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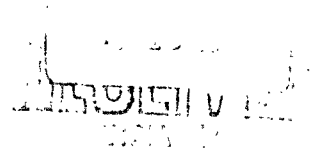
APPLICATION AND EVALUATION
OF A
DIGITAL COMPUTER PROGRAM
FOR
INTERIOR BALLISTICS

STUART LEVY
FORREST McMAINS

AMCMS 5023.11.18400

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JANUARY 1964



PICATINNY ARSENAL
DOVER, NEW JERSEY

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BY

STUART LEVY
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JANUARY 1964

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Also appreciated is the cooperation of Sidney Bernstein and Robert Garufi of the Artillery Ammunition Laboratory, Ammunition Engineering Directorate, who supplied some of the firing data used in this report.

SECTION I

INTRODUCTION

The object of this study is to compare simulated firing results -- obtained from a digital computer program -- with actual firing data. "The Digital Computer Program for Interior Ballistics" by Sidney Kravitz (Reference 1) was used, and this program was restricted to Problem 2 and 3.

In Problem 1, burning rate divided by web (B/W) and charge weight are given and the computer will calculate maximum pressure and muzzle velocity.

In Problem 2, maximum pressure and charge are given and the computer will calculate muzzle velocity and B/W.

In Problem 3, maximum pressure and muzzle velocity are given and the computer will calculate charge and B/W.

A study of Problem 1 was omitted from this report because its solution depends on a B value which is not part of the firing data. A study is under preparation which will endeavor to calculate these B values and use them in Problem 1.

In Section II, simulated and actual firing data are tabulated for eight weapon systems. Also listed are percentage errors and the burning rate factor B for Problem 2 for various pressure ranges and propellants.

A discussion of the results is given in Section III.

SECTION II
FIRING DATA STUDY OF EIGHT WEAPON SYSTEMS

1. 75MM HOWITZER, M3, M1A1

Gun Constants

Projectile Weight ----- 13.1 lbs.
 Chamber Volume ----- 59.0 in.³
 Propellant Type ----- M2 (S.P.)
 Total Travel ----- 39.3 in.

Problem 2

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Charge Weight (lbs) | Firing Velocity (ft/sec) | Simulated Velocity (ft/sec) | Burning Rate Factor B |
|-------------------------|-----------|------------------------|---------------------|--------------------------|-----------------------------|-----------------------|
| 2,000 | 0.0148 | 24,100 | 0.4125 | 1,000 | 980.9 | 0.00436 |
| | | | | | | 0.19 |
| | | | | | | 4.48 |

Problem 3

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Velocity (ft/sec) | Firing Charge Weight (lbs) | Simulated Charge Weight (lbs) | Burning Rate Factor B |
|-------------------------|-----------|------------------------|-------------------|----------------------------|-------------------------------|-----------------------|
| 2,000 | 0.0148 | 24,100 | 1,600 | 0.4125 | 0.431 | 0.00407 |
| | | | | | | 4.48 |

2. 75MM GUN, M1, M1A2

Gun Constants

Projectile Weight ----- 9.3 lbs.
 Chamber Volume ----- 200 in.³
 Propellant Type ----- M2 (M.P.)
 Total Travel ----- 156 in.

Problem 2

| | | | | | | | | | | | | | | | |
|-------------------------------|-------|-----------------|--------|------------------------------|--------|----------------------------|------|--------------------------------|-------|-----------------------------------|-------|---------------|-----|-----------------------------|--------|
| Starting Pressure (psi) ----- | 2,000 | Web (in.) ----- | 0.0598 | Maximum Pressure (psi) ----- | 46,900 | Charge Weight (lbs.) ----- | 3.86 | Firing Velocity (ft/sec) ----- | 3,400 | Simulated Velocity (ft/sec) ----- | 3,475 | % Error ----- | 2.2 | Burning Rate Factor B ----- | 0.0039 |
|-------------------------------|-------|-----------------|--------|------------------------------|--------|----------------------------|------|--------------------------------|-------|-----------------------------------|-------|---------------|-----|-----------------------------|--------|

