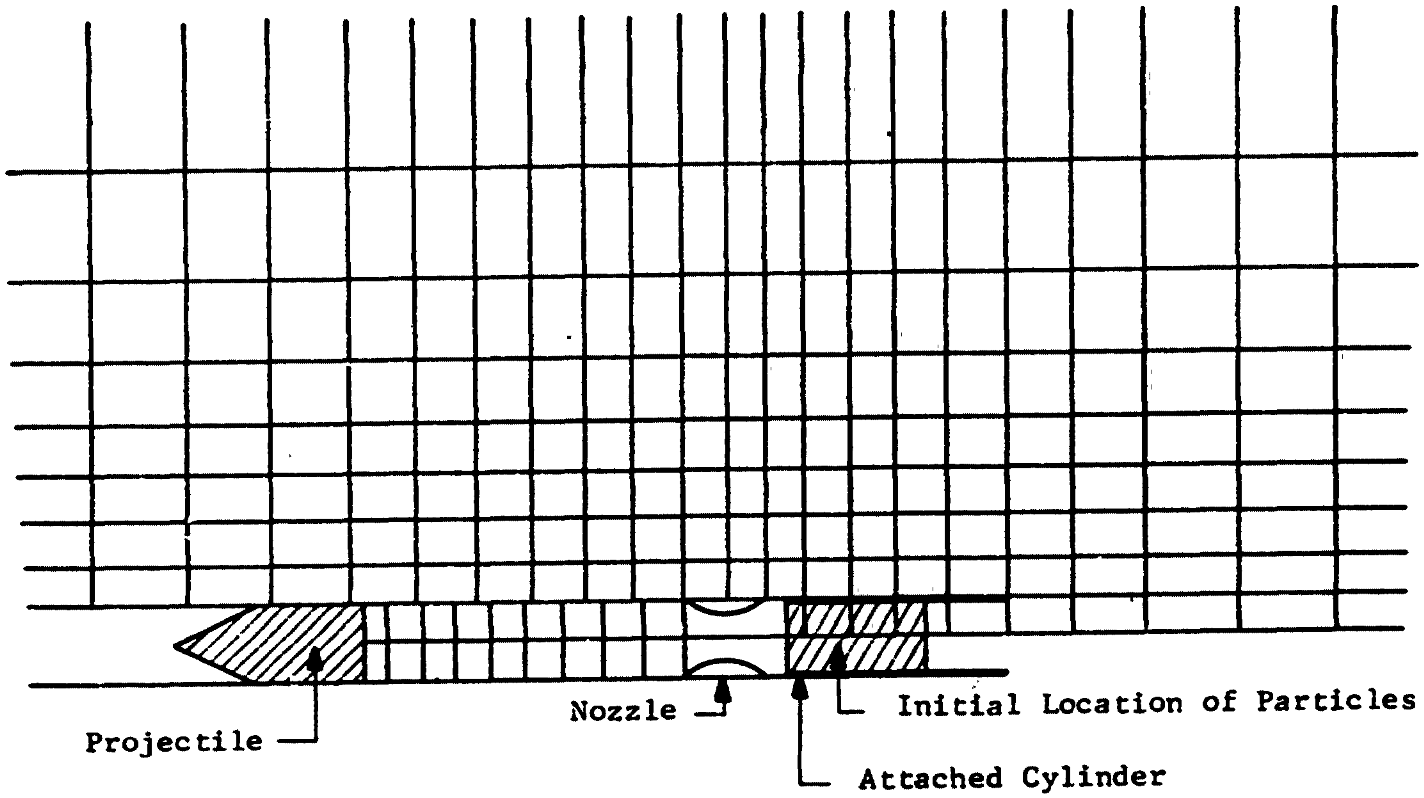


Figure 4 RECOILLESS RIFLE AND DISTRIBUTION OF NODES IN FINITE DIFFERENCE GRID

4. RESULTS

The interior ballistics and nozzle blast field were calculated for the conditions defined by the following values:

charge	8.1 lb
web	0.061 in.
bore	105 mm
barrel length	140 in.
chamber volume	200 in.
cylinder diameter	7.4 in.
cylinder length	24 in.
throat diameter (effective)	3.26 in.

Results for three different conditions in the attached cylinder are presented:

- no water in the cylinder
- 5 lb of water with a drop size of 5 mm
- 5 lb of water with a drop size of 1 mm

Results obtained with the one-dimensional model which furnished the inputs for the two-dimensional model are given in the following figures. Chamber pressures are given in Figs. 5-7.

These were obtained by calculating the average value of the pressures at nodes in the chamber region of the gun. A value of approximately 8000 lb was obtained for the peak chamber pressure in each case. The peak pressure is shown to increase slightly when water is used in the cylinder and when the drop size is diminished. This is due to the resistance to the flow or propellant gas developed by the water drops which diminish the leak rate of the rifle. The abrupt drop in chamber pressure that occurs at about 15 msec, coincides with the burnout of propellant. Values obtained for the projectile travel and velocity while in the barrel are shown in Figs. 8-10.

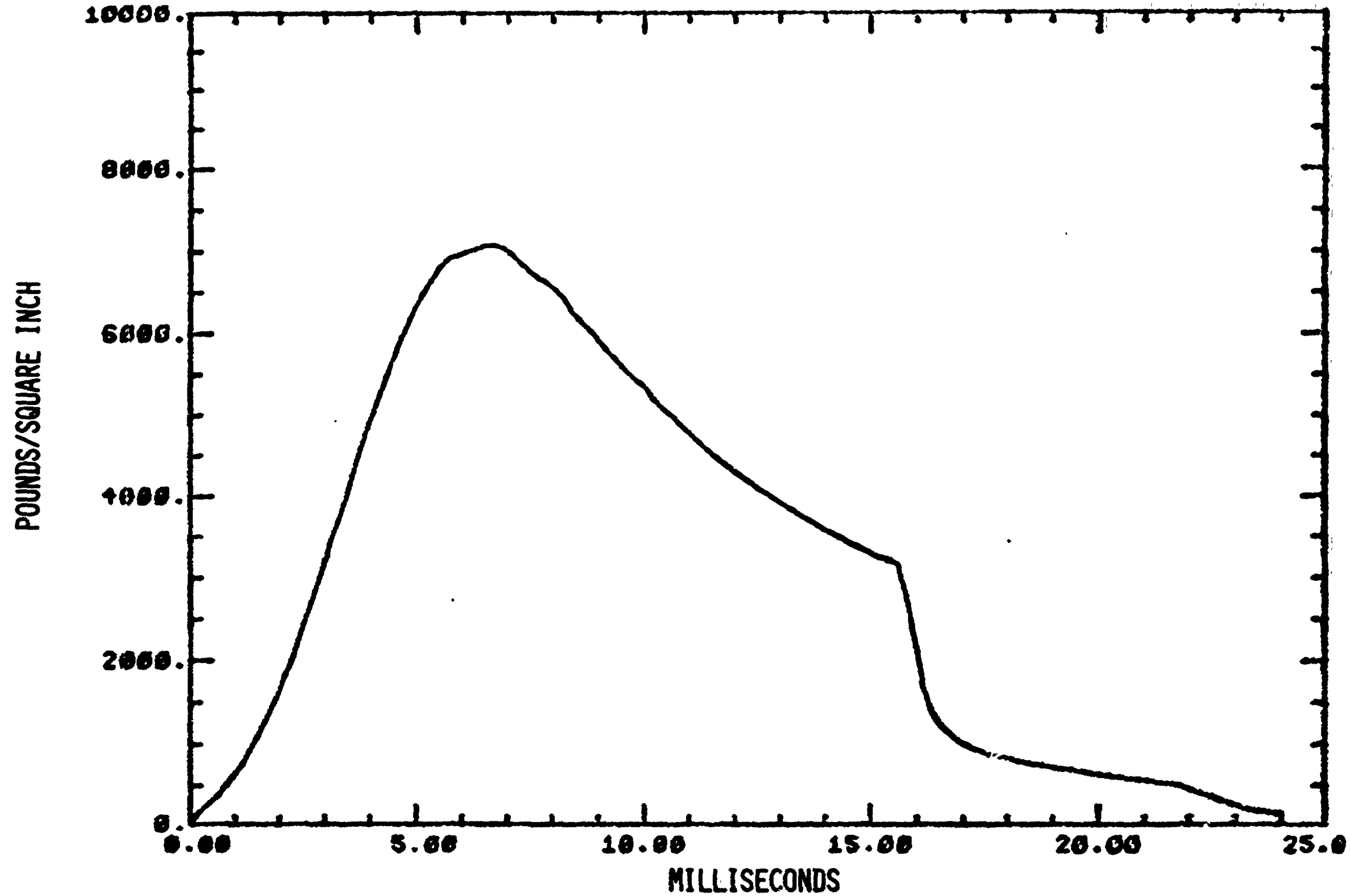


Figure 5 CHAMBER PRESSURE; NO WATER

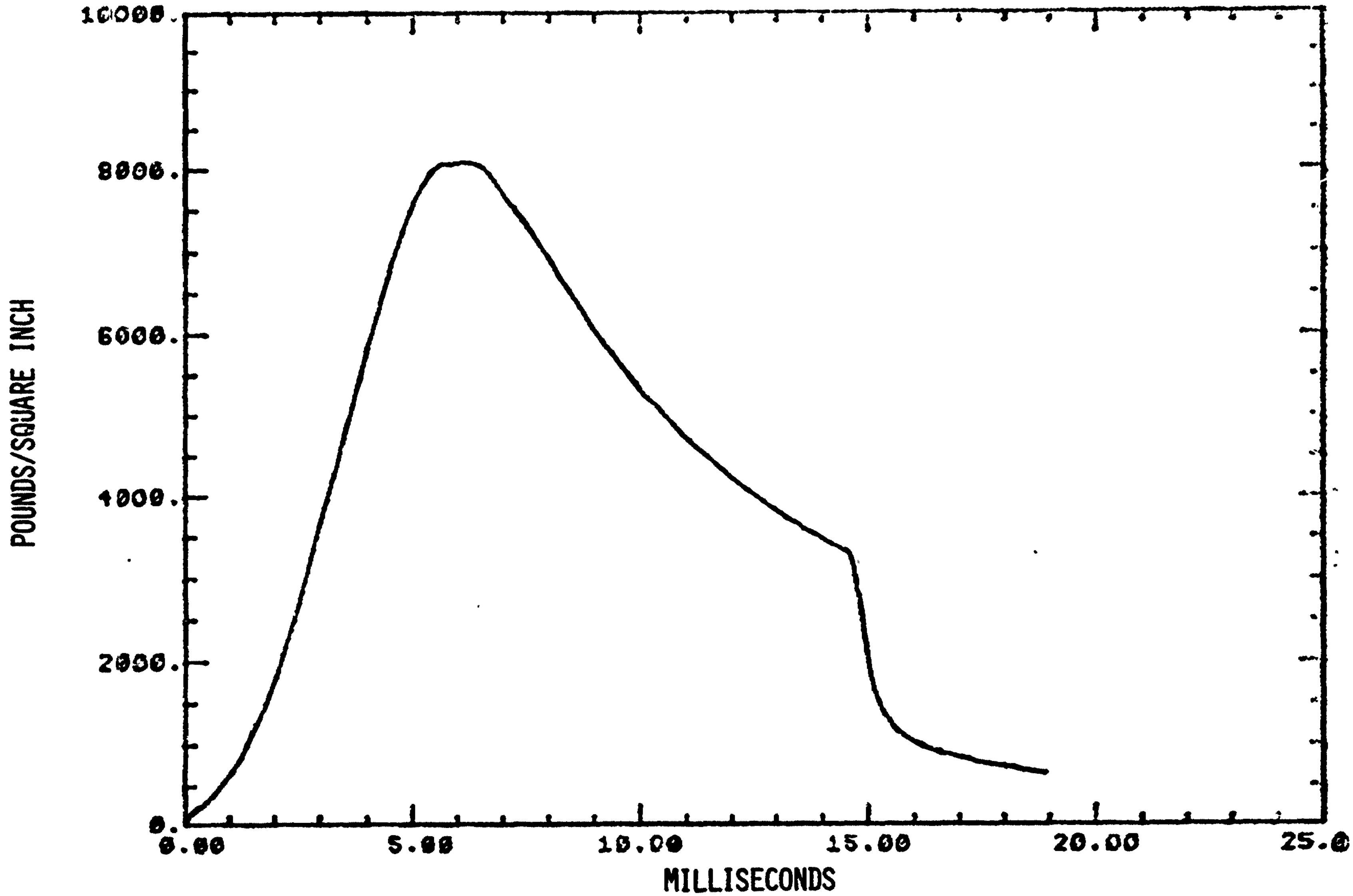


Figure 6 CHAMBER PRESSURE; 5 LB WATER, 5 MM DROP SIZE

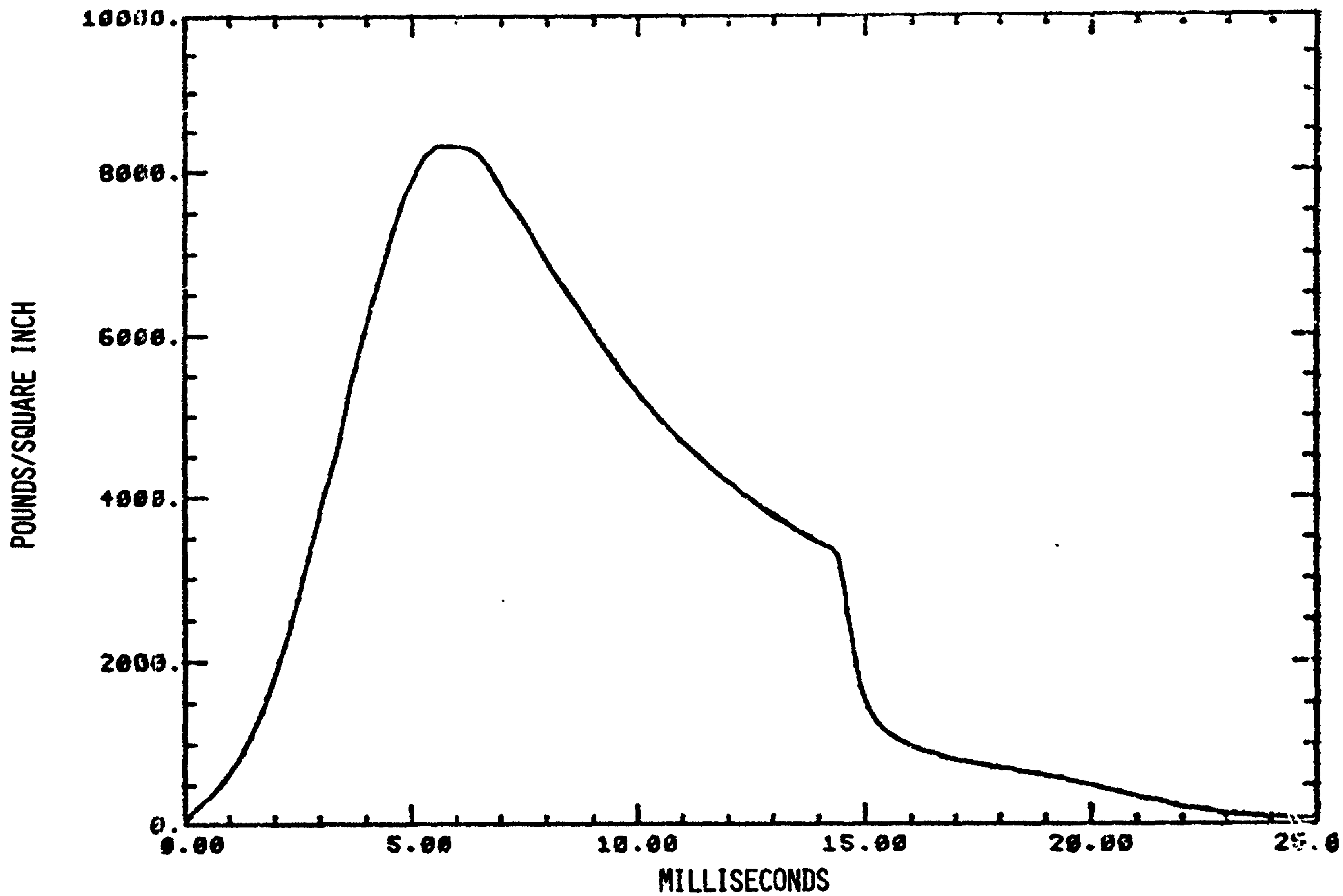


Figure 7 CHAMBER PRESSURE, 5 LB WATER, 1 MM DROP SIZE

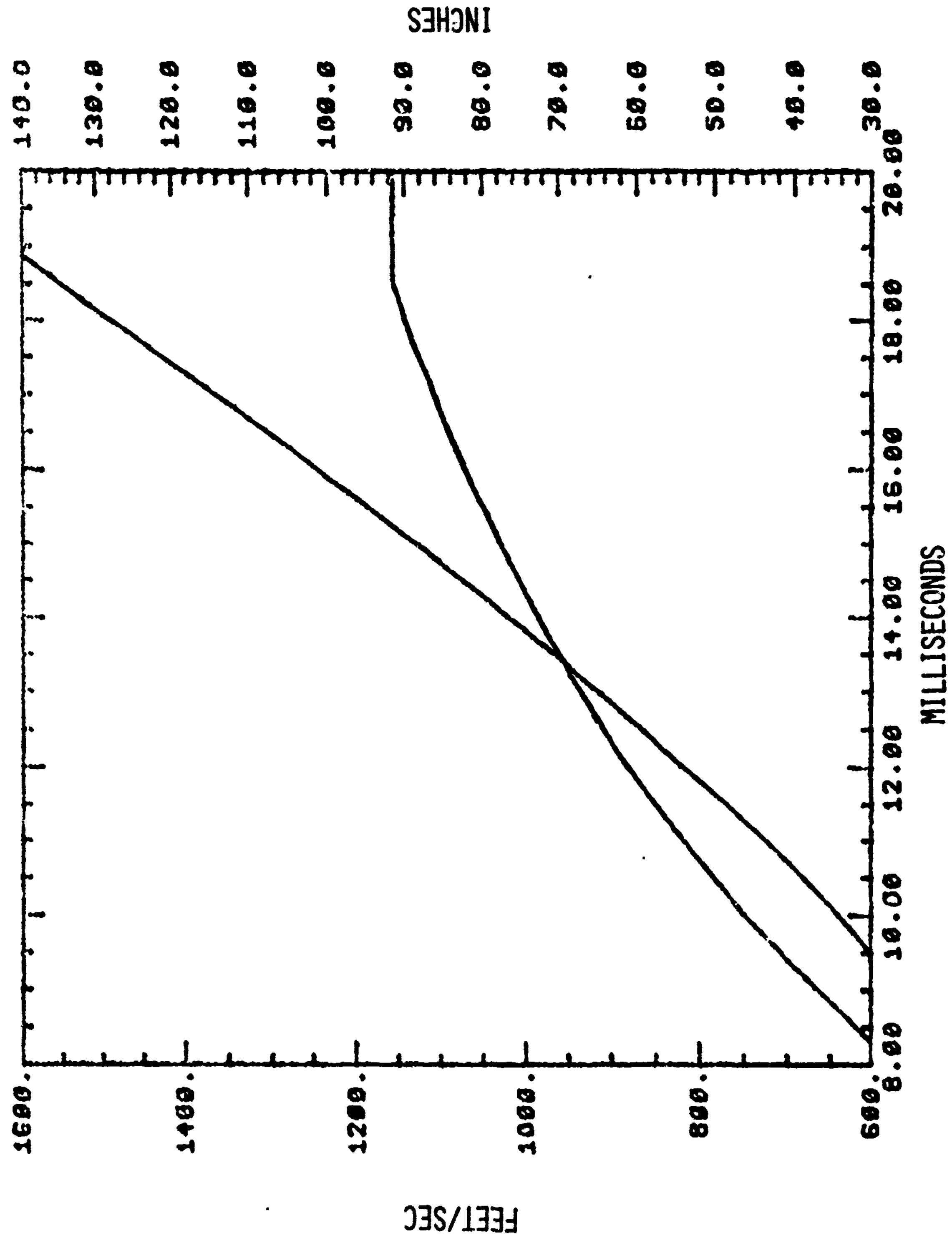


Figure 8 PROJECTILE VELOCITY AND TRAVEL DISTANCE, NO WATER

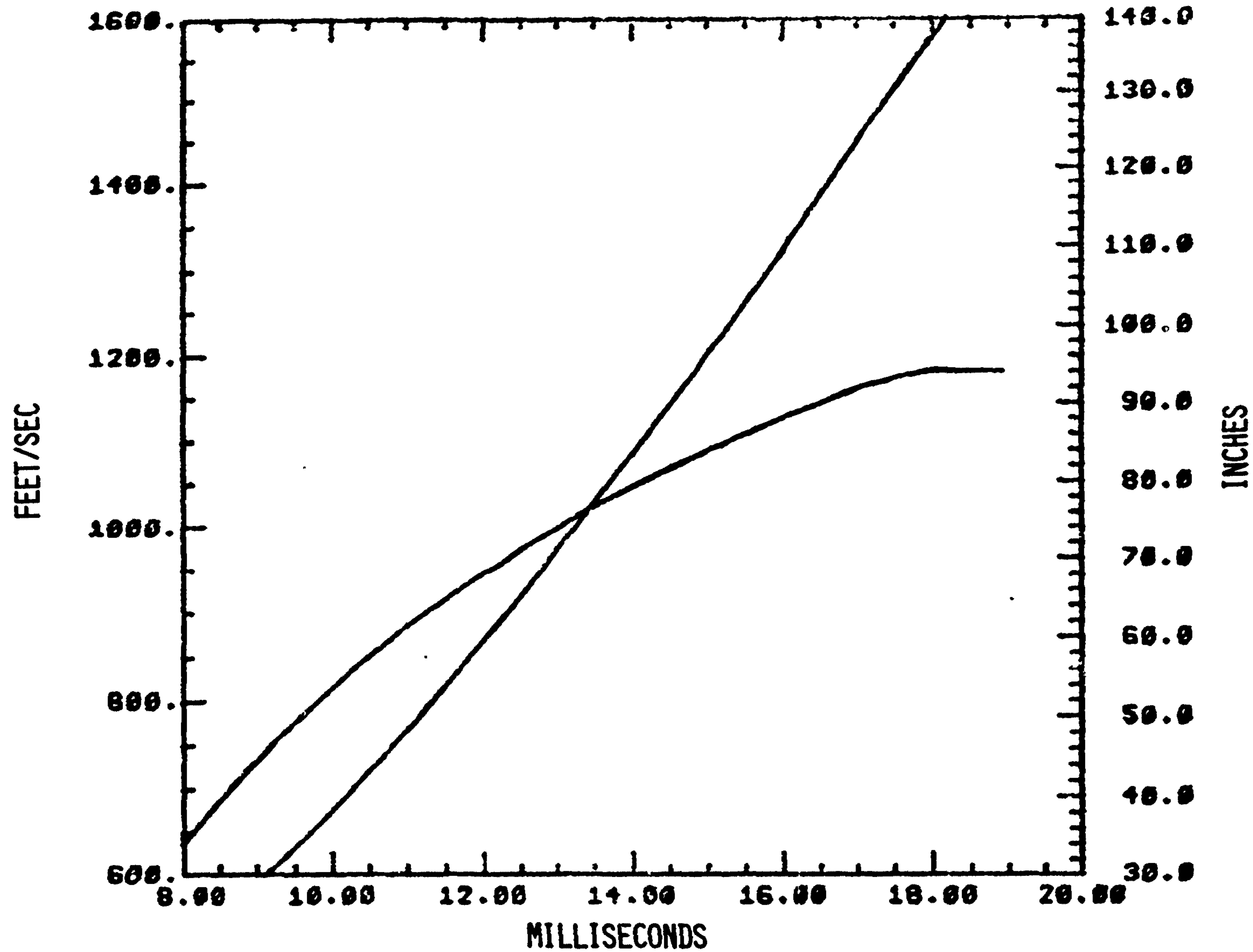


Figure 9 PROJECTILE VELOCITY AND TRAVEL DISTANCE, 5 LB WATER, 5 MM Drop Size

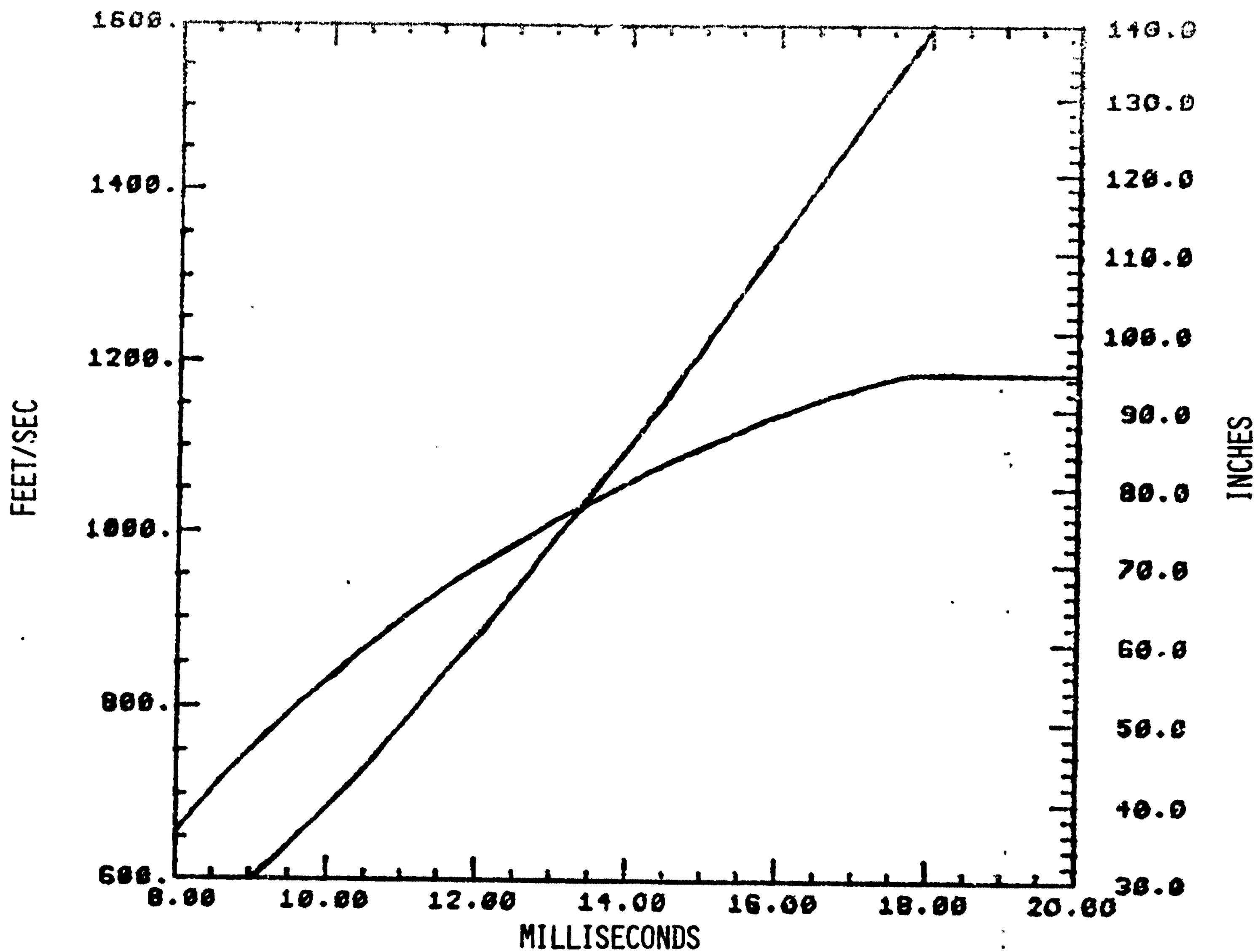


Figure 10 PROJECTILE VELOCITY AND TRAVEL DISTANCE, 5 LB WATER, 1 MM DROP SIZE

The output of the one-dimensional program was used as an input condition for the two-dimensional program. Early time examples of the spatial pressure distribution are shown in Figs. 11-12. The flow out of the attached cylinder is directed to the right and the cylinder exit is located on the horizontal axis in the center of the smallest contour. As one would expect, the pressure profile is elongated in the direction of flow. For the purpose of evaluating the effect on the blast pressure of water in the cylinder attached to the rifle, the pressure was listed for selected points for each case. The location of these points A-F is indicated in Fig. 13, and the pressure pulse profiles in Figs. 14-16. These pressure pulse profiles show that the peak pressure increases as water is added to the cylinder and the drop size is diminished.

