NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.
TECHNICAL MEMORANDUM 1404

A DIGITAL COMPUTER PROGRAM
FOR
HIRSCHFELDER INTERIOR BALLISTICS

FORREST L. McMAINS

ACMS 5523.11.565

COPY 39 OF 51

APRIL 1964

PICATINNY ARSENAL
DOVER, NEW JERSEY
The findings in this report are not to be construed as an official Department of the Army Position.

DISPOSITION
Destroy this report when it is no longer needed.
Do not return.

DDC AVAILABILITY NOTICE
Qualified requesters may obtain copies of this report from DDC.
TECHNICAL MEMORANDUM 1404

A DIGITAL COMPUTER PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTICS

BY

FORREST L. McMAINS

AMCMS 5523.11.565
APRIL 1964

REVIEWED BY: E. H. BUCHANAN
Chief, Artillery
Ammunition Laboratory

APPROVED BY: E. H. BUCHANAN
Chief, Artillery
Ammunition Laboratory

AMMUNITION ENGINEERING DIRECTORATE
PICATINNY ARSENAL
DOVER, NEW JERSEY
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>1</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>2</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td></td>
</tr>
<tr>
<td>Part I - Input and Output Formats</td>
<td>4</td>
</tr>
<tr>
<td>Part II - Numerical Calculations</td>
<td>7</td>
</tr>
<tr>
<td>Part III - Program Logic</td>
<td>10</td>
</tr>
<tr>
<td>Part IV - Examples</td>
<td>11</td>
</tr>
<tr>
<td>REFERENCE</td>
<td>15</td>
</tr>
<tr>
<td>APPENDICES</td>
<td></td>
</tr>
<tr>
<td>A. Tables</td>
<td>16</td>
</tr>
<tr>
<td>B. Program Output for Cases 1-4</td>
<td>18</td>
</tr>
<tr>
<td>C. Fortran Program for Interior Ballistics</td>
<td>22</td>
</tr>
<tr>
<td>ABSTRACT DATA</td>
<td>30</td>
</tr>
<tr>
<td>TABLE OF DISTRIBUTION</td>
<td>31</td>
</tr>
</tbody>
</table>
ACKNOWLEDGMENT

The author is grateful to Sidney Bernstein and Stuart Levy of the Artillery Ammunition Laboratory for originating the idea of writing the program and supplying the data to test it.
ABSTRACT

A digital computer program was written which will perform interior ballistic calculations on an IBM 709 or IBM 7090. A brief description is given as well as an outline of the method of analysis which this program uses. Examples are presented and both input and output formats are discussed.

CONCLUSIONS

It is not the purpose of this report to evaluate or verify the accuracy of the Hirschfelder System on Interior Ballistics. Its only purpose is to describe a digital computer program which will perform the Hirschfelder calculations.

The reader will note that the results of the hand calculations given in Part IV correspond exactly to the computer results given in Appendix B.
INTRODUCTION

This report describes a digital computer program for performing the interior ballistic calculations of J. O. Hirschfelder.

The Hirschfelder System was developed between 1942 and 1945 and makes these basic assumptions:

1. A "first-degree burning law" is used in finding solutions to the fundamental ballistic equations.

2. The powder gas is distributed according to Kent's solution of the problem of the motion of the powder gas.

3. The heat lost to the bore up to any instant is proportional to the square of the velocity.

4. The friction of the projectile is taken as equivalent to a resisting pressure on the base of the projectile which is equal to a constant fraction of the average pressure.

This report's findings are divided into four parts:

The first part discusses the input and output formats.

The second part is devoted to a study of the basic equations used in the program. (It is assumed that the calculations found in Part II will be used in conjunction with Reference 1.)

The third part is a brief presentation of program logic.

In Part IV an example is given in which Cases 2, 3 and 4 are presented.

The program will solve four different types of problems (cases). In Case 1, various $\Phi$'s are given along with maximum pressure and the computer will find velocity and web. In Case 2, charge and maximum pressure are given and web and velocity are found. In Case 3, charge and velocity are given and web and maximum pressure are found. In Case 4, charge, velocity and web are given and the burning constant is found.
The appendices include tables giving propellant codes and constants, the program output for the example given in Part IV and also the complete Fortran Program.

The reference used is a revision and consolidation of seven progress reports on interior ballistics written by J. O. Hirschfelder and others of the staff of the Geophysical Laboratory, Carnegie Institution of Washington (Reference 1).
DISCUSSION

PART I - INPUT AND OUTPUT FORMATS

Input Format

The first 104 data cards will be the same for any group of runs. These cards incorporate constant tabular values (Part III of this report).

Following this set of cards, any number of runs may be included provided each run is in correct sequence. For each run, the following format is used.

Card 1

Space 1 is reserved for a numerical code giving the type of problem to be solved. "1" means that maximum pressure and parameters $\Phi$'s are given and web and velocity are to be found. "2" means that charge and pressure are given and web and velocity are to be found. "3" means that charge and velocity are given and maximum pressure and web are to be found. "4" means that charge, velocity and web are given and the burning constant is to be found.

Spaces 2 and 3 are reserved for a numerical code which denotes the propellant to be used in accordance with Table 1. The propellant constants are (given in Table 2) automatically selected from the memory of the machine. If no propellant code is specified or if it is given as "99," these constants must be given as part of the data, appearing on Card 2 below.

Space 4 is reserved for the code form function. A "1" denotes a propellant of single perforation. A "2" denotes a multiperforated propellant (for example, seven-perforated grains).

Space 5 is reserved for the number $N$ of $\Phi$'s used. Since the maximum number of $\Phi$'s used is five, $0 < N \leq 5$, Space 6 is left blank and Spaces 7-12 are reserved for the weapon in millimeters.

Spaces 13-18 are reserved for the projectile weight in pounds.

Spaces 19-24 are reserved for the chamber volume in cubic inches.
Spaces 25-30 are reserved for the travel in inches.

Spaces 31-36 are reserved for the maximum pressure in psi.

Spaces 37-42 are reserved for the charge in pounds.

Spaces 43-48 are reserved for the muzzle velocity in ft/sec.

Spaces 49-54 are reserved for the web in inches.

Spaces 55-62 are reserved for the burning constant.

Spaces 63-64, 65-66, 67-68, 69-70, 71-72 are reserved for the values of \( \phi \)’s.

Card 2 (This card is only required if no propellant code - Spaces 2 and 3 above - is given or is given as "99,")

Spaces 1-6 are reserved for the propellant constant \( a \).

Spaces 7-12 are reserved for the propellant constant \( a^0 \).

Spaces 13-18 are reserved for the propellant density in lbs/in\(^3\).

Spaces 19-24 are reserved for the propellant co-volume in in\(^3\)/lbs.

Spaces 25-30 are reserved for the propellant force in ft-lbs/lb.

Most of these values must be punched on the card with a decimal point. The exceptions are:

The codes: Spaces 1-4.

The burning constant which may be given to eight significant digits.

The \( \phi \)'s less than unity. The values for \( \phi \) are 0.05, 0.10, 0.05, \ldots, 0.95, 1.00 and are punched as 05, 10, 15, \ldots, 95, 1.
Output Format

The output will list all input data as well as the calculated loading densities, tabular values $\phi$ and $\Xi$; velocities, pressures, web or burning constants depending on the problem being solved. If the problem is of Type 1 or 2 and the $\phi$'s given as input do not result in optimum efficiency, consecutive $\phi$'s are tried in an effort to improve the results.

$\phi$, $P_p$, $E_m$, $\dot{\xi}$, $\Xi$ are referred to as "PHI," "PP\phi," "XIM," "GAMMA" and "\Xi S" respectively.

