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**A LUMPED-PARAMETER INTERIOR BALLISTIC
COMPUTER CODE USING THE TTCP MODEL**FREDERICK W. ROBBINS
TIMOTHY S. RAAB

NOVEMBER 1988

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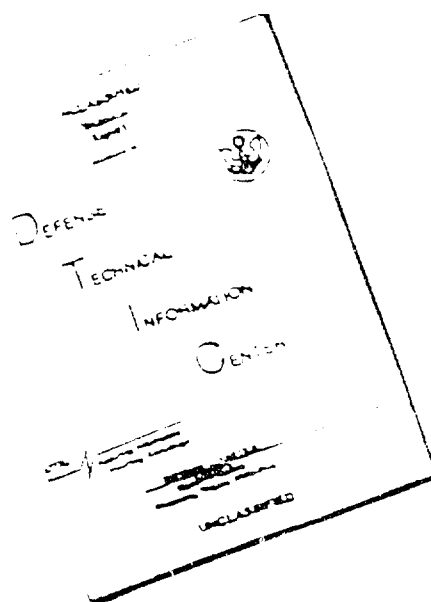
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ERRATA SHEET FOR BRL-MR-3710

A LUMPED-PARAMETER INTERIOR BALLISTIC
COMPUTER CODE USING THE TTCP MODEL

PAGE	DESCRIPTION
10	'Nordheim heat transfer coefficient' should be 'Nordheim friction factor'
10	In equation 7.19 remove dt
13	The units for h should be watt/m ² -K
14	'resistive force to projectile motion' should be 'resistive force to recoil motion' in definition of RP
14	'Nordheim heat transfer coefficient' should be 'Nordheim friction factor' in definition of lambda
28	Units for free convective heat transfer coefficient should be W/cm ² -K

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IBRGA is a simple FORTRAN code for making computer simulations of the interior ballistic performance of guns. It can be run on computers as small as an IBM PC. It is based on the lumped-parameter mathematical model of interior ballistics recently adopted by the The Technical Cooperation Program (TTCP), and therefore it permits validation of that model. While the TTCP model is limited to a Lagrange pressure gradient equation, IBRGA also permits using a gradient equation which takes into account the chambrage of the gun. Calculations with IBRGA agree with the results of gun firings, which show higher muzzle velocities for guns with chambrage than for guns with chambers of constant diameter. IBRGA is used to show gun optimizations performed with Lagrange gradients for guns without chambrage lead to nearly-optimal propellant grain dimensions for use in guns with chambrage. This report documents IBRGA thoroughly. It includes comparisons with IBHVG2, a complete FORTRAN listing of the IBRGA code, and sample inputs and outputs.					
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I. INTRODUCTION

Recently, The Technical Cooperation Program (TTCP), WTP-4 (Propulsion Technology), Key Technical Area 10 (KTA-10) adopted a lumped-parameter interior ballistics model. The model is well documented in the report of the activities of the KTA.¹ IBRGA was written in order to test that model, to compare its predictions with those of other established models, and to provide a relatively simple interior ballistics model for other uses by the community. IBRGA is a FORTRAN encoding of the TTCP model. It has been compiled and run on computers as small as an IBM PC and as large as a CRAY-2. This report documents IBRGA quite thoroughly, including comparisons with IBHVG2, a complete FORTRAN listing of the IBRGA code, and sample inputs and outputs. A machine-readable copy of the code, complete with sample inputs and outputs, may be obtained from the authors of this report.

II. DISCUSSION OF IBRGA

IBRGA performs all its calculations with variables expressed in metric units, specifically, meters, kilograms, and seconds. The input data units were made to conform to those of TDNOVA² for the sake of uniformity. Some of the required input data are therefore in centimeters, grams, and milliseconds; IBRGA converts to the basic metric units before the interior ballistic simulation begins.

There are two forms of IBRGA available, the difference between them being the method used to calculate the mass fraction of propellant burned. IBRGAS is a direct encoding of the TTCP model; it is included as Appendix A. IBRGAS uses the formula $Z_i = \left(\frac{1}{v_o} \right) \int_0^t s(t) \frac{dx}{dt} dt$, where Z_i is the mass fraction burned, v_o is the original volume of propellant, $s(t)$ is the instantaneous surface area and $\frac{dx}{dt}$ is the linear burning rate. IBRGAC is the other version of the code; it uses the relation $Z_i = \frac{v_i}{v_o}$, where Z_i is the mass fraction burned, v_i is the instantaneous volume of propellant burned, which is calculated from the regression of the propellant surface and the geometry of the propellant grains, and v_o is the original volume of propellant. This alternative solution technique was expected to yield the same answers but to be numerically quicker. The two versions of IBRGA are compared in Table 1. Calculated peak breech pressures, in MPa, are shown versus the chosen time step for the calculations. These comparisons were done with the Cray X-MP/48 computer, both for the long word length and the calculational speed. The run times are for the Cray X-MP/48. One can see that the codes converge to the same value, but that convergence is about a factor of 100 quicker with IBRGAC than with IBRGAS.

TABLE 1

COMPARISON OF IBRGAC AND IBRGAS

Calculated Peak Breech Pressures in MPa

Time Step (s)	IBRGAC	IBRGAS	Approx. Run Time (s)
.05	517.451	508.526	0.10
.005	517.574	516.642	0.44
.0005	517.582	517.489	3.90
.00005	517.583	517.574	37.40
.000005	517.583	517.582	373.00

Based on these findings, all subsequent calculations with IBGRA in this report used IBRGAC with a time step of 0.005 seconds.

The basic physical assumptions involved in IBRGAC are the same as those for the lumped-parameter interior ballistics code called IBHVG2³. Both codes can make use of the Lagrange gradient equation in addition to other gradients. To test the accuracy of IBRGAC, comparison computer runs were made with IBHVG2. Both codes used essentially the same nominal 120-mm data base and employed the Lagrange gradient equation. Results of these calculations are summarized in Table 2. The percentage difference between the results of the two codes is shown to the right. With differences between variables compared of the order of 0.01%, the agreement between the two codes is quite satisfactory.

TABLE 2
COMPARISON OF DATA BETWEEN IBRGAC AND IBHVG2

Trajectory variables	IBRGAC	IBHVG2	% difference
Maximum breech pressure(MPa)	517.574	517.588	0.003%
Maximum mean pressure(MPa)	460.047	460.060	0.003%
Maximum base pressure(MPa)	344.994	345.003	0.003%
Muzzle velocity(m/s)	1576.09	1575.95	0.009%

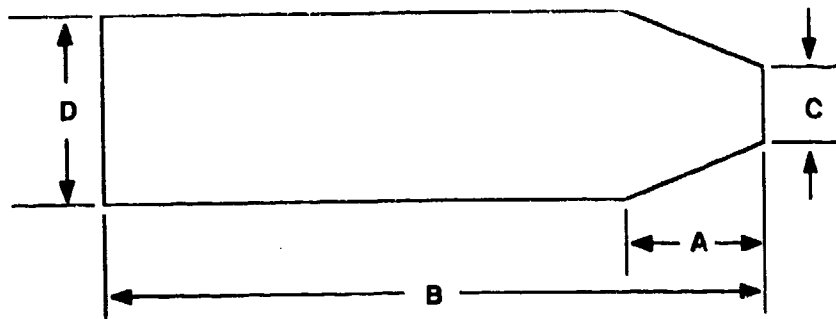
Energy variables (J)	IBRGAC	IBHVG2	% difference
Total chemical energy	48,384,300.	48,373,692.	0.022%
Energy remaining in the gas	30,765,100.	30,766,890	0.006%
Projectile kinetic energy	12,173,200.	12,164,775.	0.069%
Energy lost to gas and propellant motion	4,059,700.	4,056,875.	0.070%
Heat energy lost to convection	1,386,220.	1,385,152.	0.077%

In addition to the Lagrange pressure gradient equation, IBRGAC permits the use of an alternative gradient equation which takes into account the "chambrage" of the gun. This other equation is known as the chambrage gradient equation^{4,5} since it takes into account the effects of a chambrage chamber.

Straight and chambrage chambers are defined in the following manner. A straight or bore-diameter chamber has the same radial distance as the gun bore. A chambrage chamber has a radial distance which is larger than the bore radial distance. This larger diameter is tapered or "necked down", at the forward end of the chamber, to the same radial dimensions of the bore (see Figure 1).

We tested IBRGAC with Lagrange and chambrage gradient equations to be sure that, for data bases that specified a bore-diameter chamber, a calculation with the chambrage gradient gives essentially the same results as the Lagrange gradient. Table 3 indicates that the chambrage gradient reduces to the Lagrange gradient for a bore-diameter chamber configuration.

FIGURE 1



A is the length of the tapered section of the chambrage chamber
 B is the overall chamber length
 C is the bore diameter
 D is the chamber diameter
 D/C is defined as the "chambrage"

TABLE 3

COMPARISON OF CALCULATED RESULTS FOR THE LAGRANGE AND CHAMBRAGE GRADIENTS IN A BORE-DIAMETER CHAMBER

Trajectory	IBRGAC (Lagrange)	IBRGAC (chambrage)	% difference
Maximum breech pressure (MPa)	517.58	517.62	0.01%
Maximum mean pressure (MPa)	460.05	460.08	0.01%
Maximum base pressure (MPa)	344.99	345.02	0.01%
Muzzle velocity (m/s)	1576.09	1576.11	0.0012%

III. THE EFFECTS OF CHAMBRAGE

Table 4 demonstrates the effects of chambrage. In Table 4, calculations with IBERGAC are compared with those of XKTC⁶, which is a phenomenologically complete two-phase flow interior ballistic computer code which has a history of good agreement with gun firings. IBERGAC is used with the chambrage gradient equation for all of these calculations, since we have seen that it correctly handles both chambrage and bore-diameter chambers. All calculations are for a propellant-mass to projectile-mass ratio of one. The first line of the table compares calculations for a nominal 120-mm weapon with a bore-diameter chamber. We see that the agreement between IBERGAC and XKTC is quite good. For the second line of the table, chambrage has been introduced. The total chamber volume was maintained, but 7.62 cm of chambrage was added, so that the overall chamber length was shortened from 77.6 cm to 54.1 cm. Note the agreement between the codes, the drop in the maximum breech pressure, and the (expected) concomitant drop in the muzzle velocity. The third line of the table results from changing the propellant web so that XKTC predicted the same maximum breech pressure as had been obtained for the bore-diameter case in the first line, 345 Mpa. That same propellant web was then used in IBERGAC. Again, IBERGAC and XKTC agree quite well. By comparing this third line with the first line, we see that a gun with a chambrage chamber can achieve a higher muzzle velocity without increasing its maximum chamber pressure.

TABLE 4

EFFECT OF CHAMBRAGE BETWEEN XKTC AND IBRGAC

Chamber Volume (cm. ³)	chambrage	XKTC max breach pressure (MPa)	XKTC muzzle velocity (m/s)	IBRGAC max breach pressure (MPa)	IBRGAC muzzle velocity (m/s)
9832	none	345	1352	346	1363
9832	1.21	310	1303	305	1306
9832	1.21	345	1376	347	1390

This calculated increase in velocity due to chambrage also occurs for optimized gun systems, in which the grain dimensions and propellant mass are varied to maximize muzzle velocity while maintaining a given maximum breach pressure. To illustrate this point, Appendix D documents a calculation in which a bore-diameter gun was optimized for velocity for a maximum breach pressure of 346 MPa. For this case, a muzzle velocity of 1398 m/s was achieved using 8.7 kg of propellant with a web of 0.2299 cm. Appendix E documents a companion optimization calculation for a chambrage chamber, again for a maximum breach pressure of 346 MPa. A muzzle velocity of 1408 m/s was achieved using 8.85 kg of propellant with a web of 0.2276 cm.

Many propellant charges have been designed in the past by using codes with Lagrange gradient equations and modeling bore-diameter chambers. One might ask whether the propellant dimensions that were determined from these calculations were in fact the optimum dimensions for the real, chambrage gun. IBRGA makes this determination easy. If one takes the propellant web of 0.2299 cm from the bore-diameter optimization above and uses it in a chambrage calculation, and further increases the propellant weight to 8.91 kg to restore 346 MPa, one achieves a muzzle velocity of 1408 m/s, the same velocity as was predicted in the optimized chambrage calculation above. Thus we see that past optimizations of propellant web have, in fact, determined nearly optimal propellant web for guns with chambrage. The weight of propellant needed was not so well determined, however.

There are two factors inherent in a chambrage chamber which may account for the increased muzzle velocity which is both observed and calculated. First, the smaller chamber length of a chambrage configuration translates into a smaller pressure gradient for a significant portion of the early part of the ballistic cycle. With this condition, a higher base pressure and an increase in projectile velocity will result. Second, the increased radial dimension of the chamber means a larger amount of expanding gas is available to act on the base of the projectile, for a significantly increased duration, which would also lead to an increase in energy imparted to the projectile.

IV. CONCLUSIONS

1. IBRGA is a simple FORTRAN computer code which incorporates the TTCP lumped-parameter interior ballistic model.
2. Calculations of mass fraction burned which use the propellant form function directly are more computationally efficient than those proposed in the TTCP model.
3. Calculations with IBRGA compare favorably with those from IBHVG2.
4. IBRGA permits the use of a pressure gradient equation which takes chambrage into

account; calculations with IBRGA on the effects of chambrage compare favorably with equivalent XKTC calculations.

5. IBRGA can be used to show that a gun chamber with chambrage will, for the same conditions, give a lower maximum breech pressure, or if the propellant grain dimensions are changed to reproduce the original maximum breech pressure, will give a higher projectile velocity than a bore-diameter chamber.

6. Optimized gun calculations done with either the Lagrange gradient or the chambrage gradient in a bore-diameter chamber, will give nearly-optimal propellant grain dimensions. Thus, previous optimizations with older codes led to proper propellant grain manufacture.

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2. R. D. Anderson and K. D. Fickie, "IBHVG2--A User's Guide," BRL Report 2829, Ballistic Research Laboratory, Aberdeen Proving Ground, MD., 1987.
3. P. S. Gough, "Two-Dimensional, Two-Phase Modeling of Multi-Increment Bagged Artillery Charges," PGA-TR-82-1, Paul Gough Associates, Inc. Portsmouth, NH., 1982.
4. F. W. Robbins, R. D. Anderson and P. S. Gough, "Continued Studies of The Development of a Modified Pressure Gradient Equation for Lumped Parameter Interior Ballistics Codes," 10th International Symposium on Ballistics, Volume 1, October 1987.
5. W. F. Morrison and G. P. Wren, "A Lumped Parameter Description of Liquid Injection in A Regenerative Liquid Propellant Gun," Proceedings of the 23rd JANNAF Combustion Meeting, CPIA Publication 457, Vol II, pp 464-489, October 1986.
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APPENDIX A

Interior Ballistic Equations

IBRGA (and also IBHVG2) relies on mathematical models in which only the most essential forces are included. Following is a compilation of the relations which make up the interior ballistics governing equations.

1. The equation of motion of the center of mass of the projectile is

$$\dot{v}_p = \frac{A(P_b - br - P_g)}{m_p}, \quad (1.1)$$

where the area of the base of the projectile including the appropriate portion of the rotating band is

$$A = \frac{\pi}{4} D_b^2, \quad (1.2)$$

$$\text{where } D_b^2 = \left[\frac{GLR DG^2}{GLR + 1} + \frac{DL^2}{GLR + 1} \right]. \quad (1.3)$$

The pressure on the base of the projectile, P_b , including the approximate pressure gradient effect is, for the Lagrange gradient,

$$P_b = \frac{\left[\bar{P} + \frac{C_T(br + P_g)}{3m_p} \right]}{\left[1 + \frac{C_T}{3m_p} \right]}, \quad (1.4)$$

and for the chambrage gradient

$$P_b = \frac{\bar{P} - \delta}{\gamma}, \quad (1.5)$$

$$\text{where } \delta = -a_1 J_1 - b J_2 + \frac{J_3 a_1 + J_4 b}{V(z_p)}, \quad (1.6)$$

$$\text{and } \gamma = 1 - a_2 J_1 + \frac{J_3 a_2}{V(z_p)}, \quad (1.7)$$

$V(z_p)$ is the volume up to the base of the projectile ,

and z_p is the distance from the breech to the base of the projectile.

$$a_1 = \frac{C_T A}{V^2(z_p)} \left[\frac{A v_p^2}{V(z_p)} + \frac{A(br + P_g)}{m_p} \right], \quad (1.8)$$

$$a_2 = \frac{-C_T A^2}{m_p V^2(z_p)}, \quad (1.9)$$

$$\text{and } b = \frac{-C_T v_p^2}{2} \frac{A^2}{V^3(z_p)} \quad (1.10)$$

Also,

$$J_1 = \int_0^{z_p} \frac{V(z)}{A(z)} dz, \quad (1.11)$$

$$J_2 = \frac{V^2(z)}{A^2(z)}, \quad (1.12)$$

$$J_3 = \int_0^{z_p} A(z) J_1(z) dz, \quad (1.13)$$

$$J_4 = \int_0^{z_p} A(z) J_2(z) dz, \quad (1.14)$$

where $A(z)$ is the area at distance z from the breech,

$V(z)$ is the volume at distance z from the breech,

and J_1, J_2, J_3, J_4 are numerically evaluated at z_p .