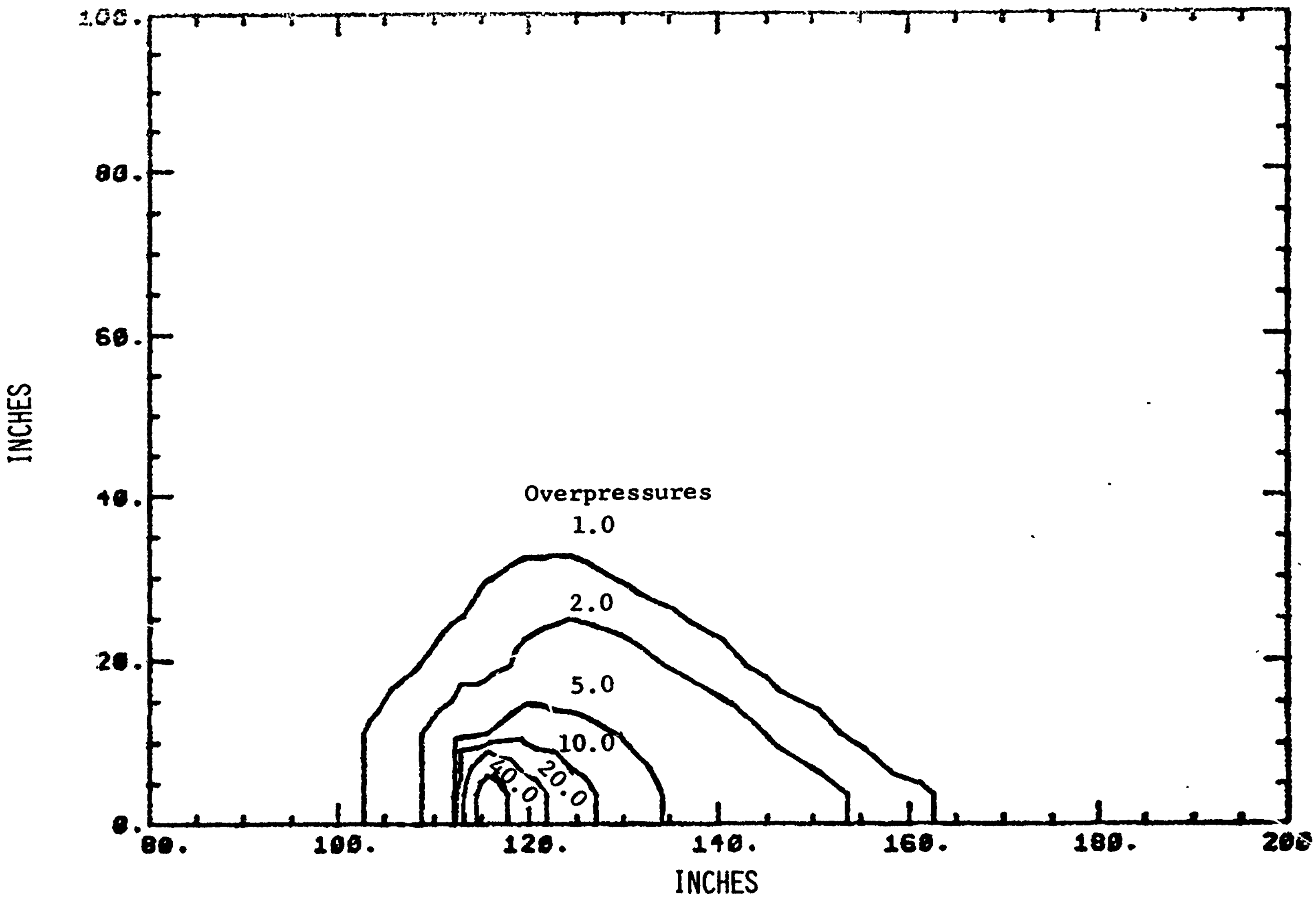


Figure 11 PRESSURE PROFILE CONTOURS, 3.5MSEC AFTER IGNITION, 5 LB WATER 1 MM DROP SIZE

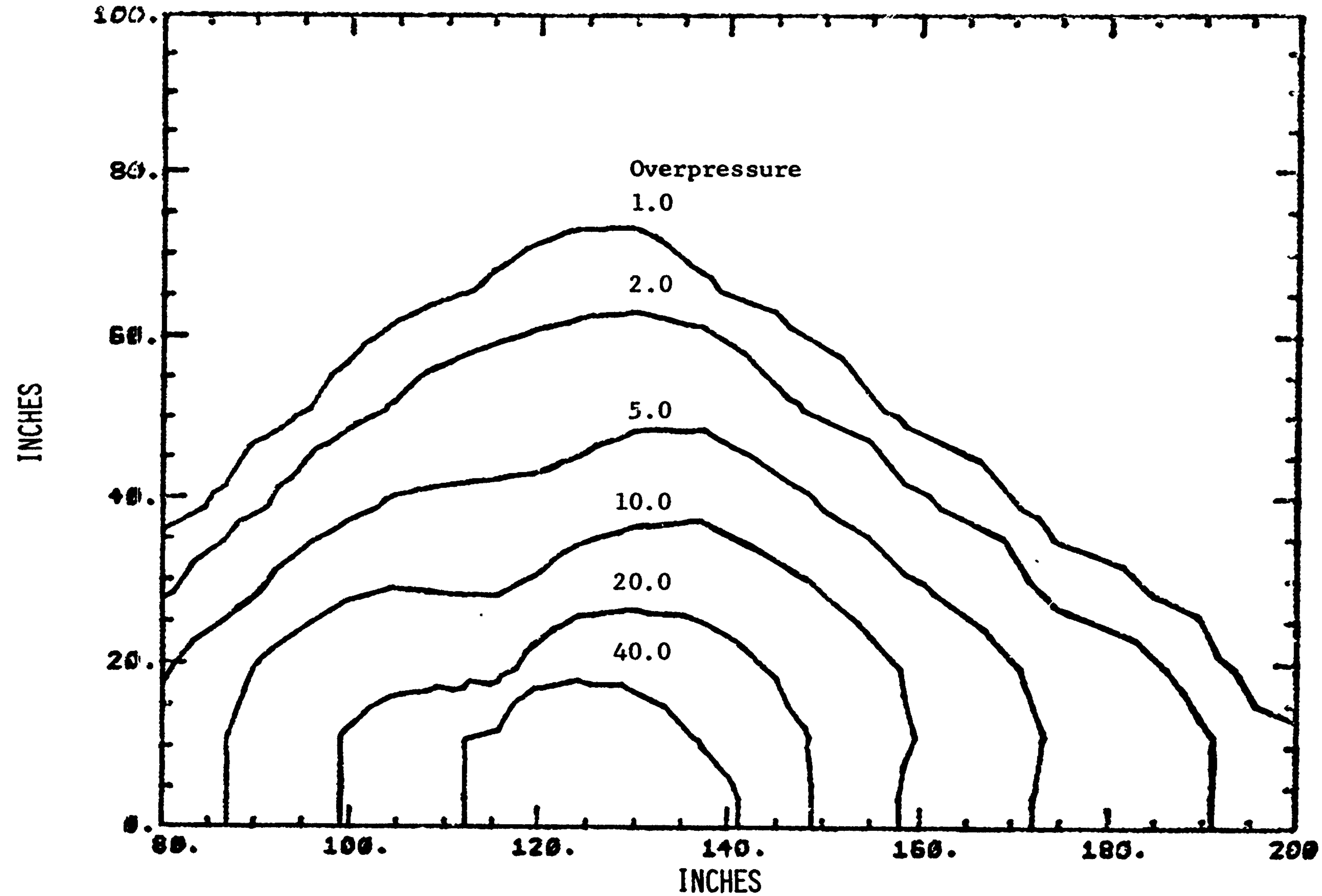


Figure 12 PRESSURE PROFILE CONTOURS, 5.7 MSEC AFTER IGNITION, 5 LB WATER, 1 MM DROP SIZE

Figure 13 LOCATION OF POINTS IN BLAST FIELD FOR WHICH PRESSURE IS PLOTTED AS A FUNCTION OF TIME

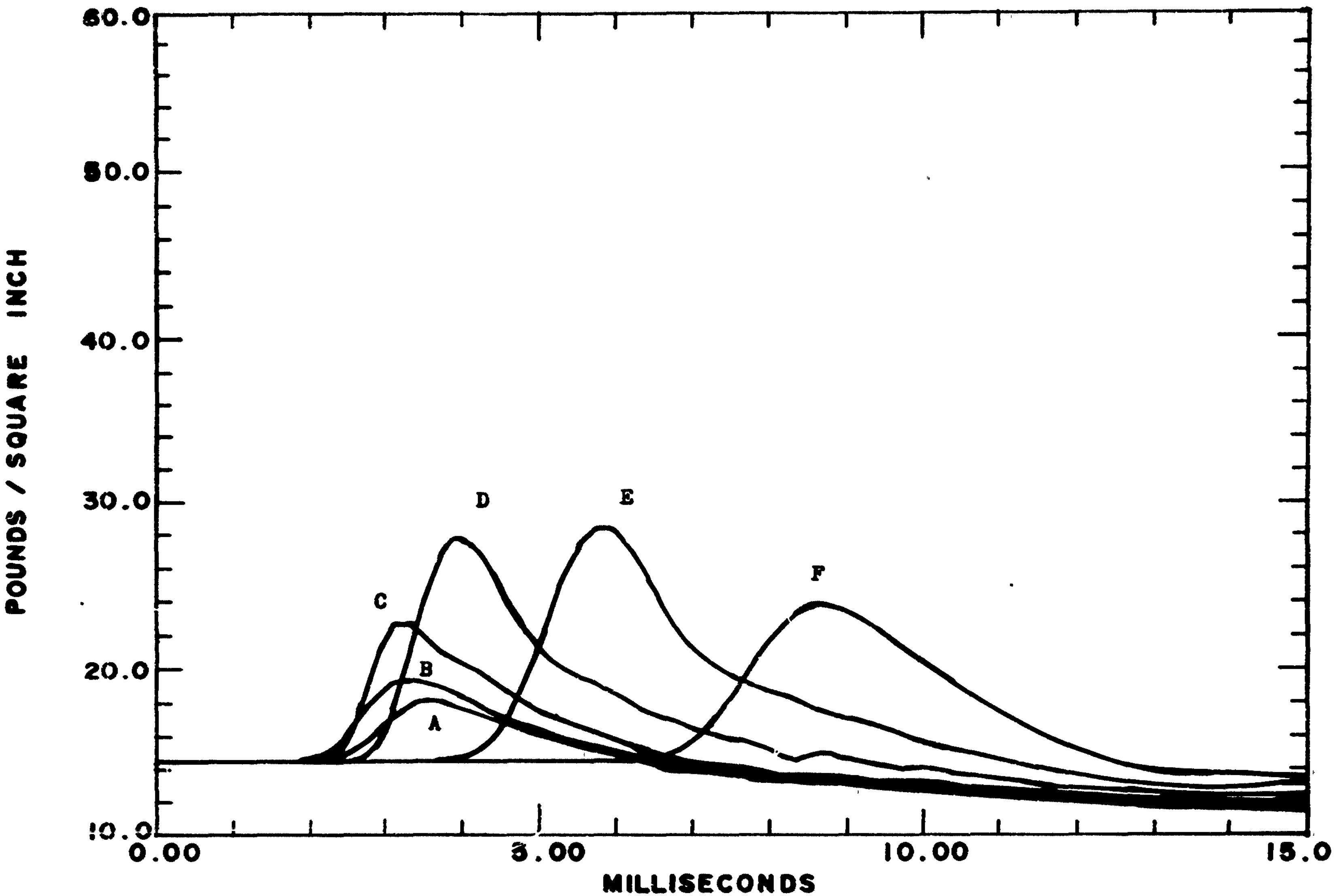


Figure 14 PRESSURE (STATIC PLUS DYNAMIC) VS TIME WITH NO WATER IN THE CYLINDER

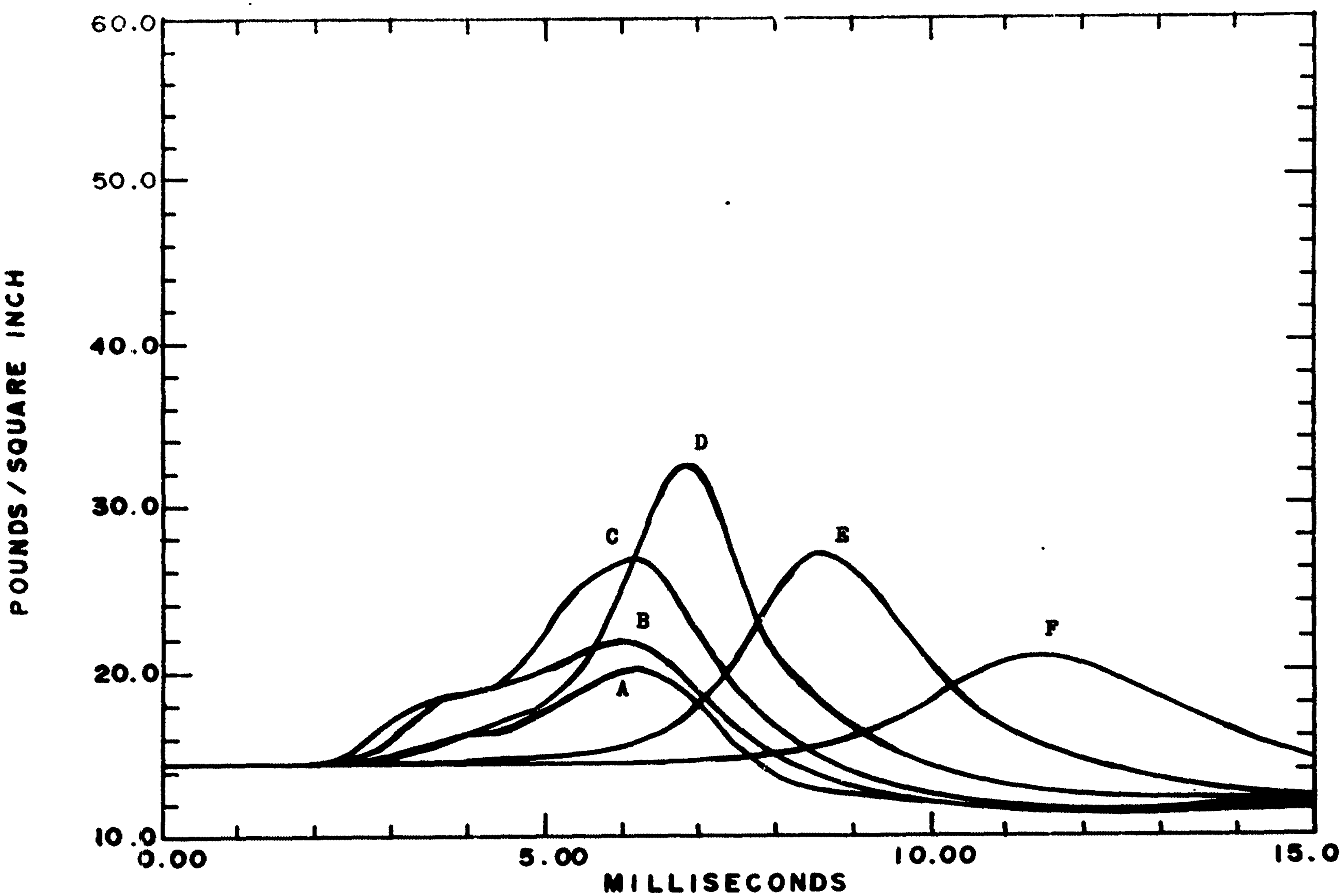


Figure 15 PRESSURE (STATIC PLUS DYNAMIC) VS TIME WITH 5 LB OF WATER IN THE CYLINDER, ASSUMED DROP SIZE - 5 MM

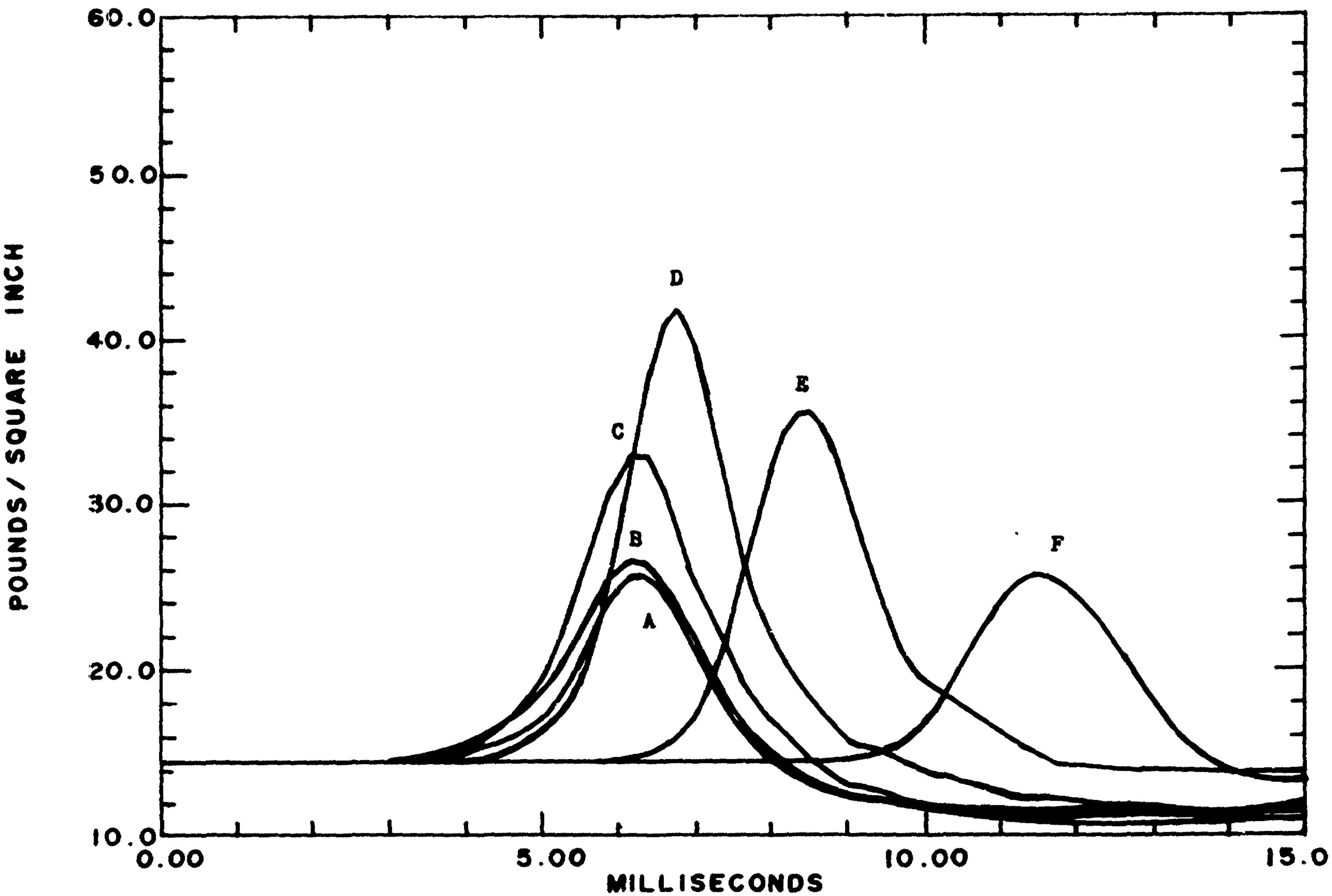


Figure 16 PRESSURE (STATIC PLUS DYNAMIC) VS TIME WITH 5 LB OF WATER IN THE CYLINDER, DROP SIZE, 1 MM

5. SUMMARY OF RESULTS AND CONCLUSIONS

Contrary to the reasons advanced for expecting blast attenuation, the results obtained show that the peak pressure is increased rather than reduced by expelling water. The duration of the pulse is shorter, however, so that the total blast load represented in the pulse may be somewhat reduced. The most probable explanation involves the effect of flow duration and perhaps also the ability of the particles to transfer momentum to the blast field after expulsion from the cylinder.

In the study of the short cylinder concept it was thought that an optimum particle size might exist that would prolong flow duration, thereby reducing the peak blast pressure. It appears, however, that particles of suitable size, on the order of 1 mm, also have a drag-to-weight ratio so large that the momentum absorbed from the propellant gas in the cylinder is given back to the air when the particles emerge. The remaining hope for reducing the blast pressure with a concept involving particle expulsion is to use considerably more water so as to absorb more energy from the propellant gas, or to exploit other phenomena not investigated in this study, such as quenching the gas by the cooling effect of droplet vaporization.

REFERENCES

1. Taylor, G., "The Formation of a Blast Wave by a Very Intense Explosion," Vol. 201.

2. Soo, S. L., Fluid Dynamics of Multiphase System, Blaudell Publishing Co., (1967).

3. Marble, F. E., "Dynamics of Dusty Gases," Annual Rev. Fluid Mech., Vol. 2, (1970).

4. Baer, P. G. and Bryson, K. R., Tables of Computed Thermodynamics Properties of Military Gun Propellants, BRL Memo. Rept. No. 1338 (Mar. 1961).

5. Perry, J. H., Chemical Engineering Handbook, McGraw-Hill Publishing Co. (1950).

6. McAdams, Heat Transmission, McGraw-Hill Publishing Co. (1954).

7. Gentry, R. A.; Martin, R. E.; and Daly, B. J., "An Eulerian Differencing Method for Unsteady Compressible Flow Problems," Computational Phys., Vol. 1, pp 87-118 (1966).

