DESIGN AND PERFORMANCE OF POWDER ACCELERATOR SYSTEMS FOR IMPACT STUDIES

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A detailed design of 16mm, 19mm and 50mm accelerator systems, which have been installed at North Carolina State University at Raleigh for studying materials' response to high strain rates resulting from high velocity impacts, is presented.

The 16mm and 19mm accelerators have been used to produce maximum projectile velocities of 2025 feet per second and 1760 feet per second respectively while velocity data has not yet been fully established for the 50mm accelerator.

Experience with these accelerator systems has shown that they meet all of the requirements stipulated for their use. Such accelerators, possessing a number of features required for research studies, may be fabricated readily by university shop facilities.

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ABSTRACT

A detailed design of 16mm, 19mm, and 50mm accelerator systems which have been installed at North Carolina State University at Raleigh for studying the materials response to high strain rates resulting from high velocity impacts, is presented.

The 16mm accelerator, which is designed to use 20 gauge shotgun shells as propellent, was fabricated in the Engineering Research shop and has been used to produce a maximum velocity of 2025 feet per second with projectiles weighing .625 ounces.

The 19mm accelerator, which uses 12 gauge shotgun shells as propellent, was designed to permit simultaneous development of new measuring systems associated with circumferential strains and strain rates, and also to serve as a back-up system to the 16mm system. This accelerator system was also fabricated in university shop facilities and has successfully accelerated one ounce projectiles up to 1760 feet per second. Special features of this system are the jacket enclosing the barrel and the modified test section and catcher.

The barrel and breech mechanism of the 50mm accelerator system, which is designed to use powder charges up to 850 grams as propellent and to accelerate projectiles up to 3000 feet per second, were designed and fabricated by The Utah Research and Development Company. The rest of the system has been designed and fabricated under the supervision of the design group of the Themis project. Velocity data has not yet been fully established for this accelerator.

Experience with the above systems has shown that they meet all of the requirements stipulated for their use. Such accelerators, possessing a number of features required for research studies, may be fabricated readily by university shop facilities.

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INTRODUCTION

In an earlier report [1] a description of 16mm and 19mm accelerator systems for axial impact studies was presented. It was also mentioned that a 50mm accelerator was under contract for final design and fabrication by the Utah Research and Development Company. This report describes further design details and theoretical and experimental curves of the 16mm and 19mm accelerators and the detailed design of the 50mm accelerator system. The design requirements and experimental procedure for the accelerator systems were discussed in Technical Reports [1], [2], [3]. However a brief description is repeated here for convenience.

It was required to develop impacting systems which could be used to impact target specimens over a range of velocities. It was planned to have diffraction grating(s) on specimens at pre-determined locations which would be illuminated by laser beam(s), and to record the diffraction pattern during impact with a high speed camera and thus determine the strain-time relationship. The projectile and target specimen must be long enough to prevent any reflected waves reach the grating before the measurement is completed.

The design of all three accelerator systems is based on the following requirements:

(1) Precise alignment of target and projectile is required to ensure co-axial impact.

(2) Optical access is necessary for incident light and diffraction phenomena to and from the impact site.

(3) There must be provision for the equivalent of free flight impact. For example, impact of closely fitted projectile and target while in an alignment sleeve would result in radial restriction of the impacting members.

(4) A vacuum must be maintained between the front of the projectile and target to prevent air shock effects from being recorded by the instrumentation system.

(5) Propelling gases must be vented from behind the projectile prior to impact to remove the possibility of their presence at the impact site during impact, and to provide free flight impact conditions.

(6) Projectile and target specimens must be of sufficient length to prevent superposition of any reflected waves upon a portion of the initial impact wave during the desired interval of study.

(7) There must be an arrangement to safely stop and retain the debris resulting from impact.

(8) The accelerators must be as quiet as possible while firing in order to avoid any disturbance to the nearby offices and laboratories.

The nature of experiments to be conducted and the instrumentation technique employed has placed particular requirements upon the impacting systems so that it was not possible to modify conventional powder guns because of such features as rifling and taper in the bore. It was decided not to use compressed-gas guns because the high areal density resulting from the projectile length requirement leads to extremely long barrels or unusually high pressure reservoirs in order to achieve the desired impact velocities. Therefore it was decided to design powder accelerators with long, smoothbore, vented barrels mounted for free recoil.

The three accelerator systems are similar in basic design. They essentially consist of a breech mechanism attachable to one end of a smoothbore barrel with gun powder employed to accelerate the projectiles. The muzzle end of the barrel is slipped within an impact chamber which is also the test chamber. The last unit on the downstream side of the accelerator is a catcher to stop and retain the debris resulting from impact. The systems are evacuated before firing for reasons mentioned earlier.