An example of this program's output is in Appendix B.
PART II - NUMERICAL CALCULATIONS

Let $W$ denote the weapon (caliber) in millimeters.
Let $M$ denote the projectile weight in lbs.
Let $V_c$ denote the chamber volume in $\text{in}^3$.
Let $L$ denote the length of travel in $\text{in}^3$.
Let $P_{\text{MAX}}$ denote the maximum pressure in psi.
Let $P_{\text{OPR}}$ denote the operating pressure in psi.
Let $B$ denote the burning constant in $(\text{in/sec})/\text{psi}$.
Let $C$ denote the charge in lbs.
Let $\text{WEB}$ denote the web in inches.
Let $\triangle$ denote the loading density in gms/cc.
Let $V_m$ denote the velocity in $\text{ft/sec}$.

The following are constant for the propellant. Their values are given in Table 2 of Appendix A.

Let $a$ and $a^0$ denote the two "propellant constants" in $\text{in}^3/\text{lb}$.
Let $\rho$ denote the propellant density in $\text{lbs}/\text{in}^3$.
Let $k$ denote the propellant covolume in $\text{in}^3/\text{lb}$.
Let $F$ denote the propellant force in $\text{ft-lbs/lb}$.

If $C$ is given (Cases 2, 3 and 4), $\triangle$ (the loading density) is obtainable:
\[ \triangle = C/V_c \]

To facilitate the calculations, the parameter $\phi$ is used and is equal to the value:
\[ \frac{a}{\left( \frac{1}{\triangle} - \frac{1}{\rho} \right)} \]

From $\phi = a/\left( \frac{1}{\triangle} - \frac{1}{\rho} \right)$, the equalities
\[ \phi\left( \frac{1}{\triangle} - \frac{1}{\rho} \right) = a \]
\[ \frac{1}{\triangle} - \frac{1}{\rho} = \frac{a}{\phi} \]
\[ \frac{1}{\triangle} = \frac{1}{\rho} + \frac{a}{\phi} \]
\[ \triangle = 1/(\frac{1}{\rho} + \frac{a}{\phi}) \]
are derived. Therefore, if $n$ $\phi$'s are chosen, $\phi_1, \ldots, \phi_n$ (as in Case 1)

-7-
and \( C \) is not given, each of the \( n \) \( \Delta \)'s are calculable:

\[
\Delta i = \frac{1}{\left( \frac{1}{\Phi} + \frac{a}{\Phi i} \right)}
\]

and hence \( C_i = \Delta i \cdot V_c, \ i = 1, \ldots, n \)

Let \( A \) denote the bore area of the projectile.

\[
A = \left( \frac{w}{25.4} \cdot \frac{1}{2} \right) \cdot \pi
\]

Let \( X = (V_c + A \cdot L)/V_c \)

Let \( \Delta_m = (a \Delta)/(X - \eta \Delta) \)

Let \( P_{pi}^0 = a^0 \text{ PMAX} \left( \frac{M + \frac{C_i}{3}}{M + \frac{C_i}{2}} \right) \) where

\( \text{PMAX} = 1.15 \text{ POPR} \)

Knowing the value of \( \phi_i \) and \( P_{pi}^0 \), the values of \( Z_i \) and \( \delta_i \) for each \( i \) are now obtainable from Tables 4, 6, 8 and 10 in Reference 1. Tables 4 and 6 give \( Z_i \) and \( \delta_i \), respectively, for single-perforated propellants. Table 8 and 10 give \( Z_i \), and \( \delta_i \), respectively, for seven-perforated propellants.

\[
\text{Let } m_i = \frac{L_02(m + \frac{3, 1}{32.175})}{Ci}
\]

The velocity \( V_{m_i} \) is then equal to the value

\[
\sqrt{(1 - \delta_i \Delta_m \cdot \frac{0.3}{0.3 m_i})^2} \cdot \frac{2CiF}{0.3 m_i}, \ i = 1, \ldots, n
\]

Consider the case (Case 3) when \( C \) and \( V_m \) are given. Here \( C_i = C \)

for each \( i \) and \( \phi_i \), \( P_{pi}^0 \), \( Z_i \), \( \delta_i \) and \( m_i \) all have the single values \( \phi \), \( P_{pi}^0 \), \( Z \), \( \delta \) and \( m \) respectively.
Therefore, since \( V_m = \sqrt{\frac{1 - \varphi \Xi_m^{0.3}}{0.3m'}} \frac{2CF}{0.3m'} \)

\( V_m^2 = (1 - \varphi \Xi_m^{0.3}) \frac{2CF}{0.3m'} \)

\( (\varphi \Xi_m^{0.3}) \frac{2CF}{0.3m'} = \frac{2CF}{0.3m'} - V_m^2 \)

\( \varphi = (\frac{0.15m'}{0.15m'} - V_m^2) \frac{0.15m'}{\Xi_m^{0.13} CF} \)

\( \varphi = (1 - \frac{0.15m' V_m^2}{CF} \frac{0.3}{0.3}) / \Xi_m^{0.3} \)

Knowing \( \varphi \) and \( \phi \), \( P_{p0} \) is obtainable from Tables 6 or 10.

From \( P_{p0} = a^0 \frac{M + \frac{c}{3}}{M + \frac{c}{2}} \)

we find \( P_{MAX} = \frac{P_{p0}}{a^0} \frac{M + \frac{c}{2}}{M + \frac{c}{3}} \)

Knowing \( P_{p0} \) and \( \phi \), \( Z \) is obtainable from Table 4 or 6

Let \( \Xi_m^{0.3} = S \)

Let \( (1 - 0.1485 Z) / \Xi_m = T_s \)

Let \( (1 - 0.242 Z) / \Xi_m = T_m \)

When a single-perforated propellant is used, \( T_s \) is calculated and the point of optimum efficiency is when \( S \) and \( T_s \) are equal. In this case

\( \text{WEB} = \frac{(B/A)^e \sqrt{\frac{CFm' Z}{0.99}}}{0.99} \)

However, when a multiperforated propellant is used, \( T_m \) is calculated and the point of optimum efficiency is when \( S \) and \( T_m \) are equal. In this case

\( \text{WEB} = \frac{(B/A) \sqrt{\frac{CFm' Z}{1.369}}}{1.369} \)
PART III - PROGRAM LOGIC

Tables 8, 10, 4 and 6 of Reference 1 appear in the first 104 data cards. As \( I = 1, 20 \) and \( J = 1, 47 \); Cards 1-24 give \( A(I, J) \), the values in Table 8. Cards 25-48 give \( C(I, J) \), the values in Table 10. Cards 49-76 give \( E(I, J) \), the values in Table 4 and Cards 77-104 give \( F(I, J) \), the values in Table 6. \( I = Pp^0 / 2,000 \) where \( Pp^0 = 2,000, 4,000, 6,000, \ldots, 90,000, 95,000, 100,000 \). \( J = 20 \phi \) where \( \phi = 0.05, 0.10, \ldots, 0.95, 1.0 \).

Linear interpolations were made within these tables when \( \theta \) and \( Z \) are known and \( Pp^0 \) is to be found. No attempt was made to interpolate between the \( \phi \)'s; instead, the tabular \( \phi \) closest to the calculated \( \phi \) has been selected.
90mm, Gun, M41

1. Gun constants
   Projectile weight $M = 12.65$ lbs.
   Chamber volume $V_c = 300$ in.$^3$
   Propellant Type $= M17$ (M.P.)
   Total Travel $L = 155$ in.

