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FA REPORT R-1578

BALLISTIC CALCULATIONS AND DESIGN CRITERIA
FOR DECOY LAUNCHING SYSTEMS

By
C. L. Fulton
and
S. Goldstein

ARPA Order No. 39-59
Task No. 8
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FRANKFORD ARSENAL
PITMAN - DUNN
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OBJECT

To study the use of ballistic systems in launching diversionary objects from ballistic missiles, and to provide design criteria for launcher development.

SUMMARY

Standard cartridge-actuated devices were surveyed to determine the feasibility of using them in decoy launching systems. Design criteria were established, simplified ballistic analyses were made, and theoretical performances were calculated for several reactionless-type launchers.

AUTHORIZATION

ARPA Order No. 39-59, Task No. 8, Sept. 1959

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DECOY LAUNCHER BALLISTIC CALCULATIONS

INTRODUCTION

The Advanced Research Projects Agency (ARPA) is conducting a research program in which methods for ejecting diversionary objects (decoys) from ballistic missiles are studied. Order No. 39-59, Task No. 6, issued by ARPA, authorized Frankford Arsenal to investigate methods for packaging and launching such objects, under the administrative guidance of the Army Ballistic Missile Agency (ABMA). This document reports the preliminary ballistic work done by Frankford Arsenal on this project.

The major objective was to achieve a decoy launching where the decoys were ejected in a manner such that no reactive force would be felt by the missile. The launching system was to be contained within the missile, but no particular missile was specified. The configuration, weight, and launching velocity of the decoys were not specified.

To avoid a reactive force, the Arsenal investigation considered the possibility of ejecting two decoys simultaneously, in diametrically opposite directions. The decoys were assumed to weigh between 5 and 100 pounds, and their ejection velocities were to be in the range of 5 to 400 feet per second. This study consisted of three parts:

(1) Standard cartridge-actuated devices, developed by FA for Air Force personnel escape systems, were reviewed, and a short ballistic analysis was made of those having potential application in decoy launcher systems.

(2) Tentative design and ballistic parameters were established for Davis gun type launchers (reactionless launchers). The functional relationships of the design and ballistic parameters were determined for two basic types of designs.

(3) A specific reactionless launcher system was analyzed to show the functional relationships of the design and ballistic parameters.

CAD LAUNCHERS

General

Standard cartridge-actuated devices (CAD) were surveyed and the results indicated that 10 CAD may give the desired velocities (5 to 400 ft/sec) to the loads selected (5 to 100 lb). Table I lists these

10 devices and their standard performance data at 70° F and sea level pressure. Standard performance data were obtained from the CAD engineering manual for loads, velocities, and angles of launch. A preliminary analysis was made to estimate their performance when used in decoy launching systems.

Catapults and Removers

Ballistic efficiency is defined as the ratio of the kinetic energy delivered to the propellant potential energy. It was assumed for this preliminary analysis that the ballistic efficiency of a standard catapult or remover is constant for the entire range of weights ejected. This assumption is not experimentally precise, since the ballistic efficiency of a cartridge-actuated device increases as the propelled weight increases. However, the assumption is considered reasonable, since the standard data are for loads not too far removed from the range under consideration.

Table 1. Physical Characteristics and Performance Data
For Standard Cartridge Actuated Devices

Device and Model	Physical Characteristics			Performance Data			
	Diameter (in.)	Length (in.)	Weight (lb)	Stroke (in.)	Propelled Weight (lb)	Velocity (ft/sec)	Stroke Time (sec)
Catapult							
M3	3.38	50.13	24.9	88	350	81	0.240
M4	2.63	30.62	6.7	45	325	41	0.234
M5	2.56	39	8.2	66	300	62	0.210
Remover							
M3	2.19	30	4.4	26	300	26	0.152
T14	3.0	14.71	3.84	19	300	26	0.110
T15	3.0	14.71	3.86	19	1000	20	0.150
Thruster							
M2	1.88	13.68	4.0	5.72	800	7.8	0.113
					1600	5.8	0.163
					2400	5.3	0.186
M3	1.44	9.15	1.0	1.41	230	NA**	0.049
					390	NA	0.071
					550	NA	0.080

** Not applicable

Table I. Physical Characteristics and Performance Data for Standard Cartridge Actuated Devices (Continued)

Device and Model	Physical Characteristics				Performance Data		
	Diameter (in.)	Length (in.)	Weight (lb)	Stroke (in.)	Propelled Weight (lb)	Velocity (ft/sec)	Stroke Time (sec)
M5	1.75	12.89	4.02	3.6	600	NA	0.071
					1200	NA	0.107
					1800	NA	0.146
M6	1.07	11.79	1.0	1.5	60*	0.8	0.025

* Plus one shear pin which shears at 600 lb.

** Not Applicable.

The mechanical energy delivered by a standard catapult or remover also was assumed to be equivalent to the kinetic energy given to the load plus the potential energy the load acquired from being projected vertically. (Catapult and remover performance data are obtained from vertical firings.)

With the above assumptions, the following formula could be used to calculate the vertical ejection velocity for a particular decoy weight:

$$v = \sqrt{\frac{2g}{L} \left[\frac{W_L}{W_L + W_C} \left(\frac{S}{L} \right) \right]} \quad (1)$$

where: $KE = \frac{1}{2} \frac{W_L}{g} v^2$

For example, the T14 remover, with a 19-inch stroke, ejects a 300-pound load at 26 feet/second; therefore, it supplies 3150 foot-pounds of kinetic energy. The estimated upward vertical velocity imparted to a 60-lb decoy is:

$$v = \sqrt{\frac{2(32.2)}{60} \left[\frac{3150 + (300 - 60) 19/12}{60} \right]}$$

$$= 61.6 \text{ ft/sec}$$

Similar calculations were made for the other catapults and removers listed in Table I. The data thus obtained are plotted as propelled weight vs velocity in Figure 1.

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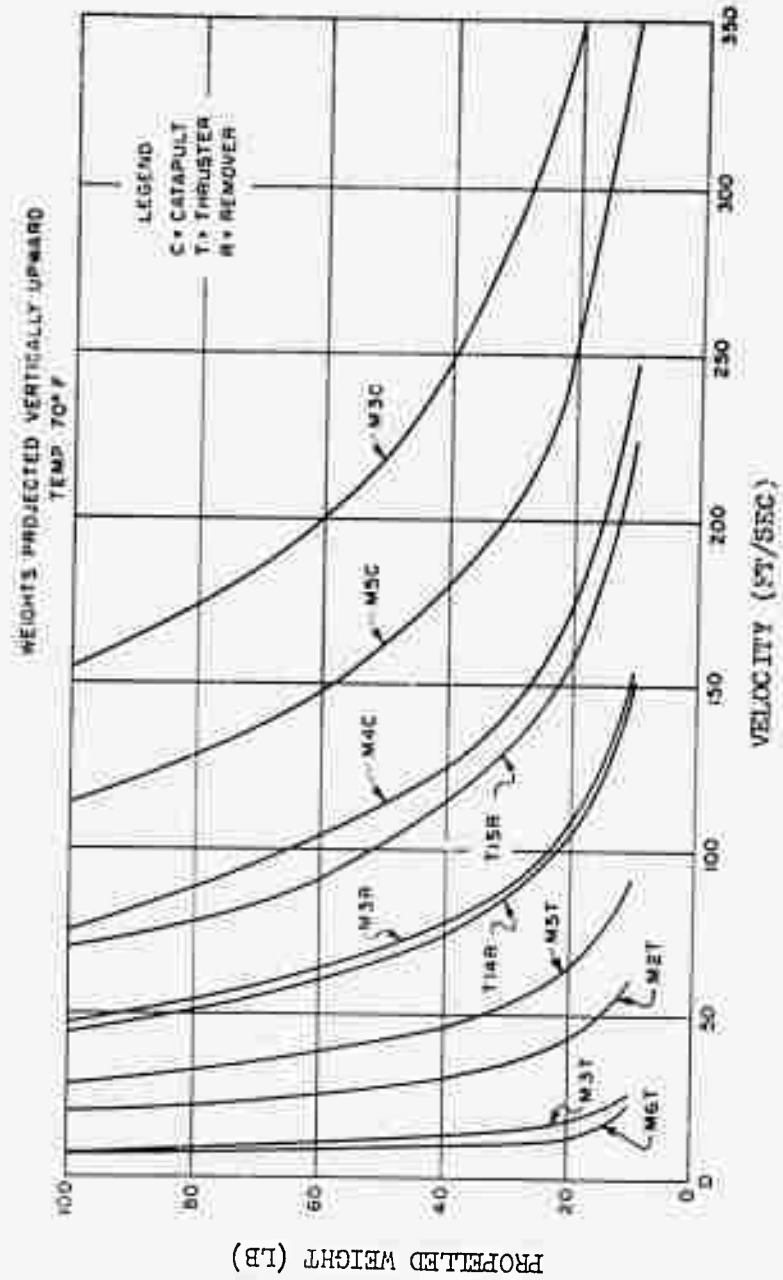


Figure 1. Performance of CAD Launchers, Estimated from Standard Data

Thrusters

Thrust-travel curves of thrusters for various loads are shown in the Cartridge Actuated Devices Engineering Manual, Frankford Arsenal. These curves were integrated to obtain the mechanical energy in foot-pounds as a function of the design load. Figure 2 shows the resulting energy-vs-load curves for the M2 and M5 thrusters. The curves then were extrapolated (dotted lines in Figure 2) to the weight range under consideration; i.e., 5 to 100 pounds. This procedure gave the total energy available for propelling the decoy weight.

To calculate the vertical ejection velocity for a particular decoy weight, the following formula was used:

$$V = \sqrt{\frac{2g (\text{Total Energy} - W_t X_L/12)}{W_t}} \quad (2)$$

where: Total Energy is read from Figure 2.

W_t - Weight of decoy to be ejected

X_L = Stroke (in.)

g = acceleration due to gravity

For example, the M2 thruster, with a stroke of 5.72 inches, supplies a total energy of approximately 620 foot-pounds for a 60-pound decoy. The estimated upward vertical velocity given to the decoy is:

$$V = \sqrt{\frac{2(32.2) [620 - 60 (5.72/12)]}{60}}$$

$$= 25.2 \text{ ft/sec}$$

Similar calculations were made for the other thrusters listed in Table I. The data thus obtained are plotted as projectile weight vs velocity in Figure 1.