Problem 3

| | | | | | | | | | | | | | | | |
|-------------------------------|-------|-----------------|--------|------------------------------|--------|-------------------------|-------|----------------------------------|------|-------------------------------------|-------|---------------|------|-----------------------------|---------|
| Starting Pressure (psi) ----- | 2,000 | Web (in.) ----- | 0.0598 | Maximum Pressure (psi) ----- | 46,900 | Velocity (ft/sec) ----- | 3,400 | Firing Charge Weight (lbs) ----- | 3.86 | Simulated Charge Weight (lbs) ----- | 3.647 | % Error ----- | 5.51 | Burning Rate Factor B ----- | 0.00417 |
|-------------------------------|-------|-----------------|--------|------------------------------|--------|-------------------------|-------|----------------------------------|------|-------------------------------------|-------|---------------|------|-----------------------------|---------|

3. 90MM GUN, M41

Gun Constants

Projectile Weight ----- 12.65 lbs.
Chamber Volume ----- 300 in.³
Propellant Type ----- M17 (M.P.)
Total Travel ----- 155 in.

Problem 2

| | | | | | | | | | | | | | | | |
|-------------------------|-------|-----------|-------|------------------------|--------|----------------------|------|--------------------------|-------|-----------------------------|-------|---------|------|-----------------------|--------|
| Starting Pressure (psi) | 2,000 | Web (in.) | 0.052 | Maximum Pressure (psi) | 50,500 | Charge Weight (lbs.) | 8.58 | Firing Velocity (ft/sec) | 4,000 | Simulated Velocity (ft/sec) | 3,946 | % Error | 1.35 | Burning Rate Factor B | 0.0103 |
|-------------------------|-------|-----------|-------|------------------------|--------|----------------------|------|--------------------------|-------|-----------------------------|-------|---------|------|-----------------------|--------|

Problem 3

DID NOT RUN

5. 105MM GUN, M68

Gun Constants

Projectile Weight ----- 12.8 lbs,
 Chamber Volume ----- 384 in.³
 Propellant Type ----- T36 (M.P.)
 Total Travel ----- 178 in.

Problem 2

| | | | | | | | | | | | | | |
|----------------------------------|-------|---------------------------------|--------|------------------------------|-------|-----------------------------------|-------|--------------------------------------|-------|---------|------|--------------------------|---------|
| Starting Pressure (psi) _____ | 2,000 | Maximum Pressure (psi) _____ | 58,500 | Charge Weight (lbs) _____ | 12.09 | Firing Velocity (ft/sec) _____ | 4,850 | Simulated Velocity (ft/sec) _____ | 4,768 | % Error | 1.69 | Burning Rate Factor B | 0.00829 |
| Web (in.) _____ | 0.046 | | | | | | | | | | | | |

Problem 3

DID NOT RUN

6. 155MM HOWITZER, M1

A. Single Perforated

Gun Constants

Projectile Weight ----- 95 lbs.
 Chamber Volume ----- 795 in.³
 Propellant Type ----- M1 (S.P.)
 Total Travel ----- 115.5 in.

Problem 2

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Charge Weight (lbs) | Firing Velocity (ft/sec) | Simulated Velocity (ft/sec) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|---------------------|--------------------------|-----------------------------|---------|-----------------------|
| 2,000 | 0.0165 | 5,520 | 1.95 | 680 | 694 | 2.05 | 0.00413 |
| 2,000 | 0.0165 | 7,130 | 2.444 | 770 | 775 | 0.65 | 0.00421 |
| 2,000 | 0.0165 | 9,666 | 3.0875 | 880 | 879 | 0.11 | 0.00439 |
| 2,000 | 0.0165 | 13,800 | 3.981 | 1,020 | 1,008 | 0.01 | 0.00465 |
| 2,000 | 0.0165 | 21,735 | 5.500 | 1,220 | 1,200 | 1.64 | 0.00495 |