APPENDIX A

ONE-DIMENSIONAL GAS PARTICLE FLOW

ONE DIMENSIONAL GAS PARTICLE FLOW

```
C       IM = MAXIMUM AXIAL NODE
C       KW = OUTPUT FREQUENCY
C       KP = PLOT FREQUENCY
C       KM = NUMBER OF RUNGE KUTTA STEPS TO BE EXECUTED ON THIS RUN
C       KST = 1 START WITH CONDITIONS AT INSTANT OF IGNITION
C       KST = 2 CONTINUE INTEGRATION WITH CONDITIONS ON A FILE PRODUCED
C             DURING A PREVIOUS RUN
C       KKST RUNGE KUTTA STEP ON FILE USED FOR STARTING CONDITIONS
C       KSMS = 1 PARTICLE SLIP ACCOUNTED FOR
C       KSMS = 2 NO SLIP IS ASSUMED
C       KSMH = 1 TEMPERATURE DIFFERENCE BETWEEN GAS AND PARTICLES IS
C                ASSUMED TO EXIST AND HEAT TRANSFER IS CALCULATED,
C       KSMH = 2 GAS AND PARTICLES HAVE THE SAME TEMPERATURE9
C       KSMM = 1 PARTICLES EVAPORATE9
C       KSMM = 2 PARTICLES DO NOT EVAPCRATE,
C       FL = ARTIFIAL VISCOSITY COEFICIENT
C       ER ALLOWABLE ERROR LIMIT IN RUNGE KUTTA INTEGRATION
C       RHOP = DENSITY OF PARTICULATE PHASE
C       VISCG = VISCOSITY OF GAS
C       VFMIN  = VALUE OF MINIMUM VOID FRACTION WHICH IF EXCEEDED
C       ACTUATES ARTIFICIAL PRESSURE IN PARTICULATE PHASE
C       PDF = FACTOR FOR ARTIFICIAL PRESSURE IN DISPERSED PHASE
C       FJ = MECHANICAL EQUIVALENT OF HEAT
C       CMAX = MAXIMUM ALLOWABLE VALUE FOR TIME STEP LIMITING COEFFICIENTS
C       PD(I)   = ARTIFICIAL PRESSURE IN MOMENTUM EQUATION FOR
C                 PARTICULATE PHASE
C       Q(I) =ARTIFICIAL VISCOSITY
C       Y(1)= UNBURNT PROPELLANT  POUNDS
C       Y(2)= PROJECTILE VELOCITY  FT/SEC
C       Y(3)=            TRAVEL    INCHES
C       Y(4)= IMPULSE    POUNDS X SEC
C       Y(5)= IMPULSE X TIME  POUND X SEC XX 2
C       FILES                                  FREQUENCY
C        8      FVST                            EVERY 5
C        9      RESTART                         KW
C       11      FEXM                            EVERY 5
C       10      FVSZ                            KW
        PARAMETER NDC=200
        PARAMETER NRKD=1830
```

```
      DIMENSION Y(NRKD),DY(NRKD),AE(NRKD),RE(NRKD),AEF(7)
      COMMON / NRKC/ NRK
      COMMON /ALL/ IM,KW,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKD,
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBB,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),
     3 FL,RHOP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,
     4 WIDTH,CPP,BL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PB,
     5 F(NDC,7),CS(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),
     7 PR(NDC),DP(NDC),DG(NDC),DF(NDC,7),G(NDC,7),Q(NDC),Z(NDC),ZB(NDC)
     8 ,TGA(NDC),QCA(NDC),QEA(NDC),VFA(NDC),FMV(NDC)
      COMMON / MO / KSWS,KSWH,KSWM
      COMMON /WC/ NZW,ZW(7),ZWC(7),IZW(7),PW(7),IEX
    1 CONTINUE
      READ (5,101) IM,KW,KP,KM,KST,KKST,KSWS,KSWH,KSWM
  101 FORMAT (8I10/I10)
      WRITE (6,102) IM,KW,KP,KM,KST,KKST,KSWS,KSWH,KSWM
  102 FORMAT (1H1,4X,2HIM      ,1H=,I5,
     2             5X,2HKW      ,1H=,I5,
```

```
    3            5X,2HKP       ,1H=,I6,                                          MAIN0580
    4            5X,2HKM       ,1H=,I6,                                          MAIN0590
    5            5X,3HKST      ,1H=,I6,                                          MAIN0600
    6            5X,4HKKST     ,1H=,I6,                                          MAIN0610
    7            5X,4HKSWS     ,1H=,I6/                                          MAIN0620
    8            5X,4HKSWH     ,1H=,I6,                                          MAIN0630
    9            5X,4HKSWM     ,1H=,I6)                                          MAIN0640
      IF (IM) 10,4,10                                                            MAIN0650
    4 STOP                                                                       MAIN0660
   10 CONTINUE                                                                   MAIN0670
      READ (5,110) IR,ZR,ZMAX,ZPL1,ZPL2                                          MAIN0680
  110 FORMAT (I10,4F10.5)                                                        MAIN0690
      READ (5,103) DPO,FL,ER,RHOP,CPP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,           MAIN0700
    2 PV3                                                                        MAIN0710
  103 FORMAT (7F10.5,E10.5 / 5F10.5)                                             MAIN0720
      WRITE (6,104) DPO,FL,ER,RHOP,CPP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,          MAIN0730
    2 PV3                                                                        MAIN0740
  104 FORMAT (1H0,8X,3HDPO       ,1H=,1PE14.6, 3H MM                     ,       MAIN0750
    2            9X,2HFL       ,1H=,  E14.6, 1H                      ,           MAIN0760
    3            9X,2HER       ,1H=,  E14.6, 1H                      /           MAIN0770
    4            9X,4HRHOP     ,1H=,  E14.6, 9H GRAMS/CC             ,           MAIN0780
    5            9X,3HCPP      ,1H=,  E14.6,15H CAL/GRAM DEG C       ,           MAIN0790
    6            9X,5HVISCG    ,1H=,  E14.6,13H GRAMS/CM SEC         /           MAIN0800
    7            9X,5HVFMIN    ,1H=,  E14.6, 1H                      ,           MAIN0810
    8            9X,3HPDF      ,1H=,  E14.6,12H DYNES/CM**2          ,           MAIN0820
    9            9X,2HFJ       ,1H=,  E14.6, 9H ERGS/CAL             /           MAIN0830
    A            9X,4HCMAX     ,1H=,  E14.6, 1H                      ,           MAIN0840
    B            9X,3HPV1      ,1H=,  E14.6, 1H                      ,           MAIN0850
    C            9X,3HPV2      ,1H=,  E14.6,12H DEGREES K-1          /           MAIN0860
    D            9X,3HPV3      ,1H=,  E14.6,10H DEGREES K            )           MAIN0870
      READ (5,105) CHARG,PROJW,WH2O,WIDTH,BL,BORE,VCHAMB,CNA1,CNA2,              MAIN0880
    2 RN,DTH,DEXC,ENL,GNWT                                                       MAIN0890
  105 FORMAT (8F10.5  / 6F10.5)                                                  MAIN0900
      WRITE (6,106) CHARG,PROJW,WH2O,WIDTH,BL,BORE,VCHAMB,CNA1,CNA2,             MAIN0910
    2 RN,DTH,DEXC,ENL,GNWT                                                       MAIN0920
  106 FORMAT (1H0, 9X,6HCHARGE ,1H=,1PE14.6, 7H POUNDS                  ,        MAIN0930
    2           ,10X,5HPROJW  ,1H=,  E14.6, 7H POUNDS                   ,        MAIN0940
    3           ,10X,4HWH2O   ,1H=,  E14.6, 7H POUNDS                   /        MAIN0950
    4           ,10X,5HWIDTH  ,1H=,  E14.6, 7H INCHES                   ,        MAIN0960
```

```
     5          ,10X,2HBL      ,1H=,  E14.6, 7H INCHES             ,   MAIN0970
     6          ,10X,4HBORE    ,1H=,  E14.6, 3H MM                 /   MAIN0980
     7          ,10X,6HVCHAMB  ,1H=,  E14.6,13H CUBIC INCHES       ,   MAIN0990
     8          ,10X,4HCNA1    ,1H=,  E14.6, 8H DEGREES            ,   MAIN1000
     9          ,10X,4HCNA2    ,1H=,  E14.6, 8H DEGREES            /   MAIN1010
     A          ,10X,2HRN      ,1H=,  E14.6, 7H INCHES             ,   MAIN1020
     B          ,10X,3HDTH     ,1H=,  E14.6, 7H INCHES             ,   MAIN1030
     C          ,10X,4HDEXC    ,1H=,  E14.6, 7H INCHES             /   MAIN1040
     D          ,10X,3HENL     ,1H=,  E14.6, 7H INCHES             ,   MAIN1050
     E          ,10X,4HSNWT    ,1H=,  E14.6, 7H POUNDS             )   MAIN1060
      KKD=-1                                                           MAIN1070
      KK=-1                                                            MAIN1080
      IRK=7*IM+5                                                       MAIN1090
      CALL CALXC (CNA1,CNA2,RN,DTH,DEXC,BL,BORE,VCHAMB,ENL,XC,XBB)     MAIN1100
      WRITE (6,108) (I,XC(I),I=1,9)                                    MAIN1110
  108 FORMAT (1H / (1H ,10X,2HI=,I2,3X,6HXC(I)=,1PE14.6))              MAIN1120
      CALL ZSPACE                                                      MAIN1130
      CALL IOFZB(ZPL1,2,54,IPL1)                                       MAIN1140
```

```
      CALL IOFZB(ZPL2*2.54,IPL2)
      IPL1=IPL1-1
      CALL IOFZ (-ENL*2.54,IEX)
      IEX=IEX+1
      WRITE (6,111) IR,ZR,ZMAX,ZPL1,ZPL2,IPL1,IPL2,IEX
  111 FORMAT (1H0,5X,3HIR=,I6,5X,3HZR=,1PE12.5,5X,5HZMAX=,E12.5,5X,
     2 5HZPL1=,E12.5,5X,5HZPL2=,E12.5, /  1H ,5X,5HIPL1=,I6,5X,
     3 5HIPL2=,I6,5X,4HIEX=,I6)
      WRITE (6,107) (I,Z(I),ZB(I),A(I),AB(I),V(I),VB(I),I=1,IM)
  107 FORMAT (1H1,5X,1HI,10X,1HZ,16X,2HZB,17X,1HA,18X,2HAB,17X,1HV,
     1 18X,2HVB / (1H ,I6,1PE19.6,5E19.6))
      READ (5,112) NZW,(ZW(I),I=1,7)
  112 FORMAT (I10,7F10.5)
      DO 5 I=1,NZW
      ZZ=2.54*(XC(3)-ZW(I))
      ZWC(I)=ZZ
      CALL IOFZ (ZZ,II)
    5 IZW(I)=II
      WRITE (6,113) (I,IZW(I),ZW(I),ZWC(I),I=1,NZW)
  113 FORMAT (1H0,14X,1HI,7X,3HIZW,8X,2HZW,12X,3HZWC /
     2 (1H ,10X,2I10,1PE14.5,E14.5))
      DSCPSI=453.59*980.616/(2.54**2)
      CCPCIN=2.54**3
      AP=2.0*CHARG*453.59/(1.6*WIDTH*(2.54**3))
      AC=0.25*3.141593*((BORE/25.4)**2)
      ZZ=0.5*(XC(3)+XC(4))*2.54
      CALL IOFZB(ZZ,NFS)
      CALL IOFZB(2.54*XC(7),NFE)
      NPS=NFE
      NFE=NFE+1
      CHAML=VCHAMB*(2.54**3)/(0.25*3.141593*(0.1*BORE)**2)
      ZZ=Z(NPS)+CHAML+2.54*4.0
      CALL IOFZ (ZZ,NPE)
      WRITE (6,109) NFS,Z(NFS),NFE,Z(NFE),NPS,Z(NPS),NPE,Z(NPE)
  109 FORMAT (1H0, 9X,4HNFS=,I6,5X,1PE14.6,
     2             10X,4HNFE=,I6,5X,  E14.6/
     3             10X,4HNPS=,I6,5X,  E14.6,
     4             10X,4HNPE=,I6,5X,  E14.6)
      FMS=(3.141593/6.0)*RHOP*((DP0/10)**3)
```

```
      CL=RHOP*(1.0-VFMIN)                                               MAIN1540
      FLLEN=WH2O*453.59/(CL*0.25*3.141593*(DEXC*2.54)**2)               MAIN1550
      ZL=2.54*XC(4)-FLLEN                                               MAIN1560
      CALL IOFZ(2.54*XC(4),I2)                                          MAIN1570
      CALL IOFZ(ZL,I1)                                                  MAIN1580
      I1=I1-1                                                           MAIN1590
      I2=I2-1                                                           MAIN1600
      VOLP=(ZB(I2)-ZB(I1-1))*0.25*3.141593*((DEXC*2.54)**2)             MAIN1610
      CL=WH2O*453.59/VOLP                                               MAIN1620
      CL=AMAX1(CL,1.0E-10)                                              MAIN1630
      FNPN=CL/FMX                                                       MAIN1640
      VF=1.0-CL/RHOP                                                    MAIN1650
      CGG=VF*0.0010694                                                  MAIN1660
      IF (KST-1) 7,2,7                                                  MAIN1670
    2 Y(1)=CHARG                                                        MAIN1680
      DO 3 I=2,5                                                        MAIN1690
    3 Y(I)=0.0                                                          MAIN1700
      FNPN1=FNPN*1.0E-3                                                 MAIN1710
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      FNPN1=AMAX1(FNPN1,1.0E-10/FMN)                                     MAIN1720
      ZP=CHAML+2.54*(4.0+XC(7))                                          MAIN1730
      CALL IOFZ (ZP,IPRJ)                                                MAIN1740
      VV=AB(IPRJ)*(ZP-ZB(IPRJ-1))                                        MAIN1750
      IMN=IPRJ                                                           MAIN1760
      IPO=IMN                                                            MAIN1770
      KSW=1                                                              MAIN1780
      DO 11 I=1,IN                                                       MAIN1790
      IF (I-IPRJ) 15,14,15                                               MAIN1800
   14 VVV=VV                                                             MAIN1810
      GO TO 20                                                           MAIN1820
   15 VVV=V(I)                                                           MAIN1830
   20 CONTINUE                                                           MAIN1840
      F(I,1)=0.0010694*VVV                                               MAIN1850
      F(I,3)=FNPN1*VVV                                                   MAIN1860
      F(I,5)=FMM*FNPN1*VVV                                               MAIN1870
      F(I,4)=298.0*F(I,5)                                                MAIN1880
      F(I,2)=F(I,1)*(-1.145E3)+F(I,4)                                    MAIN1890
      F(I,6)=0.0                                                         MAIN1900
   11 F(I,7)=0.0                                                         MAIN1910
      DO 12 I=I1,I2                                                      MAIN1920
      F(I,1)=CGG*V(I)                                                    MAIN1930
      F(I,3)=FNPN*V(I)                                                   MAIN1940
      F(I,5)=FNPN*FMM*V(I)                                               MAIN1950
      F(I,4)=F(I,5)*298.0                                                MAIN1960
   12 F(I,2)=F(I,1)*(-1.145E3)+F(I,4)                                    MAIN1970
      DT=0.00001                                                         MAIN1980
    7 CONTINUE                                                           MAIN1990
      EZ=ER*0.01                                                         MAIN2000
      DO 9 I=1,5                                                         MAIN2010
    9 RE(I)=ER                                                           MAIN2020
      AE(1)=EZ*CHARG                                                     MAIN2030
      AE(2)=EZ*2000.0                                                    MAIN2040
      AE(3)=EZ*140.0                                                     MAIN2050
      AE(4)=EZ*1000.0                                                    MAIN2060
      AE(5)=AE(4)                                                        MAIN2070
      AEF(1)=EZ*0.1                                                      MAIN2080
      AEF(2)=AEF(1)*1000.0                                               MAIN2090
      AEF(3)=EZ*FNP,                                                     MAIN2100
```

```
      AEF(5)=EZ*FMM*FNP                                         MAIN2110
      AEF(4)=AEF(5)*500.0                                       MAIN2120
      AEF(6)=AEF(1)*40000.0                                     MAIN2130
      AEF(7)=AEF(5)*40000.0                                     MAIN2140
      L=5                                                       MAIN2150
      DO 6 I=1,IM                                               MAIN2160
      DO 6 K=1,7                                                MAIN2170
      L=L+1                                                     MAIN2180
      RE(L)=ER                                                  MAIN2190
      AE(L)=AEF(K)*V(I)                                         MAIN2200
    6 V(L)=F(I,K)                                               MAIN2210
      REWIND 6                                                  MAIN2220
      REWIND 9                                                  MAIN2230
      REWIND 10                                                 MAIN2240
      REWIND 11                                                 MAIN2250
      IF (KST-2) 17,16,17                                       MAIN2260
   16 CONTINUE                                                  MAIN2270
      DO 18 LL=1,1000                                           MAIN2280
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      READ (9) KK,T,DT,IPRJ,IMW,KSW,(Y(I),I=1,IRK)                       MAIN2290
      READ  (10) K9                                                     MAIN2300
      IF (KK-KKST) 18,19,19                                             MAIN2310
   18 CONTINUE                                                          MAIN2320
   19 CONTINUE                                                          MAIN2330
      DO 8 LL=1,10000                                                   MAIN2340
      READ  (8) KK1                                                     MAIN2350
      READ (11) KK3                                                     MAIN2360
      IF (KK1-KK) 8,13,13                                               MAIN2370
    8 CONTINUE                                                          MAIN2380
   13 CONTINUE                                                          MAIN2390
      KK=KK-1                                                           MAIN2400
      IPC=IPRJ                                                          MAIN2410
   17 CONTINUE                                                          MAIN2420
      EXTERNAL DERIV,CNTRL                                              MAIN2430
      CALL RK2 (DERIV,CNTRL,Y,DY,AE,RE,T,DT,IRK,2,0E6)                  MAIN2440
      REWIND 8                                                          MAIN2450
      REWIND 9                                                          MAIN2460
      REWIND 10                                                         MAIN2470
      REWIND 11                                                         MAIN2480
      GO TO 1                                                           MAIN2490
      END                                                               MAIN2500
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE DERIV(Y,DY,T)
C     Y(1)= UNBURNT PROPELLANT  POUNDS
C     Y(2)= PROJECTILE VELOCITY  FT/SEC
C     Y(3)=            TRAVEL    INCHES
C     Y(4)= IMPULSE    POUNDS X SEC
C     Y(5)= IMPULSE X TIME  POUND X SEC XX 2
      PARAMETER NDC=200
      PARAMETER NRKD=1800
      DIMENSION Y(NRKD),DY(NRKD)
      COMMON /ALL/ IM,K,,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKO,
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBB,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),
     3 FL,RHOP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,
     4 WIDTH,CPP,BL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PB,
     5 F(NDC,7),CG(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),
     7 PD(NDC),DP(NDC),DG(NDC),DF(NDC,7),G(NDC,7),Q(NDC),Z(NDC),ZB(NDC)
     8 ,TGA(NDC),QCA(NDC),QEA(NDC),VFA(NDC),FMV(NDC)
      DATA C/0.01/
      L=5
      DO 12 I=1,IMW
      DO 12 K=1,7
      L=L+1
   12 F(I,K)=Y(L)
      ZPROJ=Y(3)
      VPROJ=Y(2)
      CALL DER1(Y(1))
      L=5
      DO 13 I=1,IMW
      DO 13 K=1,7
      L=L+1
   13 DY(L)=DF(I,K)
      DY(1)=DYDT
      IF(Y(3)+4.0-BL) 9,9,8
    8 DY(2)=0.0
      GO TO 10
    9 DY(2)=PG(IPRJ)*AC*32.1724/(PROJW*DSCPSI)
   10 DY(3)=Y(2)*12.0
      FORCE=0.0
      DO 11 I=NFS,NFE
```

```
11 FORCE=FORCE+PG(I)*(AB(I-1)-AB(I))                          DERI0400
   FORCE=FORCE/(980.616*453.59)                               DERI0410
   DY(4)=FORCE                                                DERI0420
   DY(5)=Y(4)                                                 DERI0430
   RETURN                                                     DERI0440
   END                                                        DERI0450
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE DER1 (YONE)
C     F(I,1) = MASS OF GAS
C     F(I,2) = TOTAL ENERGY, BOTH PHASES
C     F(I,3) = NUMBER OF PARTICLES
C     F(I,4) = SENSIBLE HEAT IN PARTICLE PHASE
C     F(I,5) = MASS OF PARTICLES
C     F(I,6) = TOTAL MOMENTUM, BOTH PHASES
C     F(I,7) = MOMENTUM OF PARTICLE PHASE
C     G(I,1) = FLUX OF GAS
C     G(I,2) = FLUX OF TOTAL ENERGY
C     G(I,3) = FLUX OF PARTICLES
C     G(I,4) = FLUX OF PARTICLE SENSIBLE HEAT
C     G(I,5) = FLUX OF PARTICLE MASS
C     G(I,6) = FLUX OF TOTAL MOMENTUM
C     G(I,7) = FLUX OF PARTICLE MOMENTUM
      PARAMETER NDC=200
      DIMENSION EKGA(NDC),EKPA(NDC)
      COMMON /ALL/ IM,KW,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKO,
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBB,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),
     3 FL,RHOP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,
     4 WIDTH,CPP,BL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PB,
     5 F(NDC,7),CG(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),
     7 PP(NDC),DP(NDC),DG(NDC),DF(NDC,7),G(NDC,7),Q(NDC),Z(NDC),ZB(NDC)
     8 ,TGA(NDC),GCA(NDC),GEA(NDC),VFA(NDC),FMV(NDC)
      COMMON / MD / KSWS,KSWH,KSWM
      DATA FMN/-1.0/
      IMWP1=IMW+1
      IMWM1=IMW-1
      GO TO (29,30),KSW
   29 ZP=CHAML+2.54*(ZPROJ+4.0+XC(7))
      VV=AB(IPRJ)*(ZP-ZB(IPRJ-1))
      GO TO 31
   30 VV=0.0
   31 CONTINUE
      DO 1 K=1,5
      F(1,K)=(2.0*F(2,K)/V(2)-F(3,K)/V(3))*V(1)
    1 F(IMW+1,K)=F(IMW,K)*V(IMW+1)/V(IMW)
      DO 2 I=1,IMWP1
```

```
      CG(I)=F(I,1)/V(I)                                              DER10400
      FN(I)=AMAX1(FMN,F(I,3))/V(I)                                   DER10410
      FMV(I)=AMAX1(FMN,F(I,5))/V(I)                                  DER10420
      FM(I)=FMV(I)/FN(I)                                             DER10430
    2 CONTINUE                                                       DER10440
      GO TO (41,32),KSW                                              DER10450
   41 CG(IPRJ)=F(IPRJ,1)/VV                                          DER10460
      FN(IPRJ)=AMAX1(FMN,F(IPRJ,3))/VV                               DER10470
      FMV(IPRJ)=AMAX1(FMN,F(IPRJ,5))/VV                              DER10480
   32 CONTINUE                                                       DER10490
      DO 3 I=2,IMW                                                   DER10500
      CGB=(VHR(I)*CG(I)+VHL(I+1)*CG(I+1))/VB(I)                      DER10510
      FMB=(VHR(I)*FMV(I)+VHL(I+1)*FMV(I+1))/VB(I)                    DER10520
      GO TO (42,33),KSWS                                             DER10530
   42 CONTINUE                                                       DER10540
      UP(I)=F(I,7)/(FMB*VB(I))                                       DER10550
      UG(I)=(F(I,6)-F(I,7))/(CGB*VB(I))                              DER10560
      GO TO 3                                                        DER10570
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
33 CONTINUE                                                       DER10580
   UP(I)=F(I,6)/((CGB+FMB)*VB(I))                                 DER10590
   UG(I)=UP(I)                                                    DER10600
 3 CONTINUE                                                       DER10610
   UG(1)=(2.0*UG(2)*AB(2)-UG(3)*AB(3))/AB(1)                      DER10620
   UP(1)=(2.0*UP(2)*AB(2)-UP(3)*AB(3))/AB(1)                      DER10630
   GO TO (4,5),KSW                                                DER10640
 4 UG(IPRJ)=33.45*VPROJ                                           DER10650
   UP(IPRJ)=33.45*VPROJ                                           DER10660
 5 UG(IMW+1)=UG(IMW)*AB(IMW)/AB(IMW+1)                            DER10670
   UP(IMW+1)=UP(IMW)*AB(IMW)/AB(IMW+1)                            DER10680
 6 CONTINUE                                                       DER10690
   DO 7 I=2,IMWP1                                                 DER10700
   EKG=(VHR(I)*UG(I)**2+VHL(I)*UG(I-1)**2)/(2.0*V(I))             DER10710
   EKP=(VHR(I)*UP(I)**2+VHL(I)*UP(I-1)**2)/(2.0*V(I))             DER10720
   EKGA(I)=EKG                                                    DER10730
   EKPA(I)=EKP                                                    DER10740
   GO TO (35,34),KSWW                                             DER10750
35 CONTINUE                                                       DER10760
   EG(I)=(F(I,2)-F(I,4)-F(I,5)*EKP/FJ)/F(I,1)-EKG/FJ              DER10770
   TP(I)=F(I,4)/(F(I,5)*CPP)                                      DER10780
   CALL TOEAR (EG(I),RHOG(I),TGA(I))                              DER10790
   GO TO 7                                                        DER10800
34 CONTINUE                                                       DER10810
   S=F(I,2)-(F(I,1)*EKG+F(I,5)*EKP)/FJ                            DER10820
   VF=1.0-FMV(I)/RHOP                                             DER10830
   RHO=CG(I)/VF                                                   DER10840
   F1=3.607725E3+RHO*(1.041906E3-RHO*1.501111E3)                  DER10850
   F2=1.655022+RHO*(2.115013-RHO*1.848174)                        DER10860
   F3=-0.107984E-2+RHO*(-0.686307E-3+RHO*0.422347E-2)             DER10870
   W1=F1*F(I,5)*CPP-S                                             DER10880
   W2=F2*F(I,5)*CPP+F(I,1)                                        DER10890
   W3=F3*F(I,5)*CPP                                               DER10900
   IF (F(I,5)-1.0E-4*F(I,1))23,24,24                              DER10910
23 CONTINUE                                                       DER10920
   ET=-1000.0                                                     DER10930
   ET=ET-(W1+ET*(W2+ET*-[illegible]W2+2.0*W3)                     DER10940
   ET=ET-(W1+ET*(W2+ET*[illegible]W2+2.0*W3)                      DER10950
   EG(I)=ET                                                       DER10960
```

```
      GO TO 902
C FLAG
C     EG(I)=(SQRT(W2*W2-4.0*W1*W3)-W2)/(2.0*W3)
   24 WTST=W2*W2-4.0*W1*W3
      WTST1=AMAX1(WTST,0.0)
      EG(I)=(SQRT(WTST1)-W2)/(2.0*W3)
      IF (WTST) 901,902,902
  901 WRITE (6,801) I,S,RHO,WTST,W1,W2,W3,F1,F2,F3
  801 FORMAT (1H ,5X,12HDER1 WARNING ,5X,2HI=,I5,5X,2HS=,1PE12.5,5X,
     2 4HRHO=,E12.5,5X,5HWTST=,E12.5 / 1H ,5X,3HW1=,E12.5,5X,3HW2=,
     3 E12.5,5X,3HW3=,E12.5,5X,3HF1=,E12.5,5X,3HF2=,E12.5,5X,
     4 3HF3=,E12.5)
  902 CONTINUE
      CALL TOEAR (EG(I),RHO,TP(I))
      TGA(I)=TP(I)
    7 CONTINUE
      EG(1)=2.0*EG(2)-EG(3)
      TP(1)=2.0*TP(2)-TP(3)
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      DO 11 I=1,IMWP1
      VF=1.0-FMV(I)/RHOP
      VFA(I)=VF
      RHOG(I)=CG(I)/VF
      CALL EGSTAT(EG(I),RHOG(I),PSI)
      PG(I)=PSI*DSCPSI
      IF(VF-VFMIN)9,8,9
    8 PD(I)=0.0
      GO TO 10
    9 VF=AMAX1(VF,1.0E-10)
      VR=VF/VFMIN
      PD(I)=PDF*(1.0/(VR*VR)+2.0*VR-3.0)
   10 DP3=6.0*FM(I)/(RHOP*3.141593)
   11 DP(I)=ROOT(DP3,3)
      DO 12 I=2,IMW
      DU=-(UG(I)*AB(I)-UG(I-1)*AB(I-1))/A(I)
      DU=AMAX1(DU,0.0)
      Q(I)=FL*CG(I)*DU*(DU+50000.0)
      DU=-(UP(I)*AB(I)-UP(I-1)*AB(I-1))/A(I)
      DU=AMAX1(DU,0.0)
      PD(I)=FL*DU*(DU+50000.0)+PD(I)
   12 CONTINUE
      PD(1)=0.0
      Q(1)=0.0
      DO 13 I=2,IMW
      P1=PG(I+1)+Q(I+1)+FMV(I+1)*PD(I+1)
      P2=PG(I)+Q(I)+FMV(I)*PD(I)
      DF(I,6)=-(P1-P2)*AB(I)
      GO TO (36,28),KSWS
   36 CONTINUE
      DU=UP(I)-UG(I)
      RHOGB=0.5*(RHOG(I+1)+RHOG(I))
      DPB=0.5*(DP(I)+DP(I+1))
      RE=DPB*RHOGB*ABS(DU)/VISCG
      CALL DRAG(RE,CDRE,0,0)
      DG(I)=-0.125*3.141593*CDRE*VISCG*DPB*DU
      FNB=0.5*(FN(I+1)+FN(I))
      FMVB=0.5*(FMV(I+1)+FMV(I))
      DF(I,7)=-AB(I)*(FMV(I+1)*PD(I+1)-FMV(I)*PD(I))
```

```
    2 -(PG(I+1)-PG(I))*AB(I)*FMVB/R40P
      DF(I,7)=DF(I,7)+FVB*DG(I)*VS(I)
      GO TO 13
   29 CONTINUE
      DF(I,7)=0.0
   13 CONTINUE
      DO 14 I=1,IMNP1
      IM1=I-1
      IM1=MAX0(IM1,1)
      UB=0.5*(UP(I)+UP(IM1))
      CALL LOFU (UB,L)
      G(I,7)=A(I)*FMV(I)*(UP(IM1+L)**2)
      G(I,6)=G(I,7)
      UB=0.5*(UG(I)+UG(IM1))
      CALL LOFU (UB,L)
      G(I,6)=G(I,6)+A(I)*CG(I)*UG(IM1+L)**2
      CALL LOFU(UP(I),L)
      IL=I+L
```

```
      IL=MIN0(IMWP1,IL)                                                 DER11720
      ILM1=IL-1                                                         DER11730
      ILM1=MAX0(ILM1,1)                                                 DER11740
      G(I,3)=AB(I)*UP(I)*FN(IL)                                         DER11750
      G(I,5)=AB(I)*UP(I)*FMV(IL)                                        DER11760
      G(I,4)=AB(I)*UP(I)*FMV(IL)*CPP*TP(IL)                             DER11770
      G(I,2)=G(I,4)                                                     DER11780
     2 +AB(I)*UP(I)*FMV(IL)*(EKPA(IL)+PD(IL)+(PG(IL)+Q(IL))/RHOP)/FJ    DER11790
      CALL LOFJ (UG(I),L)                                               DER11800
      IL=I+L                                                            DER11810
      IL=MIN0(IMWP1,IL)                                                 DER11820
      ILM1=IL-1                                                         DER11830
      ILM1=MAX0(ILM1,1)                                                 DER11840
      G(I,1)=AB(I)*UG(I)*CG(IL)                                         DER11850
      G(I,2)=G(I,2)+AB(I)*UG(I)*(VFA(IL)*(PG(IL)+Q(IL))/FJ              DER11860
     2 +CG(IL)*(EG(IL)+EKGA(IL)/FJ))                                    DER11870
   14 CONTINUE                                                          DER11880
      PB=0.0                                                            DER11890
      DO 51 I=NPS,NPE                                                   DER11900
   51 PB=PB+PG(I)                                                       DER11910
      PB=PB/FLOAT(NPE-NPS+1)                                            DER11920
      PB=PB/DSCPSI                                                      DER11930
      PC=AMAX1(200.0,PB)                                                DER11940
      BR=0.00186*(PC**0.83)                                             DER11950
      DYDT=-AP*BR*1.6*CCPCIN/453.59                                     DER11960
      EE=YONE/CHARG                                                     DER11970
      IF (ABS(EE)-1.0E-5) 201,202,202                                   DER11980
  201 DYDT=0.0                                                          DER11990
      GO TO 204                                                         DER12000
  202 IF (ABS(EE)-0.01) 203,204,204                                     DER12010
  203 DYDT=DYDT*EE/0.01                                                 DER12020
  204 CONTINUE                                                          DER12030
      DMDT=-DYDT*453.59/(A(NPE)*(ZB(NPE)-ZB(NPS-1)))                    DER12040
      DO 18 I=2,IMW                                                     DER12050
      GO TO (48,44),KSW                                                 DER12060
   48 IF(I-IPRJ) 44,43,44                                               DER12070
   43 VVV=VV                                                            DER12080
      GO TO 45                                                          DER12090
   44 VVV=V(I)                                                          DER12100
```

```
   45 CONTINUE                                                          DER12110
      DF(I,1)=-(G(I,1)-G(I-1,1))                                        DER12120
      IF(I-NPS)17,15,15                                                 DER12130