Equations for the velocity of the projectile and the pressure of the powder gases behind the projectile were developed based on the equations of LeDuc and Hayes [4]. They have assumed a hyperbolic relationship between the velocity and travel of the projectile inside the barrel of the accelerator. They have expressed velocity and pressure inside the barrel in terms of constants which depend on the type of accelerator, type of propellent and weight of projectile. One of the writers [5] has assumed the same hyperbolic relation between velocity and projectile travel, but has further developed the expressions for velocity and pressure and expressed them in terms of the properties of the propellent, the weight and position of the projectile and the dimensions of the barrel. These equations will enable the designer to compute the velocities and pressures without knowing the constants whose values change due to a change in any one or all of the parameters mentioned above.

French artillarist, Captain A. LeDuc carried out series of experiments and concluded that

$$v = \frac{Au}{B+u} \tag{1}$$

where u represents the displacement of the projectile, v the corresponding velocity of the projectile. A and B are the gun constants. For a particular set of values of A and B, the velocity increases very rapidly from a value of zero at u=o to a particular value and thereafter remains fairly constant. This leads to the conclusion that increasing the barrel length beyond a limiting value does not help in obtaining higher velocities. The assumption that the velocity-travel curve is hyperbolic is not always accurate but is a very good approximation in most cases. From equation (1) it is noted that for smaller values of u, v is influenced by both A and B, but as u increases the influence of B on v decreases and for infinitely long barrels, v = A.

The constants A and B are expressed as

$$A = 9170\ \Omega^{7/12} \Big/ \left(W^{1/2} \times D^{1/6} \times d^{1/12} \right) \tag{2}$$

$$B = .851\ \beta \left(1 - \frac{35.2\Omega}{\gamma D^2 d} \right) \left(\frac{D^2 d}{W} \right)^{2/3} \tag{3}$$

where Ω = Weight of powder (grains)

W = Weight of projectile (ounces)

D = I.D. of barrel (inches)

d = Distance between the back of the shell and back of the projectile in its original position (inches)

β = Powder constant

γ = Specific gravity of gun powder.

Substitution of the values of A and B in equation (1) yields

$$v = \frac{9170\ \Omega^{7/12} \times u}{W^{1/2} \times D^{1/6} \times d^{1/12} \times u + .851\beta\ (1 - 35.2\Omega/\gamma D^2 d) \left(\frac{D^{3/2} \times d^{3/4}}{W^{1/6}} \right)} \tag{4}$$

With the help of the above equation the velocity of the projectile can be computed directly without evaluating the constants A and B. Though the equation appears very lengthy and complicated, the velocity can be computed by merely substituting the values of all the parameters. For designers this equation should be helpful. Equation (4) can be written in functional form as

$$v = v\ (u, \Omega, W, \beta, \gamma, D, d). \tag{5}$$

If P represents the pressure of the powder gases behind the projectile then the force which drives the projectile at any time is given by

Force = pressure x area

= mass of projectile x acceleration of projectile, therefore $$P x \frac{\Pi}{4} D^2 = \frac{W}{g} \frac{dv}{dt}$$

where g is acceleration due to gravity.

$$\therefore \quad P = \frac{4W}{\Pi D^2 g} \cdot \frac{dv}{dt} \tag{6}$$

$\frac{dv}{dt}$ is computed from equation (4) and substituted in equation (6). Therefore

$$P = 2.825\beta \left(\frac{d^{1/2} \times \Omega^{7/6} \times u}{D \times W^{2/3} (3+u)^3} \right) \left(1 - \frac{35.2\Omega}{\gamma D^2 d} \right) 10^6. \tag{7}$$

The position of the projectile for peak pressure is determined by equating

$\frac{dP}{du}$ to zero. It is found that

$$u = B/2, \tag{8}$$

and $$P_{max} = \frac{0.577\gamma W^{2/3} d^{1/6} \Omega^{7/6}}{\beta D^{5/3} (\gamma D^2 d - 35.2\Omega)} 10^6. \tag{9}$$

When the projectile is driven by the expanding powder gases, the portion of the barrel behind the projectile acts like a thick-walled closed cylinder. The barrel must be designed to withstand the maximum pressure developed in the barrel. Every elementary cube in the walls of the barrel is subjected to three normal stresses at right angle to each other: a compressive radial stress, tensile longitudinal stress, and tensile tangential stress. The following are the simple stresses at the inner surface of the barrel which is the most critical zone.

$$\sigma_r = -P \text{ (compressive)} \tag{10}$$

$$\sigma_t = P \left(\frac{Ro^2 + Ri^2}{Ro^2 - Ri^2} \right) \text{ (tensile)} \tag{11}$$

$$\sigma_1 = P \left(\frac{Ri^2}{Ro^2 - Ri^2} \right) \text{ (tensile)} \tag{12}$$

where σ_r, σ_t and σ_1 are the radial, tangential and longitudinal stress respectively, and Ro and Ri are outer and inner radii of the barrel respectively

The expressions for radial and tangential stresses are derived from the equations of Lamé[7].