Problem 3

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Velocity (ft/sec) | Firing Charge Weight (lbs) | Simulated Charge Weight (lbs.) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|-------------------|----------------------------|--------------------------------|---------|-----------------------|
| 2,000 | 0.0165 | 5,520 | 680 | 1.95 | 1.854 | 4.92 | 0.00437 |
| 2,000 | 0.0165 | 9,666 | 880 | 3.0875 | 3.085 | 0.08 | 0.00440 |

CONTINUED

6. 155MM HOWITZER, M1 (Continued)

B. Multi-perforated

Gun Constants

Projectile Weight ----- 95 lbs.
 Chamber Volume ----- 795 in.³
 Propellant Type ----- M1 (M.P.)
 Total Travel ----- 115.5 in.

Problem 2

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Charge Weight (lbs) | Firing Velocity (ft/sec) | Simulated Velocity (ft/sec) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|---------------------|--------------------------|-----------------------------|---------|-----------------------|
| 2,000 | 0.0334 | 6,000 | 4.156 | 880 | 890 | 1.13 | 0.00300 |
| 2,000 | 0.0334 | 8,050 | 5.319 | 1,020 | 1,024 | 0.39 | 0.00324 |
| 2,000 | 0.0334 | 11,730 | 7.500 | 1,220 | 1,229 | 0.74 | 0.00312 |
| 2,000 | 0.0334 | 20,125 | 9.810 | 1,520 | 1,497 | 1.51 | 0.00349 |
| 2,000 | 0.0334 | 35,650 | 13.188 | 1,850 | 1,820 | 1.62 | 0.00369 |

Problem 3

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Velocity (ft/sec) | Firing Charge Weight (lbs.) | Simulated Charge Weight (lbs.) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|-------------------|-----------------------------|--------------------------------|---------|-----------------------|
| 2,000 | 0.0334 | 6,000 | 880 | 4.156 | 3.819 | 8.11 | 0.00340 |
| 2,000 | 0.0334 | 11,730 | 1,220 | 7.500 | 7.179 | 4.28 | 0.00326 |

7. 175MM GUN, M113

Gun Constants

Projectile Weight ----- 147.75 lbs.
 Chamber Volume ----- 2,898 in.³
 Propellant Type ----- M6 (M.P.)
 Total Travel ----- 352 in.

Problem 2

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Charge Weight (lbs.) | Firing Velocity (ft/sec) | Simulated Velocity (ft/sec) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|----------------------|--------------------------|-----------------------------|---------|-----------------------|
| 2,000 | 0.069 | 13,000 | 20.58 | 1,675 | 1,788 | 6.75 | 0.0052 |
| 2,000 | 0.069 | 21,700 | 37.75 | 2,310 | 2,373 | 2.73 | 0.00449 |
| 2,000 | 0.069 | 50,100 | 55.56 | 3,000 | 3,070 | 2.33 | 0.00498 |

Problem 3

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Velocity (ft/sec) | Firing Charge Weight (lbs.) | Simulated Charge Weight (lbs.) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|-------------------|-----------------------------|--------------------------------|---------|-----------------------|
| 2,000 | 0.069 | 13,000 | 1,675 | 20.58 | 17.234 | 16.26 | 0.00678 |
| 2,000 | 0.069 | 50,100 | 3,000 | 55.56 | 52.513 | 4.94 | 0.00534 |

8. 8-INCH HOWITZER, M2

A. Single Perforated

Gun Constants

Projectile Weight ----- 200 lbs.
 Chamber Volume ----- 1,485 in.³
 Propellant Type ----- M1 (S.P.)
 Total Travel ----- 164 in.