2. Case 4
   Given: Charge $C = 8.58$ lbs.
   Maximum Pressure $P_{\text{MAX}} = 50,500$ psi
   Velocity $V_m = 4,000$ f/s
   Web $= 0.052$ in.

\[ \Delta = \frac{C}{V_c} = \frac{8.58}{300} = 0.0286 \]

\[ \phi = \frac{\Delta}{P} = \frac{0.0286}{0.0603} = \frac{12.92}{34.965 - 16.5837} = \frac{12.92}{18.3812} = 0.70289 \approx 0.70 \]

(where $a$ and $\phi$ are found in Table 2 (9) of Appendix A).

\[ P_{p_0} = a^0 P_{\text{MAX}} \left[ \frac{M + 3}{c} \right] = (0.851)(50,500) \left[ \frac{12.65 + \frac{8.58}{3}}{12.65 + \frac{8.58}{2}} \right] \]

\[ = 42975.5 \cdot \left[ \frac{15.51}{16.94} \right] \]

\[ = 42975.5(0.915584) = 39347.697 \]

(where $a^0$ is also found in Table 2).
\[ \nu = 1.763 \text{ by Table 8 in Reference 1.} \]

\[ m' = \frac{1.02(M + 3.1)}{32.174} = \frac{1.02 \cdot (12.65 + \frac{8.58}{3.1})}{32.174} = \frac{1.02(15.4177)}{32.174} = \frac{15.7261}{32.174} \approx 0.48878 \]

\[ A = \left( \frac{90}{25.4} \cdot 0.5 \right)^2 (3.1416) = (1.772)^2 (3.1416) = 9.8607 \]

Since Webw = \( \frac{B}{A} \sqrt{Cf m' z} \)

\[ 0.052 = \frac{B}{9.8607} \cdot \sqrt{(8.58)(364,000)(0.48878)(1.763)} \]

\[ 0.5127 = B \cdot \sqrt{2681157.356} \]

\[ 0.5118 = B \cdot \left( \frac{1637.424}{1.17} \right) \]

\[ 0.598806 = 1637.424 B \]

\[ B = 0.0003657 \]

3. Case 2

Given: Charge C ------------------- 8.58 lbs.

Maximum Pressure PMAX ------ 50,500 psi

\[ \Delta = 0.0286, \phi = 0.70; Pp^0 = 39347.697 \]

\[ \delta = 1.410 \text{ by Table 10 in Hirschfelder} \]

\[ A = 9.8607 \]

\[ X = \frac{V_c + A \cdot L}{V_c} = \frac{300 + (9.8607)(155)}{300} = \frac{1828.4085}{300} = 6.0947 \]
\[ C_m = \frac{(12.92)(0.0286)}{6.0947 - (29.50)(0.0286)} \]
\[ = \frac{0.3695}{6.0947 - 0.8437} = \frac{0.3695}{5.251} = 0.07037 \]

\[ S = C_m^{0.3} = 0.451 \]

\[ V_m = \sqrt{\frac{(1 - C_m^{0.3}) \cdot 2CF}{0.3m}} \]
\[ = \sqrt{\left(1 - (1.410)(0.451)\right) \cdot \frac{2(8.58)(364000)}{(0.3)(0.48878)}} \]
\[ = \sqrt{\left(1 - 0.6359\right) \cdot \frac{6246240}{0.14669}} \]
\[ = \sqrt{\frac{2274255.984}{0.14669}} \]
\[ = \frac{1508.4577}{0.383} = 3938.532 \]

\[ T_m = \frac{1 - 0.242 \varepsilon}{\varepsilon} = \frac{1 - (0.242)(1.763)}{1.410} = \frac{0.57393}{1.410} = 0.407 \]

Since \( S = 0.451 > 0.407 = T_m \), burning is taking place outside the weapon. To attain optimum conditions, new and smaller \( \varepsilon \)'s (and hence new charges) may be chosen in an effort to minimize \( |S - T_m| \). This was done on the computer and the results are in Appendix B for Cases 1 and 2.

It is obvious that the web, calculated with \( B = 0.0003657 \), will be 0.052 since the equation for web was used in Case 4 to find \( B \).

4. Case 3
   Given: Charge \( C \) -------------------------- 8.58 lbs.
   Velocity \( V_m \) -------------------------- 4,000 f/s
\[
\delta = \left(1 - \frac{0.15m^2 Vm^{2}}{CF}\right) e^{m^{0.3}}
\]

\[
1 - \frac{(0.15)(0.48878)(4000)^2}{(8.58)(364,000)} = 0.451
\]

\[
\frac{1173072}{0.451} = 1 - 0.37561 = 0.62439 = 1.384
\]

Since \( \phi = 0.70 \), \( Pp^o = 41561.1367 \) by Table 10 in Reference 1. Therefore, \( Z = 1.693 \)

\[
P_{MAX} = \frac{Pp^o}{a^o} \left[ \frac{M + \frac{2}{C}}{M + \frac{3}{C}} \right]
\]

\[
= \left( \frac{41561.1367}{0.851} \right) \left( \frac{12.65 + \frac{8.58}{2}}{12.65 + \frac{8.58}{3}} \right)
\]

\[
= \left( \frac{41561.1367}{0.851} \right) \left( \frac{16.94}{15.51} \right)
\]

\[
= (41561.1367)(1.2834)
\]

\[
= 53340.792 \text{ psi}
\]

\( Z = 1.693 \) by Table 8 in the reference.

Therefore, \( Web = \frac{0.0003657}{9.8607} \sqrt{\frac{(8.58)(364000)(0.48878)(1.693)}{1.369}} \)

\[
= \frac{0.0003657}{9.8607} \sqrt{258439597.29} = 1.17
\]

\[
= \frac{(0.0003657)(16076.0566)}{11,537} = 0.05879
\]

\[
= \frac{0.05879}{11,537} = 0.005096
\]
REFERENCE

APPENDICES
APPENDIX A

TABLES
### TABLE 1
**PROPELLANT CODES**

<table>
<thead>
<tr>
<th>Propellant</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>1</td>
</tr>
<tr>
<td>M2</td>
<td>2</td>
</tr>
<tr>
<td>M5</td>
<td>5</td>
</tr>
<tr>
<td>M6</td>
<td>6</td>
</tr>
<tr>
<td>M9</td>
<td>9</td>
</tr>
<tr>
<td>M10</td>
<td>10</td>
</tr>
<tr>
<td>M14</td>
<td>14</td>
</tr>
<tr>
<td>M15</td>
<td>15</td>
</tr>
<tr>
<td>M17</td>
<td>17</td>
</tr>
<tr>
<td>T25</td>
<td>25</td>
</tr>
<tr>
<td>T28</td>
<td>28</td>
</tr>
<tr>
<td>T34</td>
<td>34</td>
</tr>
<tr>
<td>T36</td>
<td>36</td>
</tr>
</tbody>
</table>

In order for the propellant constants to be read in as part of the input (data Card 2), the code is "99."
TABLE 2

PROPELLANT CONSTANTS

In the following table, a and a^0 represent the propellant "a" -
-constants; \( \rho \) represents the propellant density in lbs/in^3, \( \kappa \) represents
propellant covolume in in^3/lbs., and F represents the propellant force
in ft. lbs/lbs.