REACTIONLESS LAUNCHERS

General Design Studies

Launchers employing standard CAD are limited to the range of weights and velocities shown in Figure 1, although an increase in performance can be obtained by modifying the propellant charge. Reactionless launchers

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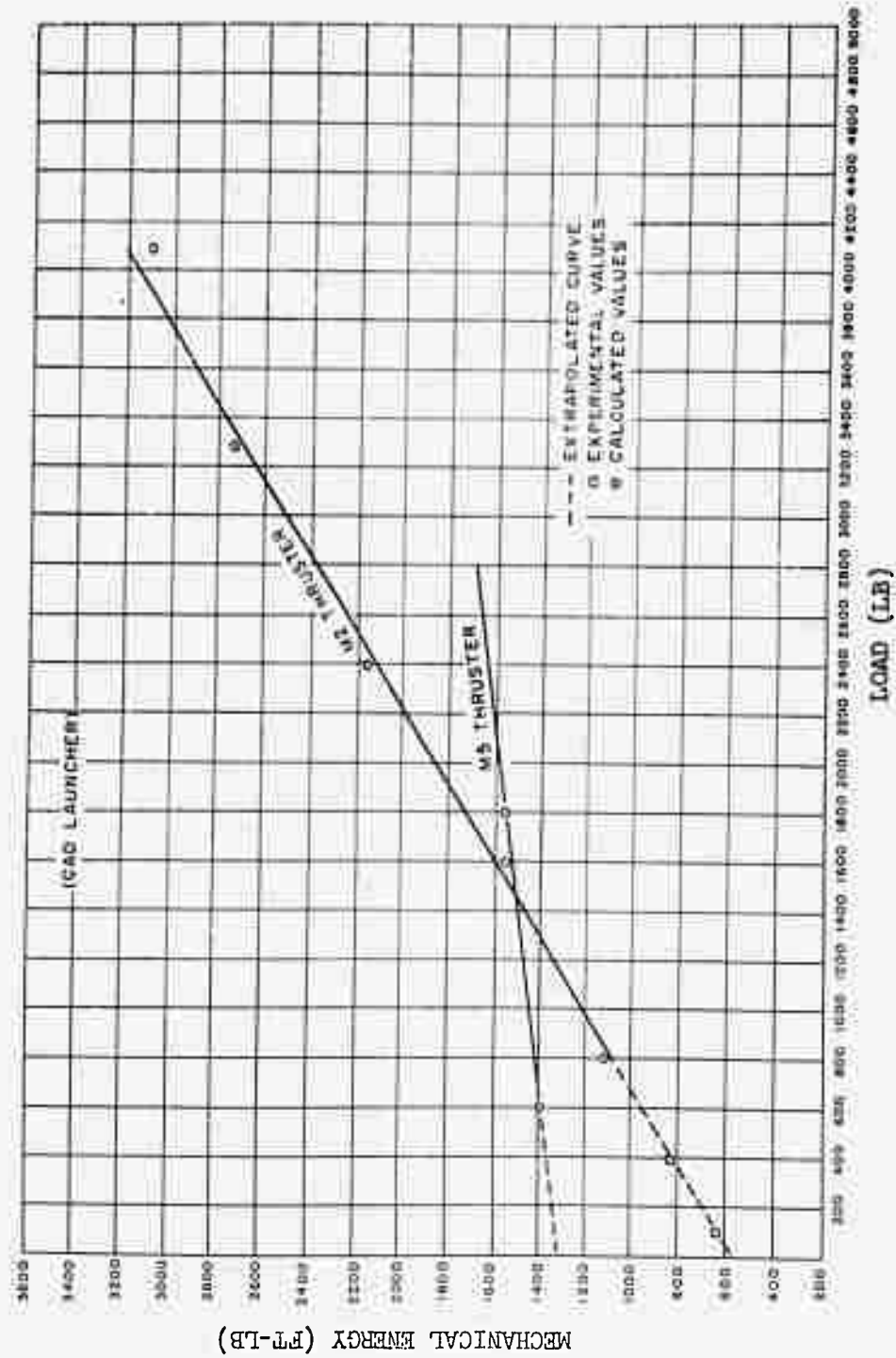


Figure 2: Mechanical Energy as a Function of Load
 Figure 2: Mechanical Energy as a Function of Load
 for M2 and M5 Thrusters

are capable of a much greater range of performance than standard CAD, and it is more likely that the two decoys will be ejected simultaneously.

Like a Davis Gun, a reactionless launcher is essentially a tube containing a centrally placed charge of propellant for simultaneous ejection of masses from both ends. The net reaction is zero, if the vector sum of the momenta of the ejected masses (the decoys) is zero. A reactionless launcher is shown in Figure 3.

Two types of design were considered in this study: full-caliber, and spigot. A full-caliber design is one in which the bore diameter of the launcher tube is the same as the largest diameter of the decoy package. A spigot design is one in which the bore diameter is smaller than the largest diameter of the decoy package. Both types are shown in Figure 4.

Design and Ballistic Parameters

Tentative design parameters for the launcher-decoy package system were established for the ballistic analysis. The dimensions selected were considered to be within a range reasonably adaptable to those missiles for which decoy installations are now being considered.

Dimensions of a maximum diameter of 12 inches and maximum length of 12 inches were selected for the decoy package when used with a spigot design (Figure 5). For a projectile to be launched by a full-caliber design, a maximum diameter of 8 inches and a maximum length of 20 inches were chosen (Figure 5). The length of the overall launcher-decoy system was established at 55 inches. This permitted a launcher tube length of 31 inches for a spigot design, and 55 inches for a full-caliber design. The maximum bore diameters were established at 6 inches and 8 inches, respectively.

On the basis of prior experience, the following values were selected for the ballistic parameters:

Piezometric efficiency (μ)	-- 0.4
Expansion ratio (E)	-- 4.0
Ballistic efficiency (η)	-- 0.3
Bore pressure (P)	-- 2000 to 10,000 psi

The piezometric efficiency is a measure of the flatness of the pressure-stroke curve -- the ratio of the mean pressure to the peak breech pressure during the acceleration of the projectile. For a closed breech gun, the piezometric efficiency is about 0.5. However, a lower value is indicative of better velocity uniformity*; therefore, a value of 0.4 was chosen.

*pp. 142-143, Corner, Theory of the Interior Ballistics of Guns.

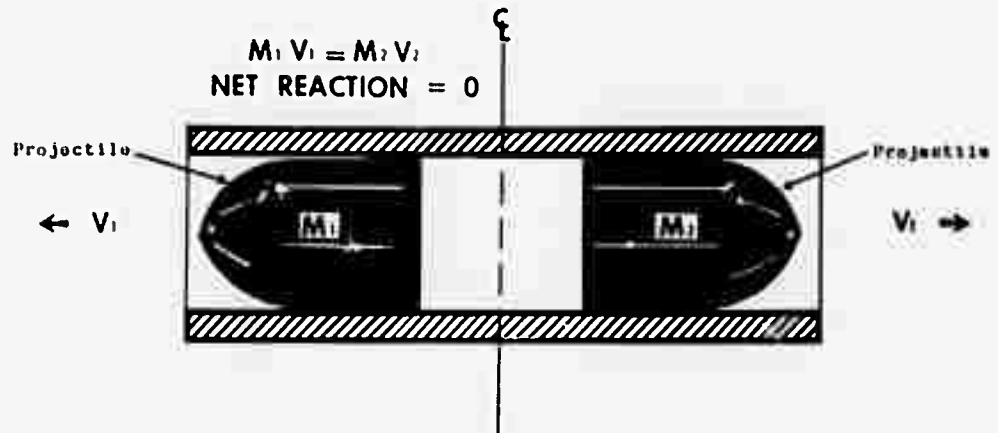


Figure 3. Reactionless Launcher

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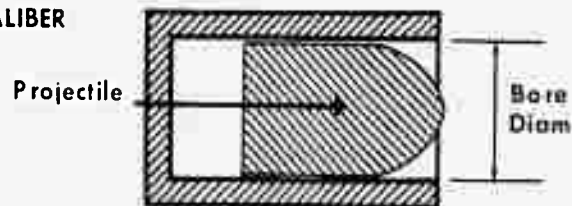
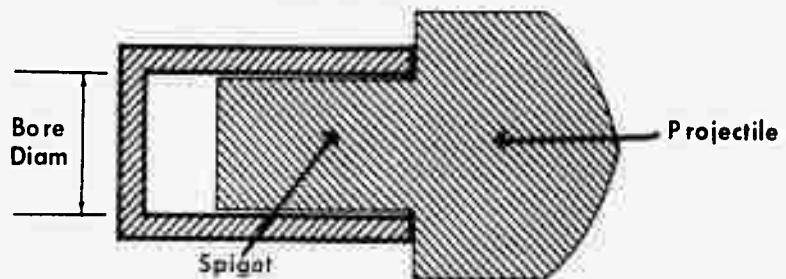
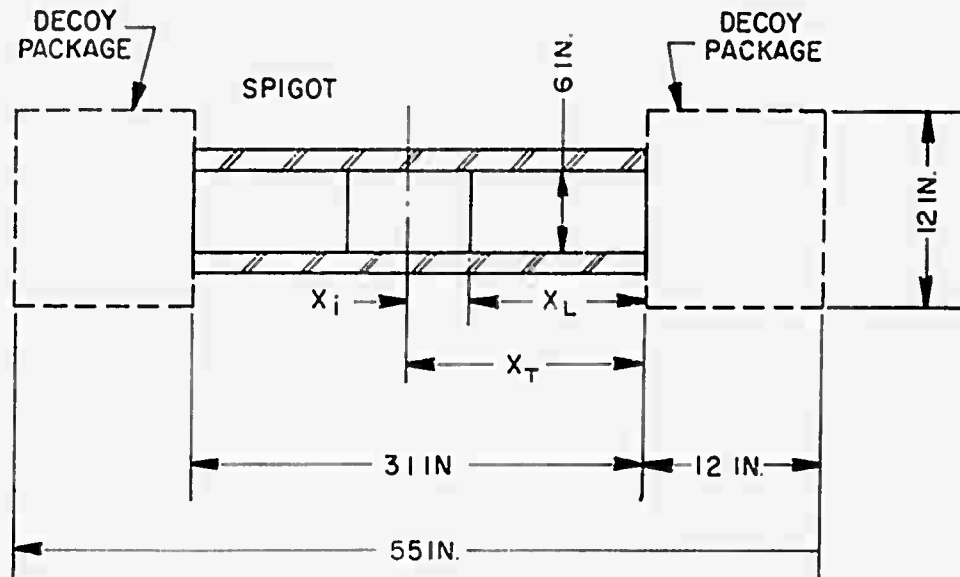
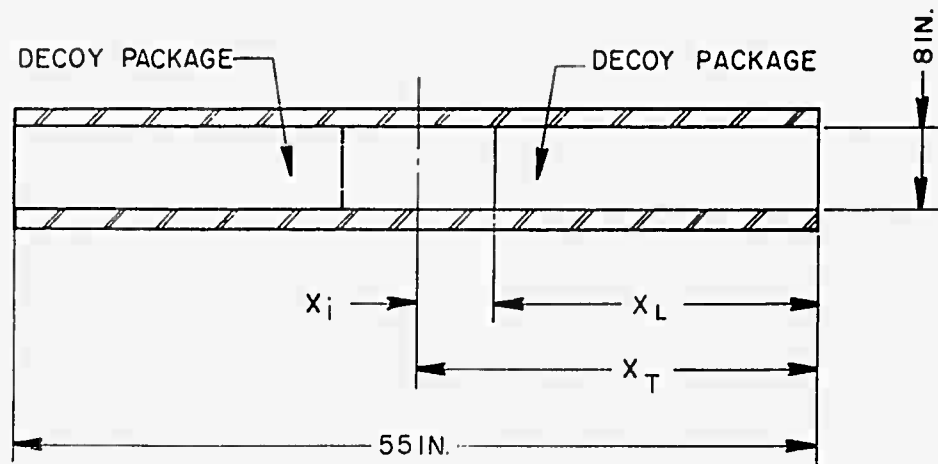
a. FULL CALIBERb. SPIGOT