Problem 2

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Charge Weight (lbs.) | Firing Velocity (ft/sec) | Simulated Velocity (ft/sec) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|----------------------|--------------------------|-----------------------------|---------|-----------------------|
| 2,000 | 0.0161 | 9,300 | 5.33 | 820 | 836 | 1.95 | 0.00396 |
| 2,000 | 0.0161 | 11,600 | 6.28 | 900 | 916 | 1.78 | 0.00413 |
| 2,000 | 0.0161 | 14,800 | 7.52 | 1,000 | 1,005 | 0.50 | 0.00427 |
| 2,000 | 0.0161 | 20,000 | 9.54 | 1,150 | 1,140 | 0.87 | 0.00428 |
| 2,000 | 0.0161 | 31,800 | 13.16 | 1,380 | 1,360 | 1.45 | 0.00448 |

Problem 3

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Velocity (ft/sec) | Firing Charge Weight (lbs.) | Simulated Charge Weight (lbs.) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|-------------------|-----------------------------|--------------------------------|---------|-----------------------|
| 2,000 | 0.0161 | 9,300 | 820 | 5.33 | 5.043 | 5.38 | 0.00430 |
| 2,000 | 0.0161 | 11,600 | 900 | 6.28 | 6.036 | 3.89 | 0.00439 |
| 2,000 | 0.0161 | 14,800 | 1,000 | 7.52 | 7.394 | 1.68 | 0.00439 |
| 2,000 | 0.0161 | 20,000 | 1,150 | 9.54 | 9.686 | 1.53 | 0.00416 |
| 2,000 | 0.0161 | 31,800 | 1,380 | 13.16 | 13.57 | 3.11 | 0.00419 |

(CONTINUED)

8. 8-INCH HOWITZER, M2 (Continued)

B. Multi-perforated

Gun Constants

Projectile Weight ----- 200 lbs.
 Chamber Volume ----- 1,485 in.³
 Propellant Type ----- M1 (M.P.)
 Total Travel ----- 164 in.

Problem 2

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Charge Weight (lbs.) | Firing Velocity (ft/sec) | Simulated Velocity (ft/sec) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|----------------------|--------------------------|-----------------------------|---------|-----------------------|
| 2,000 | 0.0414 | 15,400 | 16.63 | 1,380 | 1,384 | 0.29 | 0.00345 |
| 2,000 | 0.0414 | 23,200 | 21.84 | 1,640 | 1,628 | 0.73 | 0.00357 |
| 2,000 | 0.0414 | 37,500 | 28.05 | 1,950 | 1,917 | 1.69 | 0.00358 |

Problem 3

| Starting Pressure (psi) | Web (in.) | Maximum Pressure (psi) | Velocity (ft/sec) | Firing Charge Weight (lbs.) | Simulated Charge Weight (lbs.) | % Error | Burning Rate Factor B |
|-------------------------|-----------|------------------------|-------------------|-----------------------------|--------------------------------|---------|-----------------------|
| 2,000 | 0.0414 | 15,400 | 1,380 | 16.63 | 16.36 | 1.62 | 0.00353 |
| 2,000 | 0.0414 | 23,200 | 1,640 | 21.84 | 22.16 | 1.47 | 0.00343 |
| 2,000 | 0.0414 | 37,500 | 1,950 | 28.05 | 29.20 | 4.10 | 0.00343 |

SECTION III

DISCUSSION OF RESULTS

Most of the velocity variations for Problem 2 $\frac{V_{\text{firing}} - V_{\text{simulated}}}{V_{\text{firing}}} \times 100$ were about 2% or less.

In Problem 3, the charge variations $\frac{C_{\text{firing}} - C_{\text{simulated}}}{C_{\text{firing}}} \times 100$ ranged from 0.8% to 16.25%.

In some instances, although an answer was obtained from Problem 2, the same data in Problem 3 gave no solution. This occurred in the M68 105mm Gun and the M41 90mm Gun. Problem 2 seems to be the most reliable of the two types of problems and B values for Type 2 problems were calculated for all weapon systems.

B is defined as the burning constant, dependent on the chemical properties of the propellant. In the equation of the assumed rate of burning, R is the rate of burning, B is the burning constant, P the pressure of the gas surrounding the burning grains and n an exponent near unity. This equation is given by $R = BP^n$.