   15 IF(I-NPE)16,16,17                                                 DER12140
   16 DF(I,1)=DF(I,1)+DMDT*VVV                                          DER12150
   17 DF(I,2)=-(G(I,2)-G(I-1,2))                                        DER12160
      DF(I,3)=-(G(I,3)-G(I-1,3))                                        DER12170
      DF(I,4)=-(G(I,4)-G(I-1,4))                                        DER12180
      DF(I,5)=-(G(I,5)-G(I-1,5))                                        DER12190
      DF(I,6)=DF(I,6)-(G(I+1,6)-G(I,6))                                 DER12200
      DF(I,7)=DF(I,7)-(G(I+1,7)-G(I,7))                                 DER12210
      GO TO (37,46),KSW4                                                DER12220
   37 CONTINUE                                                          DER12230
      DU=0.5*(UP(I)-UG(I)+UP(I-1)-UG(I-1))                              DER12240
      RE=DP(I)*RHOG(I)*ABS(DU)/VISCG                                    DER12250
      REP6=ROOT(RE,5)                                                   DER12260
      REP6=REP6*REP6*REP6                                               DER12270
      FNU=2.0+0.34*.89*REP6                                             DER12280
```

```
      H=FNU*0.25*VISCG/(0.7*DP(I))
      TG=TGA(I)
      TPT=TP(I)
      QC=(TPT-TG)*H*(DP(I)**2)*3.141593
      GO TO (38,39),KSWM
   38 CONTINUE
      GK=FNU*VISCG/(PG(I)*DP(I)*0.7)
      PVL=PV1-PV2/(TP(I)-273.0+PV3)
      PVL=AMIN1(PVL,30.0)
      PV=EXP(PVL*2.302585)
C FLAG
C     PV=AMIN1(PV,760.0)
      PV=14.7*(PV/760.0)*OSCPSI
      DMDDT=3.141593*GK*(DP(I)**2)*(PV-0.19*PG(I))
      DMDDT=AMAX1(DMDDT,0.0)
      GO TO 40
   39 DMDDT=0.0
   40 CONTINUE
      DF(I,1)=DF(I,1)+DMDDT*F(I,3)
      QE=DMDDT*560.0
      DF(I,4)=DF(I,4)-(DMDDT*TP(I)*CPP+QC+QE)*F(I,3)
      DF(I,5)=DF(I,5)-DMDDT*F(I,3)
      GO TO 47
   46 QC=0.0
      GE=0.0
      DF(I,4)=0.0
   47 CONTINUE
      QCA(I)=QC
      QEA(I)=QE
   18 CONTINUE
      QEA(1)=0.0
      QEA(IMWP1)=QEA(IMW)
      DO 22 I=2,IMW
      GO TO (26,27),KSWS
   26 DF(I,7)=DF(I,7)-(QEA(I)*FN(I)*VHR(I)+QEA(I+1)*FN(I+1)*VHL(I+1))
     2 *UP(I)/560.0
      GO TO 22
   27 DF(I,7)=0.0
   22 CONTINUE
```

```
      DO 21 K=1,7                                                       DER12680
   21 DF(1,K)=0.0                                                       DER12690
      GO TO (19,20),KSW                                                 DER12700
   19 I=IPRJ                                                            DER12710
      DF(I,6)=0.0                                                       DER12720
      DF(I,7)=0.0                                                       DER12730
   20 CONTINUE                                                          DER12740
      RETURN                                                            DER12750
      END                                                               DER12740
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE CNTRL (Y,DY,DT,T,NTRY)
      PARAMETER NDC=200
      PARAMETER NRKD=1800
      DIMENSION Y(NRKD),DY(NRKD)
      COMMON /ALL/ IM,KW,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKO,
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBB,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),
     3 FL,RHOP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,
     4 WIDTH,CPP,BL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PB,
     5 F(NDC,7),CG(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),
     7 PC(NDC),DP(NDC),DG(NDC),DF(NDC,7),G(NDC,7),Q(NDC),Z(NDC),ZB(NDC)
     8 ,TGA(NDC),QCA(NDC),QEA(NDC),VFA(NDC),FMV(NDC)
      COMMON / NRKC/ NRK
      COMMON /MC/ NZW,ZW(7),ZWC(7),IZW(7),PW(7),IEX
      IF (ZPROJ+4.0-BL) 1,1,5
    1 KSW=1
      ZP=CHAML+2.54*(ZPROJ+4.0+XC(7))
      CALL IOFZ (ZP,IPRJ)
      IMW=IPRJ
      NRK=5+7*IPRJ
      IF (IPRJ-IPO)18,6,2
    2 CONTINUE
      DDD=ZP-ZB(IPRJ-2)
      VRN=(ZP-ZB(IPRJ-1))/DDD
      VRO=V(IPO)/(DDD*AB(IPO))
      DO 3 K=1,5
      F(IPRJ,K)=VRN*F(IPO,K)
    3 F(IPO,K)=VRO*F(IPO,K)
      UG(IPO)=UG(IPO-1)+(VPROJ*30,48-UG(IPO-1))*(ZB(IPO)-ZB(IPO-1))/
     2 (ZP-ZB(IPO-1))
      UP(IPO)=UP(IPO-1)+(VPROJ*30,48-UP(IPO-1))*(ZB(IPO)-ZB(IPO-1))/
     2 (ZP-ZB(IPO-1))
      F(IPO,7)=UP(IPO)*F(IPO,5)
      F(IPO,6)=F(IPO,7)+UG(IPO)*F(IPO,1)
      L=5
      DO 4 I=1,IMW
      DO 4 K=1,7
      L=L+1
    4 Y(L)=F(I,K)
```

```
17 CONTINUE                                                  CNTR0400
   CALL DERIV (Y,DY,T)                                       CNTR0410
18 IPO=IPRJ                                                  CNTR0420
   GO TO 6                                                   CNTR0430
 5 KSW=2                                                     CNTR0440
   IMW=IM-1                                                  CNTR0450
   NRK=5+7*IMW                                               CNTR0460
   IF (IMW-IPO) 13,14,13                                     CNTR0470
13 CONTINUE                                                  CNTR0480
   F(IPO,7)=UP(IPO)*F(IPO,5)                                 CNTR0490
   F(IPO,5)=F(IPO,7)+UG(IPO)*CG(IPO)                         CNTR0500
   IPO=IMW                                                   CNTR0510
14 CONTINUE                                                  CNTR0520
 6 KK=KK+1                                                   CNTR0530
   KKO=KKO+1                                                 CNTR0540
   IF (KKO-KM) 8,7,7                                         CNTR0550
 7 NTRY=2                                                    CNTR0560
   GO TO 9                                                   CNTR0570
```

```
    8 NTRY=1                                                            CNTR0580
    9 WRITE (6,101) KK,T,DT,IMW,ZP,Z (IMW)                              CNTR0590
  101 FORMAT (1H ,5X,3HKK=,I6,5X,2HT=,1PE12.5,5X,3HDT=,E12.5,5X,        CNTR0600
     2 4HIMW=,I6,5X,3HZP=,E12.5,5X,7HZ(IMW)= ,E12.5)                    CNTR0610
      DO 16 I=1,NZW                                                     CNTR0620
      I1=IZW(I)                                                         CNTR0630
      I2=I1+1                                                           CNTR0640
      ZZ=ZWC(I)                                                         CNTR0650
      P1=PG(I1)+0.5*RHOG(I1)*(UG(I1)**2)                                CNTR0660
      P2=PG(I2)+0.5*RHOG(I2)*(UG(I2)**2)                                CNTR0670
      PSAVE=P1+(ZZ-Z(I1))*(P2-P1)/(Z(I2)-Z(I1))                         CNTR0680
      PW(I)=PSAVE/DSCPSI                                                CNTR0690
   16 CONTINUE                                                          CNTR0700
      WRITE (6,109) (I,PW(I),I=1,NZW)                                   CNTR0710
  109 FORMAT (1H ,2X,5(3HPW(,I1,2H)=,1PE12.5,4X,))                      CNTR0720
      IF ((KK/5)*5-KK) 20,19,20                                         CNTR0730
   19 CONTINUE                                                          CNTR0740
      WRITE (8) KK ,T,(PW(I),I=1,NZW),PB,VPROJ,ZPROJ,Y(4),Y(5)          CNTR0750
      WRITE (11) KK,T,PG(IEX),CG(IEX),UG(IEX),UP(IEX),FMV(IEX)          CNTR0760
                                                                        CNTR0770
   20 CONTINUE                                                          CNTR0780
      IF ((KK0/KW)*KW-KK0) 11,10,11                                     CNTR0790
   10 IMWP1=IMW+1                                                       CNTR0800
      IRK=5+7*IM                                                        CNTR0810
      WRITE (9) KK,T,DT,IPRJ,IMW,KSW,(Y(I),I=1,IRK)                     CNTR0820
      WRITE (10) KK,(PG(I),FMV(I),UG(I),UP(I),Z(I),ZB(I),I=1,IM)        CNTR0830
   11 IF ((KK0/KP)*KP-KK0) 15,12,15                                     CNTR0840
   12 CONTINUE                                                          CNTR0850
      WRITE (6,102) KK0,KK,T,DT,PB,DYDT,FORCE,Y(1),Y(4),Y(5),ZPROJ,VPROJCNTR0860
  102 FORMAT (1H0,5X,4HKK0=,I6,5X,3HKK=,I6,5X,2HT=,1PE12.5,5X,3HDT=,    CNTR0870
     2 E12.5,5X,3HPB=,E12.5,5X,5HDYDT=,E12.5, / 1H ,5X,6HFORCE=,E12.5,  CNTR0880
     3 5X,20HUNBURNED PROPELLANT=,E12.5,                                CNTR0890
     4 5X,8HIMPULSE=,E12.5/5X,12HIMPULSE*SEC=,E12.5,5X,5HZPRJ=,         CNTR0900
     5 E12.5,5X,6HVPROJ=,E12.5)                                         CNTR0910
      WRITE (6,103) (I,UG(I),UP(I),PG(I),G(I),PD(I),CG(I),VFA(I),       CNTR0920
     2 RHOG(I),I=1,IMWP1)                                               CNTR0930
  103 FORMAT (1H0,7X,1HI,4X,2HUG,12X,2HUP,12X,2HPG,12X,1HG,13X,2HPD,    CNTR0940
     2 12X,2HCG,12X,3HVFA,11X,4HRHOG / (1H ,I8,1PE14.6,7E14.6))         CNTR0950
      WRITE (6,104) (I,EG(I),TGA(I),TP(I),EN(I),DP(I),DG(I),GCA(I),     CNTR0960
     2 GEA(I),I=1,IMWP1)
```

```
 104 FORMAT (1H0,7X,1HI,4X,2HEG,12X,3HTGA,11X,2HTP,12X,2HFN,12X,2HDP,     CNTR0970
    2 12X,2HDG,12X,3HGCA,11X,3HGEA / (1H ,I8,1PE14.6,7E14.6))              CNTR0980
      WRITE (6,105) (I,FM(I),FMV(I),I=1,IMWP1)                               CNTR0990
 105 FORMAT (1H0,7X,1HI,4X,2HFM,12X,3HFMV / (1H ,I8,1PE14.6,E14.6))         CNTR1000
      IPL3=MINO(IMW,IPL2)                                                     CNTR1010
      CALL PLOTS (Z,PG,PG,PG,1,IPL1,IPL3,200,1H*,1H*,1H*,0.0,0.0,0.0,       CNTR1020
    2 0.0)                                                                    CNTR1030
      CALL PLOTS (Z,FN,FV,PG,1,IPL1,IPL3,200,1HN,1H*,1H*,0.0,0.0,0.0,       CNTR1040
    2 0.0)                                                                    CNTR1050
      CALL PLOTS (ZS,UP,UG,PG,2,IPL1,IPL3,200,1HP,1HG,1H*,0.0,0.0,0.0,      CNTR1060
    2 0.0)                                                                    CNTR1070
      WRITE (6,106)                                                           CNTR1080
 106 FORMAT (1H1,10X,)                                                       CNTR1090
  15 CONTINUE                                                                 CNTR1100
      RETURN                                                                  CNTR1110
      END                                                                     CNTR1120
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE DRAG(RE,CDRE,FMACH)                                         DRAG0010
      DATA N / 1 /                                                           DRAG0020
      GO TO (1,2),N                                                          DRAG0030
   1 RE12=(24.0/18.5)**2.5                                                   DRAG0040
      RE23=(18.5/0.44)**(1.0/0.6)                                            DRAG0050
      N=2                                                                    DRAG0060
   2 IF(RE-RE12) 3,4,4                                                       DRAG0070
   3 CDRE=24.0                                                               DRAG0080
      GO TO 7                                                                DRAG0090
   4 IF(RE-RE23)5,6,6                                                        DRAG0100
   5 CDRE=18.5*RCOT(RE*RE,5)                                                 DRAG0110
      GO TO 7                                                                DRAG0120
   6 CDRE=0.44*RE                                                            DRAG0130
   7 CONTINUE                                                                DRAG0140
      IF (FMACH-0.81) 8,9,9                                                  DRAG0150
   8 RETURN                                                                  DRAG0160
   9 CDRE=RE                                                                 DRAG0170
      RETURN                                                                 DRAG0180
      END                                                                    DRAG0190
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE EQSTAT (E,RHO,P)                                       EQST0010
      F1= 1,6663384E 05+RHO*( 2,3860914E 05+RHO* 1,8121513E 05)         EQST0020
      F2= 8,804000 E 01+RHO*( 2,099948 E 02+RHO*-1,7081190E 01)         EQST0030
      F3=-3,9913083E-02+RHO*(-6,3478293E-03+RHO*-1,0366801E-01)         EQST0040
      P=RHO*(F1+E*(F2+E*F3))                                            EQST0050
      RETURN                                                            EQST0060
      END                                                               EQST0070
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE TOEAR (E,RHO,T)                                        TOEA0010
      F1=3,607725E3+RHO*(1,041906E3-RHO*1,501111E3)                     TOEA0020
      F2=1,655822+RHO*(2,115013-RHO*1,548174)                           TOEA0030
      F3=-0,107984E-2+RHO*(-0,686307E-3+RHO*0,422347E-2)                TOEA0040
      T=F1+E*(F2+E*F3)                                                  TOEA0050
      RETURN                                                            TOEA0060
      END                                                               TOEA0070
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE LOFU (U,L)                                             LOFU0010
      IF (U) 2,1,1                                                      LOFU0020
    1 L=0                                                               LOFU0030
      RETURN                                                            LOFU0040
    2 L=1                                                               LOFU0050
      RETURN                                                            LOFU0060
      END                                                               LOFU0070
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE RK2 (DERIV,CNTRL,Y,DY,A,R,T,DT,N,DTM)
C     SECOND ORDER RUNGE KUTTA
C     NTRY IS ASSIGNED ONE OF THE VALUES LISTED BELOW IN CNTRL
C     NTRY = 1  CONTINUE INTEGRATION
C     NTRY = 2  RETURN FROM RUNGE KUTTA
C     NTRY = 3  REPEAT STEP WITH NEW DT GIVEN IN CNTRL
C     NTRY 4  CONTINUE INTEGRATION WITH FIXED STEP
      PARAMETER NRKD=1800
      DIMENSION Y(NRKD),DY(NRKD),A(NRKD),R(NRKD),YST(NRKD),DYST(NRKD)
      COMMON / NRKC/ NRK
      EXTERNAL DERIV,CNTRL
      THR10=10.**(1.0/3.0)
      GAM=0.5
      BETA=0.5/GAM
      ALPHA=1.0-BETA
      CALL DERIV (Y,DY,T)
      CALL CNTRL(Y,DY,DT,T,NTRY)
    4 TST=T
      N=NRK
      DO 5 I=1,N
      YST(I)=Y(I)
    5 DYST(I)=DY(I)
    6 IF (DT) 8,7,8
    7 WRITE (6,101)
  101 FORMAT (1H0,20X,17HSTEP SIZE = ZERO,  )
      RETURN
    8 T=TST+GAM*DT
      DO 9 I=1,N
    9 Y(I)=YST(I)+GAM*DT*DYST(I)
      CALL DERIV (Y,DY,T)
      T=TST+DT
      DO 10 I=1,N
   10 Y(I)=YST(I)+DT*(ALPHA*DYST(I)+BETA*DY(I))
      CALL DERIV (Y,DY,T)
      EOCM=0.0
      DO 13 I=1,N
      E=Y(I)-(YST(I)+0.5*DT*(DYST(I)+DY(I)))
      C=A(I)+R(I)*ABS(Y(I))
      IF (C) 12,11,12
```

```
   11 WRITE (6,102) I
  102 FORMAT (1H0, 20X, 27HA(I)+R(I)*ABS(Y(I))=0 AT I= , I6)
      RETURN
   12 EOC=ABS(E/C)
C     EOCM=AMAX1(EOC,EOCM)
      IF(EOC-EOCM) 13,13,201
  201 EOCM=EOC
      LS=I
   13 CONTINUE
      IS=(LS+1)/7
      KS=LS-5-7*(IS-1)
      IF (EOCM-1.0) 17,17,14
   14 CONTINUE
      WRITE (6,301) EOCM,LS,KS,IS
  301 FORMAT (1H ,10X,5HEOCM=,1PE12.5,5X,3HLS=,I6,5X,3HKS=,I6,5X,
     2 3HIS=,I6)
C     CALL DUMPE
      T=TST
```

```
      DO 15 I=1,N                                               RK2 0580
      Y(I)=YST(I)                                               RK2 0590
   15 DY(I)=DYST(I)                                             RK2 0600
      DO 16 J=1,10                                              RK2 0610
      EOCM=EOCM/10.0                                            RK2 0620
      DT=DT/THR10                                               RK2 0630
      IF (EOCM-1.0) 6,6,16                                      RK2 0640
   16 CONTINUE                                                  RK2 0650
      GO TO 6                                                   RK2 0660
   17 CALL CNTRL (Y,DY,DT,T,NTRY)                               RK2 0670
      GO TO (21,18,19,4),NTRY                                   RK2 0680
   18 RETURN                                                    RK2 0690
   19 T=TST                                                     RK2 0700
      DO 20 I=1,N                                               RK2 0710
      Y(I)=YST(I)                                               RK2 0720
   20 DY(I)=DYST(I)                                             RK2 0730
      GO TO 6                                                   RK2 0740
   21 IF (EOCM-0.3) 23,23,22                                    RK2 0750
   22 DT=DT/THR10                                               RK2 0760
      WRITE (6,301) EOCM,LS,KS,IS                               RK2 0770
      GO TO 4                                                   RK2 0780
   23 IF (EOCM-0.03) 25,4,4                                     RK2 0790
   25 DT=DT*THR10                                               RK2 0800
      IF(ABS(DT)-ABS(DTM)) 4,4,24                               RK2 0810
   24 DT=ABS(DTM)*DT/ABS(DT)                                    RK2 0820
      GO TO 4                                                   RK2 0830
      END                                                       RK2 0840
```

```
      SUBROUTINE CALXC(CNA1,CNA2,RN,DTH,DEXC,BL,D,VCHAMB,ENL,XC,XBB)       CALX0010
      DIMENSION XC(9)                                                      CALX0020
      XC(1)=-1.0E+37                                                       CALX0030
      XC(3)=-ENL                                                           CALX0040
      XC(4)=0.0                                                            CALX0050
      TCNA1=TAN(3.141593*CNA1/180.0)                                       CALX0060
      SCNA1=TCNA1/SQRT(1.0+TCNA1**2)                                       CALX0070
      CCNA1=COS(3.141593*CNA1/180.0)                                       CALX0080
      IF (ENL-1.0E-10) 16,16,17                                            CALX0090
   16 ANG=CNA1                                                             CALX0100
      GO TO 18                                                             CALX0110
   17 ANG=0.0                                                              CALX0120
   18 SANG=SIN(3.141593*ANG/180.0)                                         CALX0130
      RC=24.0                                                              CALX0140
      RCC=RC*(SQRT(2.0)-1.0)/(SQRT(2.0)-SANG-SQRT(1.0-SANG**2))            CALX0150
      XC(2)=-ENL+RCC*(SANG-1.0/SQRT(2.0))                                  CALX0160
      RXC2=0.5*DEXC+RCC*(SQRT(1.0-SANG**2)-1.0/SQRT(2.0))                  CALX0170
      DI=D/25.4                                                            CALX0180
      XC(5)=0.5*(DEXC-DTH)/TCNA1                                           CALX0190
      XC(6)=XC(5)+12.0                                                     CALX0200
      XBB=0.5*(XC(6)+XC(5))                                                CALX0210
      XC(7)=XC(6)+0.5*(DI-DTH)/TCNA1                                       CALX0220
      CHL=4.0*VCHAMB/(3.141593*DI*DI)                                      CALX0230
      XC(8)=XC(7)+CHL+BL                                                   CALX0240
      XC(9)=1.0E37                                                         CALX0250
      X1=XC(1)                                                             CALX0260
      X2=XC(2)                                                             CALX0270
      K=1                                                                  CALX0280
      A=100.0                                                              CALX0290
      RETURN                                                               CALX0300
      ENTRY RADIUS(XCM,R)                                                  CALX0310
      X=XCM/2.54                                                           CALX0320
      IF (X-X1) 4,3,3                                                      CALX0330
    3 IF (X-X2) 7,7,4                                                      CALX0340
    4 DO 5 I=1,9                                                           CALX0350
      J=I                                                                  CALX0360
      IF (XC(I)-X) 5,5,6                                                   CALX0370
    5 CONTINUE                                                             CALX0380
    6 K=J-1                                                                CALX0390
```

```
      X1=XC(J-1)                                                        CALX0400
      X2=XC(J)                                                          CALX0410
    7 CONTINUE                                                          CALX0420
      GO TO (10,8,9,10,11,12,13,14),K                                   CALX0430
   10 R=RXC2-X+XC(2)                                                    CALX0440
      GO TO 15                                                          CALX0450
    8 Z=X-XC(3)                                                         CALX0460
      R=RCC*SQRT(1.0-SANG**2)+0.5*DEXC-SQRT(RCC**2-(Z-RCC*SANG)**2)     CALX0470
      GO TO 15                                                          CALX0480
    9 R=0.5*DEXC                                                        CALX0490
      GO TO 15                                                          CALX0500
   10 R=0.5*DEXC-X*TCNA1                                                CALX0510
      GO TO 15                                                          CALX0520
   11 R=0.5*DTH                                                         CALX0530
      GO TO 15                                                          CALX0540
   12 R=0.5*DI+(X-XC(7))*TCNA1                                          CALX0550
      GO TO 15                                                          CALX0560
   13 R=0.5*DI                                                          CALX0570
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      GO TO 15                                                          CALX0580
   14 R=0.5*DI+SQRT ((X-XC(8))**2+A*A)-A                                CALX0590
   15 CONTINUE                                                          CALX0600
      R=R*2.54                                                          CALX0610
      RETURN                                                            CALX0620
      END                                                               CALX0630
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE ZSPACE                                                 ZSPA0010
      PARAMETER NDC=200                                                 ZSPA0020
      DIMENSION ZS(202)                                                 ZSPA0030
      COMMON /ALL/ IM,KM,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKO,       ZSPA0040
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBB,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),       ZSPA0050
     3 FL,RHOP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,   ZSPA0060
     4 WIDTH,CPP,BL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PB,   ZSPA0070
     5 F(NDC,7),CG(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),        ZSPA0080
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),   ZSPA0090
     7 PD(NDC),DP(NDC),DG(NDC),DF(NDC,7),G(NDC,7),Q(NDC),Z(NDC),ZB(NDC) ZSPA0100
     8 ,TGA(NDC),GCA(NDC),GEA(NDC),VFA(NDC),FMV(NDC)                    ZSPA0110
      IM3=IM+1                                                          ZSPA0120
      ZMAXC=ZMAX*2.54                                                   ZSPA0130
      ZRC=ZR*2.54                                                       ZSPA0140
      CALL UNEQR (IM3,ZMAXC,IR,ZRC,ZS)                                  ZSPA0150
      J=IM3                                                             ZSPA0160
      I=0                                                               ZSPA0170
      DO 8 L=1,1000                                                     ZSPA0180
      J=J-1                                                             ZSPA0190
      IF (J) 2,1,2                                                      ZSPA0200
    1 J=-2                                                              ZSPA0210
    2 JA=IABS(J)                                                        ZSPA0220
      ZST=ZS(JA)                                                        ZSPA0230
      IF (J) 4,5,3                                                      ZSPA0240
    3 ZL=XBB*2.54-ZST                                                   ZSPA0250
      GO TO 5                                                           ZSPA0260
    4 ZL=XBB*2.54+ZST                                                   ZSPA0270
    5 IF ((L/2)*2-L) 6,7,6                                              ZSPA0280
    6 I=I+1                                                             ZSPA0290
      Z(I)=ZL                                                           ZSPA0300
      GO TO 8                                                           ZSPA0310
    7 ZB(I)=ZL                                                          ZSPA0320
      IF (I-IM) 8,10,10                                                 ZSPA0330
    8 CONTINUE                                                          ZSPA0340
   10 CONTINUE                                                          ZSPA0350
      R2C=0.0                                                           ZSPA0360
      DO 9 I=1,IM                                                       ZSPA0370
      CALL RADIUS (Z(I),R)                                              ZSPA0380
      CALL RADIUS (ZB(I),R2)                                            ZSPA0390
```

```
      A(I)=3.141593*R*R                                                 ZSPA0400
      AB(I)=3.141593*R2*R2                                              ZSPA0410
      IM1=MAX0(I-1,1)                                                   ZSPA0420
      VHR(I)=3.141593*(ZB(I)-Z(I))*(R2*R2+R2*R+R*R)/3.0                 ZSPA0430
      VHL(I)=3.141593*(Z(I)-ZB(IM1))*(R*R+R*R20+R20*R20)/3.0            ZSPA0440
      R20=R2                                                            ZSPA0450
    9 CONTINUE                                                          ZSPA0460
      VHL(1)=VHR(1)                                                     ZSPA0470
      VHR(IM)=VHL(IM)                                                   ZSPA0480
      VHL(IM+1)=VHR(IM)                                                 ZSPA0490
      DO 11 I=1,IM                                                      ZSPA0500
      V(I)=VHL(I)+VHR(I)                                                ZSPA0510
   11 VB(I)=VHR(I)+VHL(I+1)                                             ZSPA0520
      RETURN                                                            ZSPA0530
      END                                                               ZSPA0540
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE IOFZ(ZZ,II)                                            IOFZ0010
      PARAMETER NDC=200                                                 IOFZ0020
      COMMON /ALL/ IM,KA,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKO,       IOFZ0030
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBB,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),       IOFZ0040
     3 FL,RHOP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,   IOFZ0050
     4 WIDTH,CPP,BL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PB,   IOFZ0060
     5 F(NDC,7),CG(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),        IOFZ0070
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),   IOFZ0080
     7 PO(NDC),DP(NDC),DG(NDC),DF(NDC,7),G(NDC,7),Q(NDC),Z(NDC),ZB(NDC) IOFZ0090
     8 ,TGA(NDC),GCA(NDC),GEA(NDC),VFA(NDC),FMV(NDC)                    IOFZ0100
      DATA LLL / 1 /                                                    IOFZ0110
      GO TO (1,2),LLL                                                   IOFZ0120
    1 Z1=Z(1)                                                           IOFZ0130
      Z2=Z(2)                                                           IOFZ0140
      IO=1                                                              IOFZ0150
      LLL=2                                                             IOFZ0160
    2 IF (ZZ-Z1) 5,3,3                                                  IOFZ0170
    3 IF (ZZ-Z2) 4,6,6                                                  IOFZ0180
    4 II=IO                                                             IOFZ0190
      RETURN                                                            IOFZ0200
    5 IS=1                                                              IOFZ0210
      GO TO 7                                                           IOFZ0220
    6 IS=IO                                                             IOFZ0230
    7 DO 8 I=IS,IM                                                      IOFZ0240
      J=I                                                               IOFZ0250
      IF (ZZ-Z(I)) 10,9,8                                               IOFZ0260
    8 CONTINUE                                                          IOFZ0270
    9 II=J                                                              IOFZ0280
      GO TO 11                                                          IOFZ0290
   10 II=J-1                                                            IOFZ0300
   11 IO=II                                                             IOFZ0310
      Z1=Z(IO)                                                          IOFZ0320
      Z2=Z(IO+1)                                                        IOFZ0330
      RETURN                                                            IOFZ0340
      END                                                               IOFZ0350
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE IOFZB(ZZ,II)                                          IOFZ0010
      PARAMETER NDC=200                                                IOFZ0020
      COMMON /ALL/ IM,KA,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKO,      IOFZ0030
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBB,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),      IOFZ0040
     3 FL,RHGP,VISCG,VFMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,  IOFZ0050
     4 WIDTH,CPP,EL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PB,  IOFZ0060
     5 F(NDC,7),CG(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),       IOFZ0070