The maximum stresses in three mutually perpendicular directions at every point having been calculated, it is necessary to determine whether the stresses produce elastic or plastic deformation. Several theories of failure have been developed to predict the onset of plastic deformation. The distortion energy theory, which is the most accepted theory at the present time, is used. The United States Army Material Command has also adopted the Von Mises yield criterion (the distortion energy theory) in the design of gun tubes. According to this theory the material begins to yield when the distortion energy equals the distortion energy at yield in simple tension. In terms of stresses the yielding condition becomes

$$\sigma_t^2 + \sigma_l^2 + \sigma_r^2 - (\sigma_t\sigma_l + \sigma_l\sigma_r + \sigma_r\sigma_t) = \sigma_y^2 \tag{13}$$

where σ_y is the yield stress of the material.

Many investigators have found that materials exhibit much higher yield strength under dynamic loads than that under static conditions. In particular it has been observed that gun tubes do not show any sign of plastic deformation when fired at pressures much higher than the pressure at which they yield under hydrostatic tests. This leads to the conclusion that for designing components like an accelerator barrel, dynamic yield stress, which is a function of strain-rate, must be used. The use of static yield stress, in such cases, might result in a very conservative design thereby making the structure heavier and costlier than it should be. In cases, however, where weight of the system and cost of the material are not the basic criteria, static yield stress can be used for designing.

In research projects such as the one on "Materials Response Phenomena at High Deformation Rates," where powder accelerators are going to be used to produce impact, it is satisfactory to design the components of the system based on the static yield stress. When a dynamic yield stress is used in designing accelerators or other equipment, it is important to see that the equipment will not be highly stressed under essentially static conditions where the gain in yield strength due to high strain rate is not present.

The design of an accelerator barrel should consider thermal stresses, since the yield stress of most materials decreases with temperature. At low temperatures of operation there may not be any serious problem, but when the material temperature is high, the yield stress, σ_y, drops significantly. It has been observed that in spite of drastic decrease in the yield stress, guns still fire successfully. This accounts for the fact, mentioned earlier, that the material exhibits very high yield strength when subjected to high rate of loading of very short duration. In cases where the effects of temperature and pressure superimpose each other, the practice is to take the allowable yield stress as one half of the statically determined value. A fairly detailed discussion of the above phenomena is given in Reference [6]. When the accelerators are used in the laboratories for studying the response of material to high strain rates, the rate of firing is very slow, perhaps 10 or fewer shots a day, and therefore the accelerator barrel never attains a temperature at which thermal stresses become significant enough to influence the yield stress of the material.

Therefore the powder accelerator systems described herein are designed based on the static yield stress of the material and neglecting the effect of temperature on yield.

THE 16mm. ACCELERATOR SYSTEM

The 16mm accelerator system is designed to accelerate projectiles weighing up to 5 ounces using 20 gauge shotgun shells as propellent. Although different types of 20 gauge shells are available and can be conveniently used, 2-3/4 inch Magnum shells containing 25.7 grains of smokeless powder are used as propellent for all calculations. A detailed design of this system is given in references [1] and [5]. A brief description is however presented for the benefit of the reader.

1. Design of the Barrel

Since the accelerator system is mounted on an I-beam resting on a table, the weight of the barrel is not a critical factor. Therefore a steel tubing of AISI-4135 was machined as indicated in Figure 1. The O.D. of the barrel was not tapered along the length since additional machining would be required, although the drop in pressure along the barrel permits this. Another reason for not tapering the barrel was to increase the mass of the recoiling assembly.

The maximum theoretical pressure in the barrel when a 5 ounce projectile is accelerated is 20,400 psi. With this pressure the equivalent yield stress based on the distortion energy theory is 45,400 psi. One of the authors carried out a simple tension test and found the yield stress of AlSl-4135 to be 85,000 psi, which ensures that the barrel remains in an elastic state during firing.