2. The velocity of the center of mass of the projectile is

$$v_p = \int_0^t \dot{v}_p dt. \quad (2.1)$$

3. The breech pressure P_o is ,

for the Lagrange gradient ,

$$P_o = P_b + \frac{C_T}{2m_p} (P_b - br - P_g) \quad (3.1)$$

and for the chambrage gradient

$$P_o = P_b(1 - a_2 J_1) - a_1 J_1 - b J_2. \quad (3.2)$$

4. The travel of the projectile is

$$x = \int_0^t v_p dt + \int_0^t v_{rp} dt. \quad (4.1)$$

5. The mass fraction burning rate of the i th propellant is

$$\dot{Z}_i = \frac{S_i r_i}{V_{gi}}, \quad (5.1)$$

where r_i and S_i are the instantaneous values of the burning rate and surface area, respectively, and V_{gi} is the initial grain volume.

The linear burning rate r_i is given by

$$r_i = \beta_i \bar{P}^{\alpha_i}. \quad (5.2)$$

6. The fraction of mass burned of the i th propellant is

$$Z_i = \int_0^t \dot{Z}_i dt, \quad (6.1)$$

$$\text{or } Z_i = \frac{v_i}{V_{gi}}, \quad (6.2)$$

where v_i is the instantaneous volume of the propellant burned calculated from the distance burned into the propellant given by $\int_0^t r_i dt$.

7. The space-mean pressure $\bar{P}$ (Noble-Able Law) is

$$\bar{P} = \frac{T}{V_c} \left[\sum_i^n \frac{F_i C_i Z_i}{T_{oi}} + \frac{F_I C_I}{T_{oi}} \right], \quad (7.1)$$

where the number of propellants is n and the volume available for gases is

$$V_c = V_o + Ax - \sum_i^n \frac{C_i}{\rho_i} (1 - Z_i) - \sum_i^n C_i b_i Z_i - C_I b_I, \quad (7.2)$$

and the temperature of the gases is given by

$$T = \frac{\left[\sum_i^n \frac{F_i C_i Z_i}{(\gamma_i - 1)} + \frac{F_I C_I}{(\gamma_I - 1)} - E_{pt} - E_{pr} - E_p - E_{br} - E_r - E_d - E_h \right]}{\left[\sum_i^n \frac{F_i C_i Z_i}{(\gamma_i - 1) T_{oi}} + \frac{F_I C_I}{(\gamma_I - 1) T_{oi}} \right]}. \quad (7.3)$$

The energy loss due to projectile translation is

$$E_{pt} = \frac{m_p v_p^2}{2}, \quad (7.4)$$

the energy loss due to projectile rotation is

$$E_{pr} = \frac{\pi^2 m_p v_p^2 T w^2}{4}, \quad (7.5)$$

the energy loss due to propellant gas and unburned propellant motion is ,

for the Lagrange gradient ,

$$E_p = \frac{C_T v_p^2}{6}, \quad (7.6)$$

and for the chambrage gradient

$$E_p = \frac{C_T v_p^2}{2} \frac{A^2 J_4}{V^3(z_p)}. \quad (7.7)$$

The energy loss for work against bore resistance due to engraving and friction is

$$E_{br} = A \int_0^t b r v_p dt, \quad (7.8)$$

the energy loss due to recoil is

$$E_r = \frac{m_{rp} (v_{rp})^2}{2}, \quad (7.9)$$

and the energy lost due to air resistance is

$$E_d = A \int_0^t v_p P_g dt. \quad (7.10)$$

The energy lost due to heat transfer to the chamber walls is given by

$$E_h = \int_0^t \dot{Q} dt, \quad (7.11)$$

with

$$\dot{Q} = A w h (T - T_c), \quad (7.12)$$

where

$$A w = \frac{V_o}{A} \pi D_b + 2A + \pi D_b x, \quad (7.13)$$

and

$$h = \lambda \bar{C}_p \bar{\rho} \bar{v} + h_o, \quad (7.14)$$

where the Nordheim heat transfer coefficient λ is

$$\lambda = [13.2 + 4 \log_{10} [100 D_b]]^{-2}, \quad (7.15)$$

and

$$\bar{v} = \frac{1}{2} v_p, \quad (7.16)$$

$$\bar{\rho} = \frac{\left[\sum_i^n C_i Z_i + C_I \right]}{V_c}. \quad (7.17)$$

$$\text{Since } C_{pi} = \frac{F_i \gamma_i}{(\gamma_i - 1) T_{oi}}, \quad (7.18)$$

$$\bar{C}_p = \frac{\left[\sum_i^n \frac{F_i \gamma_i C_i Z_i}{(\gamma_i - 1) T_{oi}} dt + \frac{F_I \gamma_I C_I}{(\gamma_I - 1) T_{oi}} \right]}{\left[\sum_i^n C_i Z_i + C_I \right]}. \quad (7.19)$$

Thus the temperature of the chamber wall is

$$T_c = \frac{E_h + f E_{br}}{C_{pw} \rho_w A_w D_w} + T_o, \quad (7.20)$$

where T_o is the initial temperature of the wall.

8. The equation of motion for the recoiling parts (See figure A.) is

$$\dot{v}_{rp} = \left(\frac{A}{m_{rp}} \right) (P_o - \frac{RP}{A} - br), \quad (8.1)$$

where

$$\dot{v}_{rp} = 0 \quad \text{until} \quad P_o > \frac{RP_o}{A} + br. \quad (8.2)$$

When

$$P_o = \frac{RP_o}{A}, \quad t = t_{ro} \quad \text{and} \quad t_r = t - t_{ro}, \quad (8.3)$$

and if

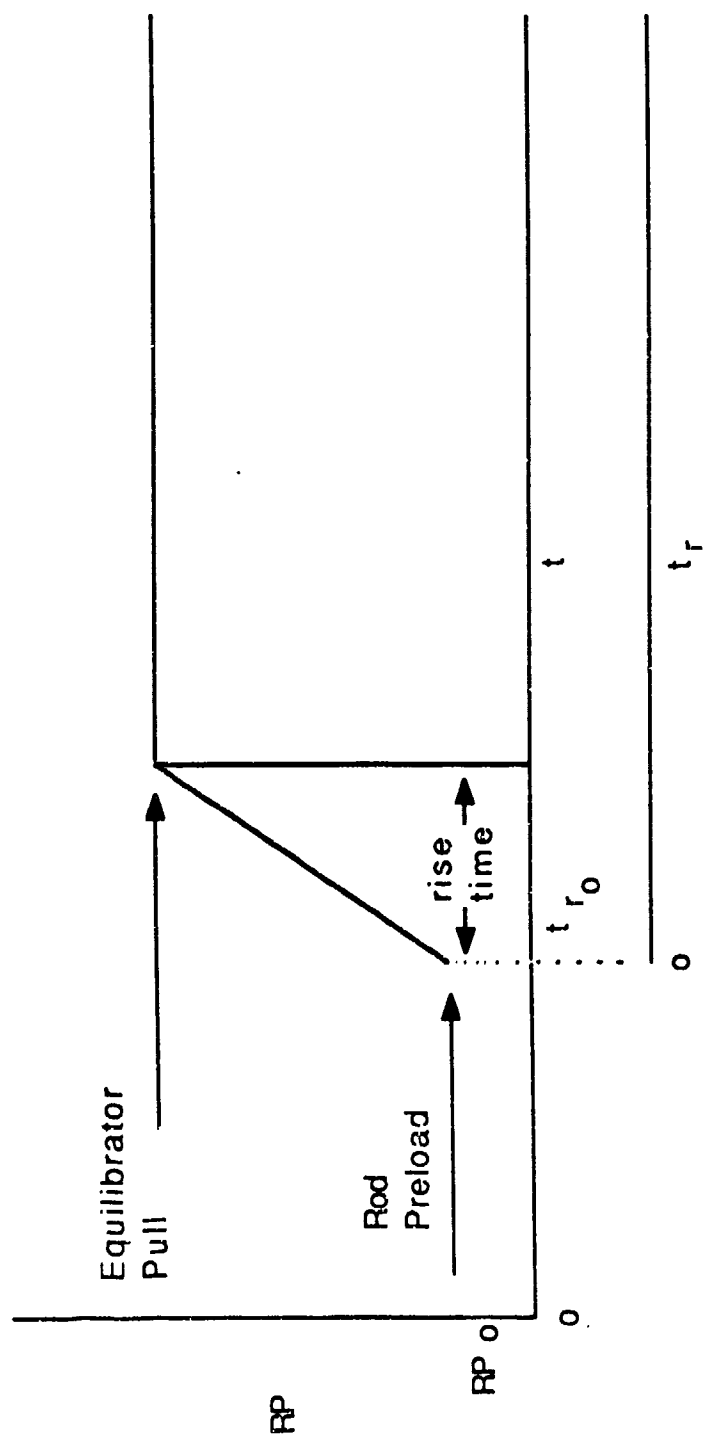
$$\dot{v}_{rp} < 0,$$

$$\dot{v}_{rp} = 0. \quad (8.4)$$

9. The velocity of the recoiling parts in the ground reference frame is

$$v_{rp} = \int_0^t \dot{v}_{rp} dt. \quad (9.1)$$

WEAPON RECOIL



TIME OF RECOIL

FIGURE A

LIST OF SYMBOLS

symbol	definition	units
A	area of base of projectile including appropriate portion of rotating band	m^2
A_w	chamber wall area plus area of gun tube wall exposed to propellant gases	m^2
$A(z)$	area at a distance z from the breech	m^2
b_i	covolume of i th propellant	m^3/kg
b_I	covolume of igniter	m^3/kg
br	bore resistance due to friction and engraving	Pa
C_i	initial mass of i th propellant	kg
C_I	initial mass of igniter	kg
$\bar{C}_p$	specific heat at constant pressure of propellant gas	J/kg-K
C_{pi}	specific heat at constant pressure of i th propellant (over temperature range T to T_{oi})	J/kg-K
C_{pw}	heat capacity of steel of chamber wall	J/kg-K
C_T	total mass of propellants and igniter	kg
D_b	diameter of bore	m
DG	diameter of grooves	m
DL	diameter of lands	m
D_w	chamber wall thickness	m
E_{br}	energy lost to work against bore resistance due to friction and engraving	J
E_d	energy lost to air resistance	J
E_h	energy loss from heat transfer to chamber wall	J
E_p	energy lost to propellant gas and unburned propellant motion	J
E_{pr}	energy loss due to projectile rotation	J
E_{pt}	energy loss due to projectile translation	J
E_r	energy loss due to recoil	J
f	fraction of work done against bore friction that preheats chamber	none
F_i	force per unit mass of i th propellant	J/kg
F_I	force per unit mass of igniter propellant	J/kg
GLR	groove to land ratio	none
h	heat transfer coefficient of Nordheim, Soodak, and Nordheim	watt/ m^2
m_p	mass of projectile	kg
m_{rp}	mass of recoiling parts	kg

$\bar{P}$	space mean pressure	Pa
P_b	pressure on base of projectile	Pa
P_g	pressure of gas or air ahead of projectile	Pa
P_o	breech pressure	Pa
$\dot{Q}$	heat flux to the chamber wall	w
r_i	linear burning rate of ith propellant	m/s
RP	resistive force to projectile motion	N
S_i	surface area of partially burned ith propellant grain	m ²
t	time	s
t_r	recoil time	s
T	mean temperature of propellant gases	K
T_c	temperature of chamber wall	K
T_{oi}	adiabatic flame temperature of ith propellant	K
T_{oi}	adiabatic flame temperature of igniter propellant	K
T_o	initial temperature of chamber wall	K
Tw	twist of rifling	turns/caliber
$V(z)$	volume at distance z from the breech	m ³
$V(z_p)$	volume up to the base of the projectile	m ³
$\bar{v}$	mean gas velocity	m/s
v_p	velocity of projectile	m/s
$\dot{v}_p$	acceleration of projectile	m/s ²
v_{rp}	velocity of recoiling parts	m/s
v_c	volume behind projectile available for propellant gas	m ³
V_{gi}	volume of an unburned ith propellant grain	m ³
v_o	volume of an empty cannon chamber	m ³
v_t	instantaneous volume of propellant burned	m ³
x	travel of projectile	m
Z_i	fraction of mass burned of the ith propellant	none
$\dot{Z}_i$	mass fraction burning rate for ith propellant	s ⁻¹
z_p	distance from the breech to the base of the projectile	m
α_i	burning rate exponent for the ith propellant	none
β_i	burning rate coefficient for the ith propellant	m/s-Pa ^{α_i}
γ_i	ratio of specific heats for ith propellant	none
γ_I	ratio of specific heats for igniter	none
λ	Nordheim heat transfer coefficient	none
$\bar{\rho}$	mean gas density	kg/m ³
ρ_i	density of ith propellant	kg/m ³
ρ_w	density of chamber wall steel	kg/m ³

APPENDIX B

Source code listing of the IBRGAC program.

```

program ibrgac
character bdfil*10,outfil*10
dimension br(10),trav(10),rp(10),tr(10),forcp(10),temp(10),covp(
&10)
dimension chwp(10),rho(10),gamap(10),nperfs(10),glenp(10),pdpi(10
&),p dpo(10),gdiap(10),dbpcp(10),alpha(10,10),beta(10,10),
&pres(10,10)
dimension a(4),b(4),ak(4),d(20),y(20),p(20),z(20),frac(10),surf(10
&),nbr(10),ibo(10)
real lambda,j1zp,j2zp,j3zp,j4zp
dimension chdist(5),chdiam(5),bint(4)
c call gettim(ihr,imin,isec,ihuns)
pi=3.14159
write(*,15)
15 format(' input name of data file to be used as input ')
read(*,10)bdfil
10 format(a10)
open(unit=2,err=999,file=bdfil,status='old',iostat=ios)
rewind 2
write(*,25)
25 format(' input name of output file ')
read(*,10)outfil
open(unit=3,err=998,file=outfil,status='new')
write(3,16)bdfil
16 format(' THE INPUT FILE IS ',a10)
read(2,*,end=20,err=30)cham,grve,aland,glr,twst,travp,igrad
if(igrad.gt.1)go to 51
write(3,55)
55 format(1x,'using Lagrange pressure gradient')
go to 52
c define chambrage assumes nchpts=number of points to define
c chamber > or = 2 < or = 5 (?),chdiam(I) defines chamber diameter
c at chdist (I) chamber distance. chdiam(nchpts) is assumed to be
c the bore diameter and chdist(i) is assumed to be 0, i.e. at the
c breech. Assumes truncated cones.
51 write(3,47,err=30)
47 format(1x,'Using chambrage pressure gradient')
read(2,*,end=20,err=30)nchpts,(chdist(I),chdiam(I),I=1,nchpts)
write(3,53,err=30)(chdist(I),chdiam(I),I=1,nchpts)
53 format(///,' chamber distance cm chamber diameter cm',/(5x,e14
&.6,5x,e14.6))
do 54 I=1,nchpts
54 chdist(I)=0.01*chdist(I)
chdiam(I)=0.01*chdiam(I)
c calculate chamber integrals and volume
if(nchpts.gt.5) write(3,44,err=30)
44 format(1x,'use first 5 points')
if(nchpts.gt.5)nchpts=5
bore=chdiam(nchpts)
if(chdist(1).ne.0.0)write(3,45,err=30)
45 format(1x,' # points ? ')