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),  IOFZ0080
     7 PD(NDC),DP(NDC),ZG(NDC),CF(NDC,7),G(NDC,7),Q(NDC),Z(NDC),ZB(NDC) IOFZ0090
     8 ,TGA(NDC),GCA(NDC),GEA(NDC),VFA(NDC),FMV(NDC)                   IOFZ0100
      DATA LLL / 1 /                                                   IOFZ0110
      GO TO (1,2),LLL                                                  IOFZ0120
    1 Z1=ZB(1)                                                         IOFZ0130
      Z2=ZB(2)                                                         IOFZ0140
      IO=1                                                             IOFZ0150
      LLL=2                                                            IOFZ0160
    2 IF (ZZ-Z1) 5,3,3                                                 IOFZ0170
    3 IF (ZZ-Z2) 4,6,6                                                 IOFZ0180
    4 II=IO                                                            IOFZ0190
      RETURN                                                           IOFZ0200
    5 IS=1                                                             IOFZ0210
      GO TO 7                                                          IOFZ0220
    6 IS=IO                                                            IOFZ0230
    7 DO 8 I=IS,IM                                                     IOFZ0240
      J=I                                                              IOFZ0250
      IF (ZZ-ZB(I)) 10,9,8                                             IOFZ0260
    8 CONTINUE                                                         IOFZ0270
    9 II=J                                                             IOFZ0280
      GO TO 11                                                         IOFZ0290
   10 II=J-1                                                           IOFZ0300
   11 IO=II                                                            IOFZ0310
      Z1=ZB(IO)                                                        IOFZ0320
      Z2=ZB(IO+1)                                                      IOFZ0330
      RETURN                                                           IOFZ0340
      END                                                              IOFZ0350
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE UNEQR(IM,RM,IR,RR,R)                                   UNEQ0010
      DIMENSION R(202)                                                  UNEQ0020
      FIR=FLOAT(IR)                                                     UNEQ0030
      FIM=FLOAT(IM)                                                     UNEQ0040
      B=1.0                                                             UNEQ0050
      DO 1 K=1,5                                                        UNEQ0060
      EX=EXP(-B*(FIM+FIR-2.0))+(1.0-EXP(-2.0*B*(FIR-1.0)))*RM/RR        UNEQ0070
      B=ALOG(EX)/(FIM-FIR)                                              UNEQ0080
      WRITE (6,101) K,B,IM,IR,RM,RR                                     UNEQ0090
  101 FORMAT (1H0,3X,2HK=,I5,3X,2HB=,1PE14.6,3X,3HIM=,I5,3X,            UNEQ0100
     2 3HIR=I5,3X,3HRM=,E14.6,3X,3HRR=,E14.6)                          UNEQ0110
    1 CONTINUE                                                          UNEQ0120
      DO 2 K=6,25                                                       UNEQ0130
      F1=RM*SINH(B*(FIR-1.0))                                           UNEQ0140
      F2=RR*SINH(B*(FIM-1.0))                                           UNEQ0150
      D0=F1-F2                                                          UNEQ0160
      D1=RM*(FIR-1.0)*COSH(B*(FIR-1.0))-RR*(FIM-1.0)*COSH(B*(FIM-1.0))  UNEQ0170
      D2=F1*(FIR-1.0)**2-F2*(FIM-1.0)**2                                UNEQ0180
      DB=SNGL(DLOG(1.0D0-DBLE(D0)*DBLE(D2)/DBLE(D1)**2)*DBLE(D1)/       UNEQ0190
     2 DBLE(D2))                                                        UNEQ0200
      B=B+DB                                                            UNEQ0210
      WRITE (6,102) K,DB,B                                              UNEQ0220
  102 FORMAT (1H0,3X,2HK=,I5,3X,3HDB=,1PE14.6,3X,2HB=,E14.6)            UNEQ0230
      IF (ABS(DB)-1.0E-7)3,3,2                                          UNEQ0240
    2 CONTINUE                                                          UNEQ0250
    3 A=RR/SINH(B*(FIR-1.0))                                            UNEQ0260
      DO 4 I=1,IM                                                       UNEQ0270
    4 R(I)=A*SINH(B*FLOAT(I-1))                                         UNEQ0280
      RETURN                                                            UNEQ0290
      END                                                               UNEQ0300
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE PLOTS (X,Y1,Y2,Y3,MM,I1,I2,ND,K1,K2,K3,XMIN,XMAX,        PLOT0010
     2 YMIN,YMAX)                                                         PLOT0020
C     PURPOSE - TO PLOT A GRAPH WITH ONE INDEPENDENT VARIABLE AND UP      PLOT0030
C     TO 9 DEPENDENT VARIABLES. THE INDEPENDENT VARIABLE IS PLOTTED ON APLOT0040
C     HORIZONTAL AXIS, THE DEPENDENT ONES ON A VERTICAL AXIS. WIDTH       PLOT0050
C     IS 100 PRINT POSITIONS, HEIGHT IS 50.                               PLOT0060
C     PARAMETER USAGE.                                                    PLOT0070
C     N     NUMBER OF OBSERVATIONS                                        PLOT0080
C     M     NUMBER OF VARIABLES (INDEPENDENT + DEPENDENT)                 PLOT0090
C     XMAX,XMIN,YMAX,YMIN  MAXIMUM AND MINIMUM VALUES OF THE INDEPENDENTPLOT0100
C     AND DEPENDENT VARIABLES TO BE USED IN THE  PLOT.                    PLOT0110
C     IF XMAX = XMIN, THE PROGRAM CALCULATES ITS OWN MAXIMUM AND MINIMUMPLOT0120
C     FOR THE INDEPENDENT VARIABLE,  SIMILARLY FOR YMAX = YMIN            PLOT0130
C     KPS  PLOTTING SYMBOL ARRAY,KPS(L) SYMBOL FOR LTH VARIABLE. AA(I,L)PLOT0140
C     REQUIRED SUBROUTINES SCAL                                           PLOT0150
C     DIMENSION OF A MUST BE THE PRODUCT OF THE DIMENSIONS OF AA.         PLOT0160
      DIMENSION X(ND),Y1(ND),Y2(ND),Y3(ND),A(800),KPS(4)                  PLOT0170
      DATA K0/1H*/                                                        PLOT0180
      N=I2-I1+1                                                           PLOT0190
      M=MM+1                                                              PLOT0200
      KPS(1)=K0                                                           PLOT0210
      KPS(2)=K1                                                           PLOT0220
      KPS(3)=K2                                                           PLOT0230
      KPS(4)=K3                                                           PLOT0240
      DO 1 I=1,N                                                          PLOT0250
      J=I+I1-1                                                            PLOT0260
      L2=I+N                                                              PLOT0270
      L3=I+2*N                                                            PLOT0280
      L4=I+3*N                                                            PLOT0290
      A(I)=X(J)                                                           PLOT0300
      A(L2)=Y1(J)                                                         PLOT0310
      A(L3)=Y2(J)                                                         PLOT0320
    1 A(L4)=Y3(J)                                                         PLOT0330
      XLAX=XMAX                                                           PLOT0340
      XLIN=XMIN                                                           PLOT0350
      YLAX=YMAX                                                           PLOT0360
      YLIN=YMIN                                                           PLOT0370
      EXTERNAL BLANK                                                      PLOT0380
      NFUNC=3                                                             PLOT0390
```

```
      CALL PLOT (G,A,N,M,NFUNC,BLANK,XLAX,XLIN,YLAX,YLIN,KPS)          PLOT0400
      RETURN                                                            PLOT0410
      END                                                               PLOT0420
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE BLANK (X,Y)                                            BLAN0010
      Y=0.0                                                             BLAN0020
      RETURN                                                            BLAN0030
      END                                                               BLAN0040
```

```
      SUBROUTINE PLOT (NO,A,N,M,NFUNC,FUNC,XLAX,XLIN,YLAX,YLIN,KFS)        PLOT0010
C     PURPOSE - TO PLOT A GRAPH WITH ONE INDEPENDENT VARIABLE AND UP       PLOT0020
C     TO 9 DEPENDENT VARIABLES, WITH THE ADDITIONAL ABILITY TO PLOT A      PLOT0030
C     CALCULATED CURVE, THE INDEPENDENT VARIABLE IS PLOTTED ON A           PLOT0040
C     HORIZONTAL AXIS, THE DEPENDENT ONES ON A VERTICAL AXIS, WIDTH        PLOT0050
C     IS 100 PRINT POSITIONS, HEIGHT IS 50, EVERY POINT OF EACH            PLOT0060
C     DEPENDENT VARIABLE IS INDICATED BY A NUMBER (1-9), WHILE THE         PLOT0070
C     CALCULATED POINTS ARE DENOTED BY ASTERISKS.                          PLOT0080
C     PARAMETER USAGE,                                                     PLOT0090
C        NO   A FIXED POINT NUMBER, UP TO 3 DIGITS, PRINTED AS THE         PLOT0100
C             CHART NUMBER                                                 PLOT0110
C        A    A VECTOR WHOSE FIRST N POSITIONS CONTAIN THE INDEPENDENT     PLOT0120
C             VARIABLE, AND WHOSE NEXT M SETS OF N POSITIONS CONTAIN       PLOT0130
C             THE DEPENDENT VARIABLES                                      PLOT0140
C        N    NUMBER OF OBSERVATIONS                                       PLOT0150
C        M    NUMBER OF VARIABLES (INDEPENDENT + DEPENDENT)                PLOT0160
C        NFUNC GREATER THAN ZERO IF A CALCULATED CURVE IS TO BE            PLOT0170
C             PRINTED                                                      PLOT0180
C        FUNC SUBROUTINE TO GENERATE CALCULATED CURVE, IF ONE WANTED,      PLOT0190
C             ELSE IS A DUMMY, PROGRAM CALLING PLOT MUST HAVE AN           PLOT0200
C             'EXTERNAL FUNC', SUBROUTINE CALLED BY CALL FUNC (X,Y),       PLOT0210
C             WHERE X IS GIVEN TO SUBROUTINE AND Y RETURNED.               PLOT0220
C        XLAX,XLIN,YLAX,YLIN  MAXIMUM AND MINIMUM VALUES OF THE            PLOT0230
C             INDEPENDENT AND DEPENDENT VARIABLES TO BE USED IN THE        PLOT0240
C             PLOT IF XLAX = XLIN, THE PROGRAM CALCULATES ITS OWN          PLOT0250
C             MAXIMUM AND MINIMUM FOR THE INDEPENDENT VARIABLE,            PLOT0260
C             SIMILARLY FOR YLAX = YLIN                                    PLOT0270
C     REQUIRED SUBROUTINES, FUNC (IF USED), AND SCAL,                      PLOT0280
C     KFS(1)= PLOTTING SYMBOL FOR FUNCTION                                 PLOT0290
C     KPS(2)=PLOTTING SYMBOL FOR DATA IN FIRST ARRAY,                      PLOT0300
C     KPS(3)=PLOTTING SYMBOL FOR DATA IN SECOND ARRAY ETC,                 PLOT0310
C     CALC IS 1 LARGER THAN NEEDED IN CASE XMIN + 100.XSCAL                PLOT0320
C     SHOULD BE LARGER THAN XMAX,  THIS PREVENTS SLOPOOVER INTO            PLOT0330
C     NEXT LOCATION.      LOOK AROUND CARD #950 TO SEE WHAT I MEAN,        PLOT0340
C     CALC IS WHERE CALCULATED FUNCTION GOES.                              PLOT0350
      DATA KB/1H  /                                                        PLOT0360
      EQUIVALENCE (IOUT(1),XPH(1))                                         PLOT0370
    1 FORMAT(1H1,60X,7H CHART ,I3)                                         PLOT0380
  113 FORMAT (1H ,12X,2H- ,101A1,1H-)                                      PLOT0390
```

```
    2 FORMAT (1H ,1PE12.3,2H+ ,101A1,1H+,E12.3)                        PLOT0400
    7 FORMAT (1H ,14X,10(10H+......... ),1H+)                          PLOT0410
    8 FORMAT(1H0,5X,1PE10.3,10E10.3)                                   PLOT0420
C     PRINT CHART NO.                                                  PLOT0430
      WRITE (6,1) NO                                                   PLOT0440
      ICOUNT = 4                                                       PLOT0450
C     IF NO EXTREMES OF X GIVEN, FIND THEM                             PLOT0460
      DIMENSION IOUT(101),XPR(11),A(800),CALC(102),KPS(4)              PLOT0470
      IF (XMAX - XMIN) 20,10,20                                        PLOT0480
   10 XMIN = A(1)                                                      PLOT0490
      XMAX = XMIN                                                      PLOT0500
      DO 15 J = 1,N                                                    PLOT0510
      IF (A(J) - XMIN) 11,12,12                                        PLOT0520
   12 IF (A(J) - XMAX) 15,15,14                                        PLOT0530
   11 XMIN = A(J)                                                      PLOT0540
      GO TO 15                                                         PLOT0550
   14 XMAX = A(J)                                                      PLOT0560
   15 CONTINUE                                                         PLOT0570
```

```
      GO TO 202                                                         PLOT0580
   20 XMAX=XLAX                                                         PLOT0590
      XMIN=XLIN                                                         PLOT0600
C     CALCULATE MAX SCALE SIZE                                          PLOT0610
  202 XSCAL=(XMAX-XMIN)/100.                                            PLOT0620
      XSCAL=AMAX1(XSCAL,1.0E-20)                                        PLOT0630
C     ROUTINE TO CALCULATE EXACT SCALE SIZE AND END POINTS              PLOT0640
      CALL SCAL (XSCAL,XMAX,XMIN)                                       PLOT0650
C     IF NO EXTREMES OF Y GIVEN, FIND THEM                              PLOT0660
      IF (YLAX - YLIN) 110,112,110                                      PLOT0670
  112 L  = N + 1                                                        PLOT0680
      YMIN = A(L)                                                       PLOT0690
      YMAX=YMIN                                                         PLOT0700
      LL = M*N                                                          PLOT0710
      DO 40 J = L,LL                                                    PLOT0720
      IF(A(J)-YMIN) 28,26,26                                            PLOT0730
   26 IF(A(J)-YMAX) 40,40,30                                            PLOT0740
   28 YMIN=A(J)                                                         PLOT0750
      GO TO 40                                                          PLOT0760
   30 YMAX=A(J)                                                         PLOT0770
   40 CONTINUE                                                          PLOT0780
      GO TO 201                                                         PLOT0790
  110 YMAX=YLAX                                                         PLOT0800
      YMIN=YLIN                                                         PLOT0810
C     GET SCALE SIZE AND END POINTS                                     PLOT0820
  201 YSCAL = (YMAX - YMIN ) / 50.                                      PLOT0830
      YSCAL=AMAX1(YSCAL,1.0E-20)                                        PLOT0840
      CALL SCAL (YSCAL,YMAX,YMIN)                                       PLOT0850
C     PRINT TOP SCALE                                                   PLOT0860
      XPR(1) = XMIN                                                     PLOT0870
      DO 200 JP=1,10                                                    PLOT0880
      XPR(JP+1) = XPR(JP) + XSCAL * 10.                                 PLOT0890
C     TO MAKE SURE THAT ZERO REALLY PRINTS AS ZERO, NOT A SMALL NUMBER  PLOT0900
C         CAUSED BY ROUNDING ERRORS.                                    PLOT0910
      IF (ABS(XPR(JP+1) - .5 * XSCAL)) 240,240,200                      PLOT0920
  240 XPR(JP+1) = 0.                                                    PLOT0930
  200 CONTINUE                                                          PLOT0940
      WRITE (6,8) (XPR(JP),JP=1,11)                                     PLOT0950
      WRITE (6,7)                                                       PLOT0960
```

```
C     IF CALCULATED CURVE WANTED GET VALUES BETWEEN XMIN AND XMAX        PLOT0970
      IF (NFUNC) 210,210,211                                             PLOT0980
  211 F = XMIN                                                           PLOT0990
      JP = 1                                                             PLOT1000
  213 CALL FUNC(F,CALC(JP))                                              PLOT1010
      IF (F - XMAX) 212,210,210                                          PLOT1020
  212 F = F + XSCAL                                                      PLOT1030
      JP = JP + 1                                                        PLOT1040
      GO TO 213                                                          PLOT1050
  210 CONTINUE                                                           PLOT1060
C     START PRINT AT MAXIMUM Y                                           PLOT1070
      YPR = YMAX                                                         PLOT1080
C     CLEAR PRINT LINE                                                   PLOT1090
  230 DO 55 JP = 1,101                                                   PLOT1100
   55 IOUT(JP) =K4                                                       PLOT1110
C     IF CALCULATED CURVE WANTED SET UP POINTS                           PLOT1120
      IF (NFUNC) 214,214,215                                             PLOT1130
  214 F = XMIN                                                           PLOT1140
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
C     SCAN ALL VALUES OF Y FOR X BETWEEN XMIN AND XMAX
      JP = 1
C     IS POINT WITHIN HALF A SCALE OF PRINT POSITION
  220 IF (ABS(YPR-CALC(JP)) - .5 * YSCAL) 216,217,218
C     IF EXACTLY  BETWEEN PRINT POSITIONS ONLY PRINT IT ONCE
  217 IF (YPR - CALC (JP)) 218,216,216
C     BELIEVE IT OR NOT THIS IS AN ASTERISK (NUMBER TOO LARGE TO WRITE
C        AS ONE NUMBER)
  216 IOUT(JP) =KPS(1)
  218 IF (F - XMAX) 219,214,214
  219 JP = JP +1
      F = F + XSCAL
      GO TO 220
C     RUN DOWN EACH SET OF DEPENDENT VARIABLES
C     IF NO POINTS WANTED
  214 IF (N) 70,70,300
  300 DO 221 J = 2,N
      DO 222 L = 1,N
C     CALCULATE SUBSCRIPT FOR A
      LL = (J - 1) * N + L
C     IS IT WITHIN HALF A SCALE OF PRINT POSITION
      IF (ABS(YPR - A(LL)) - .5 * YSCAL) 223,224,225
C     IF EXACTLY HALFWAY BETWEEN, PRINT ONLY ONCE
  224 IF (YPR - A(LL)) 225,223,223
C     FIND HORIZONTAL POSITION
  223 FJP = (A(L) -XMIN) / XSCAL + 1.5
      JP=IFIX(FJP)
C     IF OFF GRAPH, FORGET IT
      IF (JP - 1) 225,226,226
  226 IF (JP - 101) 227,227,225
C     THIS GIVES 1,2,3 ETC. FOR J=2,3,4 ETC
  227 IOUT(JP) =KPS(J)
  225 CONTINUE
  222 CONTINUE
  221 CONTINUE
   70 ICOUNT = ICOUNT +1
C     PRINT VALUE ON VERTICAL AXIS EVERY FIVE POSITIONS
      IF (ICOUNT - 5) 120,119,120
  120 WRITE (6,118)     (IOUT(JP),JP=1,101)
```

```
      GO TO 80                                                          PLOT1540
C     MAKE ZERO PRINT AS ZERO, NOT SMALL NUMBER                         PLOT1550
  119 IF (ABS(YPR )-.5 * YSCAL)  232,232,233                            PLOT1560
  232 F= 0.                                                             PLOT1570
      GO TO 234                                                         PLOT1580
  233 F = YPR                                                           PLOT1590
  234 WRITE (6,2) F, (IOUT(JP),JP=1,101),F                              PLOT1600
      ICOUNT = 0                                                        PLOT1610
C     IF REACHED YMIN, STOP                                             PLOT1620
   80 IF (YPR - YMIN) 86,86,45                                          PLOT1630
C     ELSE DECREMENT Y                                                  PLOT1640
   45 YPR = YPR - YSCAL                                                 PLOT1650
      GO TO 230                                                         PLOT1660
   86 WRITE (6,7)                                                       PLOT1670
C     PRINT BOTTOM SCALE                                                PLOT1680
      XPR(1) = XMIN                                                     PLOT1690
      DO 90 JP =1,10                                                    PLOT1700
      XPR(JP+1)=XPR(JP)+XSCAL*10.                                       PLOT1710
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      IF (ABS(XPR(JP+1) - .5*XSCAL)) 231,231,90                         PLOT1720
  231 XPR(JP+1) = 0.                                                    PLOT1730
   90 CONTINUE                                                          PLOT1740
      WRITE (6,8) (XPR(JP),JP=1,11)                                     PLOT1750
      RETURN                                                            PLOT1760
      END                                                               PLOT1770
```

```
      SUBROUTINE SCAL (XSCAL,XMAX,XMIN)
C     PURPOSE. GIVEN RAW SCALE AND END POINTS, GET ROUNDED VALUES,
      F=ALOG10(XSCAL*1.000001)
C     FIND NEXT LOWEST POWER OF 10.
      IF (F) 1,2,2
C     IF NEGATIVE, STOP FORTRAN FROM ROUNDING UP
    1 JP=-INT(-(F-1.0))
      GO TO 20
    2 JP=INT(F)
C     FIND VALUE JUST LARGER THAN RAW XSCAL, OF FORM 1,2,2.5,2,OR 10
C         TIMES 10 TO AN INTEGRAL POWER -
   20 F=10.**JP
    6 IF (F-XSCAL) 3,4,4
    3 F=F+F
      IF (F-XSCAL) 5,4,4
    5 F=1.25*F
      IF (F-XSCAL) 7,4,4
    7 F=F+F
      IF (F-XSCAL) 30,4,4
   30 F=F+F
      GO TO 6
C     SET EQUAL TO SCALE
    4 XSCAL=F
      IF (ABS(XMAX/XSCAL)-1.0E9) 8,11,11
    8 JP=INT(XMAX/XSCAL)
C     MAKE END POINTS INTEGRAL MULTIPLES OF SCALE
   12 F=XSCAL*FLOAT(JP)
      IF (F-XMAX) 10,11,11
   10 JP=JP+1
      GO TO 12
   11 XMAX=F
      IF (ABS(XMIN/XSCAL)-1.0E9) 9,14,14
    9 JP=INT(XMIN/XSCAL)
   13 F=XSCAL*FLOAT(JP)
      IF (F-XMIN) 14,14,15
   15 JP=JP-1
      GO TO 13
   14 XMIN=F
      RETURN
      END
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE DUMPE                                                   DUMP0010
      PARAMETER NDC=200                                                  DUMP0020
      COMMON /ALL/ IN,K,,KP,KM,IPL1,IPL2,KST,KKST,IMW,KSW,KK,KKO,        DUMP0030
     2 NFS,NFE,NPS,NPE,IPRJ,IPO,XBR,ZMAX,ZR,IR,VHL(NDC),VHR(NDC),        DUMP0040
     3 FL,RHOP,VISCG,VPMIN,PDF,FJ,CMAX,PV1,PV2,PV3,CHARG,PROJW,CHAML,    DUMP0050
     4 WIDTH,CPP,EL,FORCE,DSCPSI,BR,DYDT,AP,CCPCIN,AC,VPROJ,ZPROJ,PR,    DUMP0060
     5 F(NDC,7),CG(NDC),EG(NDC),FN(NDC),TP(NDC),FM(NDC),UG(NDC),         DUMP0070
     6 UP(NDC),A(NDC),AB(NDC),V(NDC),VB(NDC),XC(9),RHOG(NDC),PG(NDC),    DUMP0080
     7 PD(NDC),DP(NDC),PS(NDC),DF(NDC,7),G(NDC,7),W(NDC),Z(NDC),ZB(NDC)  DUMP0090
     8 ,TGA(NDC),GCA(NDC),SEA(NDC),VFA(NDC),FMV(NDC)                     DUMP0100
      IMWP1=IMW+1                                                        DUMP0110
      WRITE (6,101)                                                      DUMP0120
  101 FORMAT (1H0,/// 23X,10HFROM DUMPE    )                             DUMP0130
      WRITE (6,103) (I, G(I),UP(I),PG(I),G(I),PD(I),CG(I),VFA(I),        DUMP0140
     2 RHOG(I),I=1,IMWP1)                                                DUMP0150
  103 FORMAT (1H0,7X,1HI,4X,2HUG,12X,2HUP,12X,2HPG,12X,1HG,13X,2HPD,     DUMP0160
     2 12X,2HCG,12X,3HVFA,11X,4HRHOG / (1H ,I8,1PE14.4,7E14.6))          DUMP0170
      WRITE (6,104) (I,EG(I),TGA(I),TP(I),FN(I),DP(I),DG(I),GCA(I),      DUMP0180
     2 SEA(I),I=1,IMWP1)                                                 DUMP0190
  104 FORMAT (1H0,7X,1HI,4X,2HEG,12X,3HTGA,11X,2HTP,12X,2HFN,12X,2HDP,   DUMP0200
     2 12X,2HDG,12X,3HGCA,11X,3HSEA / (1H ,I8,1PE14.6,7E14.6))           DUMP0210
      WRITE (6,105) (I,FM(I),FMV(I),I=1,IMWP1)                           DUMP0220
  105 FORMAT (1H0,7X,1HI,4X,2HFM,12X,3HFMV / (1H ,I8,1PE14.6,E14.6))     DUMP0230
      WRITE (6,106) (K,K=1,7),(I,( F(I,K),K=1,7),I=1,IMWP1)              DUMP0240
  106 FORMAT (1H0,7X,1HI,4X,5H F(I,  ,I1,1H) , 6(7X,5H F(I, ,I1,1H) )/   DUMP0250
     2 (1H ,I8,1PE14.6,6E14.6))                                          DUMP0260
      WRITE (6,107) (K,K=1,7),(I,(DF(I,K),K=1,7),I=1,IMWP1)              DUMP0270
  107 FORMAT (1H0,7X,1HI,4X,5HDF(I,  ,I1,1H) , 6(7X,5HDF(I, ,I1,1H) )/   DUMP0280
     2 (1H ,I8,1PE14.6,6E14.6))                                          DUMP0290
      WRITE (6,108) (K,K=1,7),(I,( G(I,K),K=1,7),I=1,IMWP1)              DUMP0300
  108 FORMAT (1H0,7X,1HI,4X,5H G(I,  ,I1,1H) , 6(7X,5H G(I, ,I1,1H) )/   DUMP0310
     2 (1H ,I8,1PE14.6,6E14.6))                                          DUMP0320
      RETURN                                                             DUMP0330
      END                                                                DUMP0340
```

```
      GO TO 15                                                          POW 0400
   10 X2=X*X                                                            POW 0410
      X4=X2*X2                                                          POW 0420
      X8=X4*X4                                                          POW 0430
      XP=X8*X2                                                          POW 0440
   15 GO TO (16,17),KS                                                  POW 0450
   16 POW=1.0/XP                                                        POW 0460
      RETURN                                                            POW 0470
   17 POW=XP                                                            POW 0480
      RETURN                                                            POW 0490
      END                                                               POW 0500
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      FUNCTION ROOT (X,K)                                               ROOT0010
C     ROOT=KTH ROOT OF X                                                ROOT0020
C     K MUST SATISFY  .GE. 0 .AND. .LE. 10                              ROOT0030
      DATA L / 1 /, F / 0.9 /                                           ROOT0040
      DIMENSION A(10),C(11,10)                                          ROOT0050
      GO TO (1,5),L                                                     ROOT0060
    1 DO 4 M=1,10                                                       ROOT0070
      FM=FLOAT(M)                                                       ROOT0080
      A(M)=(0.75)**(1.0/FM)                                             ROOT0090
      C(1,M)=1.0                                                        ROOT0100
      DO 3 J=1,10                                                       ROOT0110
      FJ=FLOAT(J)                                                       ROOT0120
    3 C(J+1,M)=2.0**(FJ/FM)                                             ROOT0130
    4 CONTINUE                                                          ROOT0140
      L=2                                                               ROOT0150
    5 IF (K) 6,7,8                                                      ROOT0160
    6 ROOT=0.0                                                          ROOT0170
      RETURN                                                            ROOT0180
    7 ROOT=1.0                                                          ROOT0190
      RETURN                                                            ROOT0200
    8 IF (K-1) 10,9,10                                                  ROOT0210
    9 ROOT=X                                                            ROOT0220
      RETURN                                                            ROOT0230
   10 IF (X) 11,11,12                                                   ROOT0240
   11 ROOT=0.0                                                          ROOT0250
      RETURN                                                            ROOT0260
   12 N1=FLD(0,9,X)                                                     ROOT0270
      J=FLD(9,27,X)                                                     ROOT0280
      FLD(9,27,F)=J                                                     ROOT0290
      E=F-0.75                                                          ROOT0300
      U=E*4.0/3.0                                                       ROOT0310
      FK=FLOAT(K)                                                       ROOT0320
      S=A(K)*(2.0*FK+(FK+1.0)*U)/(2.0*FK+(FK-1.0)*U)                    ROOT0330
      N=N1-128                                                          ROOT0340
      M=(N+100*K)/K-100                                                 ROOT0350
      NR=N-K*M                                                          ROOT0360
      FLD(0,9,S)=M+128                                                  ROOT0370
      Y=C(NR+1,K)*S                                                     ROOT0380
      IF (K-10) 14,14,15                                                ROOT0390
```

```
15 ROOT=0.0                                                     ROOT0400
   RETURN                                                       ROOT0410
14 YS=Y                                                         ROOT0420
   DO 33 LL=1,10                                                ROOT0430
   GO TO (21,22,23,24,25,26,27,28,29,30),K                      ROOT0440
21 P=X                                                          ROOT0450
   GO TO 31                                                     ROOT0460
22 P=(Y*Y+X)/(2.0*Y)                                            ROOT0470
   GO TO 31                                                     ROOT0480
23 Y2=Y*Y                                                       ROOT0490
   P=(2.0*Y2*Y+X)/(3.0*Y2)                                      ROOT0500
   GO TO 31                                                     ROOT0510
24 Y2=Y*Y                                                       ROOT0520
   Y4=Y2*Y2                                                     ROOT0530
   P=(3.0*Y4+X)/(4.0*Y2*Y)                                      ROOT0540
   GO TO 31                                                     ROOT0550
25 Y2=Y*Y                                                       ROOT0560
   Y4=Y2*Y2                                                     ROOT0570
```