Generally an experimental B is determined from closed bomb firings, in which the volume is constant. This B usually differs from experimental Bs from field tests in which the volume is constantly changing as the propellant burns.

The assumptions upon which the ballistic calculations are based do not accurately account for energy losses and inefficiencies in the actual ballistic systems. Therefore, when calculations are made from actual ballistic firings the effect of these factors are accumulated in the B; and it is found that for a given propellant, B varies with the weapon system, the ammunition and pressure level with which it is fired. Appendix A, "B versus Pressure," illustrates this dependency. If B were independent of pressure, the graph of the 8-Inch or 155mm Howitzer would be a vertical line of constant B for varying pressure. Instead it is parabolic in shape. If B were independent of the weapon system, the graphs of the 8-Inch and 155mm Howitzer would coincide. This is to be expected since the propellants used in both systems were of identical chemical composition and granulation. However, they do not coincide -- the B value for the 8-Inch Howitzer is always less than the 155mm Howitzer.

Typical values of B are tabulated in Appendix B. These values were calculated from actual test data, and will be useful for predicting a rough estimate of web size from the output of Type 2 problems. In selecting a B value from the list in Appendix B for a given propellant, use the value of B closest to the weapon system and pressure level. It is expected that as more data is gained from different weapon systems, propellant compositions and pressure levels, the table of Bs will be expanded.

SECTION IV

CONCLUSIONS

The Digital Computer Program for Interior Ballistics was found most useful in doing Case 2 problems where maximum operating pressure and charge are given and velocity is to be calculated. Reliability in reproducing field data is good -- within 2% in most cases.

This program will be valuable in estimating charges and velocities for new weapon systems. Web size for propellant granulation may be estimated, also using the B values in Appendix B. Other B values for different propellants and weapon systems not given in the table may be easily calculated with this program and sufficient field data.

Each calculation requires two IBM Data Cards and about two minutes of machine time. Thus, many hours of laborious written calculations may be eliminated and many solutions obtained in a materially shorter time.