Figure 4. Full-Caliber and Spigot Designs



SPIGOT DESIGN



FULL-CALIBER DESIGN

Figure 5. Dimensions for Full-Caliber and Spigot Designs

An expansion ratio of 4.0 was selected as characteristic of guns having piezometric efficiency of 0.4. (Figure 6 shows what is meant by expansion ratio.) A ballistic efficiency of 0.3 is typical for an expansion ratio of 4.0*.

The chamber pressure range depends upon the type of ballistic system to be used. Ballistic systems may be characterized by their optimum bore pressure ranges as follows:

Direct system	-- 2000 to 10,000 psi
High-low system	-- 500 to 2000 psi**
Compressed gas system	-- 100 to 500 psi
Mechanical system	-- less than 100 psi (equivalent)

A direct system is one in which the projectile acquires its velocity as a direct result of pressure from the burning propellant (see Figure 7). For this kind of system, bore pressure limits of 2000

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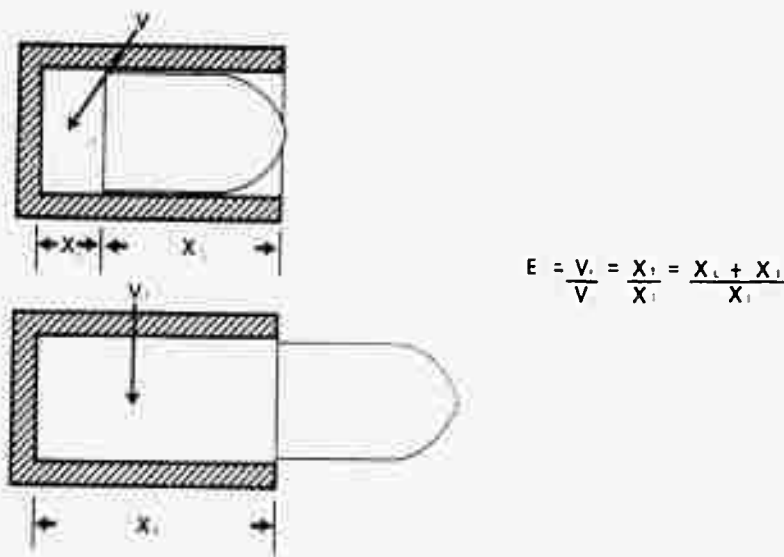


Figure 6. Expansion Ratio

* p. 145, Corner

** For 2000 to 10,000 psi gas pressure in the combustion chamber

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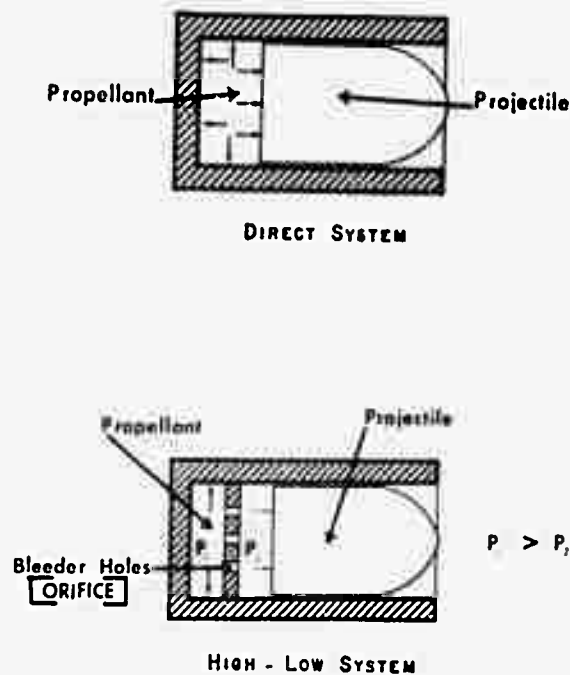


Figure 7. Direct and High-Low Systems

to 10,000 psi gives better assurance of uniform operation and good propellant burning at cold temperatures. Furthermore, maintaining the high chamber pressure below 10,000 psi keeps sealing and erosion problems within bounds.

In a high-low ballistic system, there is a vent (or vents) between the chamber in which the propellant is burned and the bore of the gun, so that the pressure in the combustion chamber is higher than the pressure in the bore. This gives better ignition and greater regularity of burning in a low-muzzle-energy gun. Figure 7 shows a high-low system. A high-to-low pressure ratio of four-to-one as a minimum and five-to-one as a maximum was considered reasonable, based on preliminary high-low system studies of other weapon systems.***

A minimum of 500 psi was selected for the low-pressure chamber, corresponding to 2000 psi in the high-pressure chamber.

*** See for example, A Theoretical Interior Ballistic Study of Recoilless High-Low-Pressure Guns, Frankford Arsenal Report R-1513.

A compressed gas system could also be used with bottled gases such as CO_2 , N_2 , or compressed air. A mechanical system would use springs to propel the decoys.

Assuming that the launcher tube will be parallel to the earth's surface, then only the kinetic energy need be considered. The defining equation is:

$$KE = \mu P_1 A \frac{X_L}{12} \quad (3)$$

The pressure is a function of the bore diameter:

$$P_1 = \frac{48 KE}{\mu \pi D^2 X_L} \quad (4)$$

where: D = Bore diameter

Full-Caliber Designs

The aforementioned assumptions, definitions, and equations were used to calculate P_1 for full-caliber launchers of 4-, 6-, and 8-inch bore diameters. The data are tabulated as a function of the decoy weight and its velocity in Table II. (Tables II, III, IV, and V in Appendix II list peak pressure vs velocity for the various reactionless launcher configurations.) The peak pressures for each of three types of ballistic systems are shown in the table.

Table II indicates that a launcher with a 4-inch bore diameter, an expansion ratio of 4, and a direct ballistic system would eject 100-pound decoys at 110 to 200 fps. A high-low system would eject these decoys at 60 to 100 fps, and a compressed gas system would eject them at velocities of 30 to 50 fps.

Since it is relatively easy to decrease the expansion ratio by positioning the decoy farther out in the launcher tube, the expansion ratio was lowered to 2, and the effect on the spread of the weight-velocity range was determined. Table III shows how lowering the expansion ratio to 2 would decrease the weight-velocity range.

Figure 8 shows the kinetic energy as a function of bore area for 55-inch full-caliber launchers.

LAUNCHER LENGTH: 55 INCHES
EXPANSION RATIO 4

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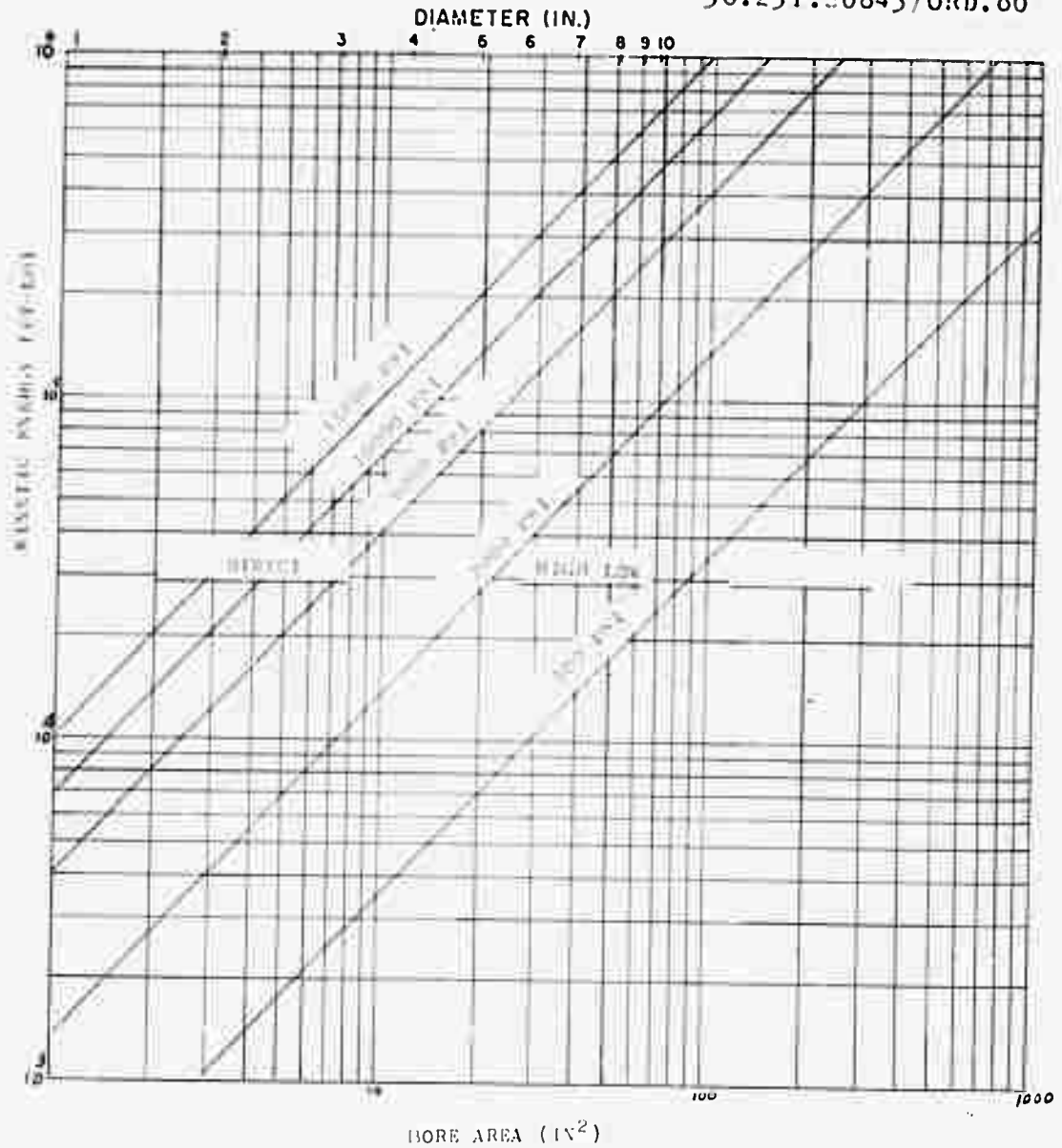


Figure 8. Kinetic Energy as a Function of Bore Area for a Full-Caliber Design

Spigot Designs

The assumptions discussed previously also were used to determine pressures for a spigot launcher design. A closed spigot* with a total stroke of 11.5 inches was assumed. The pressures were calculated for diameters of 0.5, 1.00, 2.25, 4, and 6 inches, and tabulated in Table IV. This table is summarized in Figure 9.