ONE DIMENSIONAL GAS PARTICLE FLOW

```
      P=(4.0*Y4*Y+X)/(5.0*Y4)                                     ROOT0580
      GO TO 31                                                    ROOT0590
   26 Y2=Y*Y                                                      ROOT0600
      Y4=Y2*Y2                                                    ROOT0610
      P=(5.0*Y4*Y2+X)/(6.0*Y4*Y)                                  ROOT0620
      GO TO 31                                                    ROOT0630
   27 Y2=Y*Y                                                      ROOT0640
      Y4=Y2*Y2                                                    ROOT0650
      Y6=Y4*Y2                                                    ROOT0660
      P=(6.0*Y6*Y+X)/(7.0*Y6)                                     ROOT0670
      GO TO 31                                                    ROOT0680
   28 Y2=Y*Y                                                      ROOT0690
      Y4=Y2*Y2                                                    ROOT0700
      P=(7.0*Y4*Y4+X)/(8.0*Y4*Y2*Y)                               ROOT0710
      GO TO 31                                                    ROOT0720
   29 Y2=Y*Y                                                      ROOT0730
      Y4=Y2*Y2                                                    ROOT0740
      Y8=Y4*Y4                                                    ROOT0750
      P=(8.0*Y8*Y+X)/(9.0*Y8)                                     ROOT0760
      GO TO 31                                                    ROOT0770
   30 Y2=Y*Y                                                      ROOT0780
      Y4=Y2*Y2                                                    ROOT0790
      Y8=Y4*Y4                                                    ROOT0800
      P=(9.0*Y8*Y2+X)/(10.0*Y8*Y)                                 ROOT0810
   31 IF (ABS(1.0-Y/P)-1.0E-5)34,34,32                            ROOT0820
   32 Y=P                                                         ROOT0830
   33 CONTINUE                                                    ROOT0840
   34 ROOT=P                                                      ROOT0850
      RETURN                                                      ROOT0860
      END                                                         ROOT0870
```