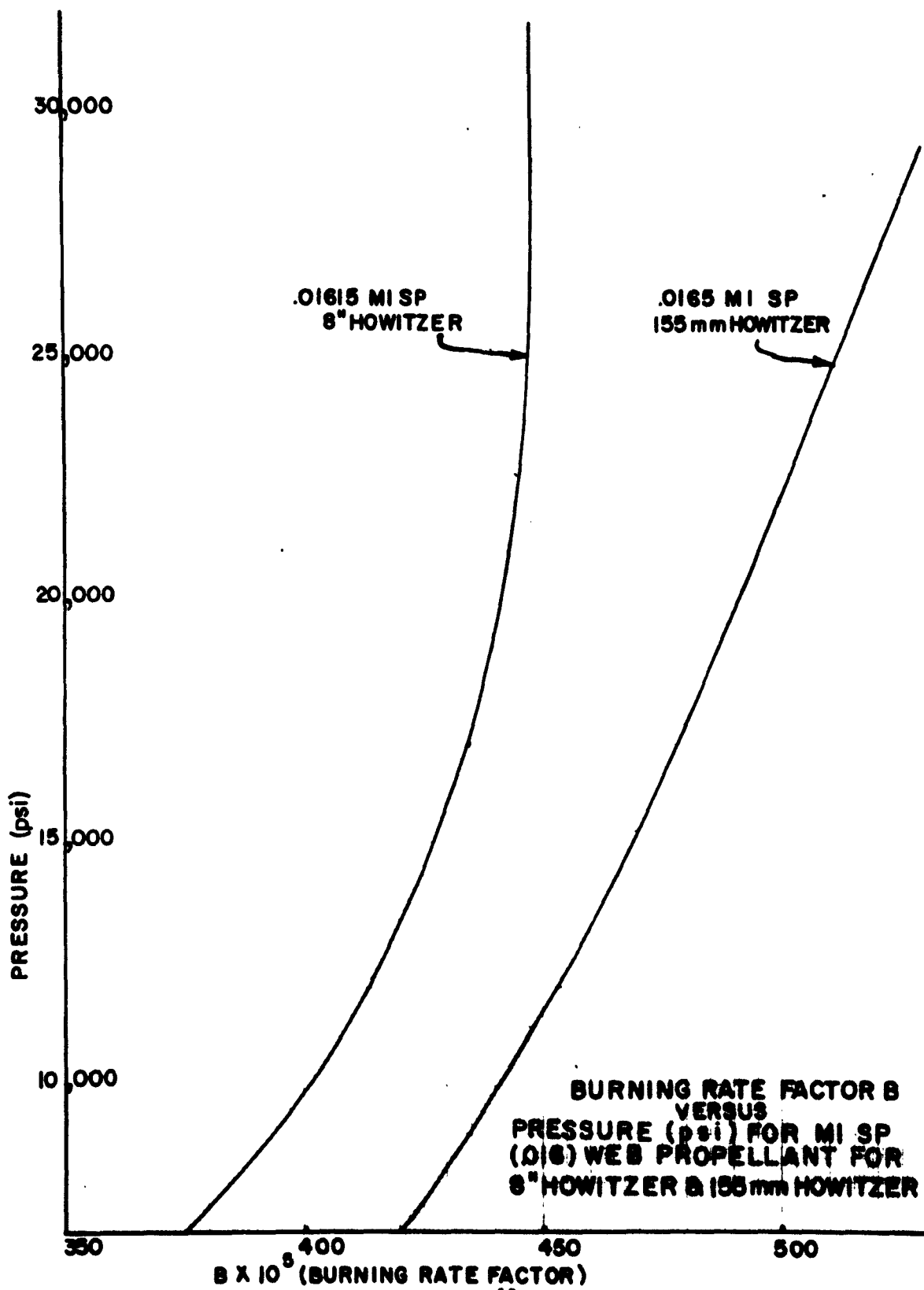
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2. A. O. Edwards and C. R. Grandee, Simulation of the 155mm Howitzer, with Standard Charges, Engineering Sciences Laboratory Information Report, Picatinny Arsenal, October 1962.
3. H. B. Anderson, Master Standard Propellant Calibration Chart for Artillery Ammunition, D&PS Report 825, January 1963.

APPENDICES

APPENDIX A

CHART



APPENDIX B

TABLE

TYPICAL VALUES OF B
(Burning Rate Factor)

| <u>Weapon</u> | <u>Pressure (psi)</u> | <u>Propellant</u> | <u>B</u> |
|-----------------|---------------------------|-------------------|----------|
| 75mm Howitzer | 25,000 | M2 SP | 0.00436 |
| 76mm Gun | 50,000 | M2 MP | 0.0039 |
| 90mm Gun | 50,000 | M17 MP | 0.0103 |
| 105mm Howitzer | 6,500 | T36E1 SP | 0.0144 |
| 105mm Gun | 60,000 | T36 MP | 0.00829 |
| 155mm Howitzer | 10,000 | M1 SP | 0.00440 |
| 155mm Howitzer | 20,000 | M1 MP | 0.00350 |
| 175mm Gun | 20,000 | M6 MP | 0.00450 |
| 175mm Gun | 50,000 | M6 MP | 0.00500 |
| 8-Inch Howitzer | 15,000 | M1 SP | 0.00430 |

ABSTRACT DATA

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II. McMains, Forrest
III. Interior ballistics computer
study

UNITERMS

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8-Inch Howitzer, M2
Levy, S.
McMains, F.

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This program will be valuable in estimating charges and velocities for the new weapon systems.

Many hours of laborious written calculations may be eliminated and solutions obtained in a shorter time by using two IBM Data Cards and about two minutes of machine time.

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90 mm Gun, M41
105 mm Gun, M68
155 mm Howitzer, M2
175 mm Gun, M113
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