The propellant charge necessary to eject two decoys at a desired velocity was calculated using the following equation:

$$C = \frac{2 KE}{\eta \left(\frac{F}{\gamma - 1} \right)} \quad (5)$$

where $F/\gamma - 1$ is the propellant potential (assumed to be 1.46×10^6 ft-lb/lb). The charge equation is derived from the definition of ballistic efficiency:

$$\eta = \frac{\text{Total KE}}{(\text{Charge}) (\text{Potential})} = \frac{2 KE}{C \left(\frac{F}{\gamma - 1} \right)}$$

Since there are two projectiles, the total kinetic energy is twice the kinetic energy of one projectile.

Specific Design Study

Assumptions

Upon completing the general ballistic analysis of 55-inch launcher systems, an analysis was made of a launcher with the shorter tube length of 31.5 inches. This launcher was to eject 25-pound decoys at 250 fps.

Essentially, the same assumptions relating various ballistic and design parameters and ballistic equations used earlier were also used for this analysis. They are:

(1) The web size is small enough so that the charge is completely burned before the decoy moves appreciably.

(2) The ballistic cycle time is so short that the loss in energy due to heat transfer is negligible. Friction also is neglected.

*A spigot is that part of the projectile which fits in the launcher tube. If the end of the spigot is closed, the design using this spigot is referred to as a closed spigot design. Conversely, if the end is open, the design is referred to as an open spigot design.

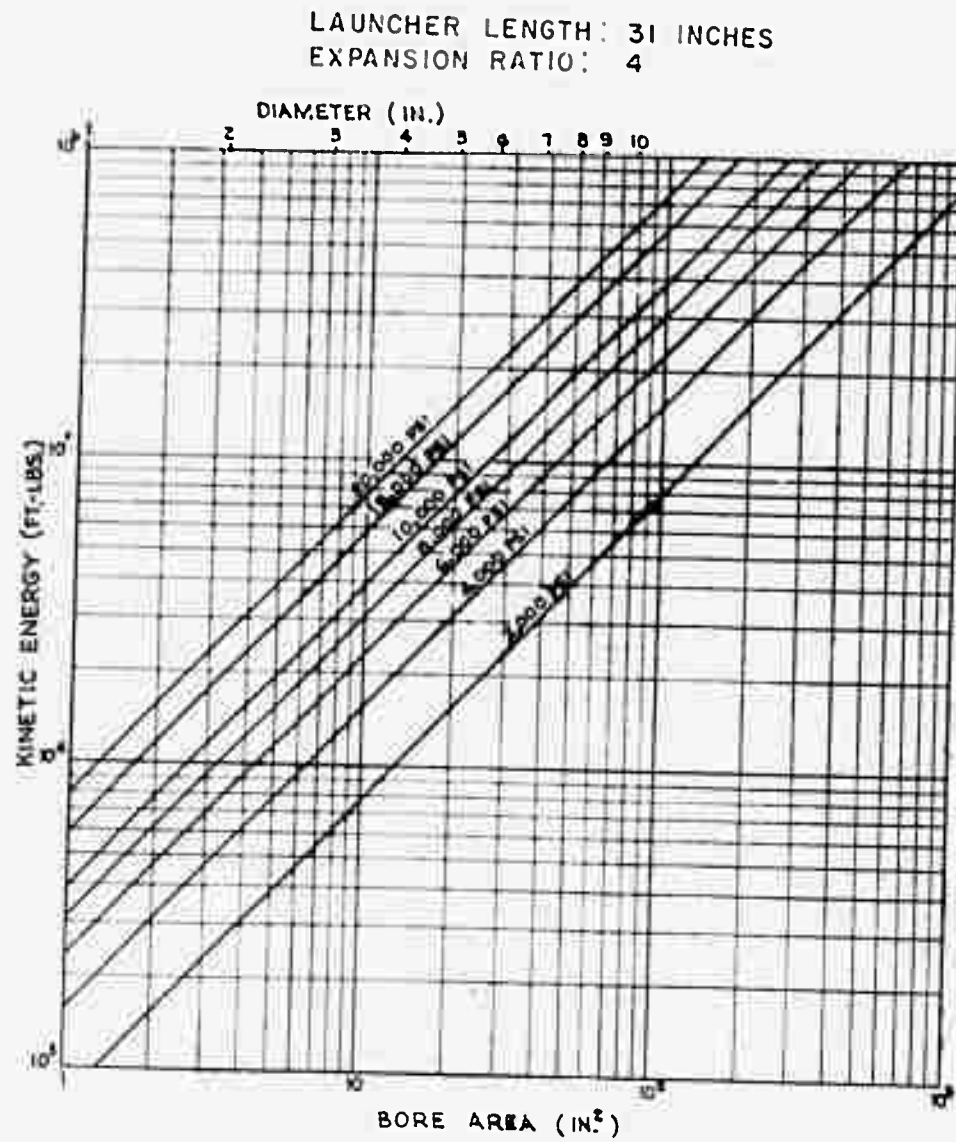


Figure 9. Kinetic Energy as a Function of Bore Area
for a Spigot Design

(3) During the ballistic cycle, the propellant gas behaves like an ideal gas undergoing an isentropic expansion.

(4) Specific heats are constant during the ballistic cycle. Covolume effects are negligible.

(5) There is no pressure gradient or temperature gradient behind the base of the decoy, and energy appearing as kinetic energy of the propellant gases is negligible.

Piezometric Efficiency

An expression for piezometric efficiency as a function of the expansion ratio can be obtained as follows. Consider that the propellant gas is an ideal gas which expands adiabatically.

Then: $P_i V_i^\gamma = P_f V_f^\gamma$ (6)

The work done by such an ideal gas with constant specific heats is:

$$W = \frac{P_f V_f - P_i V_i}{\gamma (1 - \gamma)} \quad (7)$$

which can be rewritten as:

$$W = \frac{\left[\frac{P_f V_f}{P_i V_i} - 1 \right] P_i V_i}{\gamma (1 - \gamma)} \quad (7a)$$

By definition,

$$E = \frac{V_f}{V_i}$$

Therefore, $\left(\frac{V_i}{V_f} \right)^\gamma = E^{-\gamma}$

and from equation (6):

$$\frac{P_f}{P_i} = \left(\frac{V_i}{V_f} \right)^\gamma = E^{-\gamma}$$

Substituting this equation in equation (7a) gives:

$$W = \frac{(E^{1-\gamma} - 1) P_i V_i}{\gamma (1 - \gamma)} \quad (8)$$

Piezometric efficiency is, by definition, the ratio of the mean accelerating pressure, $\bar{P}$, to the peak pressure (which is assumed to be the initial pressure, P_i):

$$\mu = \frac{\bar{P}}{P_i} \quad (9)$$

and mean pressure, by definition, is:

$$\bar{P} = \frac{\int P \, dV}{\int dV}$$

where P is the operating pressure. So,

$$\mu = \frac{\int P \, dV}{P_i \int dV}$$

Now, $\int P \, dV$ is the work done, and $P_i \int dV$ is the same as $P_i (V_f - V_i)$;

$$\text{therefore, } \frac{\int P \, dV}{P_i \int dV} = \frac{12 W}{P_i (V_f - V_i)}$$

But, from equation (8),

$$W = \frac{(E^{1-\gamma} - 1) P_i V_i}{12 (1 - \gamma)}$$

and substituting for W ,

$$\mu = \frac{(E^{1-\gamma} - 1) V_i}{(1 - \gamma) (V_f - V_i)} \quad (10)$$

so that:

$$\frac{V_i}{V_f - V_i} = \frac{1}{\frac{V_f}{V_i} - 1} = \frac{1}{E - 1}$$

Substituting in equation (10) gives:

$$\mu = \frac{(E^{1-\gamma} - 1)}{(1 - \gamma) (E - 1)}$$

Changing the signs,

$$\mu = \frac{1 - E^{1-\gamma}}{(\gamma - 1) (E - 1)} = \frac{1 - \frac{1}{E^{\gamma-1}}}{(\gamma - 1) (E - 1)} \quad (10a)$$

Equation (10a) was used to plot the piezometric efficiency vs expansion ratio for an assumed ratio of specific heats of 1.25, and the curve is shown in Figure 10. This graph shows that an expansion ratio of 4.0 is associated with a piezometric efficiency of 0.4. It is also apparent that reasonable values of piezometric efficiency are bounded by 0.3 and 0.65 for expansion ratios of 5.5 and 2.0, respectively.

Propellant Charge

An expression for the required propellant charge weight* as a function of expansion ratio can be derived as follows. If it is assumed that the entire energy developed by the burning propellant is transferred to the projectile in the form of kinetic energy, equation (3) for kinetic energy is valid:

$$KE = \frac{\mu A P_i X_L}{12}$$

Since the system is a closed system during the burning period, the equation of state at the end of this time becomes:

$$P_i V_i = 12 C F \quad (11)$$

$$\text{where: } V_i = 2 A X_i \quad (12)$$

Substituting for V_i in equation (11) and solving for P_i gives:

$$P_i = \frac{6 C F}{A X_i} \quad (13)$$

Now, substituting for P_i in equation (3):

$$KE = \frac{\mu A X_L C F}{2 A X_i}$$

and solving this for the charge weight:

$$C = \frac{2 KE X_i}{\mu F X_L} \quad (14)$$

But, the expansion ratio, by definition, is the ratio of the final volume, V_f , to the initial volume, V_i , and this ratio is the same as

*It must be understood that the charge weight is actually mass and is customarily expressed in grams.