```

```

chdist(1)=0.0
pi3=pi/3.0
b1=0.0
b2=0.0
b3=0.0
b4=0.0
points=25.0
56 points=points+points
step=chdist(nchpts)/points
zz=0.0
bint(1)=0.0
bint(3)=0.0
bint(4)=0.0
bvol=0.0
r2=0.5*chdiam(1)
k=1
j=int(points+0.5)
do 57 I=1,j
zz=zz+step
if(k.eq.nchpts-1)go to 46
do 58 I1=k,nchpts-1
if(zz.gt.chdist(I1).and. zz.lt.chdist(I1+1))go to 59
58 continue
I1=nchpts-1
59 k=I1
46 diam=(zz-chdist(k))/(chdist(k+1)-chdist(k))
diam=chdiam(k)+diam*(chdiam(k+1)-chdiam(k))
r1=0.5*diam
area=pi*(r1+r2)*(r1+r2)/4.
bvol=bvol+step*pi3*(r1*r1+r1*r2+r2*r2)
bint(1)=bint(1)+step*bvol/area
bint(3)=bint(3)+step*area*bint(1)
bint(4)=bint(4)+step*bvol*bvol/area
57 r2=r1
temp=abs(1.0-b1/bint(1))
if(abs(1.0-b3/bint(3)).gt.temp)temp=abs(1.0-b3/bint(3))
if(abs(1.0-b4/bint(4)).gt.temp)temp=abs(1.0-b4/bint(4))
if(temp.le.0.001)go to 41
b1=bint(1)
b3=bint(3)
b4=bint(4)
go to 56
41 cham=bvol*1.e6
c write(3,47,err=30)bint(1),bint(3),bint(4)
c format(1x,'bint 1 = ',e14.6,' bint 3 = ',e14.6,' bint 4 = ',e14.
c &6)
chmlen=chdist(nchpts)
52 write(3,40,err=30)cham,grve,aland,glr,twst,travp
40 format(1x,'chamber volume cm**3',e14.6,/' groove diam cm',e14.6,/'
&' land diam cm',e14.6,/' groove/land ratio',e14.6,/' twist turns
&/caliber ',e14.6,/' projectile travel cm',e14.6///)
cham=cham*1.e-6
grve=grve*1.e-2
aland=aland*1.e-2
travp=travp*1.e-2

```

```

    read(2,*,end=20,err=30)prwt,iair,htfr,pgas
    write(3,50,err=30)prwt,iair,htfr,pgas
50    format(1x,'projectile mass kg',e14.6,' switch to calculate energy
    &y lost to air resistance J',i2,' fraction of work against bore u
    &sed to heat the tube',e14.6/1x,' gas pressure Pa' ,e14.6)

    read(2,*,end=20,err=30)npts, (br(i),trav(i),i=1,npts)
    write(3,60,err=30)npts, (br(i),trav(i),i=1,npts)
60    format(1x,'number barrel resistance points',i2,' bore resistance
    & MPa - travel cm'/(1x,e14.6,e14.6))
    write(3,65)
    do 62 i=1,npts
    br(i)=br(i)*1.e6
    trav(i)=trav(i)*1.e-2
62    continue
65    format(1x)
    read(2,*,end=20,err=30)rcwt,nrp, (rp(i),tr(i),i=1,nrp)
    write(3,70,err=30)rcwt,nrp, (rp(i),tr(i),i=1,nrp)
70    format(1x,' mass of recoiling parts kg',e14.6,' number of recoi
    &l point pairs',i2,' recoil force N', ' recoil time sec'/(1x,e14
    &.6,3x,e14.6))
    write(3,65)
    read(2,*,end=20,err=30)ho,tshl,cschl,twal,hl,rhocs
    write(3,75,err=30)ho,tshl,cschl,twal,hl,rhocs
75    format(1x,' free convective heat transfer coefficient w/cm**2 K',
    &e14.6,' chamber wall thickness cm',e14.6,' heat capacity of st
    &eel of chamber wall J/g K',e14.6,' initial temperature of chambe
    &r wall K',e14.6,' heat loss coefficient',e14.6,' density of ch
    &amber wall steel g/cm**3',e14.6//)
    ho=ho/1.e-4
    tshl=tshl*1.e-2
    cschl=cschl*1.e+3
    rhocs=rhocs*1.e-3/1.e-6
    read(2,*,end=20,err=30)forcig,covi,tempi,chw, gamai
    write(3,85,err=30)forcig,covi,tempi,chw, gamai
85    format(1x,' impetus of igniter propellant J/g',e14.6,' covolume
    & of igniter cm**3/g',e14.6,' adiabatic flame temperature of igni
    &ter propellant K',e14.6,' initial mass of igniter kg',e14.6,' r
    &atio of specific heats for igniter',e14.6//)
    forcig=forcig*1.e+3
    covi=covi*1.e-6/1.e-3
    read(2,*,end=20,err=30)nprop, (forcp(i),tempp(i),covp(i),chwp(i),
    &rhop(i),gamap(i),nperfs(i),glenp(i),pdpi(i),pdpo(i),gdiap(i),dbpcp
    &(i),i=1,nprop)
    write(3,95,err=30) (i,forcp(i),tempp(i),covp(i),chwp(i)
    &,rhop(i),gamap(i),nperfs(i),glenp(i),pdpi(i),pdpo(i),gdiap(i),dbpc
    &p(i),i=1,nprop)
95    format((' for propellant number',i2,' impetus of propellant J/g
    &',e14.6,' adiabatic temperature of propellant K',e14.6,' covol
    &ume of propellant cm**3/g',e14.6,' initial mass of propellant kg'
    &,e14.6,' density of propellant g/cm**3',e14.6,' ratio of specifi
    &c heats for propellant',e14.6,' number of perforations of propell
    &ant',i2,' length of propellant grain cm',e14.6,' diameter of inn
    &er perforation in propellant grains cm',e14.6,' diameter of outer
    &perforation of propellant grains cm',e14.6,' outside diameter of

```

```

&propellant grain cm',e14.6/' distance between perf centers cm',e1
&4.6)//)
  tmpi=0.0
  do 96 i=1,nprop
    forcpi(i)=forcpi(i)*1.e+3
    covpi(i)=covpi(i)*1.e-6/1.e-3
    rhopi(i)=rhopi(i)*1.e-3/1.e-6
    glenpi(i)=glenpi(i)*0.01
    pdpi(i)=pdpi(i)*0.01
    pdpi(i)=pdpi(i)*0.01
    gdiapi(i)=gdiapi(i)*0.01
    dbpcpi(i)=dbpcpi(i)*0.01
    tmpi=tmpi+chwp(i)
96    continue
    tmpi=tmpi+chwi
    do 97 j=1,nprop
      read(2,*,end=20,err=30)nbr(j),(alpha(j,i),beta(j,i),pres(j,i),
&i=1,nbr(j))
      write(3,110,err=30)nbr(j),(alpha(j,i),beta(j,i),pres(j,i),
&i=1,nbr(j))
110    format(1x,'number of burning rate points',i2/3x,' exponent',8x,'
& coefficient',10x,' pressure'/5x,'-',15x,'cm/sec-MPa**ai',10x,'MP
&a',/(1x,e14.6,5x,e14.6,15x,e14.6))
      do 112 i=1,nbr(j)
        beta(j,i)=beta(j,i)*1.e-2
        pres(j,i)=pres(j,i)*1.e6
112    continue
97    continue
      write(3,65)
      read(2,*,end=20,err=30)deltat,deltap,tstop
      write(3,120,err=30)deltat,deltap,tstop
120    format(1x,'time increment msec',e14.6,' print increment msec',e14
&.6/1x,'time to stop calculation msec ',e14.6)
      write(*,130)
      deltat=deltat*0.001
      deltap=deltap*0.001
      tstop=tstop*0.001
130    format(1x,'the data has been read')
      if(igrad.gt.1)go to 131
      bore=(glr*grve*grve+aland*aland)/(glr+1.)
      bore=sqrt(bore)
131    areab=pi*bore*bore/4.
      lambda=1./((13.2+4.*log10(100.*bore))**2)
      pmaxm=0.0
      pmaxbr=0.0
      pmaxba=0.0
      tpmaxm=0.0
      tpmaxbr=0.0
      tpmaxba=0.0
      tpmax=0.0
      a(1)=0.5
      a(2)=1.-sqrt(2.)/2.
      a(3)=1.+sqrt(2.)/2.
      a(4)=1./6.
      b(1)=2.

```

```

b(2)=1.
b(3)=1.
b(4)=2.
ak(1)=0.5
ak(2)=a(2)
ak(3)=a(3)
ak(4)=0.5
vp0=0.0
tr0=0.0
tcw=0.0
do 5 i=1,nprop
  ibo(i)=0
5  vp0=chwp(i)/rhop(i)+vp0
  volgi=cham-vp0-chwi*covi
  pmean=forcig*chwi/volgi
  volg=volgi
  volgi=volgi+vp0
  wallt=twal
  ptime=0.0
  ibrp=8
  z(3)=1.
  nde=ibrp+nprop
  write(3,132)areab,pmean,vp0,volgi
132  format(1x,'area bore m^2 ',e16.6,' pressure from ign Pa',e16.6,/,
&1x,' volume of unburnt prop m^3 ',e16.6,' init cham vol-cov ign m
&^3 ',e16.6)
  write(3,6)
6  format(1x,'      time      acc      vel      dis      mpress
&  pbase      pbrch      ')
  iswl=0
19  continue
  do 11 J=1,4
c  FIND BARREL RESISTANCE
  do 201 k=2,npts
  if(y(2)+y(7).ge.trav(k))go to 201
  go to 203
201  continue
  k=npts
203  resp=(trav(k)-y(2)-y(7))/(trav(k)-trav(k-1))
  resp=br(k)-resp*(br(k)-br(k-1))
c  FIND MASS FRACTION BURNING RATE
  do 211 k=1,nprop
  if(ibo(k).eq.1)goto211
  call prf017(pdpo(k),pdpi(k),gdiap(k),dbpcp(k),glenp(k),surf(k),fra
&c(k),y(ibrp+k),nperfs(k),u)
  if(surf(k).lt.1.e-10) ibo(k)=1
211  continue
  k=nprop
c  ENERGY LOSS TO PROJECTILE TRANSLATION
  elpt=prwt*y(1)*y(1)/2.
c  ENERGY LOSS DUE TO PROJECTILE ROTATION
  elpr=pi*pi*prwt*y(1)*y(1)/4.*twst*twst
c  ENERGY LOSS DUE TO GAS AND PROPELLANT MOTION
  if(igrad.le.1)go to 214
  pt=y(2)+y(7)

```

```

vzp=bvol+areab*pt
j4zp=bint(4)+((bvol+areab*pt)**3-bvol**3)/3./areab/areab
elgpm=tmpi*y(1)*y(1)*areab*areab*j4zp/2./vzp/vzp/vzp
go to 216
214 elgpm=tmpi*y(1)*y(1)/6.
c ENERGY LOSS FROM BORE RESISTANCE
216 elbr=y(4)
z(4)=areab*resp*y(1)
c ENERGY LOSS DUE TO RECOIL
elrc=rcwt*y(6)*y(6)/2.
c ENERGY LOSS DUE TO HEAT LOSS
areaw=cham/areab*pi*bore+2.*areab*pi*bore*(y(2)+y(7))
avden=0.0
avc=0.0
avcp=0.0
z18=0
z19=0
do 213 k=1,nprop
z18=forc(k)*gamap(k)*chwp(k)*frac(k)/(gamap(k)-1.)/tempp(k)+z18
z19=chwp(k)*frac(k)+z19
avden=avden+chwp(k)*frac(k)
213 continue
avcp=(z18+forcig*gamai*chwi/(gamai-1.)/tempi)/(z19+chwi)
avden=(avden+chwi)/(volg+covl)
avvel=.5*y(1)
htns=lambda*avcp*avden*avvel+ho
z(5)=areaw*htns*(tgas-wallt)*hl
elht=y(5)
wallt=(elht+htfr*elbr)/cshl/rhocs/areaw/tshl+twal
c write(3,*) lambda,avcp,avden,avvel,ho,areaw,htns,tgas,wallt,hl,z(5)
c s,elht
c ENERGY LOSS DUE TO AIR RESISTANCE
air=iair
z(8)=y(1)*pgas*air
elar=areab*y(8)
c RECOIL
z(6)=0.0
if(pbrch.le.rp(1)/areab)go to 221
rfor=rp(2)
if(y(3)-tr0.ge.tr(2))go to 222
rfor=(tr(2)-(y(3)-tr0))/(tr(2)-tr(1))
rfor=rp(2)-rfor*(rp(2)-rp(1))
222 z(6)=areab/rcwt*(pbrch-rfor/areab-resp)
if(y(6).lt.0.0)y(6)=0.0
z(7)=y(6)
goto 223
221 tr0=y(3)
223 continue
c CALCULATE GAS TEMPERATURE
eprop=0.0
rprop=0.0
do 231 k=1,nprop
eprop=eprop+forc(k)*chwp(k)*frac(k)/(gamap(k)-1.)
rprop=rprop+forc(k)*chwp(k)*frac(k)/(gamap(k)-1.)/tempp(k)
231 continue

```

```

tenergy=elpt+elpr+elgpm+elbr+elrc+elht+elar
tgas=(eprop+forcig*chwi/(gamai-1.))-elpt-elpr-elgpm-elbr-elrc-elht
&-elar)/(rprop+forcig*chwi/(gamai-1.)/tempi)
c FIND FREE VOLUME
v1=0.0
cov1=0.0
do 241 k=1,nprop
v1=chwp(k)*(1.-frac(k))/rhop(k)+v1
cov1=cov1+chwp(k)*covp(k)*frac(k)
241 continue
volg=volgi+areab*(y(2)+y(7))-v1-cov1
c CALCULATE MEAN PRESSURE
r1=0.0
do 251 k=1,nprop
r1=r1+forcp(k)*chwp(k)*frac(k)/tempp(k)
251 continue
pmean=tgas/volg*(r1+forcig*chwi/tempi)
259 resp=resp+pgas*air
if(igrad.le.1)go to 252
if(isw1.ne.0)go to 253
pbase=pmean
pbrch=pmean
if(pbase.gt.resp+1.)isw1=1
go to 257
c USE CHAMBRAGE PRESSURE GRADIENT EQUATION
253 j1zp=bint(1)+(bvol*pt+areab/2.*pt*pt)/areab
j2zp=(bvol+areab*pt)**2/areab/areab
j3zp=bint(3)+areab*bint(1)*pt+bvol*pt*pt/2.+areab*pt*pt*pt/6.
a2t=-tmpi*areab*areab/prwt/vzp/vzp
alf=1.-a2t*j1zp
alt=tmpi*areab*(areab*y(1)*y(1)/vzp+areab*resp/prwt)/vzp/vzp
bt=-tmpi*y(1)*y(1)*areab*areab/2./vzp/vzp/vzp
bata=-alt*j1zp-bt*j2zp
gamma=alf+a2t*j3zp/vzp
delta=bata+alt*j3zp/vzp+bt*j4zp/vzp
c calculate base pressure
pbase=(pmean-delta)/gamma
c calculate breech pressure
pbrch=alf*pbase+bata
go to 254
c USE LAGRANGE PRESSURE GRADIENT EQUATION
252 if(isw1.ne.0)go to 256
if(pmean.lt.resp)resp=pmean
c CALCULATE BASE PRESSURE
256 pbase=(pmean+tmpi*resp/3./prwt)/(1.+tmpi/3./prwt)
if(pbase.gt.resp+1.)isw1=1
c CALCULATE BREECH PRESSURE
pbrch=pbase+tmpi/2./prwt*(pbase-resp)
c CALCULATE PROJECTILE ACCELERATION
254 z(1)=areab*(pbase-resp)/prwt
if(z(1).lt.0.0)go to 257
go to 258
257 if(isw1.eq.0)z(1)=0.0
258 if(y(1).lt.0.0)y(1)=0.0
z(2)=y(1)