<table>
<thead>
<tr>
<th>Propellant</th>
<th>a</th>
<th>a^0</th>
<th>( \rho )</th>
<th>( \kappa )</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>12.92</td>
<td>1.015</td>
<td>0.0567</td>
<td>30.57</td>
<td>305,000</td>
</tr>
<tr>
<td>M2</td>
<td>11.16</td>
<td>0.743</td>
<td>0.0597</td>
<td>27.91</td>
<td>360,000</td>
</tr>
<tr>
<td>M5</td>
<td>10.74</td>
<td>0.725</td>
<td>0.0596</td>
<td>27.52</td>
<td>355,000</td>
</tr>
<tr>
<td>M6</td>
<td>12.41</td>
<td>0.938</td>
<td>0.0571</td>
<td>29.92</td>
<td>317,000</td>
</tr>
<tr>
<td>M9</td>
<td>9.02</td>
<td>0.566</td>
<td>0.0659</td>
<td>25.97</td>
<td>382,000</td>
</tr>
<tr>
<td>M10</td>
<td>11.15</td>
<td>0.788</td>
<td>0.0602</td>
<td>27.76</td>
<td>339,000</td>
</tr>
<tr>
<td>M14</td>
<td>12.36</td>
<td>0.906</td>
<td>0.058</td>
<td>29.54</td>
<td>327,000</td>
</tr>
<tr>
<td>M15</td>
<td>14.50</td>
<td>1.034</td>
<td>0.06</td>
<td>31.17</td>
<td>336,000</td>
</tr>
<tr>
<td>M17</td>
<td>12.92</td>
<td>0.851</td>
<td>0.0603</td>
<td>29.50</td>
<td>364,000</td>
</tr>
<tr>
<td>T25</td>
<td>11.57</td>
<td>0.786</td>
<td>0.0585</td>
<td>28.66</td>
<td>353,000</td>
</tr>
<tr>
<td>T28</td>
<td>11.68</td>
<td>0.786</td>
<td>0.0585</td>
<td>28.77</td>
<td>356,000</td>
</tr>
<tr>
<td>T34</td>
<td>14.07</td>
<td>1.007</td>
<td>0.0596</td>
<td>30.85</td>
<td>335,000</td>
</tr>
<tr>
<td>T36</td>
<td>12.59</td>
<td>0.828</td>
<td>0.06</td>
<td>29.26</td>
<td>364,000</td>
</tr>
</tbody>
</table>
**INPUT**

CASE = 1

PRPOPELLANT CODE = 17  
CODE FORM FUNCTION = 2  
WEAPNO W' (MM) = 90.000  
PRPO wt. PJW (LBS) = 12.6500  
CHAMBER VOLUME VC (C.IN) = 300.000  
TRAVEL TRAV (IN) = 155.000  
MAX PRESSURE PMAX (PSI) = 50500.000  
OPERATING PRESSURE POPR (PSI) = 43913.0435  
PRPO. VOLUME ETA (C.IN/LBS) = 29.5000  
PRPO. DENSITY RHO (LBS/C.IN) = 0.0603  
PRPO. FORCE F (FT.LBS/LBS) = 364000.0000  
PRPO. CONSTANTS A_1 A_2 = 12.9200 0.8510  
BURN-CONSTANT B = 0.00036573  
BORE AREA = 9.8607

**OUTPUT**

<table>
<thead>
<tr>
<th>PHI</th>
<th>L.DENSITY</th>
<th>CHARGE</th>
<th>PP0</th>
<th>XIM</th>
<th>GAMMA</th>
<th>ZS</th>
<th>VELOCITY</th>
<th>S</th>
<th>T</th>
<th>WEB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.050</td>
<td>0.004</td>
<td>1.09</td>
<td>42383.3135</td>
<td>0.008</td>
<td>-0.</td>
<td>-0.</td>
<td>2534.419</td>
<td>0.234</td>
<td>0.</td>
<td>0.</td>
</tr>
<tr>
<td>0.300</td>
<td>0.017</td>
<td>5.03</td>
<td>40600.0542</td>
<td>0.039</td>
<td>1.527</td>
<td>0.758</td>
<td>3383.761</td>
<td>0.377</td>
<td>0.535</td>
<td>0.025117025</td>
</tr>
<tr>
<td>0.500</td>
<td>0.024</td>
<td>7.07</td>
<td>39846.1870</td>
<td>0.056</td>
<td>1.422</td>
<td>1.294</td>
<td>3808.135</td>
<td>0.422</td>
<td>0.483</td>
<td>0.039799377</td>
</tr>
<tr>
<td>0.700</td>
<td>0.029</td>
<td>8.56</td>
<td>39535.5654</td>
<td>0.070</td>
<td>1.410</td>
<td>1.763</td>
<td>3937.836</td>
<td>0.451</td>
<td>0.407</td>
<td>0.051929250</td>
</tr>
</tbody>
</table>

THE POINT OF OPTIMUM EFFICIENCY IS WHEN S AND T ARE EQUAL

TRUE PHI IS GREATER THAN 0.5000 WHERE S = 0.4221 AND T = 0.4832

<table>
<thead>
<tr>
<th>PHI</th>
<th>L.DENSITY</th>
<th>CHARGE</th>
<th>PP0</th>
<th>XIM</th>
<th>GAMMA</th>
<th>ZS</th>
<th>VELOCITY</th>
<th>S</th>
<th>T</th>
<th>WEB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.55</td>
<td>0.025</td>
<td>7.49</td>
<td>39704.6367</td>
<td>0.060</td>
<td>1.413</td>
<td>1.407</td>
<td>3861.345</td>
<td>0.430</td>
<td>0.467</td>
<td>0.042898998</td>
</tr>
<tr>
<td>0.60</td>
<td>0.026</td>
<td>7.87</td>
<td>39576.5127</td>
<td>0.064</td>
<td>1.404</td>
<td>1.531</td>
<td>3909.213</td>
<td>0.438</td>
<td>0.448</td>
<td>0.046060152</td>
</tr>
<tr>
<td>0.65</td>
<td>0.027</td>
<td>8.23</td>
<td>39459.9917</td>
<td>0.067</td>
<td>1.405</td>
<td>1.646</td>
<td>3929.880</td>
<td>0.445</td>
<td>0.428</td>
<td>0.049026169</td>
</tr>
</tbody>
</table>
**INPUT**

CASE = 2  
PRPELLANT CÓDE = .17  
CÓDE FORM FUNCTION = 2  
WEAPÓN W (MM) = 90.0000  
PRÓJ.WT. PJW (LBS.) = 12.6500  
CHAMBER VOLUME VC (C.IN) = 300.0000  
TRAVEL TRAV (IN) = 155.0000  
MAX PRESSURE PMAX (PSI) = 50500.0000  
OPERATING PRESSURE PÖPR (PSI) = 43913.0435  
PRÖP. CÖVOLUME ETA (C.IN/LBS) = 29.5000  
PRÖP. DENSITY RHÖ (LBS/C.IN) = 0.0603  
PRÖP. FORCE F (FT.LBS/LBS) = 364000.0000  
PRÖP. CONSTANTS A,AB, = 12.9200 0.8510  
BURN,CONSTANT B = 0.00036573  
BÖRE AREA = 9.8607

**OUTPUT**

<table>
<thead>
<tr>
<th>PHI</th>
<th>DENSITY</th>
<th>CHARGE</th>
<th>PPÖ</th>
<th>XIM</th>
<th>GAMMA</th>
<th>ZS</th>
<th>VELOCITY</th>
<th>S</th>
<th>T</th>
<th>WEB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.029</td>
<td>8.58</td>
<td>39347.6973</td>
<td>0.070</td>
<td>1.410</td>
<td>1.763</td>
<td>3938.532</td>
<td>0.451</td>
<td>0.407</td>
<td>0.051998682</td>
</tr>
<tr>
<td>0.65</td>
<td>0.027</td>
<td>8.25</td>
<td>39453.5811</td>
<td>0.067</td>
<td>1.405</td>
<td>1.646</td>
<td>3930.916</td>
<td>0.445</td>
<td>0.428</td>
<td>0.049098566</td>
</tr>
<tr>
<td>0.60</td>
<td>0.026</td>
<td>7.89</td>
<td>39569.4810</td>
<td>0.064</td>
<td>1.404</td>
<td>1.531</td>
<td>3910.559</td>
<td>0.438</td>
<td>0.448</td>
<td>0.046135731</td>
</tr>
</tbody>
</table>