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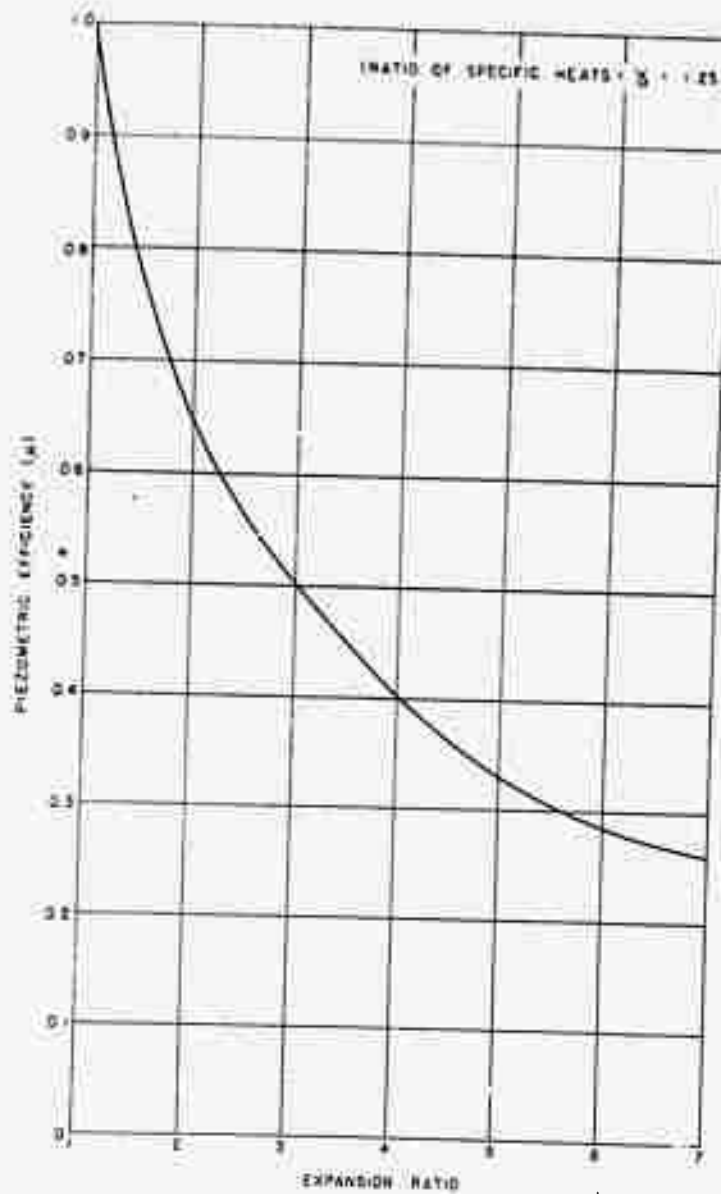


Figure 10. Piezometric Efficiency as a Function of Expansion Ratio

the ratio of the distances along the cylinder (Figure 6).

$$E = \frac{V_2}{V_1} = \frac{X_L + X_1}{X_1}$$

So,
$$E = \frac{X_L}{X_1} + 1$$

or
$$\frac{X_1}{X_L} = \frac{1}{E - 1}$$

Substituting for X_1/X_L in equation (14), the charge weight as a function of the expansion ratio becomes:

$$C = \frac{2 KE}{\mu F (E - 1)} \quad (14a)$$

This is changed to its final form by substituting equation (10a) for piezometric efficiency.

$$C = \frac{2 KE (\gamma - 1)}{F \left[1 - \left(\frac{1}{E\gamma - 1} \right) \right]} \quad (15)$$

Propellant charge weight vs expansion ratio is shown in Figure 11 for certain parameters whose values are given on the graph. From this graph, it is apparent that lower expansion ratios require increasingly larger charges, which multiplies ignition problems.

Ballistic Efficiency

An expression for ballistic efficiency as a function of the expansion ratio can be derived as follows.

The definition of ballistic efficiency is:

$$\eta = \frac{\text{total Kinetic Energy}}{\text{propellant energy}}$$

$$\eta = \frac{2 KE}{C \left(\frac{F}{\gamma - 1} \right)} \quad (16)$$

Substituting the expression for propellant charge, equation (15), an expression for ballistic efficiency as a function of the expansion ratio is obtained:

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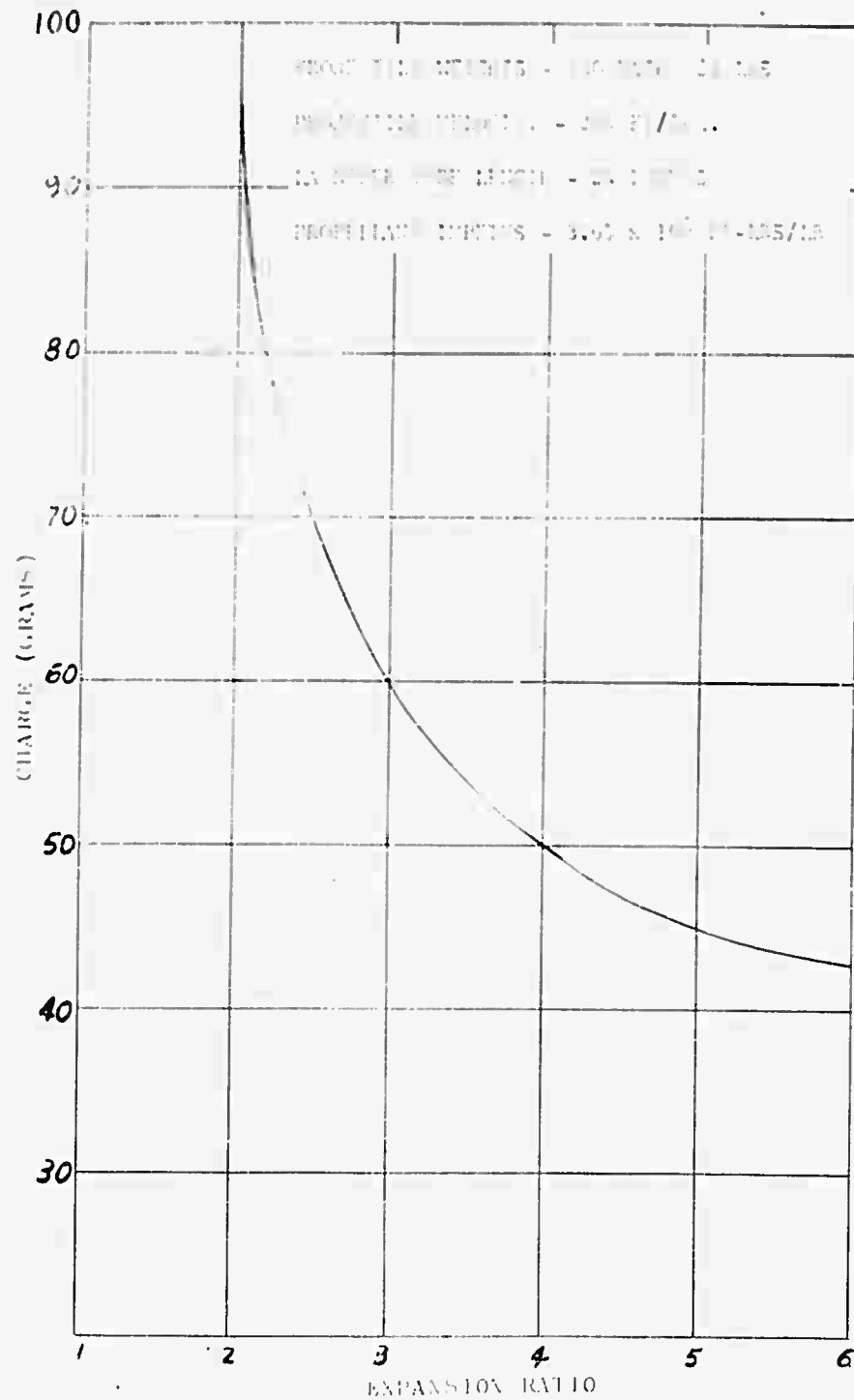


Figure 11. Charge Weight as a Function of Expansion Ratio

$$\eta = 1 - \frac{1}{E^{\frac{1}{\gamma-1}}} \quad (17)$$

A curve for $\gamma = 1.25$ is shown in Figure 12. From this graph, it is evident that ballistic efficiency falls off sharply as the expansion ratio is decreased.

Propellant Charge and Velocity

An expression for propellant charge weight in grams per pound of decoy weight as a function of velocity can be derived as follows:

Using equation (16), and substituting the expression for kinetic energy,

$$KE = \frac{1}{2} \frac{W_t}{g} v^2 \quad (18)$$

an expression for propellant charge weight per pound of decoy weight is obtained as a function of velocity:

$$\frac{C}{W_t} = \frac{kg \cdot v^2}{\eta g \left(\frac{F}{g} \right)} \quad (19)$$

with C expressed in grams.

Figure 13 shows a curve with which the propellant charge weight required to eject a pair of decoys of any weight at any desired velocity can be estimated. All that is necessary is to locate the desired velocity on the curve, and to multiply the ordinate value for this point by the weight of one decoy.

For example, the 100-fps line intersects the curve at 0.3 grain of charge per pound of decoy weight. Multiplying this by the weight of one decoy: $0.3 \times 5 = 1.5$ grams. Therefore, 1.5 grams of charge should be sufficient to eject two 5-pound decoys, simultaneously, each at 100 fps.