```

```

c   GET BURNING RATE
do 264 m=1,nprop
  z(ibrp+m)=0.0
  if(ibo(m).eq.1) goto 264
  do 262 k=1,nbr(m)
    if(pmean.gt.pres(m,k))go to 262
  go to 263
262  continue
    k=nbr(m)
263  z(ibrp+m)=beta(m,k)*(pmean*1.e-6)**alpha(m,k)
264  continue
    do 21 i=1,nde
      d(i)=(z(i)-b(j)*p(i))*a(j)
      y(i)=deltat*d(i)+y(i)
      p(i)=3.*d(i)-ak(j)*z(i)+p(i)
    21  continue
    11  continue
      t=t+deltat
      if(pmaxm.gt.pmean)go to 281
      pmaxm=pmean
      tpmaxm=y(3)
281  if(pmaxba.gt.pbase)go to 282
      pmaxba=pbase
      tpmaxba=y(3)
282  if(pmaxbr.gt.pbrch)go to 283
      pmaxbr=pbrch
      tpmaxbr=y(3)
283  continue
      if(y(3).lt.ptime)go to 272
      ptime=ptime+deltap
      write(3,7)y(3),z(1),y(1),y(2),pmean,pbase,pbrch
    7   format(1x,7e11.4)
    316 format(1x)
272  continue
      if(t.gt.tstop)goto 200
      if(y(2).gt.travp)go to 200
      rmvelo=y(1)
      tmvelo=y(3)
      disto=y(2)
      go to 19
200  write(3,311)t,y(3)
311  format(1x,'deltat t',e14.6,'intg t',e14.6)
      write(3,312)pmaxm,tpmaxm
312  format(1x,'PMAXMEAN Pa ',e14.6,'time at PMAXMEAN sec ',e14.6)
      write(3,313)pmaxba,tpmaxba
313  format(1x,'PMAXBASE Pa ',e14.6,'time at PMAXBASE sec ',e14.6)
      write(3,314)pmaxbr,tpmaxbr
314  format(1x,'PMAXBREECH Pa ',e14.6,'time at PMAXBREECH sec ',e14.6)
      if(y(2).le.travp)go to 303
      dfraction=(travp-disto)/(y(2)-disto)
      rmvel=(y(1)-rmvelo)*dfraction+rmvelo
      tmvel=(y(3)-tmvelo)*dfraction+tmvelo
      write(3,318)rmvel,tmvel
318  format(1x,'muzzle VELOCITY m/s ',e14.6,'time of muzzle velocity s
      &sec ',e14.6)

```

```

      goto 319
303  write(3,327)y(1),y(3)
327  format(1x,'velocity of projectile m/s ',e14.6,' at this time msec
&',e14.6)
319  efi=chwi*forcig/(gamai-1.)
      efp=0.0
      do 315 i=1,nprop
      efp=efp+chwp(i)*forcp(i)/(gamap(i)-1.0)
315  continue
      tenerg=efi+efp
      write(3,317)tenerg
317  format(1x,'total initial energy available J = ',e14.6)
      tengas=chwi*forcig*tgas/(gamai-1.)/tempi
      do 135 i=1,nprop
      tengas=(frac(i)*chwp(i)*forcp(i)*tgas/tempp(i)/(gamap(i)-1.))+teng
&as
      write(3,328)i,frac(i)
328  format(' FOR PROPELLANT ',I2,' MASSFRACT BURNT IS ',e14.6)
135  continue
      write(3,136)tengas
136  format(1x,'total energy remaining in gas J= ',e14.6)
      write(3,320)elpt
320  format(1x,'energy loss from projectile translation J= ',e14.6)
      write(3,321)elpr
321  format(1x,'energy loss from projectile rotation J= ',e14.6)
      write(3,322)elgpm
322  format(1x,'energy lost to gas and propellant motion J= ',e14.6)
      write(3,323)elbr
323  format(1x,'energy lost to bore resistance J= ',e14.6)
      write(3,324)elrc
324  format(1x,'energy lost to recoil J= ',e14.6)
      write(3,325)elht
325  format(1x,'energy loss from heat transfer J= ',e14.6)
      write(3,326)elar
326  format(1x,'energy lost to air resistance J= ',e14.6)
c    call gettim(ihro,imino,iseco,ihunso)
c    time=(ihro-ihr)*3600.+(imino-imin)*60.+(iseco-isec)+(ihunso-ihuns)
c    &/100.
c    write(3,*)time
      stop
      20  write(*,140)
140  format(1x,'end of file encounter')
      stop
      30  write(*,150)
999  continue
998  continue
150  format(1x,'read or write error')
      stop
      end
      SUBROUTINE PRF017(P,P1,D,D1,L,SURF,MASSF,X,NP,u)
      IMPLICIT REAL*4(A-Z)

C
C    P=OUTER PERF DIA
C    P1=INNER PERF DIA
C    D=OUTER DIA

```

```

C      D1=DISTANCE BETWEEN PERF CENTRES
C      L=GRAIN LENGTH
C      NP=NUMBER OF PERFS
C
C      SURF=OUTPUT SURFACE AREA
C      MASSF=OUTPUT MASS FRACTION OF PROPELLANT BURNER
C
C      W=WEB BETWEEN OUTER PERFS
C      W0=OUTER WEB
C      W1=WEB BETWEEN OUTER AND INNER PERFS
C      W4=MINIMUM WEB
C
C      INTEGER ITYM,NP
C      DATA PI,SQRT3/3.14159,1.732051/,ITYM/0/
C      DATA HAFPI,PIFOR,TWOPI/1.570796,.785398,6.283185/
C
C      IF(ITYM.GT.0)GO TO 10
C      P1SQ=P1*P1
C      D1SQ=D1*D1
C      PSQ=P*P
C      DSQ=D*D
C      D1SQ3=D1*SQRT3
C      D2SQ3=D1SQ*SQRT3
C      IF(NP.EQ.0)GO TO 2000
C      IF(NP.EQ.1)GO TO 3000
C      IF(NP.NE.7)GO TO 60
C      IF(P1.GT.(P+D1*(SQRT3-1))) GO TO 60
C      IF(D.GE.D1*(SQRT3+1.)-P)GO TO 130
60  WRITE(6,90)
90  FORMAT(1X,'UNACCEPTABLE GRANULATION')
C      STOP
130  W=D1-P
C      IF(W.LT.0)GO TO 60
C      W0=(D-P-2.*D1)/2.
C      IF(W0.LT.0.)GO TO 60
C      W1=(2.*D1-P-P1)/2.
C      IF(W1.LT.0.)GO TO 60
C      X1=(P1SQ-PSQ+4.*D1SQ-2.*P1*D1SQ3)/4./ (D1SQ3+P-P1)
C      X2=(4.*D1SQ+D*D-2.*D*D1SQ3-PSQ)/4./ (-D1SQ3+P+D)
C      A=PI*L*(D+P1+6.*P)+HAFPI*(D1SQ-6.*PSQ)
C      U=PI*L/4.*(DSQ-P1SQ-6.*PSQ)
C      W4=AMIN1(W,W0,W1)
10  MASSF=0.
C      TWOX=X+X
C      XSQ=X*X
C      P1P2X=P1+TWOX
C      PP2X=P+TWOX
C      DM2X=D-TWOX
C      LM2X=L-TWOX
C      P12XSQ=P1P2X*P1P2X
C      PP2XSQ=PP2X*PP2X
C      DM2XSQ=DM2X*DM2X
C      IF(NP.EQ.0)GO TO 2000
C      IF(NP.EQ.1)GO TO 3000
C      IF(IM2X.GT.0)GO TO 340

```

```

SURF=0.
V=0.
GO TO 850
340 S0=PI*LM2X*(D+P1+6.*P+12.*X)+HAFPI*(DM2X*DM2X
1 -P1P2X*P1P2X-6.*PP2X*PP2X)
V0=PIFOR*LM2X*(DM2X*DM2X-P1P2X*P1P2X-6.*PP2X*PP2X)
IF(X.GT.W4/2.)GO TO 360
MASSF=-TWOX/L/(DSQ-P1SQ-6.*PSQ)
MASSF=MASSF*(24.*XSQ+(24.*P+4.*P1+4.*D-12.*L)*X+P1SQ
1 +6.*PSQ-2.*L*D-2.*P1*L-12.*L*P-DSQ)
SURF=S0
RETURN
360 IF(X.GT.W1/2.)GO TO 390
F2=0.
L2=0.
A3=0.
A4=0.
GO TO 460
390 Z=(2.*D1+P+P1+4.*X)/4.
B3=((P1-P)*(P1+P+4.*X)+4.*D1SQ)/4./D1/P1P2X
A3=ATAN(SQRT(1.-B3*B3)/B3)
B4=((P-P1)*(P+P1+4.*X)+4.*D1SQ)/4./D1/PP2X
A4=ATAN(SQRT(1.-B4*B4)/B4)
F2=A3/4.*P12XSQ+A4/4.*PP2XSQ
1 -SQRT(Z*(Z-D1)*(2.*Z-P-TWOX)*(2.*Z-P1-TWOX))
L2=LM2X*(A4*PP2X+A3*P1P2X)
460 IF(X.GT.W/2.)GO TO 490
F3=0.
L3=0.
A5=0.
GO TO 530
490 B5=D1/PP2X
A5=ATAN(SQRT(1.-B5*B5)/B5)
F3=(A5*PP2XSQ-D1*SQRT(PP2XSQ-D1SQ))/2.
L3=2.*A5*LM2X*PP2X
530 IF(X.GT.W0/2.)GO TO 560
F1=0.
L1=0.
A1=0.
A2=0.
GO TO 650
560 Y=(2.*D1+P+D)/4.
B1=((D+P)*(D-P-4.*X)-4.*D1SQ)/4./D1/PP2X
A1=ATAN(SQRT(1.-B1*B1)/B1)
IF(A1.GT.0.)GO TO 610
A1=PI+A1
610 B2=((D+P)*(D-P-4.*X)+4.*D1SQ)/4./D1/DM2X
A2=ATAN(SQRT(1.-B2*B2)/B2)
F1=A1/4.*P12XSQ-A2/4.*DM2XSQ+SQRT(Y*(Y-D1)
1 *(2.*Y-P-TWOX)*(2.*Y-D-TWOX))
L1=LM2X*(A1*PP2X+A2*DM2X)
650 IF(X.GT.W/2.)GO TO 690
SURF=S0+12.*(F1+F2+F3)-6.*(L1+L2+L3)
V=V0+6.*(F1+F2+F3)*LM2X
GO TO 850

```

```

690 IF(X.LT.X1)GO TO 730
    S1=0.0
    V1=0.0
    GO TO 760
730 S1=3.*D2SQ3-PI*PP2XSQ-HAFPI*P12XSQ
    $ +6.*F3+12.*F2
    S1=S1+LM2X*(2.*(PI-3.*A5-3.*A4)*PP2X+(PI-6.*A3)
    $ *P1P2X)
    V1=LM2X/2.*(3.*D2SQ3-PI*PP2XSQ
    $ -HAFPI*P12XSQ+6.*F3+12.*F2)
760 IF(X.LT.X2) GO TO 800
    S2=0.0
    V2=0.0
    GO TO 830
800 S2=HAFPI*DM2XSQ-3.*D2SQ3-TWOPI*PP2XSQ
    $ +12.*F1+6.*F3
    S2=S2+LM2X*((PI-6.*A2)*DM2X+2.*(TWOPI-3.*A1-3.*A5)
    $ *PP2X)
    V2=LM2X/2.*(HAFPI*DM2XSQ-3.*D2SQ3-TWOPI
    $ *PP2XSQ+12.*F1+6.*F3)
830 SURF=S1+S2
    V=V1+V2
850 MASSF=1.-V/U
    RETURN
C
C ZERO PERF CALCULATIONS START HERE.
C
2000 if(d-2*x.le.0.0) go to 2001
    twox=x+x
    xsq=x*x
    MASSF=TWOX*(DSQ+2.*L*D-4.*X*D-TWOX*L+4.*XSQ)/(DSQ*L)
    u=dsq*1*pi/4.
    SURF=PI*(DSQ/2.-4.*D*X-TWOX*L+D*L+6.*XSQ)
    RETURN
2001 surf=0.0
    massf=1.0
    u=dsq*1*pi/4.
    return
C
C ONE PERF CALCULATIONS START HERE.
C
3000 if(d-p-4.*x.le.0.0) goto 3001
    twox=x+x
    MASSF=TWOX*(DSQ+2.*L*D-4.*X*D-PSQ+2.*P*L-4.*P*X)
    $ /(DSQ*L-PSQ*L)
    u=dsq*1*pi/4.-psq*1*pi/4.
    SURF=PI*(DSQ/2.-4.*D*X-4.*X*P+D*L+P*L-PSQ/2.)
    RETURN
3001 surf=0.0
    massf=1.0
    u=dsq*1*pi/4.-psq*1*pi/4.
    return
    END

```

APPENDIX C

USER'S MANUAL FOR IBRGA

IBRGA relies on an input data base consisting of all numerical parameters essential for running the code. All values are in metric units. Below is a compilation of a typical IBRGAC data base showing the name and location of each input parameter. The names for the numerical values are prefixed with an alphabetical designator corresponding to the position at which the data is to appear, that is, from left to right. The data may be separated by blanks or commas. The units are shown to the right of each input.

A B C D E F G H I J K

record 1

- A. - chamber volume (cm^3)
- E. - groove diameter (cm)
- C. - land diameter (cm)
- D. - groove/land ratio (none)
- E. - twist (turns/caliber)
- F. - projectile travel (cm)
- G. - gradient switch (1 = Lagrange, 2 = chambrage)

record 1a (Read only if gradient switch = 2)

- A. - number of points to describe chamber ($I \leq 10$)
- B. - initial distance from breech (must be 0.0 cm)
- C. - diameter at 0 (cm)

.
.
.

Ith distance from breech (position of base of projectile (cm))
Ith diameter at Ith distance (used to calculate bore area).(cm)

record 2

- A. - projectile mass (kg)
- B. - switch to calculate energy lost to air resistance
- C. - fraction of work done against bore to heat tube
- D. - gas pressure in front of projectile (Pa)

record 3

- A. - number of barrel resistance points ($J \leq 10$)
- B. - bore resistance (MPa)
- C. - travel (cm)

.
.
.

Jth bore resistance (MPa)
Jth travel (cm)

record 4

- A. - mass of recoiling parts (kg)
- B. - number of recoil point pairs (2)
- C. - recoil force (N)
- D. - recoil time (s)
- E. - recoil force (N)
- F. - recoil time (s)

record 5

- A. - free convective heat transfer coefficient (W/cm^2)
- B. - chamber wall thickness (cm)
- C. - heat capacity of steel of chamber wall (J/g-K)
- D. - initial temperature of chamber wall (K)
- E. - heat loss coefficient
- F. - density of chamber wall steel (g/cm^3)

record 6

- A. - impetus of igniter propellant (J/g)
- B. - covolume of igniter (cm^3/g)
- C. - adiabatic flame temperature of igniter propellant (K)
- D. - initial mass of igniter (kg)
- E. - ratio of specific heats for igniter

record 7

- A. - number of propellants ($K \leq 10$)
- B. - impetus of propellant (J/g)
- C. - adiabatic temperature of propellant (K)
- D. - covolume of propellant (cm^3/g)
- E. - initial mass of propellant (kg)
- F. - density of propellant (g/cm^3)
- G. - ratio of specific heats for propellant
- H. - number of perforations of propellant (may be 0,1, or 7 only)
- I. - length of propellant grain (cm)
- J. - diameter of inner perforations in propellant grains (cm)
- K. - diameter of outer perforations of propellant grains (cm)
- L. - outside diameter of propellant grain (cm)
- M. - distance between perf centers (cm)

(Kth propellant)

- A. - impetus of propellant (J/g)
- B. - adiabatic temperature of propellant (K)
- C. - covolume of propellant (cm^3/g)
- D. - initial mass of propellant (kg)
- E. - density of propellant (gm/cm^3)
- F. - ratio of specific heats for propellant
- G. - number of perforations of propellant
- H. - length of propellant grain (cm)
- I. - diameter of inner perforations in propellant grains (cm)
- J. - diameter of outer perforations of propellant grains (cm)
- K. - outside diameter of propellant grain (cm)
- L. - distance between perf centers (cm)

record 8

- A. - number of burning rate points ($J \leq 10$) for propellant 1
- B. - exponent
- C. - coefficient (cm/s-MPa ^{α_j})
- D. - pressure (MPa)

.
.
.

Jth exponent
Jth coefficient
Jth pressure

.
.
.

- A. - number of burning rate points ($L \leq 10$) for propellant N
- B. - exponent
- C. - coefficient (cm/s-MPa ^{α_l})
- D. - pressure (MPa)

.
.
.