APPENDIX B

TWO-DIMENSIONAL GAS PARTICLE FLOW

```
C   MAIN PROGRAM FOR 2-PHASE/2-D AXIAL SYMMETRY FLOW MODEL - NOZZLE BLAST
      PARAMETER ID=25,JD=15,LD=400,NRKD=2625
      DIMENSION Y(NRKD),DY(NRKD),AE(NRKD),RE(NRKD),REF(7),AEF(7),FMV(LD)
      DIMENSION ZPN(ID)
      COMMON/MC/NIJW,IW(8),JW(8),PW(8)
      COMMON /ALL/ F(ID,JD,7),DF(ID,JD,7),II,IS,IA,IB,IM,JA,JB,JM,IT,
     1FJ,VOLP,WM,APF,VFLMAX,PAV,FL,RG,KW,KK,KKO,KM,PIN,IRK,RHOP,
     2 TI(LD),PIND(LD),CIND(LD),WINDG(LD),NIND(LD),
     3Z(ID),ZZ(ID),DELZ(ID),DELZZ(ID),R(JD),RR(JD),DELR(JD),DELRR(JD),
     4AZ(JD),AZD(JD),AR(ID,JD),ARN(ID,JD),ARD(ID,JD),V(ID,JD),VZ(ID,JD),
     5VR(ID,JD),C(ID,JD),CZ(ID,JD),CR(ID,JD),CD(ID,JD),WG(ID,JD),
     6WGN(ID,JD),WGD(ID,JD),UG(ID,JD),UGN(ID,JD),UGD(ID,JD),WP(ID,JD),
     7WPR(ID,JD),UP(ID,JD),UPZ(ID,JD),N(ID,JD),NZ(ID,JD),NR(ID,JD),
     8E(ID,JD),EI(ID,JD),P(ID,JD),GR(ID,JD),PD(ID,JD),DR(ID,JD),
     9PZ(ID,JD),LWP(ID,JD),KUP(ID,JD),LWG(ID,JD),KUG(ID,JD),GZ(ID,JD)
     A ,WINDP(LD)
      REAL N,NIND,NR,NZ
 1000 READ (5,1002) II,IP,JM,KW,KM,KST,KKST,KMID
 1002 FORMAT (8I10)
      READ (5,1004) RG,PATM,DATM,FJ,RHOP,DIAP,VFLMAX,PAV,FL,ER
 1004 FORMAT (8F10.5/2F10.5)
C   PRELIMINARY CALCULATIONS
      VOLP = .5236*(DIAP**3)
      WM = VOLP*RHOP
      APF = .172*(DIA**2)
      AEF(1)=ER*VFLMAX/VOLP
      AEF(2)=ER*1.0E5
      AEF(3)=AEF(2)
      AEF(4)=ER*0.002
      AEF(5)=AEF(4)*1.0E5
      AEF(6)=AEF(5)
      AEF(7)=ER*0.002*200.0
      DO 36 I=1,7
   36 REF(I)=ER
      REWIND 8
      REWIND 9
      REWIND 11
      DO 37 LLL=2,LD
      LS=LLL
```

```
      READ (11) K1,TI(LLL),PIND(LLL),CIND(LLL),WINDG(LLL),WINDP(LLL),     MAIN0400
     2 FMV(LLL)                                                          MAIN0410
      IF (K1-KMID) 37,38,38                                              MAIN0420
   37 CONTINUE                                                           MAIN0430
   38 CONTINUE                                                           MAIN0440
      REWIND 11                                                          MAIN0450
      DO 39 LLL=2,LS                                                     MAIN0460
      WINDG(LLL)=-WINDG(LLL)                                             MAIN0470
      WINDP(LLL)=-WINDP(LLL)                                             MAIN0480
   39 NIND(LLL)=FMV(LLL)/(RHOP*3.14159*0.25*DIAP**3)                     MAIN0490
      TI(1) = 0.                                                         MAIN0500
      PIND(1)=PATM                                                       MAIN0510
      CIND(1) = PATM                                                     MAIN0520
      WINDG(1) = 0.                                                      MAIN0530
      WINDP(1) = 0.                                                      MAIN0540
      NIND(1) = 0.                                                       MAIN0550
      READ (5,1030) NIJW,(IW(I),I=1,8),(JW(I),I=1,8)                     MAIN0560
 1030 FORMAT (I10/8I10/8I10)                                             MAIN0570
```

```
      KK = -1                                                          MAIN0580
      KKO=-1                                                           MAIN0590
      IM=II+IP-1                                                       MAIN0600
      IT = II+2                                                        MAIN0610
      IS = II+1                                                        MAIN0620
      IA = IM-2                                                        MAIN0630
      IB = IM-1                                                        MAIN0640
      JA = JM-2                                                        MAIN0650
      JB = JM-1                                                        MAIN0660
      READ (5,1102) RMAX,ZMAX,ZREF                                     MAIN0670
 1102 FORMAT (3E10.5)                                                  MAIN0680
      WRITE (6,2001) RMAX,ZMAX,ZREF                                    MAIN0690
 2001 FORMAT (1H ,5X,5HRMAX=,1PE14.5,5X,5HZMAX=,E14.5,5X,5HZREF=,E14.5) MAIN0700
      CALL UNEQR (JM,RMAX,2,2.0,RG,RR,JD)                              MAIN0710
      IMPI=MAX0(II,IP)                                                 MAIN0720
      CALL UNEQR (IMPI,ZMAX,2,ZREF,ZPN,ID)                             MAIN0730
      DO 10 I=1,II                                                     MAIN0740
   10 Z(I)=ZPN(II)-ZPN(II+1-I)                                         MAIN0750
      DO 12 I=IS,IM                                                    MAIN0760
   12 Z(I)=ZPN(II)+ZPN(I+1-II)                                         MAIN0770
      DO 14  J=1,JB                                                    MAIN0780
   14 R(J+1)=0.5*(RR(J)+RR(J+1))                                       MAIN0790
      R(1)=-R(2)                                                       MAIN0800
      DO 16  I=1,IM                                                    MAIN0810
   16 ZZ(I) = .5*(Z(I+1)+Z(I))                                         MAIN0820
      DO 18  I=2,IM                                                    MAIN0830
   18 DELZ(I) = Z(I)-Z(I-1)                                            MAIN0840
      DO 20  I=2,IB                                                    MAIN0850
   20 DELZZ(I) = ZZ(I)-ZZ(I-1)                                         MAIN0860
      DO 22  J=2,JM                                                    MAIN0870
   22 DELR(J) = R(J)-R(J-1)                                            MAIN0880
      DO 24  J=2,JB                                                    MAIN0890
      DELRR(J) = RR(J)-RR(J-1)                                         MAIN0900
      AZ(J) = 3.142*(RR(J)**2-RR(J-1)**2)                              MAIN0910
   24 AZR(J) = 3.142*(R(J+1)**2-R(J)**2)                               MAIN0920
      DO 26  I=2,IB                                                    MAIN0930
      DO 26  J=2,JB                                                    MAIN0940
      AR(I,J) = 6.283*RR(J)*DELZZ(I)                                   MAIN0950
      ARZ(I,J) = 6.283*RR(J)*DELZ(I+1)                                 MAIN0960
```

```
26 ARM(I,J) = 6.283*R(J)*DELZZ(I)                                            MAIN0970
   DO 28  I=2,IA                                                             MAIN0980
   DO 28  J=2,JA                                                             MAIN0990
   V(I,J) = AV(J)*DELZZ(I)                                                   MAIN1000
   VZ(I,J) = AZ(J)*DELZ(I+1)                                                 MAIN1010
28 VR(I,J) = AZR(J)*DELZZ(I)                                                 MAIN1020
   WRITE (6,2002) II,IM,JM,KW,KM,KST,KKST                                    MAIN1030
2002 FORMAT (1H1,26X45HNOZZLE BLAST EFFECTS WITH PARTICULATE EJECTION//     MAIN1040
  130X37H2-PHASE/2-D AXIAL SYMMETRY FLOW MODEL///                            MAIN1050
  245X4HII =,I6/45X4HIM =,I6/45X4HJM =,I6/45X4HKW =,I6/45X4HKM =,I6/         MAIN1060
  3 45X,4HKST=,I6,/ 45X,5HKKST=,I4 // 1X)                                    MAIN1070
   WRITE (6,2004) RG,PATM,DATM,FJ,RHOP,DIAP,VFLMAX,PAV,FL,ER                 MAIN1080
2004 FORMAT (1H0,                                                            MAIN1090
  119X30HNOZZLE RADIUS,RG                  ,E10.4,2X12H(CM)                 /MAIN1100
  220X30HATMOSPHERIC PRESSURE,PATM         ,E10.4,2X12H(DY/SQ-CM)           /MAIN1110
  320X30HATMOSPHERIC DENSITY,DATM          ,E10.4,2X12H(GR/CC)              /MAIN1120
  420X30HMECHANICAL-HEAT EQUIV.,FJ         ,E10.4,2X12H(DY-CM/CAL)          /MAIN1130
  520X30HPARTICULATE DENSITY,RHOP          ,E10.4,2X12H(GR/CC)              /MAIN1140
```

```
     620X30HPARTICLE DIAMETER,DIAP          ,E10.4,2X12H(CM)            /MAIN1150
     720X30HMAX. ALLOWABLE VFL,VFLMAX        ,E10.4,                     /MAIN1160
     820X30HPARTICLE PRESSURE FACTOR,PAV     ,E10.4,2X12H(DY/SQ-CM)      /MAIN1170
     920X30HARTIFICIAL VISC. FACTOR,FL       ,E10.4,                      MAIN1180
     A 20X,30HERROR LIMIT, ER                 ,E10.4, ///1X)               MAIN1190
      WRITE (6,2006)                                                       MAIN1200
2006  FORMAT (1H0,3X10HEQ. TYPE,M,4X28HRELATIVE ERROR FACTOR,REF(M),10X2MAIN1210
     18HABSOLUTE ERROR FACTOR,AEF(M)//1X)                                  MAIN1220
      DO 2008   M=1,7                                                      MAIN1230
2008  WRITE (6,2010) M,REF(M),AEF(M)                                       MAIN1240
2010  FORMAT (I8,F22.2,E43.2)                                              MAIN1250
      WRITE (6,2030) (I,IW(I),JW(I),I=1,NIJW)                              MAIN1260
2030  FORMAT (1H0,19X,1HI,8X,2HIW,8X,2HJW / (1H ,10X,3I10))                MAIN1270
      WRITE (6,2012)                                                       MAIN1280
2012  FORMAT (1H1,27X25HRADIAL POSITION DATA (CM)//3X31HNODE NUMBER,J   NMAIN1290
     1ODE RADIUS,R(J),6X5HRR(J),5X7HDELR(J),5X8HDELRR(J)//1X)              MAIN1300
      DO 2014   J=1,JM                                                     MAIN1310
2014  WRITE (6,2016) J,R(J),RR(J),DELR(J),DELRR(J),AZ(J),AZD(J)            MAIN1320
2016  FORMAT (I10,F18.1,F17.2,F11.2,F13.2,2F13.6)                          MAIN1330
      WRITE (6,2018)                                                       MAIN1340
2018  FORMAT (1H1,27X24HAXIAL POSITION DATA (CM)//3X33HNODE NUMBER,I  NOMAIN1350
     1DE POSITION,Z(I),5X5HZZ(I),5X7HDELZ(I),5X8HDELZZ(I)//1X)             MAIN1360
      DO 2020   I=1,IM                                                     MAIN1370
2020  WRITE (6,2022) I,Z(I),ZZ(I),DELZ(I),DELZZ(I)                         MAIN1380
2022  FORMAT (I10,F18.1,F18.2,F11.2,F13.2)                                 MAIN1390
      WRITE (6,2024)                                                       MAIN1400
2024  FORMAT (1H1,30X17HNOZZLE INPUT DATA//5X1HM,8X5HTI(M),13X7HPIND(M),MAIN1410
     111X7HCIND(M),11X8HWINDG(M),10X,8HWINDP(M),10X,7HNIND(M)//1X)         MAIN1420
      DO 2026   M=1,LS                                                     MAIN1430
2026  WRITE (6,2028) M,TI(M),PIND(M),CIND(M),WINDG(M),WINDP(M),NIND(M)     MAIN1440
2028  FORMAT (1H ,I5,1PE18.5,5E18.5)                                       MAIN1450
C  INITIALIZE PHYSICAL VARIABLES AND F(I,J,M) - COMPUTE ERROR LIMITS FORMAIN1460
      DO 50   I=2,IA                                                       MAIN1470
      DO 50   J=2,JA                                                       MAIN1480
      IF (J .EQ. 2 .AND. I .LT. IS)   GO TO 50                             MAIN1490
      N(I,J) = 0.                                                          MAIN1500
      UP(I,J) = 0.                                                         MAIN1510
      WP(I,J) = 0.                                                         MAIN1520
      C(I,J) = DATM                                                        MAIN1530
```

```
      UG(I,J) = 0.                                                      MAIN1540
      WG(I,J) = 0.                                                      MAIN1550
      E(I,J) = 2.5*PATM/FJ                                              MAIN1560
      F(I,J,1) = N(I,J)                                                 MAIN1570
      F(I,J,2) = UP(I,J)                                                MAIN1580
      F(I,J,3) = WP(I,J)                                                MAIN1590
      F(I,J,4) = C(I,J)                                                 MAIN1600
      F(I,J,5) = 0.                                                     MAIN1610
      F(I,J,6) = 0.                                                     MAIN1620
      F(I,J,7) = E(I,J)                                                 MAIN1630
   50 CONTINUE                                                          MAIN1640
C  INITIALIZE Y(L)                                                      MAIN1650
      L = 0                                                             MAIN1660
      DO 60   I=2,IA                                                    MAIN1670
      DO 60   J=2,JA                                                    MAIN1680
      IF (J .EQ. 2 .AND. I .LT. IS)   GO TO 60                          MAIN1690
      DO 62   M=1,7                                                     MAIN1700
      L = L+1                                                           MAIN1710
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      RE(L) = REF(M)
      AE(L) = REF(M)*AEF(M)
   62 Y(L) = F(I,J,M)
   60 CONTINUE
      IRK =L
      T = 0.
      DT = .0001
      EXTERNAL DERIV,CNTRL
      REWIND 8
      REWIND 9
      REWIND 10
      IF (KST-2) 34,30,34
   30 DO 31 LL=1,10000
      READ  (9) KK,T,DT,(Y(I),I=1,IRK)
      READ (10) KK1
      IF (KK-KKST) 31,32,32
   31 CONTINUE
   32 CONTINUE
      DO 41 LL=1,10000
      READ (8) KK1
      IF (KK1-KK) 41,42,42
   41 CONTINUE
   42 CONTINUE
      KK=KK-1
   34 CONTINUE
      CALL RK2 (DERIV,CNTRL,Y,DY,AE,RE,T,DT,IRK,2,0E6)
      REWIND 8
      REWIND 9
      REWIND 10
      STOP
      END
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE DERIV(Y,DY,T)
C     CELL AND DEFINITION OF ASSOCIATED VARIABLES
C
C           (I,J+1)*                                                       *
C
C
C
C                    F(I,J,2)
C                    F(I,J,5)
C                    GR(I,J,4)
C                    GR(I,J,7)
C                    U
C--------------------------------------------------+
C                    DR(I,J)                        I
C                                                   I
C                                                   I
C                                                   I
C                                                   IW
C                    C,N,E,P                        I
C                    F(I,J,1)                       I F(I,J,3)
C                    F(I,J,4)                       I F(I,J,6)
C                    F(I,J,7)                       I GZ(I,J,1)
C           (I,J) *  GZ(I,J,3)                      I GZ(I,J,4)               (I+1,J)
C                    GZ(I,J,6)                      I GZ(I,J,7)
C                    GR(I,J,2)                      I DZ(I,J)
C                    GR(I,J,5)                      I
C                                                   I
C                                                   I
C                                                   I
C                                                   I
C--------------------------------------------------+
C                                                   I
C                                                   I
C                                                   I
C
C
C
C
C     BARREL AND DISTRIBUTION OF NODES
```

```
C                                                                          DERI0400
C                                                                          DERI0410
C  *      *      *      *      *      *      *      *      *      *      *      *  JMDERI0420
C                                                                          DERI0430
C  *      *      *      *      *      *      *      *      *      *      *      *    DERI0440
C                                                                          DERI0450
C  *      *      *      *      *      *      *      *      *      *      *      *    DERI0460
C                                                                          DERI0470
C  *      *      *      *      *      *      *      *      *      *      *      *    DERI0480
C                                                                          DERI0490
C  *      *      *      *      *      *      *      *      *      *      *      *    DERI0500
C                                                                       R  DERI0510
C  *      *      *      *      *      *      *      *      *      *      *      *    DERI0520
C                                                                          DERI0530
C  *      *      *      *      *      *      *      *      *      *      *      *    DERI0540
C-----------------------------------------------+                          DERI0550
C  *      *      *      *      *      *      *  I   *      *      *      *  IBL *    DERI0560
C                                               I                          DERI0570
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
C  *     *     *     *     *     *     *   I  *     *     *     *     *        DERI0580
C                                          I                                   DERI0590
C  *     *     *     *     *     *     *   I  *     *     *     *     *        DERI0600
C                                          I                                   DERI0610
C  *     *     *     *     *     *     *   I  *     *     *     *     *        DERI0620
C+++++++++++++++++++++++++++++++++++++++++++I++++++++++++++++++++++++++++++++++DERI0630
C  *     *     *     *     *     *     *   I  *     *     *     *     *        DERI0640
C  IN                          II                                   IP       DERI0650
C  1                                 Z                              IM       DERI0660
C                                                                             DERI0670
C                                                                             DERI0680
C                                                                             DERI0690
C       F(I,J,1) = NUMBER OF PARTICLES PER UNIT VOLUME                        DERI0700
C       F(I,J,2) = RADIAL MOMENTUM OF PARTILES                                DERI0710
C       F(I,J,3) = AXIAL  MOMENTUM OF PARTILES                                DERI0720
C       F(I,J,4) = GAS CONCENTRATION                                          DERI0730
C       F(I,J,5) = RADIAL MOMENTUM OF GAS                                     DERI0740
C       F(I,J,6) = AXIAL  MOMENTUM OF GAS                                     DERI0750
C       F(I,J,7) = TOTAL ENERGY OF GAS                                        DERI0760
C       GZ(I,J,K) = FLUX IN AXIAL DIRECTION                                   DERI0770
C       GR(I,J,K) = FLUX IN RADIAL DIRECTION                                  DERI0780
        PARAMETER ID=25,JD=15,LD=400,NRKD=2625                                DERI0790
        DIMENSION Y(NRKD),DY(NRKD)                                            DERI0800
        DIMENSION QPR(ID,JD),QPZ(ID,JD)                                       DERI0810
        COMMON /AL-/ F(ID,JD,7),DF(ID,JD,7),II,IS,IA,IB,IM,JA,JB,JM,IT,       DERI0820
       1FJ,VOLP,AM,APF,VELMAX,PAV,EL,RG,KW,KK,KKO,KM,PIN,IRK,RHOP,            DERI0830
       2 YI(LD),PIND(LD),CIND(LD),WINDG(LD),NIND(LD),                         DERI0840
       3Z(ID),ZZ(ID),DELZ(ID),DELZZ(ID),R(JD),RR(JD),DELR(JD),DELRR(JD),      DERI0850
       4AZ(JD),AZD(JD),AR(ID,JD),ARN(ID,JD),ARD(ID,JD),V(ID,JD),VZ(ID,JD),    DERI0860
       5VR(ID,JD),C(ID,JD),CZ(ID,JD),CR(ID,JD),CD(ID,JD),WG(ID,JD),           DERI0870
       6WGN(ID,JD),WGD(ID,JD),UG(ID,JD),UGN(ID,JD),UGD(ID,JD),WP(ID,JD),      DERI0880
       7WPR(ID,JD),UP(ID,JD),UPZ(ID,JD),N(ID,JD),NZ(ID,JD),NR(ID,JD)          DERI0890
       8E(ID,JD),EI(ID,JD),P(ID,JD),GR(ID,JD),PD(ID,JD),DR(ID,JD),            DERI0900
       9DZ(ID,JD),WP(ID,JD),KUP(ID,JD),LWG(ID,JD),KUG(ID,JD),QZ(ID,JD)        DERI0910
       A ,WINDF(LD)                                                           DERI0920
        COMMON /DC/ CIN,WING,WINP,NIN,                                        DERI0930
       2 GRU(ID,JD),GZU(ID,JD),GRW(ID,JD),GZW(ID,JD)                          DERI0940
        DATA/SS/30000./                                                       DERI0950
        REAL N,NIND,NR,NZ,NIN                                                 DERI0960
```

```
C   CONVERT F(I,J,M) FROM Y(L)                                         DERI0970
      L=0                                                              DERI0980
      DO 1 I=2,IA                                                      DERI0990
      DO 1 J=2,JA                                                      DERI1000
      IF(J.EQ.2.AND.I.LT.IS) GO TO 1                                   DERI1010
      DO 3 M=1,7                                                       DERI1020
      L=L+1                                                            DERI1030
    3 F(I,J,M)=Y(L)                                                    DERI1040
    1 CONTINUE                                                         DERI1050
C   CONVERT PHYSICAL VARIABLES FROM F(I,J,M) EXCEPT CR*UG AND CZ*WG    DERI1060
      DO 10 I=2,IA                                                     DERI1070
      DO 10 J=2,JA                                                     DERI1080
      IF(J.EQ.2.AND.I.LT.IS) GO TO 15                                  DERI1090
      N(I,J)=F(I,J,1)                                                  DERI1100
      UP(I,J)=F(I,J,2)                                                 DERI1110
      WP(I,J)=F(I,J,3)                                                 DERI1120
      C(I,J)=F(I,J,4)                                                  DERI1130
      E(I,J)=F(I,J,7)                                                  DERI1140
```

```
 10  CONTINUE
C BOUNDARY VALUES FOR C(I,J)
     C(IB,2)=C(IA,2)
     DO 12 J=3,JA
     C(IB,J)=C(IA,J)
 12  C(1,J)=C(2,J)
     DO 14 I=IS,IB
 14  C(I,1)=C(I,2)
     DO 16 I=1,IS
 16  C(I,JB)=C(I,JA)
      DO 18 I=2,II
 18  C(I,2)=C(I,3)
C EVALUATE CZ AND CR
C CONVERT UG AND WG FROM F(I,J,M)
     DO 24 I=2,IA
     DO 24 J=2,JA
     IF(J.EQ.2.AND.I.LT.IS) GO TO 24
     CZ(I,J)=.5*(C(I+1,J)+C(I,J))
     CR(I,J)=.5*(C(I,J+1)+C(I,J))
     UG(I,J)=F(I,J,5)/CR(I,J)
     WG(I,J)=F(I,J,6)/CZ(I,J)
 24  CONTINUE
C SET BOUNDARY VALUES FOR PHYSICAL VARIABLES
     DO 30 J=3,JA
     E(1,J)=E(2,J)
     N(1,J)=N(2,J)
     UP(1,J)=UP(2,J)
     UG(1,J)=UG(2,J)
     WP(1,J)=WP(2,J)
 30  WG(1,J)=WG(2,J)
     DO 32 J=2,JA
     E(IB,J)=E(IA,J)
     N(IB,J)=N(IA,J)
     WP(IB,J)=WP(IA,J)
     WG(IB,J)=WG(IA,J)
     UP(IB,J)=UP(IA,J)
 32  UG(IB,J)=UG(IA,J)
     DO 34 I=1,IA
     E(I,JB)=E(I,JA)
```

```
      N(I,JB)=N(I,JA)                                                   DERI1540
      UP(I,JB)=UP(I,JA)                                                 DERI1550
      UG(I,JB)=UG(I,JA)                                                 DERI1560
      WP(I,JB)=WP(I,JA)                                                 DERI1570
   34 WG(I,JB)=WG(I,JA)                                                 DERI1580
      DO 36 I=2,II                                                      DERI1590
      E(I,2)=E(I,3)                                                     DERI1600
      N(I,2)=N(I,3)                                                     DERI1610
      WP(I,2)=WP(I,3)                                                   DERI1620
      WG(I,2)=WG(I,3)                                                   DERI1630
      UP(I,2)=0.                                                        DERI1640
   36 UG(I,2)=0.                                                        DERI1650
      DO 38 I=IS,IB                                                     DERI1660
      E(I,1)=E(I,2)                                                     DERI1670
      N(I,1)=N(I,2)                                                     DERI1680
      WP(I,1)=WP(I,2)                                                   DERI1690
      WG(I,1)=WG(I,2)                                                   DERI1700
      UG(I,1)=0.                                                        DERI1710
```

```
   38 UP(I,1)=0.
C     COMPUTE INPUT VALUES AT NOZZLE CELL
      CALL NZLINP (TI,PIND,CIND,WINDG,WINDP,NIND,T,PIN,CIN,WING,WINP,
     2 NIN,LD)
      VFLIN=NIN*VOLP
      VFLIN=AMIN1(VFLIN,.9999)
      VFLIN=AMAX1(VFLIN,.0)
      EIIN=PIN*(1.0-VFLIN)/(0.4*FJ*CIN)
      EIN=CIN*(EIIN+(WING**2)/(2.0*FJ))
C     COMPUTE COMPUTED VARIABLES FOR NOZZLE CELL
      EI(IS,2)=E(IS,2)/C(IS,2)
     2 -0.25*(WG(IS,2)**2+WING**2+UG(IS,2)**2)/FJ
      VFL=N(IS,2)*VOLP
      VFL=AMIN1(VFL,.9999)
      VFL=AMAX1(VFL,.0)
      PD(IS,2) = 0.
      VFR=(1.0-VFL)/(1.0-VFLMAX)
      VFR=AMAX1(VFR,1.0E-10)
      IF (VFL .GE. VFLMAX) PD(IS,2)=PAV*(1.0/(VFR*VFR)+2.0*VFR-3.0)
      P(IS,2) = .4*FJ*EI(IS,2)*C(IS,2)/(1.-VFL)
      RHOG = C(IS,2)/(1.-VFL)
      DELW = WING-WG(IS,2)
      DELW = AMAX1(DELW,0.)
      QZ(IS,2) = FL*C(IS,2)*(SS+DELW)*DELW
      DELWP=WINP-WP(IS,2)
      DELWP=AMAX1(DELWP,0.0)
      QPZ(IS,2)=-WM*N(IS,2)*DELWP*(SS+DELWP)
      DELU = -UG(IS,2)
      DELU = AMAX1(DELU,0.)
      QR(IS,2) = FL*C(IS,2)*(SS+DELU)*DELU
      DELUP=-UP(IS,2)
      DELUP=AMAX1(DELUP,0.0)
      QPR(IS,2)=-WM*N(IS,2)*DELUP*(SS+DELUP)
      NZ(IS,2) = .5*(N(IS,2)+N(IT,2))
      NR(IS,2) = .5*(N(IS,2)+N(IS,3))
      CD(IS,2) = .25*(C(IS,2)+C(IT,2)+C(IS,3)+C(IT,3))
      WPR(IS,2) = .25*(WP(IS,2)+WP(IS,3)+WINP+WP(I,3))
      UPZ(IS,2) = .25*(UP(IS,2)+UP(IT,2))
      WGC(IS,2) = .5*(WG(IS,2)+WG(IS,3))
```

```
      WGN(IS,2) = .5*(WG(IS,2)+WING)                                    DERI2110
      UGN(IS,2) = .5*UG(IS,2)                                           DERI2120
      UGD(IS,2) = .5*(UG(IS,2)+UG(IT,2))                                DERI2130
      ADEN = C(IS,2)/(1.-VFL)                                           DERI2140
      DUD = UG(IS,2)-UP(IS,2)                                           DERI2150
      DWD = WG(IS,2)-WP(IS,2)                                           DERI2160
      VFS=DUD*DUD+DWD*DWD                                               DERI2170
      DFP = -APF*ADEN*VFS                                               DERI2180
      ANG=ATAN(DUD/DWD)                                                 DERI2190
      DZ(IS,2) = DFP*COS(ANG)                                           DERI2200
      DR(IS,2) = DFP*SIN(ANG)                                           DERI2210
      LWP(IS,2) = 1                                                     DERI2220
      KUP(IS,2) = 1                                                     DERI2230
      LWG(IS,2) = 1                                                     DERI2240
      KUG(IS,2) = 1                                                     DERI2250
      IF (WP(IS,2) .GT. 0)   LWP(IS,2) = 0                              DERI2260
      IF (UP(IS,2) .GT. 0)   KUP(IS,2) = 0                              DERI2270
      IF (WG(IS,2) .GT. 0)   LWG(IS,2) = 0                              DERI2280
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      IF (UG(IS,2) .GT. 0)   KUG(IS,2) = 0
C   INTERIOR REGION CALCULATIONS FOR COMPUTED VARIABLES
      DO 40 I=2,IA
      DO 40 J=2,JA
      IF(J.EQ.2.AND.I.LT.IT) GO TO 45
      EI(I,J)=E(I,J)/C(I,J)
     2 -0.25*(WG(I,J)**2+WG(I-1,J)**2+UG(I,J)**2+UG(I,J-1)**2)/FJ
      VFL=N(I,J)*VOLP
      VFL=AMIN1(VFL,.9999)
      VFL=AMAX1(VFL,.0)
      PD(I,J)=0.
      IF(VFL.GE.VFLMAX) PD(I,J)=PAV
      P(I,J)=.4*FJ*EI(I,J)*C(I,J)/(1.-VFL)
      RHOG = C(I,J)/(1.-VFL)
      DELW = WG(I-1,J)-WG(I,J)
      DELW = AMAX1(DELW,0.)
      QZ(I,J) = FL*C(I,J)*(SS+DELW)*DELW
      DELWP=WP(I-1,J)-WP(I,J)
      DELWP=AMAX1(DELWP,0.0)
      QPZ(I,J)=FL*WM*N(I,J)*DELWP*(SS+DELWP)
      DELU = UG(I,J-1)-UG(I,J)
      DELU = AMAX1(DELU,0.)
      QR(I,J) = FL*C(I,J)*(SS+DELU)*DELU
      DELUP=UP(I,J-1)-UP(I,J)
      DELUP=AMAX1(DELUP,0.0)
      QPR(I,J)=FL*WM*N(I,J)*DELUP*(SS+DELUP)
      NZ(I,J)=.5*(N(I,J)+N(I+1,J))
      NR(I,J)=.5*(N(I,J)+N(I,J+1))
      CD(I,J)=.25*(C(I,J)+C(I+1,J)+C(I,J+1)+C(I+1,J+1))
      WPR(I,J)=.25*(WP(I,J)+WP(I,J+1)+WP(I-1,J)+WP(I-1,J+1))
      UPZ(I,J)=.25*(UP(I,J)+UP(I,J-1)+UP(I+1,J)+UP(I+1,J-1))
      WGD(I,J)=.5*(WG(I,J)+WG(I,J+1))
      WGN(I,J)=.5*(WG(I,J)+WG(I-1,J))
      UGN(I,J)=.5*(UG(I,J)+UG(I,J-1))
      UGD(I,J)=.5*(UG(I,J)+UG(I+1,J))
      ADEN=C(I,J)/(1.-VFL)
      DUD=UG(I,J)-UP(I,J)
      DWD=WG(I,J)-WP(I,J)
      VFS=DUD*DUD+DWD*DWD
```

```
      DFP = -APF*ADEN*VFS                                               DERI2680
      ANG=ATAN(DUD/DWD)                                                 DERI2690
      DZ(I,J)=DFP*COS(ANG)                                              DERI2700
      DR(I,J)=DFP*SIN(ANG)                                              DERI2710
      LWP(I,J)=1                                                        DERI2720
      KUP(I,J)=1                                                        DERI2730
      LWG(I,J)=1                                                        DERI2740
      KUG(I,J)=1                                                        DERI2750
      IF(WP(I,J).GT.0) LWP(I,J)=0                                       DERI2760
      IF(UP(I,J).GT.0) KUP(I,J)=0                                       DERI2770
      IF(WG(I,J).GT.0) LWG(I,J)=0                                       DERI2780
      IF(UG(I,J).GT.0) KUG(I,J)=0                                       DERI2790
   40 CONTINUE                                                          DERI2800
C  SET BOUNDARY VALUES FOR COMPUTED VARIABLES                           DERI2810
      DO 50 J=3,JA                                                      DERI2820
      P(1,J)=P(2,J)                                                     DERI2830
      QZ(1,J) = QZ(2,J)                                                 DERI2840
      CD(1,J)=CD(2,J)                                                   DERI2850
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      DZ(1,J)=DZ(2,J)                                                   DERI2860
      LWP(1,J) = LWP(2,J)                                               DERI2870
      LWG(1,J) = LWG(2,J)                                               DERI2880
      UGD(1,J) = UGD(2,J)                                               DERI2890
   50 WGD(1,J)=WGD(2,J)                                                 DERI2900
      DO 52 J=2,JA                                                      DERI2910
      P(IB,J)=P(IA,J)                                                   DERI2920
      QZ(IB,J) = QZ(IA,J)                                               DERI2930
      PD(IB,J)=PD(IA,J)                                                 DERI2940
      WGN(IB,J)=WGN(IA,J)                                               DERI2950
   52 UGN(IB,J)=UGN(IA,J)                                               DERI2960
      DO 54 I=2,IA                                                      DERI2970
      P(I,JB)=P(I,JA)                                                   DERI2980
      QR(I,JB) = QR(I,JA)                                               DERI2990
      UGN(I,JB)=UGN(I,JA)                                               DERI3000
   54 PD(I,JB)=PD(I,JA)                                                 DERI3010
      DO 56 I=2,II                                                      DERI3020
      P(I,2)=P(I,3)                                                     DERI3030
      P(I,1)=P(I,2)                                                     DERI3040
      QR(I,2) = QR(I,3)                                                 DERI3050
      CD(I,2)=CD(I,3)                                                   DERI3060
      DR(I,2)=DR(I,3)                                                   DERI3070
      WGD(I,2)=WGD(I,3)                                                 DERI3080
      KUP(I,2) = KUP(I,3)                                               DERI3090
      KUG(I,2) = KUG(I,3)                                               DERI3100
   56 UGD(I,2)=0.                                                       DERI3110
      DO 58 I=IS,IA                                                     DERI3120
      P(I,1)=P(I,2)                                                     DERI3130
      QR(I,1) = QR(I,2)                                                 DERI3140
      CD(I,1)=CD(I,2)                                                   DERI3150
      DR(I,1)=DR(I,2)                                                   DERI3160
      WGD(I,1)=WGD(I,2)                                                 DERI3170
      KUP(I,1) = KUP(I,2)                                               DERI3180
      KUG(I,1) = KUG(I,2)                                               DERI3190
   58 UGD(I,1)=0.                                                       DERI3200
      P(IM-1,1)=P(IM-1,2)                                               DERI3210
C     CALCULATE GAS MOMENTUM FLUXES                                     DERI3220
      DO 300 I=1,IM                                                     DERI3230
      DO 300 J=1,JM                                                     DERI3240
```

```
      IM1=MAX0(I-1,1)
      WGB=0.5*(WG(IM1,J)+WG(I,J))                                       DERI3250
      CALL LOFU (WGB,L)                                                 DERI3260
      IM1PL=MIN0(I-1+L,IM)                                              DERI3270
      IM1PL=MAX0(IM1PL,1)                                               DERI3280
      GZW(I,J)=AZ(J)*C(I,J)*(WG(IM1PL,J)**2)                            DERI3290
      IP1=MIN0(I+1,IM)                                                  DERI3300
      UGB=0.5*(UG(I,J)+UG(IP1,J))                                       DERI3310
      CALL LOFU(UGB,K)                                                  DERI3320
      JPK=MIN0(J+K,JM)                                                  DERI3330
      JP1=MIN0(J+1,JM)                                                  DERI3340
      CB=(C(I,J)+C(IP1,J)+C(I,JP1)+C(IP1,JP1))/4.0                      DERI3350
      GRW(I,J)=A*G(I,J)*CB*UGB*WG(I,JPK)                                DERI3360
      JM1=MAX0(J-1,1)                                                   DERI3370
      UGB=0.5*(UG(I,JM1)+UG(I,J))                                       DERI3380
      CALL LOFU (UGB,K)                                                 DERI3390
      JM1PK=MIN0(J-1+K,IM)                                              DERI3400
      JM1PK=MAX0(JM1PK,1)                                               DERI3410
                                                                        DERI3420
```

```
      GRU(I,J)=ARN(I,J)*C(I,J)*(UG(I,JM1PK)**2)
      WGB=0.5*(WG(I,J)+WG(I,JP1))
      CALL LOFU(WGB,L)
      IPL=MING(I+L,IM)
  300 GZU(I,J)=AZD(J)*CB*WGB*UG(IPL,J)
C  COMPUTE DF(IS,2,M) AT NOZZLE CELL
C
      LP = LWP(IS,2)
      KP = KUP(IS,2)
C
      DF(IS,2,1) = (AZ(2)*(WINP*WIN-WP(IS,2)*N(IS+LP,2))
     1             -AR(IS,2)*UP(IS,2)*N(IS,2+KP))/V(IS,2)
C
      TERM1 = -UP(IS,2)/DELZ(IS)
      IF (UPR(IS,2) .LT. 0.)   TERM1 = (UP(IS,2)-UP(IT,2))/DELZ(IT)
C
      DF(IS,2,2) = WPR(IS,2)*TERM1-UP(IS,2)*(UP(IS,2+KP)-UP(IS,1+KP))/
     1DELRR(2+KP)-DR(IS,2)/WM-(PD(IS,3)-PD(IS,2))/(NR(IS,2)*WM*DELR(3))
     2-(QPR(IS,3)-QPR(IS,2))/(WM*NR(IS,2)*DELR(3))
C
      TERM1 = (WINP-WP(IS,2))/DELZZ(IS)
      IF (WP(IS,2) .LT. 0.)   TERM1 = (WP(IS,2)-WP(IT,2))/DELZZ(IT)
      TERM2 = 0.
      IF (UPZ(IS,2) .LT. 0.)   TERM2 = (WP(IS,3)-WP(IS,2))/DELR(3)
C
      DF(IS,2,3) = WP(IS,2)*TERM1-UPZ(IS,2)*TERM2-DZ(IS,2)/WM
     1-(PD(IT,2)-PD(IS,2))/(NZ(IS,2)*WM*DELZ(IT))
     2 -(QPZ(IT,2)-QPZ(IS,2))/(NZ(IS,2)*WM*DELZ(IT))
C
      LP = LWG(IS,2)
      KP = KUG(IS,2)
C
      DF(IS,2,4) = (AZ(2)*(WING*CIN-WG(IS,2)*C(IS+LP,2))-
     1             AR(IS,2)*UG(IS,2)*C(IS,2+KP))/V(IS,2)
C
      DF(IS,2,5)=(-GZU(IS,2)+GRU(IS,2)-GRU(IS,3)
     2-AR(IS,2)*(P(IS,3)+QR(IS,3)-P(IS,2)-GR(IS,2)))/VR(IS,2)
     3+NR(IS,2)*DR(IS,2)
C
```

```
      WB=0.5*(WING+WG(IS,2))
      IF (WB) 302,301,301
  301 WBB=WING
      GO TO 303
  302 WBB=WG(IS,2)
  303 GZW1=AZ(2)*C(IS,2)*(WBB**2)
      DF(IS,2,6)=(GZW1-GZW(IS+1,2)-GRW(IS,2)
     2 -AZ(2)*(P(IT,2)+QZ(IT,2)-P(IS,2)-GZ(IS,2)))/VZ(IS,2)
     3 +NZ(IS,2)*DZ(IS,2)
C
      DF(IS,2,7) = ((AZ(2)*(WING*(EIN*FJ+PIN)-WG(IS,2)*(E(IS+LP,2)*FJ+
     1P(IS+LP,2)+QZ(IS+LP,2)))-AR(IS,2)*UG(IS,2)*(E(IS,2+KP)*FJ+
     2P(IS,2+KP)+QR(IS,2+KP)))/V(IS,2)+.5*N(IS,2)*(DZ(IS,2)*WF(IS,2)+
     3DR(IS,2)*U2(IS,2)))/FJ
C
C  CALCULATE DF VALUES AT INTERIOR NODES
C
      DO 200 I=2,IA
```

```
      DO 200 J=2,JA                                                     DERI4000
      IF(J.EQ.2.AND.I.LT.IT) GO TO 200                                  DERI4010
      LP=LWP(I,J)                                                       DERI4020
      LN=LWP(I-1,J)                                                     DERI4030
      KP=KUP(I,J)                                                       DERI4040
      KN=KUP(I,J-1)                                                     DERI4050
      LS=1                                                              DERI4060
      KS=1                                                              DERI4070
      IF(WPR(I,J) .GT. 0.)   LS = 0                                     DERI4080
      IF(UPZ(I,J).GT.0.) KS=0                                           DERI4090
C                                                                       DERI4100
      DF(I,J,1)=(AZ(J)*(WP(I-1,J)*N(I-1+LN,J)-WP(I,J)*N(I+LP,J))        DERI4110
     1-AR(I,J)*UP(I,J)*N(I,J+KP)+AR(I,J-1)*UP(I,J-1)*N(I,J-1+KN))/V(I,J)DERI4120
C                                                                       DERI4130
      DF(I,J,2)=WPR(I,J)*(UP(I-1+LS,J)-UP(I+LS,J))/DELZ(I+LS)           DERI4140
     1           -UP(I,J)*(UP(I,J+KP)-UP(I,J-1+KP))/DELRR(J+KP)         DERI4150
     2           -DR(I,J)/WM-(PD(I,J+1)-PD(I,J))/(NR(I,J)*WM*DELR(J+1)) DERI4160
     3 -(GPR(I,J+1)-GPR(I,J))/(WM*NR(I,J)*DELR(J+1))                    DERI4170
C                                                                       DERI4180
      DF(I,J,3) = WP(I,J)*(WP(I-1+LP,J)-WP(I+LP,J))/DELZZ(I+LP)         DERI4190
     1           -UPZ(I,J)*(WP(I,J+KS)-WP(I,J-1+KS))/DELR(J+KS)         DERI4200
     2           -DZ(I,J)/WM-(PD(I+1,J)-PD(I,J))/(NZ(I,J)*WM*DELZ(I+1)) DERI4210
     3 -(GPZ(I+1,J)-GPZ(I,J))/(NZ(I,J)*WM*DELZ(I+1))                    DERI4220
C                                                                       DERI4230
      LP=LWG(I,J)                                                       DERI4240
      LN=LWG(I-1,J)                                                     DERI4250
      KP=KUG(I,J)                                                       DERI4260
      KN=KUG(I,J-1)                                                     DERI4270
C                                                                       DERI4280
      DF(I,J,4)=(AZ(J)*(WG(I-1,J)*C(I-1+LN,J)-WG(I,J)*C(I+LP,J))        DERI4290
     1-AR(I,J)*UG(I,J)*C(I,J+KP)+AR(I,J-1)*UG(I,J-1)*C(I,J-1+KN))/V(I,J)DERI4300
C                                                                       DERI4310
      DF(I,J,5)=(GRU(I,J)-GRU(I,J+1)+GZU(I-1,J)-GZU(I,J)                DERI4320
     2 -AR(I,J)*(P(I,J+1)+QR(I,J+1)-P(I,J)-QR(I,J)))/VR(I,J)            DERI4330
     3 +NR(I,J)*DR(I,J)                                                 DERI4340
C                                                                       DERI4350
      DF(I,J,6)=(GZW(I,J)-GZW(I+1,J)+GRW(I,J-1)-GRW(I,J)                DERI4360
     2 -AZ(J)*(P(I+1,J)+QZ(I+1,J)-P(I,J)-QZ(I,J)))/VZ(I,J)              DERI4370
     3 +NZ(I,J)*DZ(I,J)                                                 DERI4380
```

```
C
      DF(I,J,7) = ((AZ(J)*(WG(I-1,J)*(E(I-1+LN,J)*FJ+P(I-1+LN,J)+
     1QZ(I-1+LN,J))-WG(I,J)*(E(I+LP,J)*FJ+P(I+LP,J)+QZ(I+LP,J)))-
     2AR(I,J)*UG(I,J)*(E(I,J+KP)*FJ+P(I,J+KP)+QR(I,J+KP))+AR(I,J-1)*
     3UG(I,J-1)*(E(I,J-1+KN)*FJ+P(I,J-1+KN)+QR(I,J-1+KN)))/V(I,J)+
     4.5*N(I,J)*(DZ(I,J)*WP(I,J)+DZ(I-1,J)*WP(I-1,J)+DR(I,J)*UP(I,J)+
     5DR(I,J-1)*UP(I,J-1)))/FJ
  200 CONTINUE
C  CONVERT DY(L) FROM DF(I,J,M)
      L=0
      DO 2 I=2,I1
      DO 2 J=2,J1
      IF(J.EQ.2.AND.I.LT.IS) GO TO 2
      DO 4 M=1,7
      L=L+1
    4 DY(L)=DF(I,J,M)
    2 CONTINUE
      RETURN
      END
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE CNTRL(Y,DY,DT,T,NTRY)
      PARAMETER ID=25,JD=15,LD=400,NRKD=2625
      DIMENSION Y(NRKD),DY(NRKD)
      DIMENSION CP(ID,JD)
      COMMON /DC/ CIN,WING,WINP,NIN,
     2 GRU(ID,JD),GZU(ID,JD),GRW(ID,JD),GZW(ID,JD)
      COMMON /AL-/ F(ID,JD,7),DF(ID,JD,7),II,IS,IA,IB,IM,JA,JB,JM,IT,
     1FJ,VOLP,WM,APF,VELMAX,PAV,FL,RG,KW,KK,KKO,KM,PIN,IRK,RHOP,
     2 TI(LD),PIND(LD),CIND(LD),WINDG(LD),NIND(LD),
     3Z(ID),ZZ(ID),DELZ(ID),DELZZ(ID),R(JD),RR(JD),DELR(JD),DELRR(JD),
     4AZ(JD),AZC(JD),AR(ID,JD),ARN(ID,JD),ARD(ID,JD),V(ID,JD),VZ(IB,JD),
     5VR(ID,JD),C(ID,JD),CZ(ID,JD),CR(ID,JD),CD(ID,JD),WG(ID,JD),
     6WGN(ID,JD),WGD(ID,JD),UG(ID,JD),UGN(ID,JD),UGD(ID,JD),WP(ID,JD),
     7WPR(ID,JD),UP(ID,JD),UPZ(ID,JD),N(ID,JD),NZ(ID,JD),NR(ID,JD),
     8E(ID,JD),EI(ID,JD),P(ID,JD),3R(ID,JD),PD(ID,JD),DR(ID,JD),
     9DZ(ID,JD),LWP(ID,JD),KUP(ID,JD),LWG(ID,JD),KUG(ID,JD),QZ(ID,JD)
     A ,WINDP(LD)
      COMMON/MC/NIJW,IW(8),JW(8),PW(8)
      REAL N,NIND,NR,NZ
      DATA PB/0.0/,VPROJ/0.0/,ZPROJ/0.0/
      KK = KK+1
      KKO=KKO+1
      IF (KKO-KM) 1,2,2
    1 NTRY = 1
      GO TO 3
    2 NTRY = 2
    3 CONTINUE
      WRITE (6,108) KK,KKO,DT,T,PIN
  108 FORMAT (1H ,10X,3HKK=,I6,10X,4HKKO=,I6,10X,3HDT=,1PE14.6,
     2 5X,2HT=,E14.6,5X,4HPIN=E14.5 )
      DO 6 I=1,NIJW
      IWW=IW(I)
      JWW=JW(I)
      PL=P(IWW,JWW)+0.5*C(IWW,JWW)*(WGN(IWW,JWW)**2+UGN(IWW,JWW)**2)
     2 +0.5*WM*N(IWW,JWW)*(WP(IWW,JWW)**2+UP(IWW,JWW)**2)
    6 PW(I)=PL*2.54*2.54/(980.616*453.59)
      WRITE (6,300) (I,PW(I),I=1,NIJW)
  300 FORMAT (1H , 6(3X,3HPW(,I1,2H)=,1PE11.4))
      IF ((KK/5)*5-KK) 8,7,8
```

```
    7 CONTINUE                                                                CNTR0400
      WRITE (8) <K ,T,(PW(I),I=1,NIJW),PB,VPROJ,ZPROJ,Y(4),Y(5)               CNTR0410
    8 CONTINUE                                                                CNTR0420
      IF ((KK/KW)*KW-KK) 5,4,5                                                CNTR0430
    4 CONTINUE                                                                CNTR0440
      WRITE (9) <K,T,DT,(Y(I),I=1,IRK)                                        CNTR0450
      DO 9 I=1,IM                                                             CNTR0460
      DO 9 J=1,JM                                                             CNTR0470
    9 CP(I,J)=N(I,J)*WM                                                       CNTR0480
      WRITE(10) <K,(R(J),J=1,JM),(Z(I),I=1,IM),                               CNTR0490
     2 ((P(I,J),J=1,JM),I=1,IM),((CP(I,J),J=1,JM),I=1,IM)                     CNTR0500
      WRITE (6,320) PIN,CIN,WING,WINP,NIN                                     CNTR0510
  320 FORMAT (1H1,2X,4HPIN=,1PE11.5,2X,4HCIN=,E11.5,2X,5HWING=,               CNTR0520
     2 E11.5,2X,5HWINP=,E11.5,2X,4HNIN=,E11.5)                                CNTR0530
      CALL OUTPT (1H0,P    ,ID,JD,IM,JM,10,10HP      FIELD )                  CNTR0540
      CALL OUTPT (1H0,WG   ,ID,JD,IM,JM,10,10HWG     FIELD )                  CNTR0550
      CALL OUTPT (1H0,UG   ,ID,JD,IM,JM,10,10HUG     FIELD )                  CNTR0560
      CALL OUTPT (1H0,WP   ,ID,JD,IM,JM,10,10HWP     FIELD )                  CNTR0570
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      CALL OUTPT (1H0,UP   ,ID,JD,IM,JM,10,10HUP    FIELD )        CNTR0580
      CALL OUTPT (1H0,C    ,ID,JD,IM,JM,10,10HC     FIELD )        CNTR0590
      CALL OUTPT (1H0,N    ,ID,JD,IM,JM,10,10HN     FIELD )        CNTR0600
      CALL OUTPT (1H0,EI   ,ID,JD,IM,JM,10,10HEI    FIELD )        CNTR0610
    5 CONTINUE                                                     CNTR0620
      RETURN                                                       CNTR0630
      END                                                          CNTR0640
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE LOFU (U,L)                                        LOFU0010
      IF (U) 2,1,1                                                 LOFU0020
    1 L=0                                                          LOFU0030
      RETURN                                                       LOFU0040
    2 L=1                                                          LOFU0050
      RETURN                                                       LOFU0060
      END                                                          LOFU0070
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE UNEQR(IM,RM,IR,RR,R,ID)
      DIMENSION R(ID)
      FIR=FLOAT(IR)
      FIM=FLOAT(IM)
      B=1.0
      DO 1 K=1,5
      EX=EXP(-B*(FIM+FIR-2.0))+(1.0-EXP(-2.0*B*(FIR-1.0)))*RM/RR
      B=ALOG(EX)/(FIM-FIR)
      WRITE (6,101) K,B,IM,IR,RM,RR
  101 FORMAT (1H0,3X,2HK=,I5,3X,2HB=,1PE14.6,3X,3HIM=,I5,3X,
     2 3HIR=,I5,3X,3HRM=,E14.6,3X,3HRR=,E14.6)
    1 CONTINUE
      DO 2 K=6,25
      F1=RM*SINH(B*(FIR-1.0))
      F2=RR*SINH(B*(FIM-1.0))
      D0=F1-F2
      D1=RM*(FIR-1.0)*COSH(B*(FIR-1.0))-RR*(FIM-1.0)*COSH(B*(FIM-1.0))
      D2=F1*(FIR-1.0)**2-F2*(FIM-1.0)**2
      DB=SNGL(DLOG(1.0D0-DBLE(D0)*DBLE(D2)/DBLE(D1)**2)*DBLE(D1)/
     2 DBLE(D2))
      B=B+DB
      WRITE (6,102) K,DB,B
  102 FORMAT (1H0,3X,2HK=,I5,3X,3HDB=,1PE14.6,3X,2HB=,E14.6)
      IF (ABS(DB)-1.0E-7)3,3,2
    2 CONTINUE
    3 A=RR/SINH(B*(FIR-1.0))
      DO 4 I=1,IM
    4 R(I)=A*SINH(B*FLOAT(I-1))
      RETURN
      END
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE NZLINP (TI,PIND,CIND,WINDG,WINDP,NIND,T,PIN,CIN,WING,
     2 WINP,NIN,LD)
      REAL NIND,NIN
      DIMENSION TI(LD),PIND(LD),CIND(LD),WINDG(LD),WINDP(LD),NIND(LD)
      DATA LLL/1/
      GO TO (1,2),LLL
    1 T1=TI(1)
      T2=TI(2)
      I=1
      LLL=2
    2 IF (T-T1) 7,3,3
    3 IF (T-T2) 10,10,11
   11 KS=I+1
      DO 4 K=KS,LD
      J=K
      IF (TI(K)-T) 4,5,6
    4 CONTINUE
    5 CONTINUE
      I=J
      T1=TI(I)
      T2=TI(I+1)
      GO TO 10
    6 I=J-1
      T1=TI(I)
      T2=TI(I+1)
      GO TO 10
    7 ME=I-1
      DO 8 M=1,ME
      N=I-M
      IF (TI(N)-T) 9,9,8
    8 CONTINUE
    9 T1=TI(N)
      T2=TI(N+1)
      I=N
   10 TF=(T-T1)/AMAX1((T2-T1),1.0E-11)
      TF2=1.0-TF
      PIN =TF2*PIND (I)+TF*PIND (I+1)
      CIN =TF2*CIND (I)+TF*CIND (I+1)
      WING=TF2*WINDG(I)+TF*WINDG(I+1)
```

```
      WINP=TF2*WINDP(I)+TF*WINDP(I+1)                                  NZL10400
      NIN =TF2*NIND (I)+TF*NIND (I+1)                                  NZL10410
      RETURN                                                           NZL10420
      END                                                              NZL10430
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE RK2 (DERIV,CNTRL,Y,DY,A,R,T,DT,N,DTM)
C     SECOND ORDER RUNGE KUTTA
C     NTRY IS ASSIGNED ONE OF THE VALUES LISTED BELOW IN CNTRL
C     NTRY = 1  CONTINUE INTEGRATION
C     NTRY = 2  RETURN FROM RUNGE KUTTA
C     NTRY = 3  REPEAT STEP WITH NEW DT GIVEN IN CNTRL
C     NTRY 4  CONTINUE INTEGRATION WITH FIXED STEP
      PARAMETER NRKD=2625
      DIMENSION Y(NRKD),DY(NRKD),A(NRKD),R(NRKD),YST(NRKD),DYST(NRKD)
      EXTERNAL DERIV,CNTRL
      THR10=10.**(1.073,0)
      GAM=0.5
      BETA=0.5/GAM
      ALPHA=1.0-BETA
      CALL DERIV (Y,DY,T)
      CALL CNTRL (Y,DY,DT,T,NTRY)
    4 TST=T
      DO 5 I=1,N
      YST(I)=Y(I)
    5 DYST(I)=DY(I)
    6 IF (DT) 8,7,8
    7 WRITE (6,101)
  101 FORMAT (1H0,20X,17HSTEP SIZE = ZERO,  )
      RETURN
    8 T=TST+GAM*DT
      DO 9 I=1,N
    9 Y(I)=YST(I)+GAM*DT*DYST(I)
      CALL DERIV (Y,DY,T)
      T=TST+DT
      DO 10 I=1,N
   10 Y(I)=YST(I)+DT*(ALPHA*DYST(I)+BETA*DY(I))
      CALL DERIV (Y,DY,T)
      EOCM=0.0
      DO 13 I=1,N
      E=Y(I)-(YST(I)+0.5*DT*(DYST(I)+DY(I)))
      C=A(I)+R(I)*ABS(Y(I))
      IF (C) 12,11,12
   11 WRITE (6,102) I
  102 FORMAT (1H0, 20X, 27HA(I)+R(I)*ABS(Y(I))=0 AT I= , I6)
```

```
      RETURN
   12 EOC=ABS(E/C)
C     EOCM=AMAX1(EOC,EOCM)
      IF (EOC-EOCM) 13,13,901
  901 EOCM=EOC
      LSV=I
   13 CONTINUE
      IF (EOCM-1.0) 17,17,14
   14 T=TST
      DO 15 I=1,N
      Y(I)=YST(I)
   15 DY(I)=DYST(I)
      CALL IJM (LSV ,EOCM)
      DO 16 J=1,10
      EOCM=EOCM/10.0
      DT=DT/THR10
      IF (EOCM-0.3) 6,5,16
   16 CONTINUE
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      GO TO 6                                                           RK2 0580
   17 CALL CNTRL (Y,DY,DT,T,NTRY)                                       RK2 0590
      GO TO (21,18,19,4),NTRY                                           RK2 0600
   18 RETURN                                                            RK2 0610
   19 T=TST                                                             RK2 0620
      DO 20 I=1,N                                                       RK2 0630
      Y(I)=YST(I)                                                       RK2 0640
   20 DY(I)=DYST(I)                                                     RK2 0650
      GO TO 6                                                           RK2 0660
   21 IF (EOCM-0.3) 25,25,22                                            RK2 0670
   22 DT=DT/THR10                                                       RK2 0680
      CALL IJM (-SV ,EOCM)                                              RK2 0690
      GO TO 4                                                           RK2 0700
   25 IF (EOCM-0.03 ) 26,4,4                                            RK2 0710
   26 DT=DT*THR10                                                       RK2 0720
      IF(ABS(DT)-ABS(DTM)) 4,4,24                                       RK2 0730
   24 DT=ABS(DTM)*DT/ABS(DT)                                            RK2 0740
      GO TO 4                                                           RK2 0750
      END                                                               RK2 0760
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE IJM (LSV,EOCM)
      PARAMETER ID=25,JD=15,LD=400,NRKD=2625
      COMMON /ALL/ F(ID,JD,7),DF(ID,JD,7),II,IS,IA,IB,IM,JA,JB,JM,IT,
     1FJ,VOLP,WM,APF,VFLMAX,PAV,FL,RG,KW,KK,KKO,KM,PIN,IRK,RHOP,
     2 TI(LD),PIND(LD),CIND(LD),WINDG(LD),NIND(LD),
     3Z(ID),ZZ(ID),DELZ(ID),DELZZ(ID),R(JD),RR(JD),DELR(JD),DELRR(JD),
     4AZ(JD),AZD(JD),AR(ID,JD),ARN(ID,JD),ARD(ID,JD),V(ID,JD),VZ(ID,JD),
     5VR(ID,JD),C(ID,JD),CZ(ID,JD),CR(ID,JD),CD(ID,JD),WG(ID,JD),
     6WGN(ID,JD),WGD(ID,JD),UG(ID,JD),UGN(ID,JD),UGD(ID,JD),WP(ID,JD),
     7WPR(ID,JD),UP(ID,JD),UPZ(ID,JD),N(ID,JD),NZ(ID,JD),NR(ID,JD),
     8E(ID,JD),EI(ID,JD),P(ID,JD),OR(ID,JD),PD(ID,JD),DR(ID,JD),
     9DZ(ID,JD),LWP(ID,JD),KUP(ID,JD),LWG(ID,JD),KUG(ID,JD),GZ(ID,JD)
     A ,WINDP(LD)
      L=U
      DO 2 I=2,IA
      ISV=I
      DO 2 J=2,JA
      JSV=J
      IF (J .EQ. 2 .AND. I .LT. IS) GO TO 2
      DO 1 M=1,7
      MSV=M
      L=L+1
      IF (L-LSV) 1,3,1
    1 CONTINUE
    2 CONTINUE
    3 CONTINUE
      WRITE (6,101) EOCM,LSV,ISV,JSV,MSV
  101 FORMAT (1H ,10X,5HEOCM=,1PE12.5,10X,2HL=,I6,10X,2HI=,I6,10X,
     2 2HJ=,I6,10X,2HM=,I6)
      RETURN
      END
```