Closed Spigot Design

Figure 14 shows open and closed spigots with equivalent expansion ratios. The closed spigot fills only part of the launcher tube. Consequently, the combustion chamber volume is the internal volume of the launcher tube beyond the end of the spigot, and the expansion ratio is equivalent to the ratio of the tube length to the combustion chamber length. The open spigot fills the entire launcher tube, but has an open end and a thick wall. The combustion chamber volume is determined by the thickness of the spigot's wall and the location of its base plate. The expansion ratio is equivalent to the

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(RATIO OF SPECIFIC HEATS = 0.125)

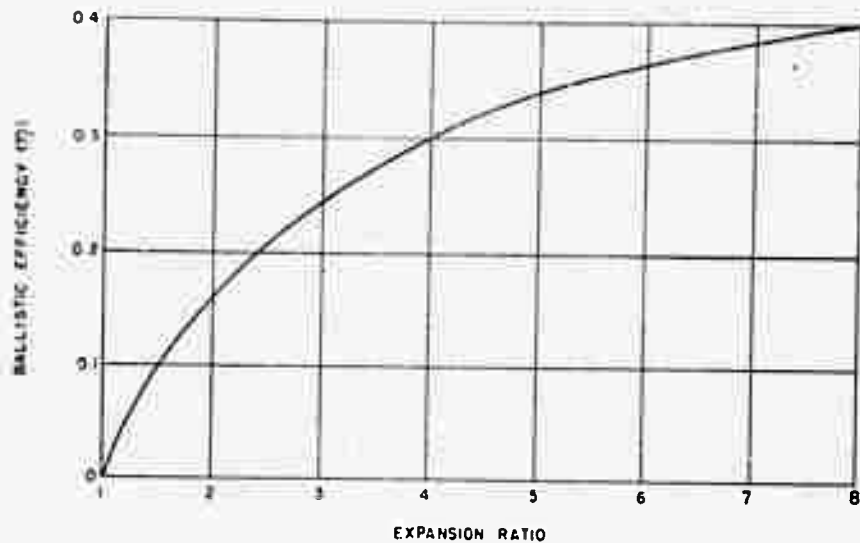


Figure 12. Ballistic Efficiency as a Function of Expansion Ratio

ratio of the volume of the launcher tube to the internal volume of the open end of the spigot.

The peak pressure vs expansion ratio for a closed spigot design can be derived as follows. The length of the tube is (see Figure 5):

tube length = stroke length + initial chamber length

$$X_T = X_L + X_i$$

So,

$$\frac{X_L}{X_T} = 1 - \frac{X_i}{X_T} = 1 - \frac{1}{E}$$

Therefore,

$$X_L = \frac{X_T (E-1)}{E}$$

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BALLISTIC EFFICIENCY = 0.3

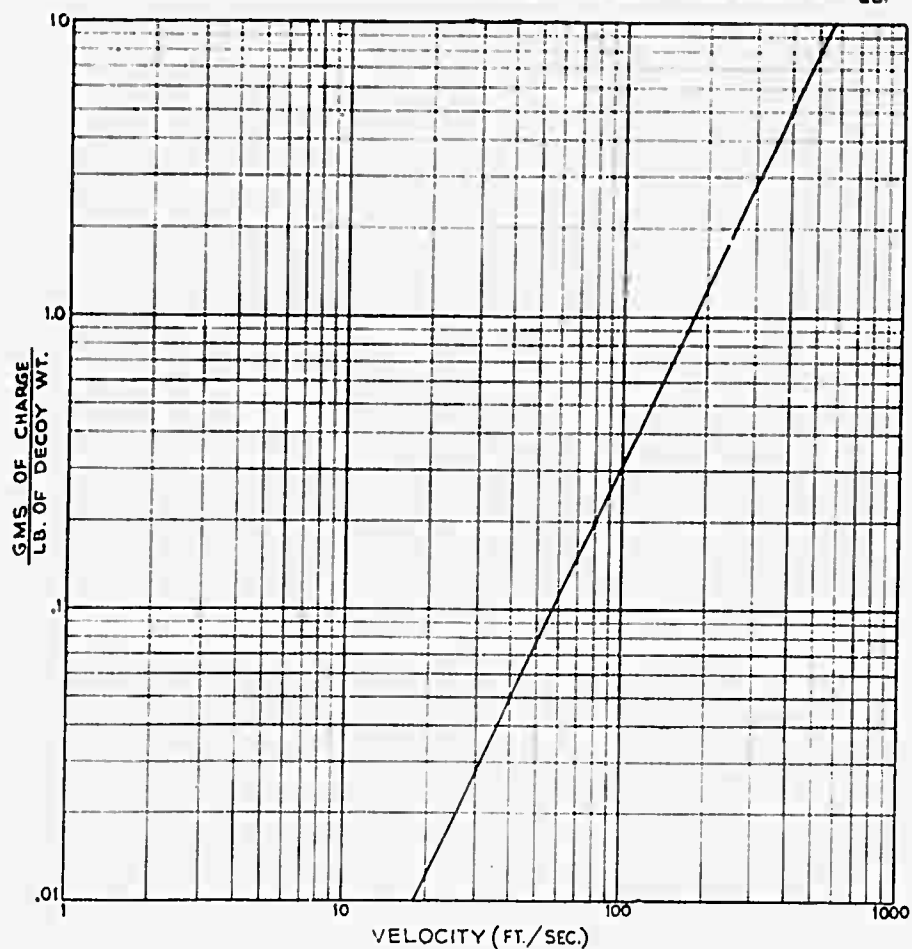
PROPELLANT POTENTIAL = $1.46 \times 10^6 \frac{\text{FT-LBS.}}{\text{LB.}}$ 

Figure 13. Ratio of Charge Weight per Pound of Projectile Weight as a Function of Velocity

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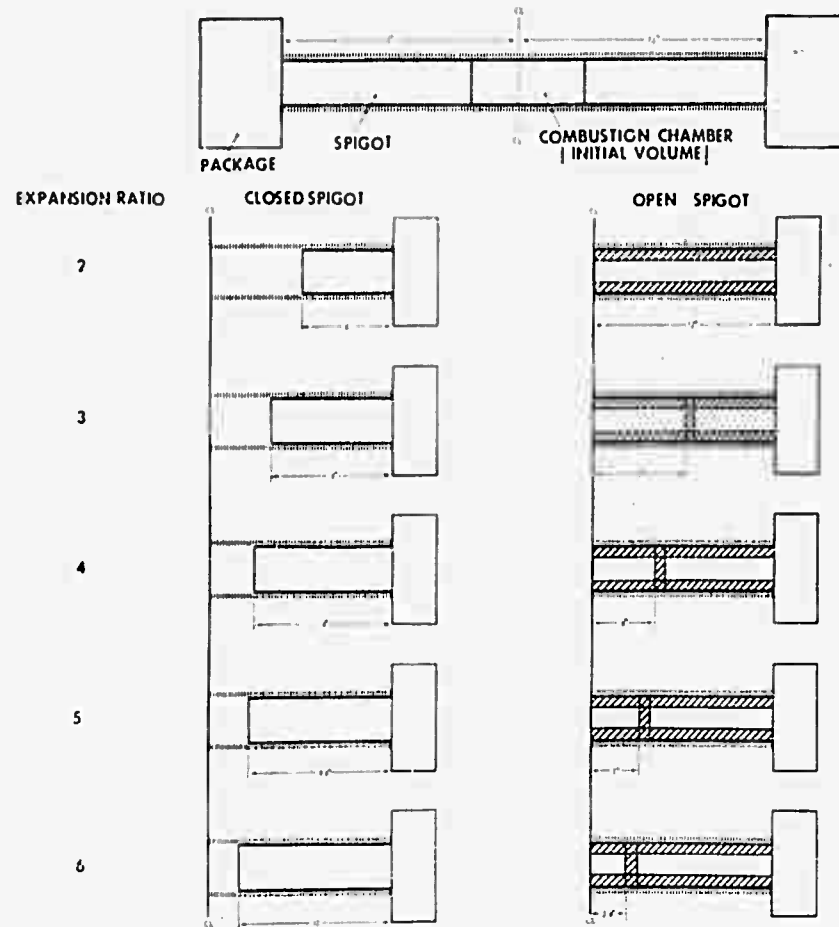


Figure 14. Comparison of Closed and Open Spigot Designs
For a Given Expansion Ratio

Substituting for X_L in equation (3),

$$KE = \frac{\mu P_i A X_T (E - 1)}{12E} \quad (3a)$$

But $A = \frac{\pi D^2}{4}$

Substituting for A,

$$KE = \frac{\mu P_i \pi D^2 X_T (E - 1)}{48E} \quad (3b)$$

From equation (10a),

$$\mu = \frac{1 - \frac{1}{E\gamma-1}}{(E-1)(\gamma-1)}$$

Substituting for μ ,

$$KE = \frac{1 - \frac{1}{E\gamma-1}}{48E(\gamma-1)} P_i \pi D^2 X_T \quad (3c)$$

Solving for P_i ,

$$P_i = \frac{48E(KE)(\gamma-1)}{\left[1 - \left(\frac{1}{E\gamma-1}\right)\right] \pi D^2 X_T} \quad (20)$$

Open Spigot Design

In an open spigot design, the spigot occupies the entire length of the tube. Consequently, the tube length is the same as the stroke length:

$$X_T = X_L$$

So equation (16) becomes:

$$KE = \mu P_i A \frac{X_T}{L}$$

Substituting for A ,

$$KE = \frac{\mu P_i \pi D^2 X_T}{48}$$

From equation (10a),

$$\mu = \frac{1 - \frac{1}{E\gamma-1}}{(E-1)(\gamma-1)}$$

Substituting for μ ,

$$KE = \frac{\left(1 - \frac{1}{E\gamma-1}\right) P_i \pi D^2 X_T}{48(E-1)(\gamma-1)}$$

Solving for P_i ,

$$P_i = \frac{48(KE)(E-1)(\gamma-1)}{\pi D^2 X_T \left(1 - \frac{1}{E\gamma-1}\right)} \quad (21)$$

Equations (20) and (21) are plotted in Figures 15 and 16. Figure 15 shows that with a closed spigot design the peak pressure is a minimum for an expansion ratio of 2.5. Figure 16 shows that with an open spigot design the peak pressure increases with the expansion ratio at an almost uniform rate. The peak pressure obtained is always less for an open spigot with the same expansion ratio. For example, a 4-inch diameter open spigot with an expansion ratio of 4.0 gives 4800 psi peak pressure to eject a 25-pound projectile at 250 feet/second. Under the same conditions, a closed spigot gives 6400 psi peak pressure. A choice of an open or closed spigot design would depend on the requirements for a specific system.

Launcher Weight

Since the launcher weight may be a critical factor, it was calculated for both open and closed spigots as a function of the expansion ratio.

The weight of a hollow launcher tube can be expressed as:

$$W_t = 2 \rho \pi D t X_T \quad (22)$$

where D is half the sum of the external and internal diameters, and t is half the difference. The "2" occurs because there are two tubes.