**THE POINT OF OPTIMUM EFFICIENCY IS WHEN S AND T ARE EQUAL**

TRUE PHI IS LESS THAN 0.7029 WHERE S = 0.4510 AND T = 0.4067
INPUT

CASE = 3
PROPPELLANT CODE = 17
CODE FORM FUNCTION = Z
WEAP W (MM) = 90.0000
PRJ.WT. PJW (LBS.) = 12.6500
CHAMBER VOLUME VC (C.IN) = 300.0000
TRAVEL TRAV (IN) = 155.0000
CHARGE CH(1) (LBS) = 8.5800
VELOCITY VM(1) (F/S) = 4000.0000
PROP. CVOLUME ETA (C.IN/LBS) = 29.5000
PROP. DENSITY RH0 (LBS/C.IN) = 0.0603
PROP. FORCE F (FT.LBS/LBS) = 364000.0000
PROP. CONSTANTS A, A0, = 12.9200 0.8510
BURN. CONSTANT b = 0.00036573
BORE AREA = 9.8607

OUTPUT

PHI  1.DENSITY  CHARGE  PP0  XIM  GAMMA  ZS  PRESSURE  S  T  WEB

 0.703  0.029  8.58  41561.1367  0.070  1.384  1.693  53340.792  0.451  0.426  0.050960869
**Input**

CASE = 4
PRPELLANT CODE = 17
CODE FORM FUNCTION = 2
WEAPON W (MM) = 90.0000
PRJ.WT. PJW (LBS.) = 12.6500
CHAMBER VOLUME VC (C.IN) = 300.0000
TRAVEL TRAV (IN) = 155.0000
MAX PRESSURE PMAX (PSI) = 50500.0000
OPERATING PRESSURE P0PR (PSI) = 43913.0435
CHARGE (LBS) = 8.5800
VELOCITY (F/S) = 4000.0000
WEB = 0.0520
PRP. C0VOLUME ETA (C.IN/LBS) = 29.5000
PRP. DENSITY RH0 (LBS/C.IN) = 0.0603
PRP. FORCE F (FT.LBS/LBS) = 364000.0000
PRP. CONSTANTS A,AB, = 12.9200 0.8510
BORE AREA = 9.8607

**Output**

<table>
<thead>
<tr>
<th>PHI</th>
<th>L.DENSITY</th>
<th>CHARGE</th>
<th>PP0</th>
<th>XIM</th>
<th>GAMMA</th>
<th>ZS</th>
<th>VELOCITY</th>
<th>S</th>
<th>T</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.703</td>
<td>0.029</td>
<td>8.58</td>
<td>39347.6973</td>
<td>0.070</td>
<td>1.410</td>
<td>1.763</td>
<td>4000.000</td>
<td>0.451</td>
<td>0.407</td>
<td>0.000365734</td>
</tr>
</tbody>
</table>

The point of optimum efficiency is when S and T are equal.
APPENDIX C

FORTRAN PROGRAM FOR INTERIOR BALLISTICS
FÖRTRAN PROGRAM FÖR_HIRSCHFELDER INTERIÖR BALLISTIC CALCULATIONS

DIMENSION A(25,55), B(25,55), C(25,55), D(25), PH(15), DELTA(15), CH(15), PØ 1P(15), XIM(15), ZS(15), GAMMA(15), H(15), VM(15), S(15), T(15), WEB(15), E( 225,55), F(25,55), AB(50), ABV(50)

READ INPUT TAPE 2,2,(A(1,J),J=1,4), (A(2,J),J=2,8), (A(3,J),J=3,13), 1(A(4,J),J=4,19), (A(5,J),J=5,24), (A(6,J),J=6,31), (A(7,J),J=7,38), (A 2(8,J),J=8,45), (A(9,J),J=9,47), (A(10,J),J=10,47), 3(A(12,J),J=11,47), (A(13,J),J=12,47), (A(14,J),J=13,47), (A(15,J),J=14, 4,47), (A(16,J),J=15,47), (A(17,J),J=16,47), (A(18,J),J=17,47), (A(19,J) 5),J=18,47), (A(20,J),J=19,47), (A(21,J),J=20,47),

1 FORMAT(24F3.2)/(24F3.2)

READ INPUT TAPE 2,2,(C(1,J),J=1,4), (C(2,J),J=2,8), (C(3,J),J=3,13), 1(C(4,J),J=4,19), (C(5,J),J=5,24), (C(6,J),J=6,31), (C(7,J),J=7,38), (C 2(8,J),J=8,45), (C(9,J),J=9,47), (C(10,J),J=10,47), 3(C(12,J),J=11,47), (C(13,J),J=12,47), (C(14,J),J=13,47), (C(15,J),J=14, 4,47), (C(16,J),J=15,47), (C(17,J),J=16,47), (C(18,J),J=17,47), (C(19,J) 5),J=18,47), (C(20,J),J=19,47), (D(I),I=1,5)

3 FORMAT(24F3.2)/(24F3.2)

READ INPUT TAPE 2,8,(E(1,J),J=1,7), (E(2,J),J=2,15), (E(3,J),J=3,25) 1,(E(4,J),J=4,35), (E(5,J),J=5,46), (E(6,J),J=6,57), (E(7,J),J=7,64), 2(E(8,J),J=7,74), (E(9,J),J=8,47), (E(10,J),J=9,47), (E(11,J),J=10,47) 3(E(12,J),J=11,47), (E(13,J),J=12,47), (E(14,J),J=13,47), (E(15,J),J=1 4,47), (E(16,J),J=15,47), (E(17,J),J=16,47), (E(18,J),J=17,47), (E(19, 5),J=19,47), (E(20,J),J=20,47)

8 FORMAT(24F3.2)/(24F3.2)

READ INPUT TAPE 2,8,(F(1,J),J=1,7), (F(2,J),J=2,15), (F(3,J),J=3,25) 1,(F(4,J),J=4,35), (F(5,J),J=5,46), (F(6,J),J=6,57), (F(7,J),J=7,64), 2(F(8,J),J=7,74), (F(9,J),J=8,47), (F(10,J),J=9,47), (F(11,J),J=10,47) 3(F(12,J),J=11,47), (F(13,J),J=12,47), (F(14,J),J=13,47), (F(15,J),J=1 4,47), (F(16,J),J=15,47), (F(17,J),J=16,47), (F(18,J),J=17,47), (F(19, 5),J=19,47), (F(20,J),J=20,47)

9 FORMAT(24F3.2)/(24F3.2)

1 READ INPUT TAPE 2,4,KASE,KØDE,M,V,W,PJW,VC,TRAV,PMAX,CH(1),VM(1),W 1ED(1),Y,(PH(1),I=1,N)

4 FORMAT(12,21,1X,3F6.0,F8.8,5F2.2)

500 CONTINUE

CONTINUE IF(KØDE=99)60,61,60

60 READ INPUT TAPE 2,62,V,AØ,RHØ,ETÄ,U

62 FORMAT(5F6.0)

GØ,TØ,300

64 V=12.92

AØ=1.015

RHØ=0.0567

ETÄ=30.57

U=35000.0.
FORTTRAN PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTIC CALCULATIONS