Lth exponent
Lth coefficient
Lth pressure

record 9

- A. - time increment (ms)
- B. - print increment (ms)
- C. - time to stop calculation (ms)

APPENDIX D

Input data base for the bore-diameter calculation.

```
9832.2384 12.7 12.7 1.0 0.0 457.2 1
9.796 0 0.0 0.0
5 0.0 0.0 0.0 .6 0.0 1.3 0.0 300. 0. 457.
1.e20 2 3.0e+4 0.0 8.0e+5 0.2
0.001135 .01143 .46028 273. 1. 7.8612
84.5535 .9755 294. .004712 1.4
1 1135.99 3141. .9755 8.7 1.6605 1.23 7 3.175 .0508 .0508 1.07208908 .28072226
1 1.0 .1105187 689.476
0.005 .05 30.
```

APPENDIX D

Output for the bore-diameter calculation.

```

THE INPUT FILE IS iclopt
using Lagrange pressure gradient
chamber vclume cm**3  0.983224E+04
  groove diam cm  0.127000E+02
land diam cm  0.127000E+02
  groove/land ratio  0.100000E+01
  twist turns/caliber  0.000000E+00
projectile travel cm  0.457200E+03

projectile mass kg  0.979600E+01
switch to calculate energy lost to air resistance J 0
fraction of work against bore used to heat the tube  0.000000E+00
gas pressure Pa  0.000000E+00
number barrel resistance points 5
bore resistance MPa - travel cm
  0.000000E+00  0.000000E+00
  0.000000E+00  0.600000E+00
  0.000000E+00  0.130000E+01
  0.000000E+00  0.300000E+03
  0.000000E+00  0.457000E+03

  mass of recoiling parts kg  0.100000E+21
number of recoil point pairs 2
recoil force N  recoil time sec
  0.300000E+05      0.000000E+00
  0.800000E+06      0.200000E+00

  free convective heat transfer coefficient w/cm**2 K  0.113500E-02
chamber wall thickness cm  0.114300E-01
heat capacity of steel of chamber wall J/g K  0.460280E+00
initial temperature of chamber wall K  0.273000E+03
heat loss coefficient  0.100000E+01
density of chamber wall steel g/cm**3  0.786120E+01

  impetus of igniter propellant J/g  0.845535E+02
covolume of igniter cm**3/g  0.975500E+00
adiabatic flame temperature of igniter propellant K  0.294000E+03
initial mass of igniter kg  0.471200E-02
ratio of specific heats for igniter  0.140000E+01

for propellant number 1
  impetus of propellant J/g  0.113599E+04
  adiabatic temperature of propellant K  0.314100E+04
  covolume of propellant cm**3/g  0.975500E+00
  initial mass of propellant kg  0.870000E+01
  density of propellant g/cm**3  0.166050E+01
  ratio of specific heats for propellant  0.123000E+01

```

number of perforations of propellant 7
 length of propellant grain cm 0.317500E+01
 diameter of inner perforation in propellant grains cm 0.508000E-01
 diameter of outerperforation of propellant grains cm 0.508000E-01
 outside diameter of propellant grain cm 0.107209E+01
 distance between perf centers cm 0.280722E+00

number of burning rate points 1
 exponent coefficient pressure
 - cm/sec-MPa**ai MPa
 0.100000E+01 0.110519E+00 0.689476E+03

time increment msec 0.500000E-02 print increment msec 0.500000E-01
 time to stop calculation msec 0.300000E+02
 area bore m^2 0.126677E-01 pressure from ign Pa 0.868339E+05
 volume of unburnt prop m^3 0.523939E-02
 init cham vol-cov ign m ^3 0.982764E-02

time	acc	vel	dis	mpress	pbase	pbrch
0.5000E-05	0.8761E+02	0.4356E-03	0.1087E-08	0.8782E+05	0.6775E+05	0.9785E+05
0.5000E-04	0.9693E+02	0.4585E-02	0.1125E-06	0.9716E+05	0.7496E+05	0.1083E+06
0.1050E-03	0.1095E+03	0.1026E-01	0.5174E-06	0.1098E+06	0.8471E+05	0.1223E+06
0.1550E-03	0.1223E+03	0.1605E-01	0.1172E-05	0.1226E+06	0.9456E+05	0.1366E+06
0.2000E-03	0.1349E+03	0.2183E-01	0.2022E-05	0.1352E+06	0.1043E+06	0.1506E+06
0.2500E-03	0.1502E+03	0.2895E-01	0.3289E-05	0.1505E+06	0.1161E+06	0.1677E+06
0.3050E-03	0.1687E+03	0.3771E-01	0.5117E-05	0.1691E+06	0.1305E+06	0.1885E+06
0.3550E-03	0.1873E+03	0.4660E-01	0.7221E-05	0.1878E+06	0.1449E+06	0.2092E+06
0.4050E-03	0.2077E+03	0.5647E-01	0.9793E-05	0.2081E+06	0.1606E+06	0.2319E+06
0.4550E-03	0.2298E+03	0.6740E-01	0.1289E-04	0.2304E+06	0.1777E+06	0.2567E+06
0.5050E-03	0.2539E+03	0.7949E-01	0.1655E-04	0.2545E+06	0.1964E+06	0.2836E+06
0.5550E-03	0.2801E+03	0.9283E-01	0.2086E-04	0.2807E+06	0.2166E+06	0.3128E+06
0.6000E-03	0.3055E+03	0.1060E+00	0.2532E-04	0.3062E+06	0.2362E+06	0.3412E+06
0.6500E-03	0.3358E+03	0.1220E+00	0.3102E-04	0.3366E+06	0.2597E+06	0.3751E+06
0.7000E-03	0.3686E+03	0.1396E+00	0.3755E-04	0.3695E+06	0.2850E+06	0.4117E+06
0.7500E-03	0.4039E+03	0.1589E+00	0.4501E-04	0.4048E+06	0.3123E+06	0.4511E+06
0.8000E-03	0.4417E+03	0.1800E+00	0.5347E-04	0.4428E+06	0.3416E+06	0.4934E+06
0.8500E-03	0.4824E+03	0.2031E+00	0.6305E-04	0.4835E+06	0.3730E+06	0.5388E+06
0.9000E-03	0.5260E+03	0.2283E+00	0.7382E-04	0.5272E+06	0.4067E+06	0.5874E+06
0.9500E-03	0.5726E+03	0.2558E+00	0.8592E-04	0.5739E+06	0.4428E+06	0.6395E+06
0.1000E-02	0.6224E+03	0.2856E+00	0.9944E-04	0.6239E+06	0.4813E+06	0.6951E+06
0.1050E-02	0.6756E+03	0.3181E+00	0.1145E-03	0.6772E+06	0.5225E+06	0.7546E+06
0.1100E-02	0.7324E+03	0.3533E+00	0.1313E-03	0.7341E+06	0.5664E+06	0.8180E+06
0.1150E-02	0.7930E+03	0.3914E+00	0.1499E-03	0.7949E+06	0.6132E+06	0.8857E+06
0.1200E-02	0.8576E+03	0.4326E+00	0.1705E-03	0.8596E+06	0.6632E+06	0.9579E+06
0.1250E-02	0.9265E+03	0.4772E+00	0.1932E-03	0.9287E+06	0.7165E+06	0.1035E+07
0.1300E-02	0.9999E+03	0.5254E+00	0.2183E-03	0.1002E+07	0.7733E+06	0.1117E+07
0.1350E-02	0.1078E+04	0.5773E+00	0.2458E-03	0.1081E+07	0.8338E+06	0.1204E+07
0.1400E-02	0.1162E+04	0.6333E+00	0.2761E-03	0.1164E+07	0.8983E+06	0.1297E+07
0.1450E-02	0.1251E+04	0.6935E+00	0.3092E-03	0.1253E+07	0.9670E+06	0.1397E+07
0.1500E-02	0.1345E+04	0.7584E+00	0.3455E-03	0.1348E+07	0.1040E+07	0.1503E+07
0.1550E-02	0.1446E+04	0.8282E+00	0.3851E-03	0.1450E+07	0.1119E+07	0.1615E+07
0.1600E-02	0.1554E+04	0.9032E+00	0.4284E-03	0.1558E+07	0.1202E+07	0.1736E+07
0.1650E-02	0.1669E+04	0.9837E+00	0.4755E-03	0.1673E+07	0.1291E+07	0.1864E+07
0.1700E-02	0.1792E+04	0.1070E+01	0.5269E-03	0.1796E+07	0.1386E+07	0.2001E+07
0.1750E-02	0.1923E+04	0.1163E+01	0.5827E-03	0.1927E+07	0.1487E+07	0.2147E+07

0.1800E-02	0.2062E+04	0.1263E+01	0.6433E-03	0.2067E+07	0.1595E+07	0.2303E+07
0.1850E-02	0.2211E+04	0.1369E+01	0.7091E-03	0.2216E+07	0.1710E+07	0.2470E+07
0.1900E-02	0.2370E+04	0.1484E+01	0.7804E-03	0.2376E+07	0.1833E+07	0.2647E+07
0.1950E-02	0.2540E+04	0.1607E+01	0.8576E-03	0.2546E+07	0.1964E+07	0.2837E+07
0.2000E-02	0.2721E+04	0.1738E+01	0.9412E-03	0.2728E+07	0.2104E+07	0.3039E+07
0.2050E-02	0.2915E+04	0.1879E+01	0.1032E-02	0.2922E+07	0.2254E+07	0.3256E+07
0.2100E-02	0.3122E+04	0.2030E+01	0.1129E-02	0.3129E+07	0.2414E+07	0.3486E+07
0.2150E-02	0.3342E+04	0.2191E+01	0.1235E-02	0.3350E+07	0.2585E+07	0.3733E+07
0.2200E-02	0.3578E+04	0.2364E+01	0.1349E-02	0.3587E+07	0.2767E+07	0.3996E+07
0.2255E-02	0.3856E+04	0.2569E+01	0.1484E-02	0.3865E+07	0.2982E+07	0.4307E+07
0.2305E-02	0.4127E+04	0.2768E+01	0.1617E-02	0.4137E+07	0.3191E+07	0.4609E+07
0.2355E-02	0.4416E+04	0.2982E+01	0.1761E-02	0.4426E+07	0.3415E+07	0.4932E+07
0.2405E-02	0.4725E+04	0.3210E+01	0.1916E-02	0.4736E+07	0.3654E+07	0.5277E+07
0.2455E-02	0.5055E+04	0.3454E+01	0.2082E-02	0.5067E+07	0.3909E+07	0.5646E+07
0.2505E-02	0.5407E+04	0.3716E+01	0.2262E-02	0.5420E+07	0.4181E+07	0.6039E+07
0.2555E-02	0.5783E+04	0.3996E+01	0.2454E-02	0.5797E+07	0.4472E+07	0.6459E+07
0.2605E-02	0.6185E+04	0.4295E+01	0.2662E-02	0.6200E+07	0.4783E+07	0.6908E+07
0.2655E-02	0.6614E+04	0.4615E+01	0.2884E-02	0.6630E+07	0.5115E+07	0.7387E+07
0.2705E-02	0.7072E+04	0.4957E+01	0.3123E-02	0.7089E+07	0.5469E+07	0.7899E+07
0.2755E-02	0.7561E+04	0.5322E+01	0.3380E-02	0.7579E+07	0.5847E+07	0.8445E+07
0.2805E-02	0.8083E+04	0.5713E+01	0.3656E-02	0.8102E+07	0.6251E+07	0.9028E+07
0.2855E-02	0.8640E+04	0.6131E+01	0.3952E-02	0.8661E+07	0.6682E+07	0.9650E+07
0.2905E-02	0.9235E+04	0.6578E+01	0.4270E-02	0.9257E+07	0.7141E+07	0.1031E+08
0.2955E-02	0.9869E+04	0.7055E+01	0.4610E-02	0.9893E+07	0.7632E+07	0.1102E+08
0.3005E-02	0.1055E+05	0.7566E+01	0.4976E-02	0.1057E+08	0.8155E+07	0.1178E+08
0.3055E-02	0.1127E+05	0.8111E+01	0.5367E-02	0.1129E+08	0.8714E+07	0.1258E+08
0.3105E-02	0.1204E+05	0.8693E+01	0.5787E-02	0.1207E+08	0.9309E+07	0.1344E+08
0.3155E-02	0.1286E+05	0.9315E+01	0.6237E-02	0.1289E+08	0.9943E+07	0.1436E+08
0.3205E-02	0.1373E+05	0.9980E+01	0.6720E-02	0.1377E+08	0.1062E+08	0.1534E+08
0.3255E-02	0.1466E+05	0.1069E+02	0.7236E-02	0.1470E+08	0.1134E+08	0.1638E+08
0.3305E-02	0.1566E+05	0.1145E+02	0.7789E-02	0.1569E+08	0.1211E+08	0.1749E+08
0.3355E-02	0.1672E+05	0.1226E+02	0.8382E-02	0.1675E+08	0.1293E+08	0.1867E+08
0.3405E-02	0.1784E+05	0.1312E+02	0.9016E-02	0.1788E+08	0.1380E+08	0.1993E+08
0.3455E-02	0.1904E+05	0.1404E+02	0.9695E-02	0.1908E+08	0.1472E+08	0.2126E+08
0.3505E-02	0.2031E+05	0.1503E+02	0.1042E-01	0.2036E+08	0.1571E+08	0.2269E+08
0.3555E-02	0.2167E+05	0.1607E+02	0.1120E-01	0.2172E+08	0.1676E+08	0.2420E+08
0.3605E-02	0.2311E+05	0.1719E+02	0.1203E-01	0.2316E+08	0.1787E+08	0.2581E+08
0.3655E-02	0.2464E+05	0.1839E+02	0.1292E-01	0.2470E+08	0.1905E+08	0.2752E+08
0.3705E-02	0.2627E+05	0.1966E+02	0.1387E-01	0.2633E+08	0.2031E+08	0.2934E+08
0.3755E-02	0.2799E+05	0.2102E+02	0.1489E-01	0.2806E+08	0.2165E+08	0.3126E+08
0.3805E-02	0.2982E+05	0.2246E+02	0.1597E-01	0.2989E+08	0.2306E+08	0.3331E+08
0.3855E-02	0.3177E+05	0.2400E+02	0.1713E-01	0.3184E+08	0.2456E+08	0.3548E+08
0.3905E-02	0.3382E+05	0.2564E+02	0.1837E-01	0.3390E+08	0.2616E+08	0.3778E+08
0.3955E-02	0.3600E+05	0.2738E+02	0.1970E-01	0.3609E+08	0.2784E+08	0.4021E+08
0.4005E-02	0.3831E+05	0.2924E+02	0.2111E-01	0.3840E+08	0.2962E+08	0.4278E+08
0.4055E-02	0.4075E+05	0.3122E+02	0.2263E-01	0.4084E+08	0.3151E+08	0.4551E+08
0.4105E-02	0.4332E+05	0.3332E+02	0.2424E-01	0.4342E+08	0.3350E+08	0.4839E+08
0.4155E-02	0.4604E+05	0.3555E+02	0.2596E-01	0.4615E+08	0.3560E+08	0.5142E+08
0.4205E-02	0.4891E+05	0.3792E+02	0.2780E-01	0.4903E+08	0.3782E+08	0.5463E+08
0.4255E-02	0.5193E+05	0.4044E+02	0.2975E-01	0.5206E+08	0.4016E+08	0.5800E+08
0.4305E-02	0.5512E+05	0.4312E+02	0.3184E-01	0.5525E+08	0.4262E+08	0.6156E+08
0.4355E-02	0.5846E+05	0.4596E+02	0.3407E-01	0.5860E+08	0.4521E+08	0.6530E+08
0.4405E-02	0.6198E+05	0.4897E+02	0.3644E-01	0.6213E+08	0.4793E+08	0.6923E+08
0.4455E-02	0.6567E+05	0.5216E+02	0.3897E-01	0.6583E+08	0.5078E+08	0.7335E+08
0.4505E-02	0.6954E+05	0.5554E+02	0.4166E-01	0.6970E+08	0.5378E+08	0.7767E+08