The tensile stress on a thin-walled cylinder as a result of internal gas pressure is commonly expressed as:

$$\sigma = \frac{P_i D}{2t} \quad (23)$$

This can be rewritten as:

$$t = \frac{P_i D}{2\sigma} \quad (23a)$$

Substituting this expression in equation (22) gives:

$$W_t = \frac{\rho \pi D^2 P_i X_T}{\sigma} \quad (24)$$

Substituting equation (20) in equation (24) gives an expression for the weight of a closed spigot system in terms of E :

$$W_t = \frac{4 \rho (KE) E (\gamma - 1)}{\sigma \left(1 - \frac{1}{E\gamma - 1} \right)} \quad (25)$$

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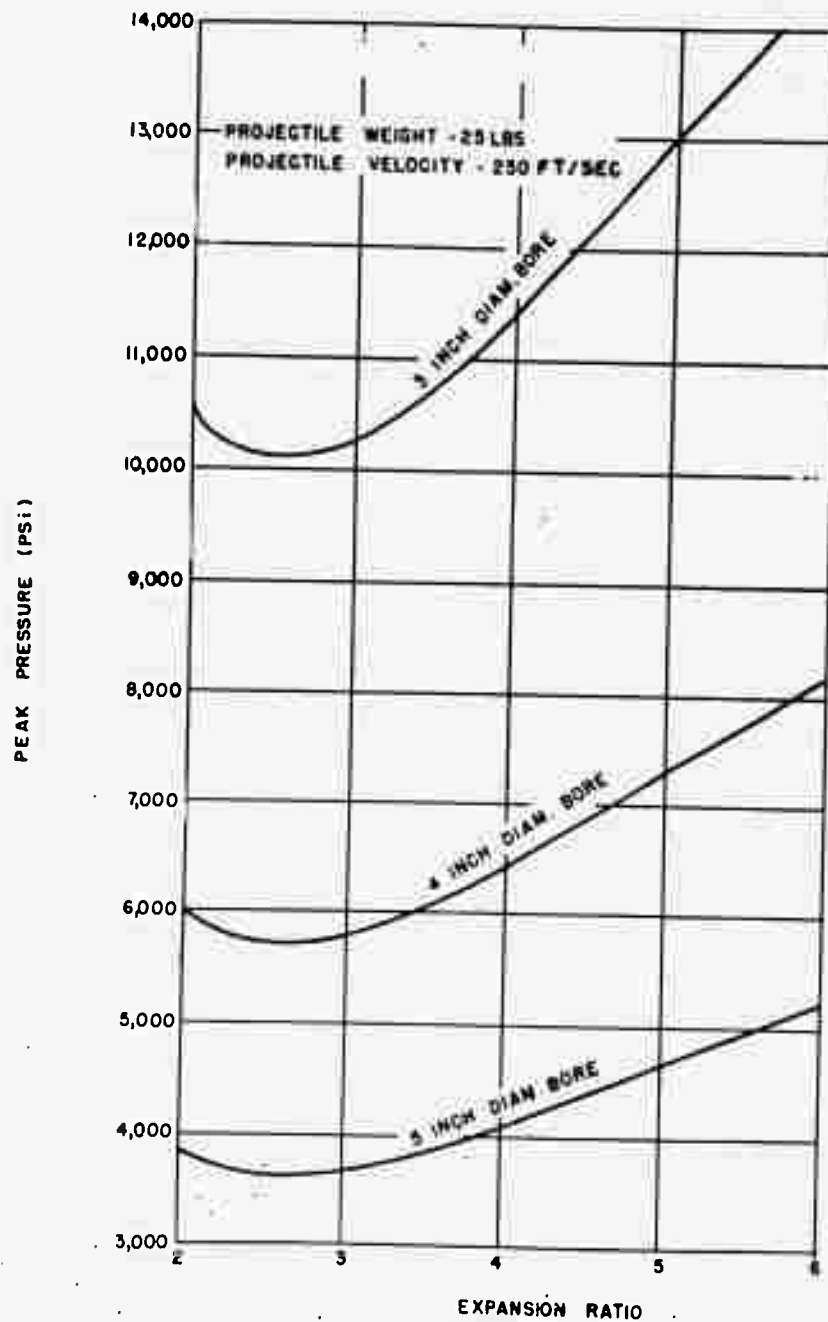


Figure.15. Peak Pressure as a Function of Expansion Ratio
for a Closed Spigot

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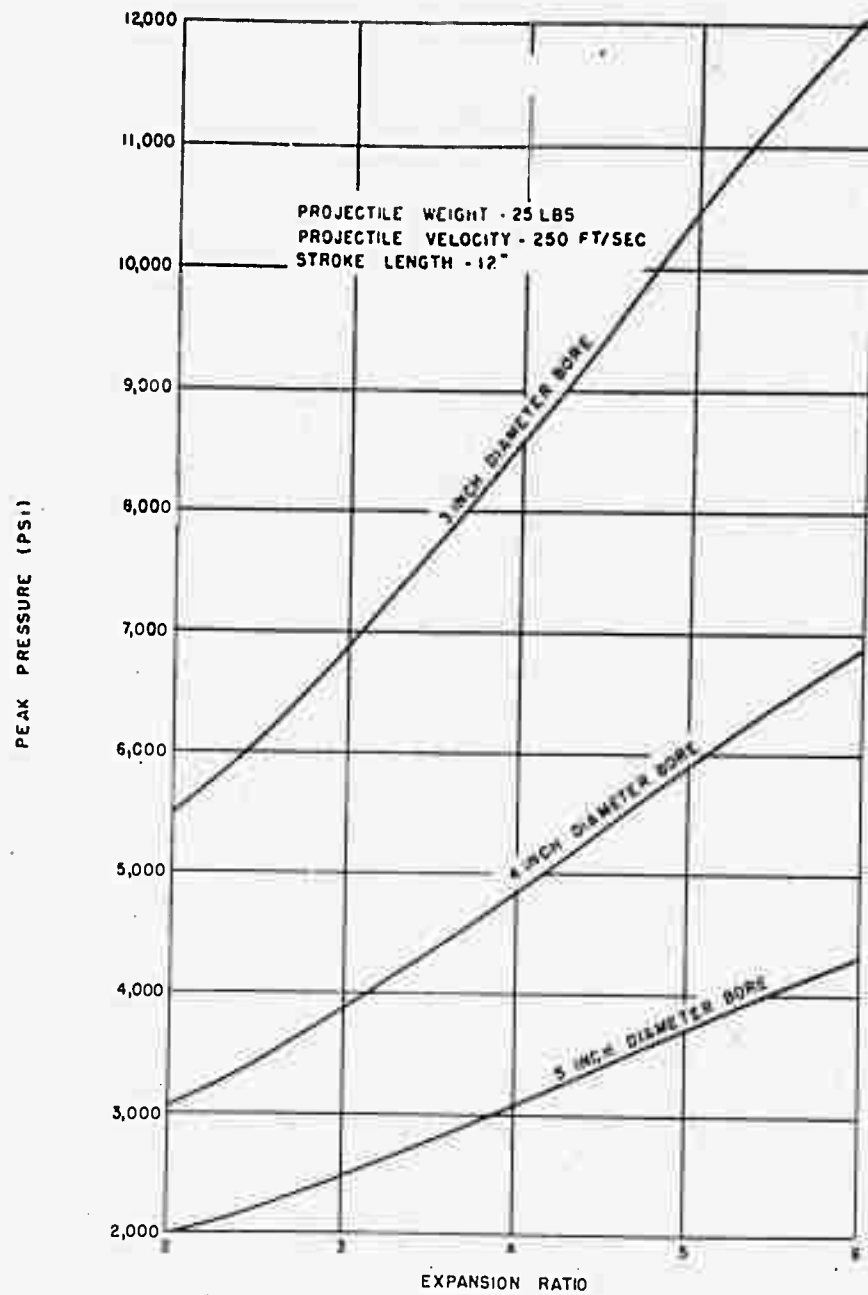


Figure 16. Peak Pressure as a Function of Expansion Ratio for an Open Spigot

Substituting equation (21) in equation (24), an expression for the weight of an open spigot system is obtained in terms of E:

$$W_t = \frac{4\rho(KE)(E-1)(\sigma-1)}{\sigma\left(1 - \frac{1}{E\sigma-1}\right)} \quad (26)$$

Figures 17 and 18 show curves of launcher weight vs expansion ratio for launchers of steel, aluminum, or titanium. These curves are similar to the curves for peak pressure as a function of expansion ratio. Figure 17 shows that for a closed spigot design the launcher weight is a minimum for an expansion ratio of 2.5. Figure 18 shows that for an open spigot design the launcher weight increases with the expansion ratio at an almost uniform rate. The launcher weight required is always less for an open spigot with the same expansion ratio.

Acceleration

An expression for acceleration as a function of the expansion ratio can be obtained as follows. It is common engineering practice to express maximum acceleration for a projectile hurled from a gun as:

$$a = \frac{P_i A_G}{W_t} \quad (27)$$

Substituting for P_i from equation (20),

$$a = \frac{48E(KE)(\sigma-1)A_G}{W_t X_t \left(1 - \frac{1}{E\sigma-1}\right) \pi D^2}$$

But, $4A = \pi D^2$

So, acceleration for a closed spigot system is:

$$a = \frac{12E(KE)(\sigma-1)g}{W_t X_t \left(1 - \frac{1}{E\sigma-1}\right)} \quad (28)$$

To find an expression for acceleration for an open spigot system, substitute for P_i in equation (27) from equation (21):

$$a = \frac{12KE(E-1)(\sigma-1)g}{W_t X_t \left(1 - \frac{1}{E\sigma-1}\right)} \quad (29)$$

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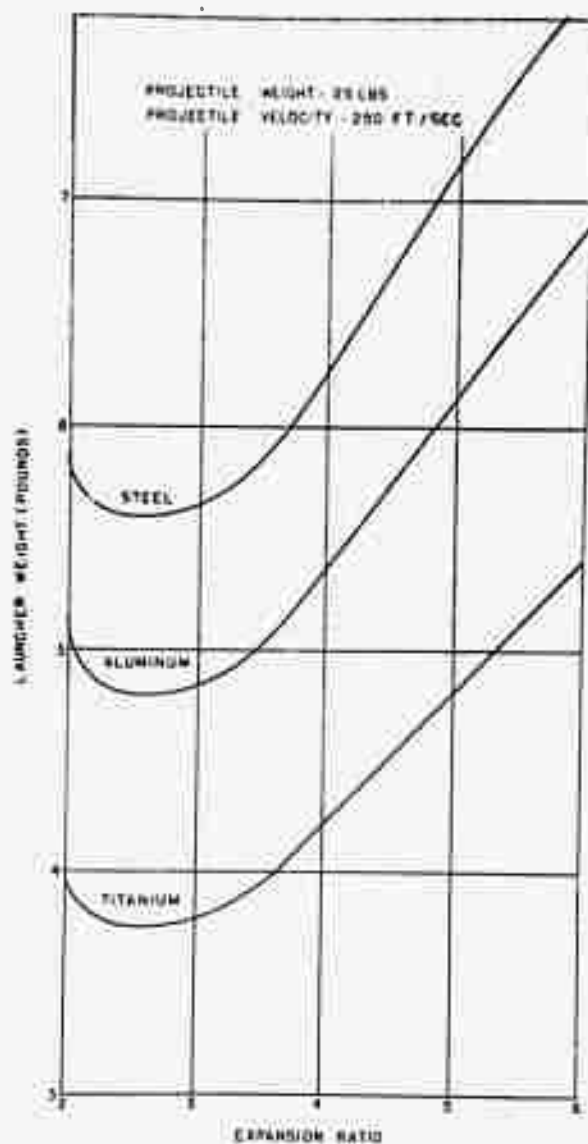