63 IF(KODE=2) 65, 66, 65
66 V=11.16
   AØ=0.743
   RHØ= 0.0597
   ETA= 27.91
   U= 360000.
65 IF(KODE=5) 67, 68, 67
68 V=10.74
   AØ=0.725
   RHØ= 0.0596
   ETA= 27.52
   U= 355000.
67 IF(KODE=6) 69, 70, 69
69 V=10.73
   AØ=0.938
   RHØ= 0.0571
   ETA= 29.92
   U= 317000.
70 IF(KODE=6) 71, 72, 71
71 V=9.02
   AØ= 0.566
   RHØ= 0.6590
   ETA= 25.97
   U= 382000.
72 IF(KODE=10) 73, 74, 73
73 IF(KODE=14) 75, 76, 75
74 V=11.19
   AØ= 0.788
   RHØ= 0.0602
   ETA= 27.76
   U= 339000.
75 IF(KODE=15) 77, 78, 77
76 V=12.33
   AØ= 0.906
   RHØ= 0.0582
   ETA= 29.54
   U= 327000.
77 IF(KODE=17) 79, 80, 79
78 V=14.50
   AØ= 1.034
   RHØ= 0.0600
   ETA= 31.17
   U= 336000.
79 IF(KODE=19) 81, 82, 81
80 V=12.92
   AØ= 0.851
   RHØ= 0.0603
   ETA= 29.50
   U= 366000.
81 IF(KODE=28) 83, 84, 83
82 V=11.57
   AØ= 0.786
   RHØ= 0.0585
   ETA= 28.66
   U= 353000.
83 V=11.68
84 V=11.68
FORTRAN PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTIC CALCULATIONS

\[ A_\theta = 0.786 \]
\[ \rho = 0.0585 \]
\[ \eta = 28.77 \]
\[ U = 356000. \]

83 IF(K0DE-34)B5,86,85

86 \[ V = 14.07 \]
\[ A_\theta = 1.007 \]
\[ \rho = 0.0596 \]
\[ \eta = 30.85 \]
\[ U = 335000. \]

85 IF(K0DE-36)300,89,300

88 \[ V = 12.59 \]
\[ A_\theta = 0.828 \]
\[ \rho = 0.060 \]
\[ \eta = 29.26 \]
\[ U = 364500. \]

300 S1\[\text{STEV}_0 = 0.0 \]

IF(KASE=1)100,31,100

100 IF(KASE=2)102,103,102

N=1

I=1

\[ \Delta(1)=CH(1)/VC \]
\[ PH(1)=V/(1./\Delta(1))-1./\rho \]

GØ TO 106

102 IF(KASE=3)104,105,600

600 I=2

\[ \Delta(1)=CH(1)/VC \]
\[ PH(1)=V/(1./\Delta(1))-1./\rho \]
\[ CH(2)=CH(1) \]
\[ WEB(2)=WEB(1) \]
\[ VM(2)=VM(1) \]

GØ TO 106

105 \[ \Delta(1)= CH(1)/VC \]
\[ PH(1)=V/(1./\Delta(1))-1./\rho \]
\[ AREA = ((H/25.4)**2)*(3.1416/4.) \]
\[ X = (VC + (AREA*TRAV))/VC \]
\[ XIM(1) = (V*\Delta(1))/[X-(\eta*\Delta(1))] \]
\[ S(1) = XI(1)**0.3*T \]
\[ H(1) = 0.317*(P1W+.3226*CH(1)) \]
\[ GAMMA(1) = (1-((.15*H(1)*VM(1)**2)/(CH(1)*U)))/S(1) \]
\[ Q = (PH(1)**20.1 + 0.4) \]
\[ L=Q \]

12=0

DØ 120 I=1,20

IF(L=1)120,140,120

140 I=1

120 CONTINUE

IF(I)122,121,122

121 WRITE OUTPUT TAPE 3,123,KASE,PH(1)

123 FORMAT(1H1,10X,7HA CASE 13.63H TYPE PROBLEM HAS BEEN REJECTED HERE

1 BECAUSE CALCULATED PHI IS F10.4,38H FOR WHICH THE TABLES ARE NOT

2ADEQUATE)

GØ TO 40

122 IF(M=1)108,108,107

107 DØ 109 I=1,47

ABV(1) = ABS(FC(L,1) - GAMMA(1))
FORTRAN PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTIC CALCULATIONS

109 CONTINUE
VAL = ABV(1)
DO 129 I=1,147
  VAL = MIN1F(VAL,ABV(I))
129 CONTINUE
DO 110 I=1,147
  IF(ABV(I) - VAL) 110,112,110
112 K = I
  TK = K
110 CONTINUE
  IF(GAMMA(1) - C(L,K))113,114,115
113 R=(C(L,K)-GAMMA(1))/(C(L,K)-C(L,K+1))+TK
  G0 T0 116
114 R=TK
  G0 T0 116
115 R=(C(L,K-1)-GAMMA(1))/(C(L,K-1)-C(L,K))+TK-1.
J=R
Z=1
ZS(1) = A(L,J)-(ABSF(R-Z)*ABSF(A(L,J) - A(L,J+1))
T(1)=(1.-242*ZS(1))/GAMMA(1)
151 WEB(1)=Y/SQRTF((1.369*AREA**2)/(CH(1)*U*H(1)*ZS(1))
  PMAX=(POP(I)/A0)*(1.+CH(1)/(6.*PJW+2.*CH(1))))
  G0 T0 137
108 DO 130 I=1,147.
  ABV(I)=ABSF(F(L,I)-GAMMA(1))
130 CONTINUE
  VAL=ABV(1)
  DO 131 I=1,147.
  VAL=MIN1F(VAL,ABV(I))
131 CONTINUE
  DO 132 I=1,147.
  IF(ABV(I)-VAL) 132,133,132
133 K=I
  TK=K
132 CONTINUE
  IF(GAMMA(1)-F(L,K))150,134,135
150 R=(F(L,K)-GAMMA(1))/(F(L,K)-F(L,K+1))+TK
  G0 T0 136
134 R=TK
  G0 T0 136
135 R=(F(L,K-1)-GAMMA(1))/(F(L,K-1)-F(L,K))+TK-1.
J=R
Z=1
ZS(1) = E(L,J)-(ABSF(R-Z)*ABSF(E(L,J) - E(L,J+1))
T(1)=(1.-1485*ZS(1))/GAMMA(1)
161 WEB(1)=Y/SQRTF((0.990*AREA**2)/(CH(1)*U*H(1)*ZS(1))
  PMAX=(POP(I)/A0)*(1.+CH(1)/(6.*PJW+2.*CH(1))))
137 WRITE OUTPUT TAPE 3,138,KASE,KODE,M,W,PJW,VC,TRAV,CH(1),VM(1),ETA,
  RH0,U,V,A0,Y,AREA
138 FORMAT(1H1,5X,9HI N P U T//5X,7HCASE = 11/5X,18HRPPELANT C0DE =
  12/5X,21HCODE FORM FUNCTION = 12/5X,16HWEP0N W (MM) = F
  212.4/5X,22HHRPELANT WT. PJW (LBS.) = F12.4/5X,27HCHAMBER VOLUME VC (C.
  .3IN) = F12.4/5X,19HTRAVEL TRAV (IN) = F12.4/5X,21HCHARGE CH(1) (LBS.
  4) = F12.4/5X,23HV0L0CITY VM(1) (F/S) = F12.4,10H
  /5X,32HP
PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTIC CALCULATIONS

580P. COVOLUME ETA (C. IN/LBS) = F12.4/5X31HPROP. DENSITY RHO (LBS/6C.IN) = F12.4/5X29HPROP. FORCE F (FT. LBS/LBS) = F12.4/5X24HPROP. 7 CONSTANTS A0,A1 = F12.4/5X12HB0RE AREA = F12.4