0.4555E-02	0.7359E+05	0.5912E+02	0.4453E-01	0.7376E+08	0.5691E+08	0.8219E+08
0.4605E-02	0.7782E+05	0.6290E+02	0.4758E-01	0.7800E+08	0.6018E+08	0.8692E+08
0.4655E-02	0.8224E+05	0.6690E+02	0.5082E-01	0.8243E+08	0.6359E+08	0.9185E+08
0.4705E-02	0.8684E+05	0.7113E+02	0.5427E-01	0.8704E+08	0.6715E+08	0.9699E+08
0.4755E-02	0.9163E+05	0.7559E+02	0.5794E-01	0.9185E+08	0.7086E+08	0.1023E+09
0.4805E-02	0.9660E+05	0.8029E+02	0.6183E-01	0.9683E+08	0.7470E+08	0.1079E+09
0.4855E-02	0.1018E+06	0.8525E+02	0.6597E-01	0.1020E+09	0.7869E+08	0.1137E+09
0.4905E-02	0.1071E+06	0.9047E+02	0.7036E-01	0.1074E+09	0.8282E+08	0.1196E+09
0.4955E-02	0.1126E+06	0.9597E+02	0.7502E-01	0.1129E+09	0.8709E+08	0.1258E+09
0.5005E-02	0.1183E+06	0.1017E+03	0.7996E-01	0.1186E+09	0.9149E+08	0.1321E+09
0.5050E-02	0.1236E+06	0.1072E+03	0.8466E-01	0.1239E+09	0.9555E+08	0.1380E+09
0.5100E-02	0.1296E+06	0.1135E+03	0.9018E-01	0.1299E+09	0.1002E+09	0.1447E+09
0.5150E-02	0.1357E+06	0.1201E+03	0.9602E-01	0.1360E+09	0.1049E+09	0.1516E+09
0.5200E-02	0.1420E+06	0.1271E+03	0.1022E+00	0.1423E+09	0.1098E+09	0.1586E+09
0.5250E-02	0.1484E+06	0.1343E+03	0.1087E+00	0.1487E+09	0.1147E+09	0.1657E+09
0.5300E-02	0.1549E+06	0.1419E+03	0.1156E+00	0.1552E+09	0.1198E+09	0.1730E+09
0.5350E-02	0.1615E+06	0.1498E+03	0.1229E+00	0.1618E+09	0.1249E+09	0.1803E+09
0.5400E-02	0.1681E+06	0.1581E+03	0.1306E+00	0.1685E+09	0.1300E+09	0.1878E+09
0.5450E-02	0.1749E+06	0.1666E+03	0.1387E+00	0.1753E+09	0.1352E+09	0.1953E+09
0.5500E-02	0.1816E+06	0.1756E+03	0.1473E+00	0.1821E+09	0.1405E+09	0.2029E+09
0.5550E-02	0.1884E+06	0.1848E+03	0.1563E+00	0.1889E+09	0.1457E+09	0.2104E+09
0.5600E-02	0.1952E+06	0.1944E+03	0.1658E+00	0.1957E+09	0.1510E+09	0.2180E+09
0.5650E-02	0.2020E+06	0.2043E+03	0.1757E+00	0.2024E+09	0.1562E+09	0.2256E+09
0.5700E-02	0.2087E+06	0.2146E+03	0.1862E+00	0.2092E+09	0.1614E+09	0.2331E+09
0.5750E-02	0.2153E+06	0.2252E+03	0.1972E+00	0.2158E+09	0.1665E+09	0.2405E+09
0.5800E-02	0.2218E+06	0.2361E+03	0.2087E+00	0.2224E+09	0.1715E+09	0.2478E+09
0.5850E-02	0.2283E+06	0.2474E+03	0.2208E+00	0.2288E+09	0.1765E+09	0.2549E+09
0.5900E-02	0.2345E+06	0.2589E+03	0.2335E+00	0.2351E+09	0.1814E+09	0.2620E+09
0.5950E-02	0.2407E+06	0.2708E+03	0.2467E+00	0.2412E+09	0.1861E+09	0.2688E+09
0.6000E-02	0.2466E+06	0.2830E+03	0.2606E+00	0.2472E+09	0.1907E+09	0.2754E+09
0.6050E-02	0.2523E+06	0.2955E+03	0.2750E+00	0.2529E+09	0.1951E+09	0.2818E+09
0.6100E-02	0.2579E+06	0.3082E+03	0.2901E+00	0.2585E+09	0.1994E+09	0.2880E+09
0.6150E-02	0.2632E+06	0.3213E+03	0.3059E+00	0.2638E+09	0.2035E+09	0.2939E+09
0.6200E-02	0.2682E+06	0.3345E+03	0.3223E+00	0.2688E+09	0.2074E+09	0.2995E+09
0.6250E-02	0.2730E+06	0.3481E+03	0.3393E+00	0.2736E+09	0.2111E+09	0.3049E+09
0.6300E-02	0.2775E+06	0.3618E+03	0.3571E+00	0.2781E+09	0.2146E+09	0.3099E+09
0.6350E-02	0.2817E+06	0.3758E+03	0.3755E+00	0.2824E+09	0.2178E+09	0.3146E+09
0.6400E-02	0.2856E+06	0.3900E+03	0.3947E+00	0.2863E+09	0.2209E+09	0.3190E+09
0.6450E-02	0.2893E+06	0.4044E+03	0.4145E+00	0.2899E+09	0.2237E+09	0.3231E+09
0.6500E-02	0.2926E+06	0.4189E+03	0.4351E+00	0.2933E+09	0.2263E+09	0.3268E+09
0.6550E-02	0.2956E+06	0.4336E+03	0.4564E+00	0.2963E+09	0.2286E+09	0.3302E+09
0.6600E-02	0.2983E+06	0.4485E+03	0.4785E+00	0.2991E+09	0.2307E+09	0.3332E+09
0.6650E-02	0.3008E+06	0.4635E+03	0.5013E+00	0.3015E+09	0.2326E+09	0.3359E+09
0.6700E-02	0.3029E+06	0.4786E+03	0.5248E+00	0.3036E+09	0.2342E+09	0.3383E+09
0.6750E-02	0.3047E+06	0.4937E+03	0.5491E+00	0.3055E+09	0.2357E+09	0.3404E+09
0.6800E-02	0.3063E+06	0.5090E+03	0.5742E+00	0.3070E+09	0.2369E+09	0.3421E+09
0.6850E-02	0.3076E+06	0.5244E+03	0.6000E+00	0.3083E+09	0.2378E+09	0.3435E+09
0.6900E-02	0.3086E+06	0.5398E+03	0.6266E+00	0.3093E+09	0.2386E+09	0.3446E+09
0.6950E-02	0.3093E+06	0.5552E+03	0.6540E+00	0.3100E+09	0.2392E+09	0.3454E+09
0.7000E-02	0.3098E+06	0.5707E+03	0.6821E+00	0.3105E+09	0.2396E+09	0.3460E+09
0.7050E-02	0.3100E+06	0.5862E+03	0.7111E+00	0.3108E+09	0.2397E+09	0.3463E+09
0.7100E-02	0.3100E+06	0.6017E+03	0.7408E+00	0.3108E+09	0.2397E+09	0.3463E+09
0.7150E-02	0.3098E+06	0.6172E+03	0.7712E+00	0.3105E+09	0.2396E+09	0.3460E+09
0.7200E-02	0.3094E+06	0.6327E+03	0.8025E+00	0.3101E+09	0.2393E+09	0.3456E+09
0.7250E-02	0.3088E+06	0.6481E+03	0.8345E+00	0.3095E+09	0.2388E+09	0.3449E+09

0.7300E-02	0.3080E+06	0.6636E+03	0.8673E+00	0.3087E+09	0.2382E+09	0.3440E+09
0.7350E-02	0.3070E+06	0.6789E+03	0.9009E+00	0.3077E+09	0.2374E+09	0.3429E+09
0.7400E-02	0.3058E+06	0.6942E+03	0.9352E+00	0.3066E+09	0.2365E+09	0.3416E+09
0.7450E-02	0.3045E+06	0.7095E+03	0.9703E+00	0.3053E+09	0.2355E+09	0.3401E+09
0.7500E-02	0.3031E+06	0.7247E+03	0.1006E+01	0.3038E+09	0.2344E+09	0.3385E+09
0.7550E-02	0.3015E+06	0.7398E+03	0.1043E+01	0.3022E+09	0.2332E+09	0.3368E+09
0.7600E-02	0.2998E+06	0.7549E+03	0.1080E+01	0.3005E+09	0.2319E+09	0.3349E+09
0.7650E-02	0.2980E+06	0.7698E+03	0.1118E+01	0.2987E+09	0.2305E+09	0.3329E+09
0.7700E-02	0.2961E+06	0.7847E+03	0.1157E+01	0.2968E+09	0.2290E+09	0.3307E+09
0.7750E-02	0.2941E+06	0.7994E+03	0.1197E+01	0.2948E+09	0.2275E+09	0.3285E+09
0.7800E-02	0.2921E+06	0.8141E+03	0.1237E+01	0.2927E+09	0.2259E+09	0.3262E+09
0.7850E-02	0.2899E+06	0.8286E+03	0.1278E+01	0.2906E+09	0.2242E+09	0.3238E+09
0.7900E-02	0.2877E+06	0.8431E+03	0.1320E+01	0.2884E+09	0.2225E+09	0.3213E+09
0.7950E-02	0.2854E+06	0.8574E+03	0.1362E+01	0.2861E+09	0.2207E+09	0.3188E+09
0.8000E-02	0.2831E+06	0.8716E+03	0.1406E+01	0.2837E+09	0.2189E+09	0.3162E+09
0.8050E-02	0.2807E+06	0.8857E+03	0.1450E+01	0.2814E+09	0.2171E+09	0.3135E+09
0.8100E-02	0.2783E+06	0.8997E+03	0.1494E+01	0.2789E+09	0.2152E+09	0.3108E+09
0.8150E-02	0.2758E+06	0.9135E+03	0.1540E+01	0.2765E+09	0.2133E+09	0.3081E+09
0.8200E-02	0.2733E+06	0.9272E+03	0.1586E+01	0.2740E+09	0.2114E+09	0.3053E+09
0.8250E-02	0.2708E+06	0.9408E+03	0.1632E+01	0.2715E+09	0.2094E+09	0.3025E+09
0.8300E-02	0.2683E+06	0.9543E+03	0.1680E+01	0.2689E+09	0.2075E+09	0.2997E+09
0.8350E-02	0.2658E+06	0.9677E+03	0.1728E+01	0.2664E+09	0.2055E+09	0.2968E+09
0.8400E-02	0.2632E+06	0.9809E+03	0.1776E+01	0.2638E+09	0.2036E+09	0.2940E+09
0.8450E-02	0.2607E+06	0.9940E+03	0.1826E+01	0.2613E+09	0.2016E+09	0.2911E+09
0.8500E-02	0.2581E+06	0.1007E+04	0.1876E+01	0.2587E+09	0.1996E+09	0.2883E+09
0.8550E-02	0.2556E+06	0.1020E+04	0.1926E+01	0.2562E+09	0.1976E+09	0.2854E+09
0.8600E-02	0.2530E+06	0.1033E+04	0.1978E+01	0.2536E+09	0.1956E+09	0.2826E+09
0.8650E-02	0.2502E+06	0.1045E+04	0.2030E+01	0.2507E+09	0.1934E+09	0.2794E+09
0.8700E-02	0.2466E+06	0.1058E+04	0.2082E+01	0.2472E+09	0.1907E+09	0.2754E+09
0.8750E-02	0.2428E+06	0.1070E+04	0.2135E+01	0.2433E+09	0.1877E+09	0.2711E+09
0.8800E-02	0.2387E+06	0.1082E+04	0.2189E+01	0.2393E+09	0.1846E+09	0.2666E+09
0.8850E-02	0.2345E+06	0.1094E+04	0.2244E+01	0.2350E+09	0.1813E+09	0.2619E+09
0.8900E-02	0.2302E+06	0.1105E+04	0.2299E+01	0.2308E+09	0.1780E+09	0.2571E+09
0.8950E-02	0.2259E+06	0.1117E+04	0.2354E+01	0.2264E+09	0.1747E+09	0.2523E+09
0.9005E-02	0.2211E+06	0.1129E+04	0.2416E+01	0.2216E+09	0.1710E+09	0.2469E+09
0.9055E-02	0.2167E+06	0.1140E+04	0.2473E+01	0.2173E+09	0.1676E+09	0.2421E+09
0.9105E-02	0.2124E+06	0.1151E+04	0.2530E+01	0.2129E+09	0.1643E+09	0.2372E+09
0.9155E-02	0.2081E+06	0.1161E+04	0.2588E+01	0.2086E+09	0.1609E+09	0.2324E+09
0.9205E-02	0.2039E+06	0.1171E+04	0.2646E+01	0.2043E+09	0.1576E+09	0.2277E+09
0.9255E-02	0.1996E+06	0.1182E+04	0.2705E+01	0.2001E+09	0.1544E+09	0.2230E+09
0.9305E-02	0.1955E+06	0.1191E+04	0.2764E+01	0.1960E+09	0.1512E+09	0.2183E+09
0.9355E-02	0.1914E+06	0.1201E+04	0.2824E+01	0.1919E+09	0.1480E+09	0.2138E+09
0.9405E-02	0.1874E+06	0.1211E+04	0.2884E+01	0.1878E+09	0.1449E+09	0.2093E+09
0.9455E-02	0.1835E+06	0.1220E+04	0.2945E+01	0.1839E+09	0.1419E+09	0.2049E+09
0.9505E-02	0.1796E+06	0.1229E+04	0.3006E+01	0.1800E+09	0.1389E+09	0.2006E+09
0.9555E-02	0.1758E+06	0.1238E+04	0.3068E+01	0.1762E+09	0.1360E+09	0.1964E+09
0.9605E-02	0.1721E+06	0.1246E+04	0.3130E+01	0.1725E+09	0.1331E+09	0.1923E+09
0.9655E-02	0.1685E+06	0.1255E+04	0.3193E+01	0.1689E+09	0.1303E+09	0.1882E+09
0.9705E-02	0.1650E+06	0.1263E+04	0.3256E+01	0.1654E+09	0.1276E+09	0.1843E+09
0.9755E-02	0.1616E+06	0.1271E+04	0.3319E+01	0.1620E+09	0.1250E+09	0.1805E+09
0.9805E-02	0.1583E+06	0.1279E+04	0.3383E+01	0.1587E+09	0.1224E+09	0.1768E+09
0.9855E-02	0.1551E+06	0.1287E+04	0.3447E+01	0.1555E+09	0.1199E+09	0.1732E+09
0.9905E-02	0.1519E+06	0.1295E+04	0.3511E+01	0.1523E+09	0.1175E+09	0.1697E+09
0.9955E-02	0.1489E+06	0.1303E+04	0.3576E+01	0.1492E+09	0.1151E+09	0.1663E+09
0.1000E-01	0.1459E+06	0.1310E+04	0.3642E+01	0.1462E+09	0.1128E+09	0.1630E+09

0.1005E-01	0.1430E+06	0.1317E+04	0.3707E+01	0.1433E+09	0.1106E+09	0.1597E+09
0.1010E-01	0.1402E+06	0.1324E+04	0.3773E+01	0.1405E+09	0.1084E+09	0.1566E+09
0.1015E-01	0.1374E+06	0.1331E+04	0.3840E+01	0.1377E+09	0.1063E+09	0.1535E+09
0.1020E-01	0.1347E+06	0.1338E+04	0.3906E+01	0.1351E+09	0.1042E+09	0.1505E+09
0.1025E-01	0.1321E+06	0.1345E+04	0.3974E+01	0.1325E+09	0.1022E+09	0.1476E+09
0.1030E-01	0.1296E+06	0.1351E+04	0.4041E+01	0.1299E+09	0.1002E+09	0.1448E+09
0.1035E-01	0.1271E+06	0.1358E+04	0.4109E+01	0.1274E+09	0.9832E+08	0.1420E+09
0.1040E-01	0.1247E+06	0.1364E+04	0.4177E+01	0.1250E+09	0.9646E+08	0.1393E+09
0.1045E-01	0.1224E+06	0.1370E+04	0.4245E+01	0.1227E+09	0.9466E+08	0.1367E+09
0.1050E-01	0.1201E+06	0.1376E+04	0.4314E+01	0.1204E+09	0.9289E+08	0.1342E+09
0.1055E-01	0.1179E+06	0.1382E+04	0.4383E+01	0.1182E+09	0.9118E+08	0.1317E+09
0.1060E-01	0.1158E+06	0.1388E+04	0.4452E+01	0.1160E+09	0.8951E+08	0.1293E+09
0.1065E-01	0.1136E+06	0.1394E+04	0.4521E+01	0.1139E+09	0.8788E+08	0.1269E+09
deltat t 0.106950E-01 intg t 0.106948E-01						
PMAXMEAN Pa		0.310784E+09	time at PMAXMEAN sec		0.707511E-02	
PMAXBASE Pa		0.239766E+09	time at PMAXBASE sec		0.707511E-02	
PMAXBREECH Pa		0.346294E+09	time at PMAXBREECH sec		0.707511E-02	
muzzle VELOCITY m/s		0.139773E+04	time of muzzle velocity sec		0.106910E-01	
total initial energy available J =		0.429710E+08				
FOR PROPELLANT 1 MASSFRACT BURNT IS		0.996610E+00				
total energy remaining in gas J=		0.289575E+08				
energy loss from projectile translation J=		0.957471E+07				
energy loss from projectile rotation J=		0.000000E+00				
energy lost to gas and propellant motion J=		0.283602E+07				
energy lost to bore resistance J=		0.000000E+00				
energy lost to recoil J=		0.187099E-11				
energy loss from heat transfer J=		0.145715E+07				
energy lost to air resistance J=		0.000000E+00				

APPENDIX E

Input data base for the chambrage calculation.

```
9832.2384 12.7 12.7 1.0 0.0 457.2 2
3 0. 15.39110755 46.4820 15.39110755 54.1020 12.70
  9.796 0. 0.0 0.0
5 0.0 0.0 0.0 .6 0.0 1.3 0.0 300. 0. 457.
  1.e20 2 3.0e+4 0.0 8.0e+5 0.2
  .001135 .01143 .46028 273. 1. 7.8612
  84.5535 .9755 294. .004712 1.4
1 1135.99 3141. .9755 8.85 1.6605 1.23 7 3.175 .0508 .0506 1.06290007 .27842504
1 1.0 .1105187 689.476
  .005 .05 30.
```

APPENDIX E

Output for the chambrage chamber calculation.