Figure 17. Launcher Weight as a Function of Expansion Ratio for a Closed Spigot

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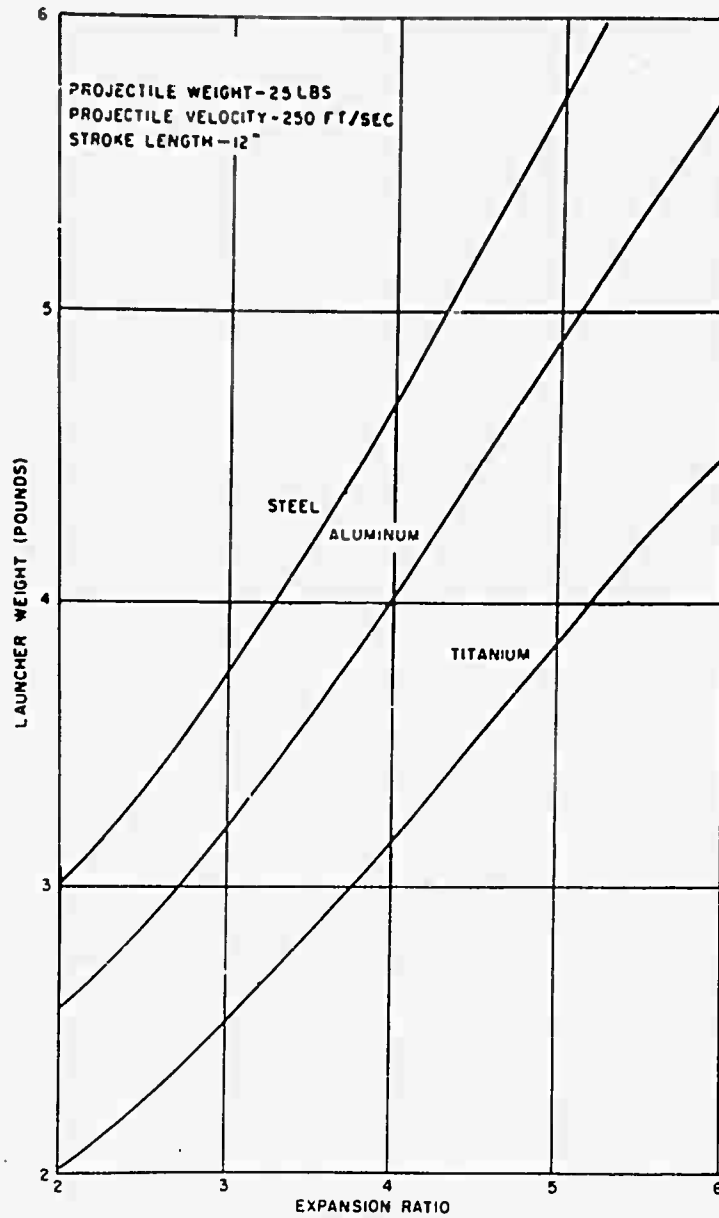


Figure 13. Launcher Weight as a Function of Expansion Ratio for an Open Spigot

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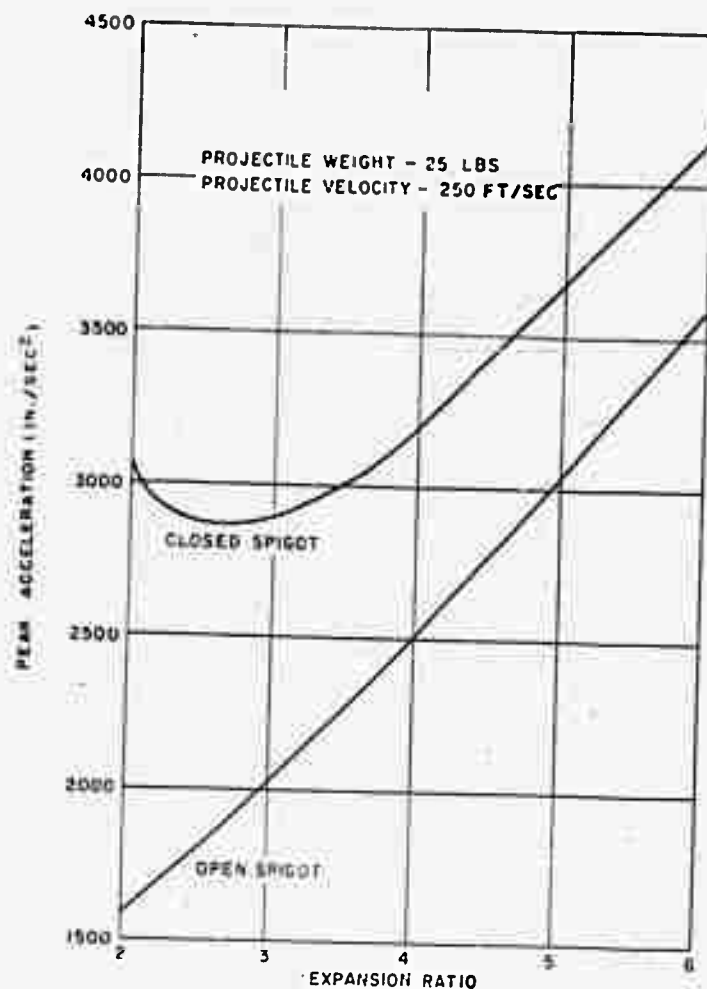


Figure 19. Peak Acceleration as a Function of Expansion Ratio

The resulting curves are plotted in Figure 19. Again, the closed spigot has a minimum peak acceleration at $E \sim 2.5$, since the acceleration is directly related to the peak pressures. The open spigot, of course, shows substantially lower acceleration, since it operates at lower pressures and has a longer stroke.

CONCLUSIONS

It is concluded that the use of standard CAD as decoy launchers is entirely feasible, with each particular unit covering a certain weight-velocity range.

The design of a reactionless launcher to cover any specific weight-velocity combination is possible for the ranges tabulated. This launcher could be either spigot or full-caliber, depending on the weight-velocity range desired. It was concluded that the use of a high-low ballistic spigot system is not desirable where a smaller caliber direct system can be used. If launcher weight or the G loading on the decoys is critical and a spigot design is used, the open spigot will give reduced values, in which case, the use of a high-low ballistic system may be desirable. In fact, the pressures may become so low that the use of compressed gas or a mechanical system is recommended. Equal or greater launcher weight savings can be obtained by choosing aluminum or titanium over steel.

RECOMMENDATIONS

It is recommended that the analytical methods developed in this study be made available to those groups within government and industry who are designing decoy launchers or other package-ejecting devices for use on missiles.

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APPENDIX I

List of Symbols

- A -- Cross-sectional area of launcher bore (in.²)
 C -- Charge weight (grams)
 D -- Diameter of bore (in.)
 E -- Expansion ratio (dimensionless)
 F -- Potential of propellant (ft-lb/lb)
 G -- Acceleration in g units (dimensionless)
 g -- Acceleration due to gravity (32.2 ft/sec²)
 P_i -- Initial pressure (assumed to be peak pressure) (lb/in.²)
 P_f -- Final pressure (lb/in.²)
 T -- Thickness of launcher tube wall (in.)
 V_i -- Initial volume of launcher (in.³)
 V_f -- Final volume of launcher (in.³)
 v -- Velocity of projectile (ft/sec)
 W_L -- Propelled weight (lb)
 W_t -- Weight of decoy package (lb)
 w -- Work done in adiabatic expansion (ft-lb)
 X_i -- Initial length of launcher chamber; length of combustion chamber (in.)
 X_L -- Length of stroke (in.)
 X_T -- Length of launcher tube (in.)
 η -- Ballistic efficiency (dimensionless)
 γ -- Ratio of specific heats (dimensionless)
 μ -- Piezometric efficiency (dimensionless)
 ρ -- Density of launcher tube (lb/in.³)
 σ -- Yield strength (lb/in.²)

APPENDIX II

Tables of Peak Pressure vs Velocity
for Reactionless Launchers

Tables II, III, IV, and V list peak pressure data for reactionless launchers at various velocities. The data is tabulated for the various full-caliber and spigot configurations, with data on each type obtained for several different bore diameters.

Table III. Peak Pressures for Full-Caliber, Direct System, Reactionless Launchers (Length - 55 in.; Stroke - 13.75 in.; Expansion Ratio - 2)

[illegible]

Table IV. Peak Pressures for Closed Spigot, Direct System, Reactionless Launchers
(Length - 31 in.; Stroke - 11.5 in.; Expansion Ratio = 4)

[illegible]

[illegible]

Table V. Peak Pressure for Closed Spigot, High-Low System Reactionless Launchers
(Length - 31 in.; Stroke - 11.5 in.; Expansion Ratio - 4)

Proj. Wt. (lb)	Velocity (ft/sec)												
	30	40	50	60	70	80	90	100	110	120	130	140	150
5								510	620	730	860	1000	1150
10								820	1000	1500	1700		
20								1300					
30								2000					
40								500					
50								1000					
60								1500					
70								1800					
80								510					
90								760					
100								1000					
								1300					
								1500					
								1800					
								550					
								640					
								730					
								820					
								930					
								1000					
								1100					
								1200					
								1300					
								1400					
								1500					
								1600					
Bore Dia - 2.25 in.													

Bore Dia - 2.25 in.

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BALLISTIC CALCULATIONS AND DESIGN CRITERIA FOR DECOY
LAUNCHING SYSTEMS
By C. L. Fulton and S. Goldstein
Report R-1578, Feb 61; 44 pages incl illus and tables
ARPA Order 39-59, Task 8; ARPA Contr ID-395-00-60
SPR 2-2219-50

Standard cartridge actuated devices were surveyed to
determine the feasibility of using them in decoy launching
systems. Design criteria were established, simplified
ballistic analyses were made, and theoretical performances
were calculated for several reactionless type launchers.

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