N=1
WRITE OUTPUT TAPE 3,89,(PH(I),DELTA(I),CH(I),P0P(I),XIM(I),GAMMA(I),ZS(I),PMAX(S),T(I),WEB(I),I=1,N)


G0 TO 40

153 WRITE OUTPUT TAPE 3,155,KASE,KODE,M,W,04,VE,TRAV,PMAX,P0PR,CH(I),
VM(I),WEB(I),ETA,RH0,U,H,AREA

155 FORMAT(1/Hl,5OX,9HNP U T//5X,7HCASE = 11/5X,18HPROPPELLANT CODE = 1 I 1/5X,21HC0DE F0RM FUNCTION = 11.6H /5X,16WEAP0N W (MM) = F
212.4/5X22HPROJ.WT. PJW (LBS) = F12.4/5X7CHAMBER VOLUME VC (C. 3IN) = F12.4/5X19HTRAVEL TRAV (IN) = F12.4/5X26HM0X PRESSURE PMAX
4 (PSI) = F12.4/5X32HOPERATING PRESSURE P0PR (PSI) = F12.4/5X15HC
5HARGE (LBS) = F12.4/5X17HEVELOCITY (F/S) = F12.4/5X6MWEB = F12.4
654H /5X,32HP
7R0P. COVOLUME ETA (C. IN/LBS) = F12.4/5X31HPROP. DENSITY RHO (LBS/8C.IN) = F12.4/5X29HPROP. FORCE F (FT. LBS/LBS) = F12.4/5X24HPROP.
9 CONSTANTS A0,A1 = F12.4/5X,12HB0RE AREA = F12.4

N=1
WRITE OUTPUT TAPE 3,700,PH(2),DELTA(2),CH(1),P0P(2),XIM(2),GAMMA(2)
1, ZS(2),VM(2),WEB(2),ETA,RH0,U,V,A0,AREA


WRITE OUTPUT TAPE 3,156

156 FORMAT(1X//3OX,57HPH THE POINT OF OPTIMUM EFFICIENCY IS WHEN S AND T 1ARE EQUAL)

104 G0 TO 40
31 DO 5 I = 1,N
5 DELTA(I) = 1./(IV/PH(I)+1./RHO)
CH(I)=VC*DELTA(I)

106 P0P(I) = PMAX*A0*(((PFJ +CH(I)/3.)/PFJ +CH(I)/2.))
AREA = ((W/25.4)**2)*(3.1416/4.)
X = (VC+(AREA*TRAV))/VC
XIM(I)=X*DELTA(I)/(X-(ETA*DELTA(I)))
Q=(PH(I)**100.)**/5.
Q=Q+0.4
R = P0P(I)/2000.
R=R+1.**(10.**7))
L=Q
J=R
Z=J
IF(M-111,11.10
11 ZS(I)=E(L,J)-ABS(P0P(I)/2000.)-Z*ABS(E(L,J)-E(L,J+1))
GAMMA(I)=F(L,J)-ABS((P0P(I)/2000.)-Z)*ABS(F(L,J)-F(L,J+1))
H(I)=.0317*(PFJ +.3226*CH(I)))
VM(I)=SQR(F1.-GAMMA(I)*(XIM(I)**0.3)*(2.*CH(I)*U)/(0.3*H(I)))))
S(I)=XIM(I)**0.3
T(I)=(1.-(.1485*ZS(I))/GAMMA(I)

Page 5
FØRTRAN PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTIC CALCULATIONS

WEB(I)=Y/SQRTF((1.99*AREA**2)/(CH(I)*U*H(I)*ZS(I)))
IF(KASE=4) 5,162,162
162 Y = WEB(I)*SQRTF((1.99*AREA**2)/(CH(I)*U*H(I)*ZS(I)))
GØ TØ 153
10 ZS(I)=ABS(ABS((POPF(I)/2000.0)-Z)*ABS(A(L,J)-A(L,J+1)))
GAMMA(I)=C(L,J)-ABS((POPF(I)/2000.0)-Z)*ABS(C(L,J)-C(L,J+1)))
H(I)=0317*(P(JW+1).3226*CH(I))
VM(I)=SQRTF((1.0-2.3)*XIM(I)**0.3)*(2.0*CH(I)*U)/(0.3*H(I)))
S(I)=XIM(I)**0.3
T(I)=(1.-1.242*ZS(I))/GAMMA(I)
WEB(I)=Y/SQRTF((1.369*AREA**2)/(CH(I)*U*H(I)*ZS(I)))
IF(KASE=4) 5,152,152
152 Y = WEB(I)*SQRTF((1.369*AREA**2)/(CH(I)*U*H(I)*ZS(I)))
GØ TØ 153
5 CONTINUE
IF(STEVE=201, 200, 201
200 WRITE OUTPUT TAPE 3,6, KASE, KØDE, M, W, PJW, VC, TRAV, PMAX, POPR, ETA, RHØ, 
10, V, AO, Y, AREA
6 FORMAT(I18,I18,S18) CASE = 11/5X, 18HP40PELLANT GØDE = 1 I2/5X, 21HCØDE FORM FUNCTION = I1.6H 
5/5X, 16HWEAPØN W (MM) = F 
212.4/5X, 22HPRØJ. WT. PJW (LBS.) = F12.4/5X, 27HCHAMBER VOLUME VC (C. 
3IN) = F12.4/5X, 19HTRAVEL TRAV (IN) = F12.4/5X, 26HMAX PRESSURE PMAX 
4 (PSI) = F12.4/5X, 32HPRESSURE POVR (PSI) = F12.4/5X, 32HP 
5RØP. CVOLUME ETA (C. LN/LBS) = F12.4/5X, 31HPRØP. DENSITY RHØ (LBS/ 
6C. IN) = F12.4/5X, 29HPRØP. FØRCE F (FT. LBS/LBS) = F12.4/5X, 24HPRØP. 
7 CONSTANTS A, AO, = F12.4/5X, 5X, F12.4/5X, 18HBURN, CONSTANT B = F12.8/5X 
8, 12HBØRE AREA = F12.4
WRITE OUTPUT TAPE 3, 20, (PH(I), DELTA(I), CH(I), PØP(I), XIM(I), GAMMA(I) 
11, ZS(I), VM(I), 3(I), T(I), WEB(I), I=1,N)
20 FORMAT(I18,S18) PHI L. DENSITY CHARGE 
1 PØP. XIM GAMMA ZS VELOCITY S T 
3, 1X, F12.4, 1X, F8.3, 1X, F8.3, 1X, F6.3, 1X, F6.3 
3) WRITE OUTPUT TAPE 3, 7 
7 FORMAT(I18, 54) THE PRINT OØ OPTIMUM EFFICIENCY IS WHEN S AND T 
ARE EQUAL
IF(STEVE=40, 32, 40
32 N4=2
N5=1
DØ 30 I=1,N 
IF(S(I)=T(I))29, 27, 25
25 AB(I)=100. 
N5=2
GØ TØ 30
27 WRITE OUTPUT TAPE 3, 28, PH(I), S(I)
28 FORMAT(1X/30X, 6HPHI = F12.3, 15H SINCE S = T = F12.4) 
N4 = 1
GØ TØ 30
29 AB(I) = ABS(S(I) - T(I)) 
VALUE=AB(I)
30 CONTINUE
GØ TØ(40, 35), N4
35 DØ 23 I=1,N 
VALUE=MINF(VALUE, AB(I))
23 CONTINUE
K=10
FORTRAN PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTIC CALCULATIONS