THE INPUT FILE IS ic1ch2

Using chambrage pressure gradient

chamber distance cm	chamber diameter cm
0.000000E+00	0.153911E+02
0.464820E+02	0.153911E+02
0.541020E+02	0.127000E+02

chamber volume cm**3 0.983215E+04
groove diam cm 0.127000E+02
land diam cm 0.127000E+02
groove/land ratio 0.100000E+01
twist turns/caliber 0.000000E+00
projectile travel cm 0.457200E+03

projectile mass kg 0.979600E+01
switch to calculate energy lost to air resistance J 0
fraction of work against bore used to heat the tube 0.000000E+00
gas pressure Pa 0.000000E+00
number barrel resistance points 5
bore resistance MPa - travel cm

0.000000E+00	0.000000E+00
0.000000E+00	0.600000E+00
0.000000E+00	0.130000E+01
0.000000E+00	0.300000E+03
0.000000E+00	0.457000E+03

mass of recoiling parts kg 0.100000E+21
number of recoil point pairs 2
recoil force N recoil time sec

0.300000E+05	0.000000E+00
0.800000E+06	0.200000E+00

free convective heat transfer coefficient w/cm**2 K 0.113500E-02
chamber wall thickness cm 0.114300E-01
heat capacity of steel of chamber wall J/g K 0.460280E+00
initial temperature of chamber wall K 0.273000E+03
heat loss coefficient 0.100000E+01
density of chamber wall steel g/cm**3 0.786120E+01

impetus of igniter propellant J/g 0.845535E+02
covolume of igniter cm**3/g 0.975500E+00
adiabatic flame temperature of igniter propellant K 0.294000E+03
initial mass of igniter kg 0.471200E-02
ratio of specific heats for igniter 0.140000E+01

for propellant number 1
impetus of propellant J/g 0.113599E+04

adiabatic temperature of propellant K 0.314100E+04
 covolume of propellant cm**3/g 0.975500E+00
 initial mass of propellant kg 0.885000E+01
 density of propellant g/cm**3 0.166050E+01
 ratio of specific heats for propellant 0.123000E+01
 number of perforations of propellant 7
 length of propellant grain cm 0.317500E+01
 diameter of inner perforation in propellant grains cm 0.508000E-01
 diameter of outerperforation of propellant grains cm 0.508000E-01
 outside diameter of propellant grain cm 0.106290E+01
 distance between perf centers cm 0.278425E+00

number of burning rate points 1		
exponent	coefficient	pressure
-	cm/sec-MPa**ai	MPa
0.100000E+01	0.110519E+00	0.689476E+03

time increment msec 0.500000E-02 print increment msec 0.500000E-01
 time to stop calculation msec 0.300000E+02
 area bore m^2 0.126677E-01 pressure from ign Pa 0.885796E+05
 volume of unburnt prop m^3 0.532972E-02
 init cham vol-cov ign m ^3 0.982755E-02

time	acc	vel	dis	mpress	pbase	pbrch
0.5000E-05	0.9985E+02	0.4141E-03	0.8272E-09	0.8963E+05	0.7721E+05	0.9509E+05
0.5000E-04	0.1110E+03	0.5154E-02	0.1242E-06	0.9964E+05	0.8584E+05	0.1057E+06
0.1050E-03	0.1262E+03	0.1167E-01	0.5830E-06	0.1133E+06	0.9757E+05	0.1202E+06
0.1550E-03	0.1416E+03	0.1835E-01	0.1330E-05	0.1271E+06	0.1095E+06	0.1348E+06
0.2000E-03	0.1568E+03	0.2506E-01	0.2305E-05	0.1408E+06	0.1213E+06	0.1493E+06
0.2500E-03	0.1755E+03	0.3336E-01	0.3761E-05	0.1575E+06	0.1357E+06	0.1671E+06
0.3050E-03	0.1982E+03	0.4363E-01	0.5873E-05	0.1779E+06	0.1533E+06	0.1888E+06
0.3550E-03	0.2210E+03	0.5410E-01	0.8311E-05	0.1984E+06	0.1709E+06	0.2105E+06
0.4050E-03	0.2461E+03	0.6577E-01	0.1130E-04	0.2209E+06	0.1903E+06	0.2343E+06
0.4550E-03	0.2735E+03	0.7875E-01	0.1491E-04	0.2455E+06	0.2115E+06	0.2604E+06
0.5050E-03	0.3033E+03	0.9315E-01	0.1920E-04	0.2723E+06	0.2346E+06	0.2889E+06
0.5550E-03	0.3339E+03	0.1091E+00	0.2425E-04	0.3015E+06	0.2597E+06	0.3199E+06
0.6000E-03	0.3675E+03	0.1249E+00	0.2951E-04	0.3299E+06	0.2842E+06	0.3500E+06
0.6500E-03	0.4054E+03	0.1443E+00	0.3623E-04	0.3640E+06	0.3135E+06	0.3861E+06
0.7000E-03	0.4465E+03	0.1655E+00	0.4397E-04	0.4008E+06	0.3452E+06	0.4252E+06
0.7500E-03	0.4907E+03	0.1889E+00	0.5282E-04	0.4405E+06	0.3795E+06	0.4673E+06
0.8000E-03	0.5384E+03	0.2147E+00	0.6290E-04	0.4833E+06	0.4163E+06	0.5127E+06
0.8500E-03	0.5896E+03	0.2428E+00	0.7433E-04	0.5293E+06	0.4559E+06	0.5615E+06
0.9000E-03	0.6446E+03	0.2737E+00	0.8723E-04	0.5787E+06	0.4985E+06	0.6140E+06
0.9500E-03	0.7036E+03	0.3074E+00	0.1017E-03	0.6317E+06	0.5441E+06	0.6702E+06
0.1000E-02	0.7669E+03	0.3441E+00	0.1180E-03	0.6885E+06	0.5930E+06	0.7304E+06
0.1050E-02	0.8346E+03	0.3841E+00	0.1362E-03	0.7493E+06	0.6454E+06	0.7949E+06
0.1100E-02	0.9070E+03	0.4277E+00	0.1565E-03	0.8143E+06	0.7014E+06	0.8639E+06
0.1150E-02	0.9845E+03	0.4749E+00	0.1790E-03	0.8839E+06	0.7613E+06	0.9377E+06
0.1200E-02	0.1067E+04	0.5262E+00	0.2041E-03	0.9583E+06	0.8254E+06	0.1017E+07
0.1250E-02	0.1156E+04	0.5818E+00	0.2317E-03	0.1038E+07	0.8939E+06	0.1101E+07
0.1300E-02	0.1251E+04	0.6419E+00	0.2623E-03	0.1123E+07	0.9671E+06	0.1191E+07
0.1350E-02	0.1352E+04	0.7069E+00	0.2960E-03	0.1214E+07	0.1045E+07	0.1288E+07
0.1400E-02	0.1460E+04	0.7772E+00	0.3331E-03	0.1311E+07	0.1129E+07	0.1391E+07
0.1450E-02	0.1576E+04	0.8531E+00	0.3738E-03	0.1415E+07	0.1219E+07	0.1501E+07
0.1500E-02	0.1700E+04	0.9349E+00	0.4185E-03	0.1526E+07	0.1314E+07	0.1619E+07

0.1550E-02	0.1832E+04	0.1023E+01	0.4674E-03	0.1645E+07	0.1417E+07	0.1745E+07
0.1600E-02	0.1974E+04	0.1118E+01	0.5209E-03	0.1772E+07	0.1526E+07	0.1880E+07
0.1650E-02	0.2125E+04	0.1221E+01	0.5794E-03	0.1909E+07	0.1643E+07	0.2025E+07
0.1700E-02	0.2287E+04	0.1331E+01	0.6431E-03	0.2054E+07	0.1769E+07	0.2179E+07
0.1750E-02	0.2461E+04	0.1450E+01	0.7126E-03	0.2210E+07	0.1903E+07	0.2345E+07
0.1800E-02	0.2647E+04	0.1577E+01	0.7882E-03	0.2377E+07	0.2047E+07	0.2522E+07
0.1850E-02	0.2846E+04	0.1715E+01	0.8705E-03	0.2556E+07	0.2201E+07	0.2712E+07
0.1900E-02	0.3059E+04	0.1862E+01	0.9598E-03	0.2748E+07	0.2365E+07	0.2915E+07
0.1950E-02	0.3287E+04	0.2021E+01	0.1057E-02	0.2953E+07	0.2542E+07	0.3133E+07
0.2000E-02	0.3531E+04	0.2191E+01	0.1162E-02	0.3173E+07	0.2731E+07	0.3366E+07
0.2050E-02	0.3793E+04	0.2374E+01	0.1276E-02	0.3408E+07	0.2933E+07	0.3616E+07
0.2100E-02	0.4074E+04	0.2571E+01	0.1400E-02	0.3661E+07	0.3150E+07	0.3883E+07
0.2150E-02	0.4374E+04	0.2782E+01	0.1533E-02	0.3931E+07	0.3382E+07	0.4170E+07
0.2200E-02	0.4696E+04	0.3008E+01	0.1678E-02	0.4220E+07	0.3631E+07	0.4477E+07
0.2255E-02	0.5076E+04	0.3277E+01	0.1851E-02	0.4563E+07	0.3925E+07	0.4840E+07
0.2305E-02	0.5447E+04	0.3540E+01	0.2021E-02	0.4897E+07	0.4213E+07	0.5195E+07
0.2355E-02	0.5845E+04	0.3822E+01	0.2205E-02	0.5256E+07	0.4520E+07	0.5576E+07
0.2405E-02	0.6272E+04	0.4125E+01	0.2404E-02	0.5640E+07	0.4850E+07	0.5983E+07
0.2455E-02	0.6728E+04	0.4450E+01	0.2618E-02	0.6051E+07	0.5203E+07	0.6419E+07
0.2505E-02	0.7217E+04	0.4798E+01	0.2849E-02	0.6492E+07	0.5581E+07	0.6887E+07
0.2555E-02	0.7740E+04	0.5172E+01	0.3098E-02	0.6963E+07	0.5985E+07	0.7387E+07
0.2605E-02	0.8300E+04	0.5573E+01	0.3367E-02	0.7469E+07	0.6418E+07	0.7923E+07
0.2655E-02	0.8899E+04	0.6003E+01	0.3656E-02	0.8010E+07	0.6882E+07	0.8497E+07
0.2705E-02	0.9540E+04	0.6463E+01	0.3968E-02	0.8589E+07	0.7377E+07	0.9111E+07
0.2755E-02	0.1023E+05	0.6957E+01	0.4303E-02	0.9208E+07	0.7908E+07	0.9769E+07
0.2805E-02	0.1096E+05	0.7487E+01	0.4664E-02	0.9871E+07	0.8475E+07	0.1047E+08
0.2855E-02	0.1174E+05	0.8054E+01	0.5052E-02	0.1058E+08	0.9082E+07	0.1122E+08
0.2905E-02	0.1258E+05	0.8662E+01	0.5470E-02	0.1134E+08	0.9731E+07	0.1203E+08
0.2955E-02	0.1348E+05	0.9314E+01	0.5919E-02	0.1215E+08	0.1042E+08	0.1289E+08
0.3005E-02	0.1444E+05	0.1001E+02	0.6402E-02	0.1302E+08	0.1116E+08	0.1381E+08
0.3055E-02	0.1546E+05	0.1076E+02	0.6921E-02	0.1395E+08	0.1196E+08	0.1480E+08
0.3105E-02	0.1655E+05	0.1156E+02	0.7479E-02	0.1494E+08	0.1280E+08	0.1585E+08
0.3155E-02	0.1772E+05	0.1242E+02	0.8078E-02	0.1600E+08	0.1370E+08	0.1697E+08
0.3205E-02	0.1896E+05	0.1333E+02	0.8721E-02	0.1713E+08	0.1466E+08	0.1817E+08
0.3255E-02	0.2029E+05	0.1431E+02	0.9412E-02	0.1833E+08	0.1569E+08	0.1945E+08
0.3305E-02	0.2170E+05	0.1536E+02	0.1015E-01	0.1962E+08	0.1678E+08	0.2081E+08
0.3355E-02	0.2321E+05	0.1648E+02	0.1095E-01	0.2099E+08	0.1795E+08	0.2227E+08
0.3405E-02	0.2481E+05	0.1768E+02	0.1180E-01	0.2246E+08	0.1919E+08	0.2382E+08
0.3455E-02	0.2652E+05	0.1897E+02	0.1272E-01	0.2402E+08	0.2051E+08	0.2548E+08
0.3505E-02	0.2834E+05	0.2034E+02	0.1370E-01	0.2568E+08	0.2191E+08	0.2724E+08
0.3555E-02	0.3027E+05	0.2180E+02	0.1476E-01	0.2744E+08	0.2340E+08	0.2911E+08
0.3605E-02	0.3231E+05	0.2337E+02	0.1588E-01	0.2932E+08	0.2499E+08	0.3111E+08
0.3655E-02	0.3449E+05	0.2504E+02	0.1709E-01	0.3132E+08	0.2667E+08	0.3323E+08
0.3705E-02	0.3680E+05	0.2682E+02	0.1839E-01	0.3344E+08	0.2845E+08	0.3548E+08
0.3755E-02	0.3924E+05	0.2872E+02	0.1978E-01	0.3569E+08	0.3035E+08	0.3787E+08
0.3805E-02	0.4183E+05	0.3074E+02	0.2126E-01	0.3808E+08	0.3235E+08	0.4040E+08
0.3855E-02	0.4457E+05	0.3290E+02	0.2285E-01	0.4061E+08	0.3446E+08	0.4309E+08
0.3905E-02	0.4746E+05	0.3520E+02	0.2456E-01	0.4329E+08	0.3670E+08	0.4593E+08
0.3955E-02	0.5051E+05	0.3765E+02	0.2638E-01	0.4613E+08	0.3906E+08	0.4894E+08
0.4005E-02	0.5373E+05	0.4026E+02	0.2832E-01	0.4912E+08	0.4155E+08	0.5212E+08
0.4055E-02	0.5712E+05	0.4303E+02	0.3041E-01	0.5228E+08	0.4417E+08	0.5548E+08
0.4105E-02	0.6068E+05	0.4597E+02	0.3263E-01	0.5562E+08	0.4693E+08	0.5902E+08
0.4155E-02	0.6443E+05	0.4910E+02	0.3501E-01	0.5913E+08	0.4982E+08	0.6275E+08
0.4205E-02	0.6836E+05	0.5242E+02	0.3754E-01	0.6282E+08	0.5286E+08	0.6668E+08
0.4255E-02	0.7247E+05	0.5594E+02	0.4025E-01	0.6670E+08	0.5604E+08	0.7080E+08