TWO DIMENSIONAL GAS PARTICLE FLOW

```
      SUBROUTINE OUTPT (IPC,F,ID,JD,IM,JM,NL,LABEL)                    OUTP0010
      DIMENSION F(ID,JD),LABEL(22),LAB2(20)                            OUTP0020
      DATA LBW/6H      /                                               OUTP0030
      GO TO 200                                                        OUTP0040
      ENTRY OUTPT7 (IPC,G,K3,ID,JD,IM,JM,NL,LABEL)                     OUTP0050
      DIMENSION G(ID,JD,7)                                             OUTP0060
      DO 201 I=1,IM                                                    OUTP0070
      DO 201 J=1,JM                                                    OUTP0080
  201 F(I,J)=G(I,J,K3)                                                 OUTP0090
  200 CONTINUE                                                         OUTP0100
      JMM=MIN0(JM,12)                                                  OUTP0110
      NW=1+(NL-1)/6                                                    OUTP0120
      NST=10-(NW+1)/2                                                  OUTP0130
      DO 1 I=1,20                                                      OUTP0140
    1 LAB2(I)=LBW                                                      OUTP0150
      DO 2 I=1,NW                                                      OUTP0160
      K=NST+I-1                                                        OUTP0170
    2 LAB2(K)=LABEL(I)                                                 OUTP0180
      WRITE (6,101) IPC,(LAB2(I),I=1,20),(J,J=1,JMM)                   OUTP0190
  101 FORMAT (A1,20A6, // 1H ,2X,1HI,2X,2HJ=,I2,11I10)                 OUTP0200
      DO 3 I=1,IM                                                      OUTP0210
    3 WRITE (6,102) I,(F(I,J),J=1,JMM)                                 OUTP0220
  102 FORMAT (1H ,I3,1PE10.3,11E10.3)                                  OUTP0230
      RETURN                                                           OUTP0240
      END                                                              OUTP0250
```