DO 24, I = 1, N
   IF(ABS(I-VALUE) > 24, 26, 24
  26 K = I
   CONTINUE
   IF(K-10) 950, 951, 951
951 WRITE OUTPUT TAPE 3, 952, PH(1), S(1), T(1)
952 FORMAT(1X//20X, 22H TRUE PHI IS LESS THAN F12.4, 11H WHERE S = F12.4,
   1.9H AND T = F12.4//)
961 PH(1) = PH(1) - 0.05
   IF(PH(1) - 0.05) 40, 970, 970
.970 N = 1
   STEV0 = 2.0
   GO TO 31
950 IF(STEV0) 900, 905, 900
900 IF(K-2) 201, 201, 902
905 WRITE OUTPUT TAPE 3, 33, PH(K), S(K), T(K)
33 FORMAT(1X//20X, 25H TRUE PHI IS GREATER THAN F12.4, 11H WHERE S = F12
   1.9H AND T = F12.4//)
902 IF(PH(K) - 1.0) 141, 40, 40
41 IF(PH(K) - PH(1)) 40, 42, 43
42 IF(PH(1) - 0.95) 50, 51, 51
51 PH(1) = 1.0
   N = 1
   GO TO 48
50 IF(PH(1) - 0.90) 53, 52, 52
52 PH(1) = 0.95
   PH(2) = 1.0
   N = 2
   GO TO 48
53 PH(1) = PH(1) + 0.05
   PH(2) = PH(1) + 0.05
   PH(3) = PH(2) + 0.05
   N = 3
   GO TO 48
43 IF(PH(K) - 0.95) 44, 45, 45
45 PH(1) = PH(K) + 0.05
   N = 1
   GO TO 48
44 IF(PH(K) - 0.90) 46, 47, 47
47 PH(1) = PH(K) + 0.05
   PH(2) = PH(1) + 0.1
   N = 2
   GO TO 48
46 PH(1) = PH(K) + 0.05
   PH(2) = PH(1) + 0.05
   PH(3) = PH(2) + 0.05
   N = 3
48 STEV0 = 1.0
   GO TO 31
201 WRITE OUTPUT TAPE 3, 202, (PH(I), DELTA(I), CH(I), P0P(I), XIM(I), GAMMA(I)
   11I, ZS(I), VM(I), S(I), T(I), WEB(I), I = 1, N)
202 FORMAT(1X//1X, F8.2, 1X, F8.3, 1X, F10.2, 1X, F12.4, 1X, F8.3, 1X, F6.3, 1X, F
   IF(STEV0 - 1.) 40, 920, 960
960 IF(S(I) - T(I)) 40, 27, 961
920 DO 921 I = 1, N
-28-
FORTRAN PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTIC CALCULATIONS

IF(S(1)-T(1))921,921,922
922 N5=2
921 CONTINUE
   IF(N5-2)32,40,40
40 GO TO 1
   END(1,1,0,0,0,0,1,1,0,0,0,0,0,0)
Accession No. AD

Picatinny Arsenal, Dover, New Jersey

A DIGITAL COMPUTER PROGRAM FOR
HIRSCHFELDER INTERIOR BALLISTICS

Forrest L. McMains


A digital computer program was written which will perform interior ballistic calculations on an IBM 709 or IBM 7090. A brief description is given as well as an outline of the method of analysis which this program uses. Examples are presented and both input and output formats are discussed.
A DIGITAL COMPUTER PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTICS

Forrest L. McMains

Technical Memorandum 1404, April 1964, 31 pp, tables.

UNCLASSIFIED

1. Digital Computer Program — Programming (Computers)
2. Ballistics — Interior
I. TITLE
II. McMains, Forrest L.

UNITERMS

Digital computer
Input format
Output format
Interior ballistic calculations
Hirschfelder System
Velocity
Web
Propellant codes
McMains, F. L.

UNCLASSIFIED

A digital computer program was written which will perform interior ballistic calculations on an IBM 709 or IBM 7090. A brief description is given as well as an outline of the method of analysis which this program uses. Examples are presented and both input and output formats are discussed.
**UNCLASSIFIED**

1. Digital Computer Program — Programming (Computers)
2. Ballistics — Interior

**TITLE**

Hirschfelder Interior Ballistics

**UNITERMS**

Digital computer
Input format
Output format
Interior ballistic calculations
Hirschfelder System
Velocity
Web
Propellant codes
McMains, F. L.

---

**UNCLASSIFIED**

1. Digital Computer Program — Programming (Computers)
2. Ballistics — Interior

**TITLE**

Hirschfelder Interior Ballistics

**UNITERMS**

Digital computer
Input format
Output format
Interior ballistic calculations
Hirschfelder System
Velocity
Web
Propellant codes
McMains, F. L.
TABLE OF DISTRIBUTION
<table>
<thead>
<tr>
<th>Copy Number</th>
<th>TABLE OF DISTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Commanding General</td>
</tr>
<tr>
<td></td>
<td>U. S. Army Materiel Command</td>
</tr>
<tr>
<td></td>
<td>Washington, 25, D. C.</td>
</tr>
<tr>
<td></td>
<td>ATTN: AMCRD-RD</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>Commanding General</td>
</tr>
<tr>
<td></td>
<td>U. S. Army Munitions Command</td>
</tr>
<tr>
<td></td>
<td>Dover, New Jersey</td>
</tr>
<tr>
<td></td>
<td>ATTN: SMSMU-AA</td>
</tr>
<tr>
<td>2-3</td>
<td>Commanding Officer</td>
</tr>
<tr>
<td></td>
<td>Picatinny Arsenal</td>
</tr>
<tr>
<td></td>
<td>Dover, New Jersey</td>
</tr>
<tr>
<td></td>
<td>ATTN: SMUPA-VA6</td>
</tr>
<tr>
<td></td>
<td>SMUPA-DX1</td>
</tr>
<tr>
<td></td>
<td>SMUPA-DR3</td>
</tr>
<tr>
<td></td>
<td>SMUPA-VC4</td>
</tr>
<tr>
<td>4-8</td>
<td>Commanding Officer</td>
</tr>
<tr>
<td></td>
<td>Harry Diamond Laboratories</td>
</tr>
<tr>
<td></td>
<td>Washington 25, D. C.</td>
</tr>
<tr>
<td></td>
<td>ATTN: Library, Bldg. 92</td>
</tr>
<tr>
<td>28</td>
<td>Commandant</td>
</tr>
<tr>
<td></td>
<td>U. S. Army Ordnance Center and School</td>
</tr>
<tr>
<td></td>
<td>Aberdeen Proving Ground, Maryland</td>
</tr>
<tr>
<td></td>
<td>ATTN: AISO-SL</td>
</tr>
<tr>
<td>29</td>
<td>Commanding Officer</td>
</tr>
<tr>
<td></td>
<td>Ammunition Procurement and Supply Agency</td>
</tr>
<tr>
<td></td>
<td>Joliet, Illinois</td>
</tr>
<tr>
<td></td>
<td>ATTN: SMUAP-AE</td>
</tr>
<tr>
<td>30</td>
<td>Commanding Officer</td>
</tr>
<tr>
<td></td>
<td>U. S. Army Engineer Research &amp; Development Laboratories</td>
</tr>
<tr>
<td></td>
<td>Fort Belvoir, Virginia</td>
</tr>
<tr>
<td></td>
<td>ATTN: STINFO Branch</td>
</tr>
<tr>
<td>31</td>
<td>Defense Documentation Center</td>
</tr>
<tr>
<td></td>
<td>Cameron Station</td>
</tr>
<tr>
<td></td>
<td>Alexandria, Virginia</td>
</tr>
<tr>
<td>32-51</td>
<td></td>
</tr>
</tbody>
</table>