0.4305E-02	0.7678E+05	0.5967E+02	0.4314E-01	0.7077E+08	0.5937E+08	0.7513E+08
0.4355E-02	0.8127E+05	0.6362E+02	0.4622E-01	0.7504E+08	0.6285E+08	0.7966E+08
0.4405E-02	0.8596E+05	0.6780E+02	0.4951E-01	0.7950E+08	0.6647E+08	0.8440E+08
0.4455E-02	0.9083E+05	0.7222E+02	0.5301E-01	0.8415E+08	0.7024E+08	0.8936E+08
0.4505E-02	0.9589E+05	0.7689E+02	0.5673E-01	0.8901E+08	0.7415E+08	0.9453E+08
0.4555E-02	0.1011E+06	0.8181E+02	0.6070E-01	0.9406E+08	0.7821E+08	0.9991E+08
0.4605E-02	0.1066E+06	0.8700E+02	0.6492E-01	0.9930E+08	0.8241E+08	0.1055E+09
0.4655E-02	0.1122E+06	0.9247E+02	0.6940E-01	0.1047E+09	0.8675E+08	0.1113E+09
0.4705E-02	0.1180E+06	0.9822E+02	0.7417E-01	0.1104E+09	0.9121E+08	0.1173E+09
0.4755E-02	0.1239E+06	0.1043E+03	0.7923E-01	0.1162E+09	0.9581E+08	0.1235E+09
0.4805E-02	0.1300E+06	0.1106E+03	0.8460E-01	0.1221E+09	0.1005E+09	0.1299E+09
0.4855E-02	0.1362E+06	0.1173E+03	0.9030E-01	0.1283E+09	0.1053E+09	0.1365E+09
0.4905E-02	0.1426E+06	0.1242E+03	0.9633E-01	0.1346E+09	0.1102E+09	0.1432E+09
0.4955E-02	0.1490E+06	0.1315E+03	0.1027E+00	0.1410E+09	0.1152E+09	0.1501E+09
0.5005E-02	0.1556E+06	0.1391E+03	0.1095E+00	0.1476E+09	0.1203E+09	0.1572E+09
0.5050E-02	0.1616E+06	0.1463E+03	0.1159E+00	0.1536E+09	0.1249E+09	0.1637E+09
0.5100E-02	0.1683E+06	0.1545E+03	0.1234E+00	0.1604E+09	0.1301E+09	0.1709E+09
0.5150E-02	0.1750E+06	0.1631E+03	0.1314E+00	0.1672E+09	0.1353E+09	0.1783E+09
0.5200E-02	0.1818E+06	0.1720E+03	0.1397E+00	0.1741E+09	0.1406E+09	0.1858E+09
0.5250E-02	0.1886E+06	0.1813E+03	0.1486E+00	0.1811E+09	0.1458E+09	0.1933E+09
0.5300E-02	0.1953E+06	0.1909E+03	0.1579E+00	0.1880E+09	0.1510E+09	0.2009E+09
0.5350E-02	0.2020E+06	0.2008E+03	0.1677E+00	0.1950E+09	0.1562E+09	0.2085E+09
0.5400E-02	0.2087E+06	0.2111E+03	0.1780E+00	0.2019E+09	0.1614E+09	0.2161E+09
0.5450E-02	0.2153E+06	0.2217E+03	0.1888E+00	0.2088E+09	0.1665E+09	0.2236E+09
0.5500E-02	0.2218E+06	0.2326E+03	0.2001E+00	0.2156E+09	0.1715E+09	0.2311E+09
0.5550E-02	0.2281E+06	0.2439E+03	0.2121E+00	0.2223E+09	0.1764E+09	0.2385E+09
0.5600E-02	0.2343E+06	0.2554E+03	0.2245E+00	0.2289E+09	0.1812E+09	0.2457E+09
0.5650E-02	0.2404E+06	0.2673E+03	0.2376E+00	0.2353E+09	0.1859E+09	0.2529E+09
0.5700E-02	0.2462E+06	0.2794E+03	0.2513E+00	0.2416E+09	0.1904E+09	0.2599E+09
0.5750E-02	0.2519E+06	0.2919E+03	0.2655E+00	0.2477E+09	0.1948E+09	0.2667E+09
0.5800E-02	0.2573E+06	0.3046E+03	0.2805E+00	0.2535E+09	0.1990E+09	0.2733E+09
0.5850E-02	0.2626E+06	0.3176E+03	0.2960E+00	0.2592E+09	0.2030E+09	0.2798E+09
0.5900E-02	0.2675E+06	0.3309E+03	0.3122E+00	0.2646E+09	0.2069E+09	0.2859E+09
0.5950E-02	0.2723E+06	0.3444E+03	0.3291E+00	0.2698E+09	0.2105E+09	0.2918E+09
0.6000E-02	0.2767E+06	0.3581E+03	0.3467E+00	0.2747E+09	0.2140E+09	0.2975E+09
0.6050E-02	0.2809E+06	0.3720E+03	0.3649E+00	0.2793E+09	0.2172E+09	0.3028E+09
0.6100E-02	0.2848E+06	0.3862E+03	0.3839E+00	0.2836E+09	0.2203E+09	0.3079E+09
0.6150E-02	0.2885E+06	0.4005E+03	0.4035E+00	0.2877E+09	0.2231E+09	0.3127E+09
0.6200E-02	0.2918E+06	0.4150E+03	0.4239E+00	0.2914E+09	0.2257E+09	0.3171E+09
0.6250E-02	0.2949E+06	0.4297E+03	0.4451E+00	0.2949E+09	0.2281E+09	0.3212E+09
0.6300E-02	0.2977E+06	0.4445E+03	0.4669E+00	0.2980E+09	0.2302E+09	0.3250E+09
0.6350E-02	0.3002E+06	0.4595E+03	0.4895E+00	0.3008E+09	0.2321E+09	0.3285E+09
0.6400E-02	0.3024E+06	0.4745E+03	0.5129E+00	0.3034E+09	0.2339E+09	0.3317E+09
0.6450E-02	0.3044E+06	0.4897E+03	0.5370E+00	0.3056E+09	0.2354E+09	0.3345E+09
0.6500E-02	0.3061E+06	0.5050E+03	0.5618E+00	0.3076E+09	0.2367E+09	0.3370E+09
0.6550E-02	0.3075E+06	0.5203E+03	0.5875E+00	0.3092E+09	0.2378E+09	0.3392E+09
0.6600E-02	0.3086E+06	0.5357E+03	0.6139E+00	0.3106E+09	0.2387E+09	0.3411E+09
0.6650E-02	0.3095E+06	0.5512E+03	0.6410E+00	0.3117E+09	0.2394E+09	0.3427E+09
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0.6750E-02	0.3106E+06	0.5822E+03	0.6977E+00	0.3131E+09	0.2402E+09	0.3450E+09
0.6800E-02	0.3108E+06	0.5977E+03	0.7272E+00	0.3135E+09	0.2404E+09	0.3457E+09
0.6850E-02	0.3108E+06	0.6133E+03	0.7575E+00	0.3136E+09	0.2404E+09	0.3462E+09
0.6900E-02	0.3106E+06	0.6288E+03	0.7885E+00	0.3135E+09	0.2402E+09	0.3464E+09
0.6950E-02	0.3102E+06	0.6443E+03	0.8204E+00	0.3132E+09	0.2399E+09	0.3463E+09
0.7000E-02	0.3096E+06	0.6598E+03	0.8530E+00	0.3127E+09	0.2395E+09	0.3460E+09

0.7050E-02	0.3089E+06	0.6753E+03	0.8863E+00	0.3120E+09	0.2389E+09	0.3455E+09
0.7100E-02	0.3080E+06	0.6907E+03	0.9205E+00	0.3111E+09	0.2382E+09	0.3448E+09
0.7150E-02	0.3069E+06	0.7061E+03	0.9554E+00	0.3101E+09	0.2373E+09	0.3439E+09
0.7200E-02	0.3057E+06	0.7214E+03	0.9911E+00	0.3089E+09	0.2364E+09	0.3429E+09
0.7250E-02	0.3043E+06	0.7367E+03	0.1028E+01	0.3075E+09	0.2353E+09	0.3416E+09
0.7300E-02	0.3029E+06	0.7518E+03	0.1065E+01	0.3060E+09	0.2342E+09	0.3402E+09
0.7350E-02	0.3013E+06	0.7669E+03	0.1103E+01	0.3045E+09	0.2330E+09	0.3386E+09
0.7400E-02	0.2996E+06	0.7820E+03	0.1141E+01	0.3027E+09	0.2317E+09	0.3369E+09
0.7450E-02	0.2978E+06	0.7969E+03	0.1181E+01	0.3009E+09	0.2303E+09	0.3351E+09
0.7500E-02	0.2959E+06	0.8117E+03	0.1221E+01	0.2990E+09	0.2288E+09	0.3331E+09
0.7550E-02	0.2939E+06	0.8265E+03	0.1262E+01	0.2970E+09	0.2273E+09	0.3310E+09
0.7600E-02	0.2919E+06	0.8411E+03	0.1304E+01	0.2950E+09	0.2257E+09	0.3289E+09
0.7650E-02	0.2898E+06	0.8557E+03	0.1346E+01	0.2928E+09	0.2241E+09	0.3266E+09
0.7700E-02	0.2876E+06	0.8701E+03	0.1389E+01	0.2906E+09	0.2224E+09	0.3243E+09
0.7750E-02	0.2854E+06	0.8844E+03	0.1433E+01	0.2884E+09	0.2207E+09	0.3219E+09
0.7800E-02	0.2831E+06	0.8986E+03	0.1478E+01	0.2860E+09	0.2189E+09	0.3194E+09
0.7850E-02	0.2808E+06	0.9127E+03	0.1523E+01	0.2837E+09	0.2172E+09	0.3169E+09
0.7900E-02	0.2785E+06	0.9267E+03	0.1569E+01	0.2813E+09	0.2153E+09	0.3143E+09
0.7950E-02	0.2761E+06	0.9406E+03	0.1616E+01	0.2789E+09	0.2135E+09	0.3117E+09
0.8000E-02	0.2737E+06	0.9543E+03	0.1663E+01	0.2764E+09	0.2117E+09	0.3090E+09
0.8050E-02	0.2713E+06	0.9680E+03	0.1711E+01	0.2740E+09	0.2098E+09	0.3063E+09
0.8100E-02	0.2688E+06	0.9815E+03	0.1760E+01	0.2715E+09	0.2079E+09	0.3036E+09
0.8150E-02	0.2664E+06	0.9948E+03	0.1809E+01	0.2690E+09	0.2060E+09	0.3009E+09
0.8200E-02	0.2639E+06	0.1008E+04	0.1859E+01	0.2664E+09	0.2041E+09	0.2981E+09
0.8250E-02	0.2614E+06	0.1021E+04	0.1910E+01	0.2639E+09	0.2022E+09	0.2954E+09
0.8300E-02	0.2590E+06	0.1034E+04	0.1962E+01	0.2614E+09	0.2003E+09	0.2926E+09
0.8350E-02	0.2563E+06	0.1047E+04	0.2014E+01	0.2586E+09	0.1982E+09	0.2895E+09
0.8400E-02	0.2527E+06	0.1060E+04	0.2066E+01	0.2551E+09	0.1954E+09	0.2856E+09
0.8450E-02	0.2488E+06	0.1072E+04	0.2120E+01	0.2511E+09	0.1924E+09	0.2812E+09
0.8500E-02	0.2447E+06	0.1085E+04	0.2173E+01	0.2470E+09	0.1892E+09	0.2766E+09
0.8550E-02	0.2404E+06	0.1097E+04	0.2228E+01	0.2426E+09	0.1859E+09	0.2718E+09
0.8600E-02	0.2361E+06	0.1109E+04	0.2283E+01	0.2382E+09	0.1825E+09	0.2669E+09
0.8650E-02	0.2316E+06	0.1120E+04	0.2339E+01	0.2337E+09	0.1791E+09	0.2619E+09
0.8700E-02	0.2271E+06	0.1132E+04	0.2395E+01	0.2292E+09	0.1756E+09	0.2568E+09
0.8750E-02	0.2226E+06	0.1143E+04	0.2452E+01	0.2246E+09	0.1722E+09	0.2518E+09
0.8800E-02	0.2181E+06	0.1154E+04	0.2509E+01	0.2201E+09	0.1687E+09	0.2467E+09
0.8850E-02	0.2137E+06	0.1165E+04	0.2567E+01	0.2156E+09	0.1652E+09	0.2417E+09
0.8900E-02	0.2093E+06	0.1176E+04	0.2626E+01	0.2111E+09	0.1618E+09	0.2367E+09
0.8950E-02	0.2049E+06	0.1186E+04	0.2685E+01	0.2067E+09	0.1585E+09	0.2318E+09
0.9005E-02	0.2002E+06	0.1197E+04	0.2751E+01	0.2019E+09	0.1548E+09	0.2265E+09
0.9055E-02	0.1959E+06	0.1207E+04	0.2811E+01	0.1976E+09	0.1515E+09	0.2217E+09
0.9105E-02	0.1918E+06	0.1217E+04	0.2871E+01	0.1934E+09	0.1483E+09	0.2170E+09
0.9155E-02	0.1877E+06	0.1226E+04	0.2932E+01	0.1893E+09	0.1451E+09	0.2124E+09
0.9205E-02	0.1837E+06	0.1235E+04	0.2994E+01	0.1853E+09	0.1421E+09	0.2078E+09
0.9255E-02	0.1798E+06	0.1245E+04	0.3056E+01	0.1813E+09	0.1390E+09	0.2034E+09
0.9305E-02	0.1760E+06	0.1253E+04	0.3118E+01	0.1774E+09	0.1361E+09	0.1991E+09
0.9355E-02	0.1722E+06	0.1262E+04	0.3181E+01	0.1737E+09	0.1332E+09	0.1949E+09
0.9405E-02	0.1686E+06	0.1271E+04	0.3245E+01	0.1700E+09	0.1304E+09	0.1908E+09
0.9455E-02	0.1651E+06	0.1279E+04	0.3308E+01	0.1665E+09	0.1277E+09	0.1868E+09
0.9505E-02	0.1617E+06	0.1287E+04	0.3372E+01	0.1630E+09	0.1250E+09	0.1829E+09
0.9555E-02	0.1583E+06	0.1295E+04	0.3437E+01	0.1596E+09	0.1224E+09	0.1792E+09
0.9605E-02	0.1551E+06	0.1303E+04	0.3502E+01	0.1563E+09	0.1199E+09	0.1755E+09
0.9655E-02	0.1519E+06	0.1311E+04	0.3567E+01	0.1531E+09	0.1175E+09	0.1719E+09
0.9705E-02	0.1488E+06	0.1318E+04	0.3633E+01	0.1500E+09	0.1151E+09	0.1684E+09
0.9755E-02	0.1458E+06	0.1326E+04	0.3699E+01	0.1470E+09	0.1128E+09	0.1650E+09

0.9805E-02	0.1429E+06	0.1333E+04	0.3766E+01	0.1441E+09	0.1105E+09	0.1617E+09
0.9855E-02	0.1401E+06	0.1340E+04	0.3832E+01	0.1412E+09	0.1083E+09	0.1585E+09
0.9905E-02	0.1373E+06	0.1347E+04	0.3900E+01	0.1384E+09	0.1062E+09	0.1554E+09
0.9955E-02	0.1346E+06	0.1354E+04	0.3967E+01	0.1357E+09	0.1041E+09	0.1523E+09
0.1000E-01	0.1320E+06	0.1360E+04	0.4035E+01	0.1331E+09	0.1021E+09	0.1494E+09
0.1005E-01	0.1295E+06	0.1367E+04	0.4103E+01	0.1305E+09	0.1001E+09	0.1465E+09
0.1010E-01	0.1270E+06	0.1373E+04	0.4172E+01	0.1280E+09	0.9821E+08	0.1437E+09
0.1015E-01	0.1246E+06	0.1379E+04	0.4240E+01	0.1256E+09	0.9635E+08	0.1409E+09
0.1020E-01	0.1222E+06	0.1386E+04	0.4309E+01	0.1232E+09	0.9453E+08	0.1383E+09
0.1025E-01	0.1200E+06	0.1392E+04	0.4379E+01	0.1209E+09	0.9277E+08	0.1357E+09
0.1030E-01	0.1177E+06	0.1398E+04	0.4449E+01	0.1186E+09	0.9105E+08	0.1332E+09
0.1035E-01	0.1156E+06	0.1403E+04	0.4519E+01	0.1165E+09	0.8937E+08	0.1307E+09
deltat t 0.103950E-01 intg t 0.103948E-01						
PMA XMEAN Pa 0.313603E+09 time at PMA XMEAN sec 0.685009E-02						
PMA XBASE Pa 0.240397E+09 time at PMA XBASE sec 0.682509E-02						
PMA XBREECH Pa 0.346365E+09 time at PMA XBREECH sec 0.691510E-02						
muzzle VELOCITY m/s 0.140782E+04 time of muzzle velocity sec 0.103927E-01						
total initial energy available J = 0.437119E+08						
FOR PROPELLANT 1 MASSFRACT BURNT IS 0.997470E+00						
total energy remaining in gas J= 0.295069E+08						
energy loss from projectile translation J= 0.971088E+07						
energy loss from projectile rotation J= 0.000000E+00						
energy lost to gas and propellant motion J= 0.292176E+07						
energy lost to bore resistance J= 0.000000E+00						
energy lost to recoil J= 0.182576E-11						
energy loss from heat transfer J= 0.146181E+07						
energy lost to air resistance J= 0.000000E+00						

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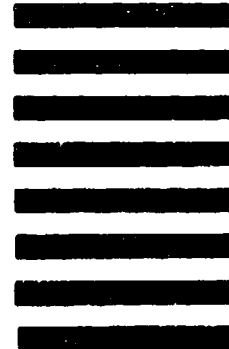
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