2. Breechblock and Firing Mechanism

The breech mechanism is a mechanical device for closing the breech end of the accelerator after loading, and for firing the ammunition which

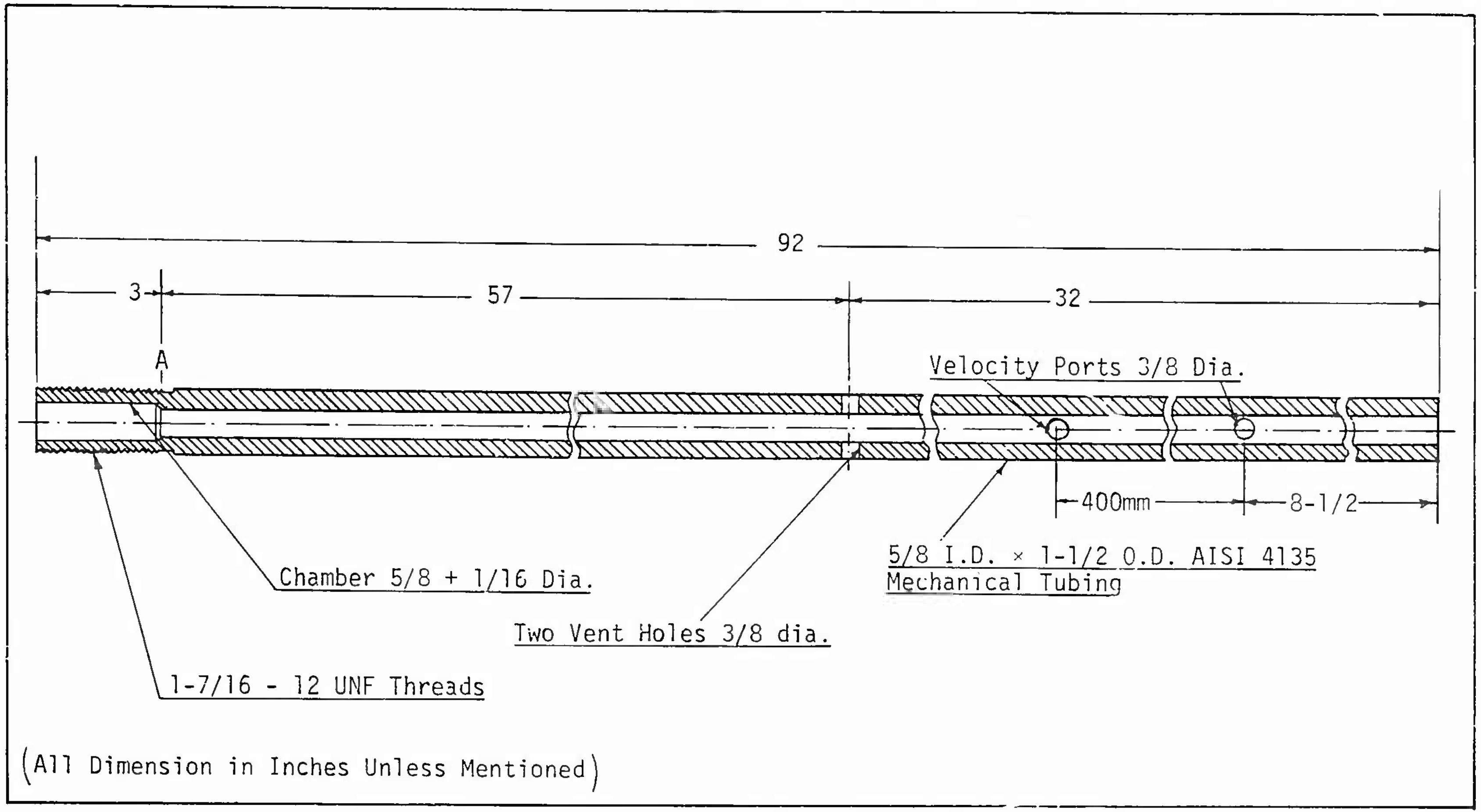


Figure 1. Accelerator Barrel for 16mm System.

has been inserted. The component parts of the breech mechanism include (a) the breechblock and (b) the firing mechanism. The design requirements of the breechblock are: safety, ease of fabrication, ease of handling and good vacuum seal. Application of the Von Mises yield criterion [5] yields that the breech mechanism for the 16mm accelerator can withstand a maximum internal pressure of 39,300 psi. Refer to Figure (2).

3. Impact Chamber

The impact chamber is located at the muzzle end of the barrel. From Figure (2) it is evident that it is a machined mechanical tubing one end of which fits on the barrel while the other end goes over the target holder. Horizontal slits are provided for optical measurements. The slits are covered by a plastic sleeve for vacuum seal. In addition to being vacuum tight, the impact chamber meets the following design requirements.

(a) It is strong enough to stop all fragments, resulting from impact, flying in lateral directions.

(b) The inner dimensions are large enough that the target and projectile will not become jammed in it after impact.

(c) The slits serve as optical windows for the laser beam and diffraction pattern.

4. Target Holder and Catcher

The target holder (Figure 2.) which is kept in alignment with the accelerator barrel, is designed to hold the target which is identical to the projectile. After the impact, the target specimen and the projectile remain in this tube, hence it also serves as a catcher. Deformable material may be provided at the end of the catcher to absorb the kinetic energy of

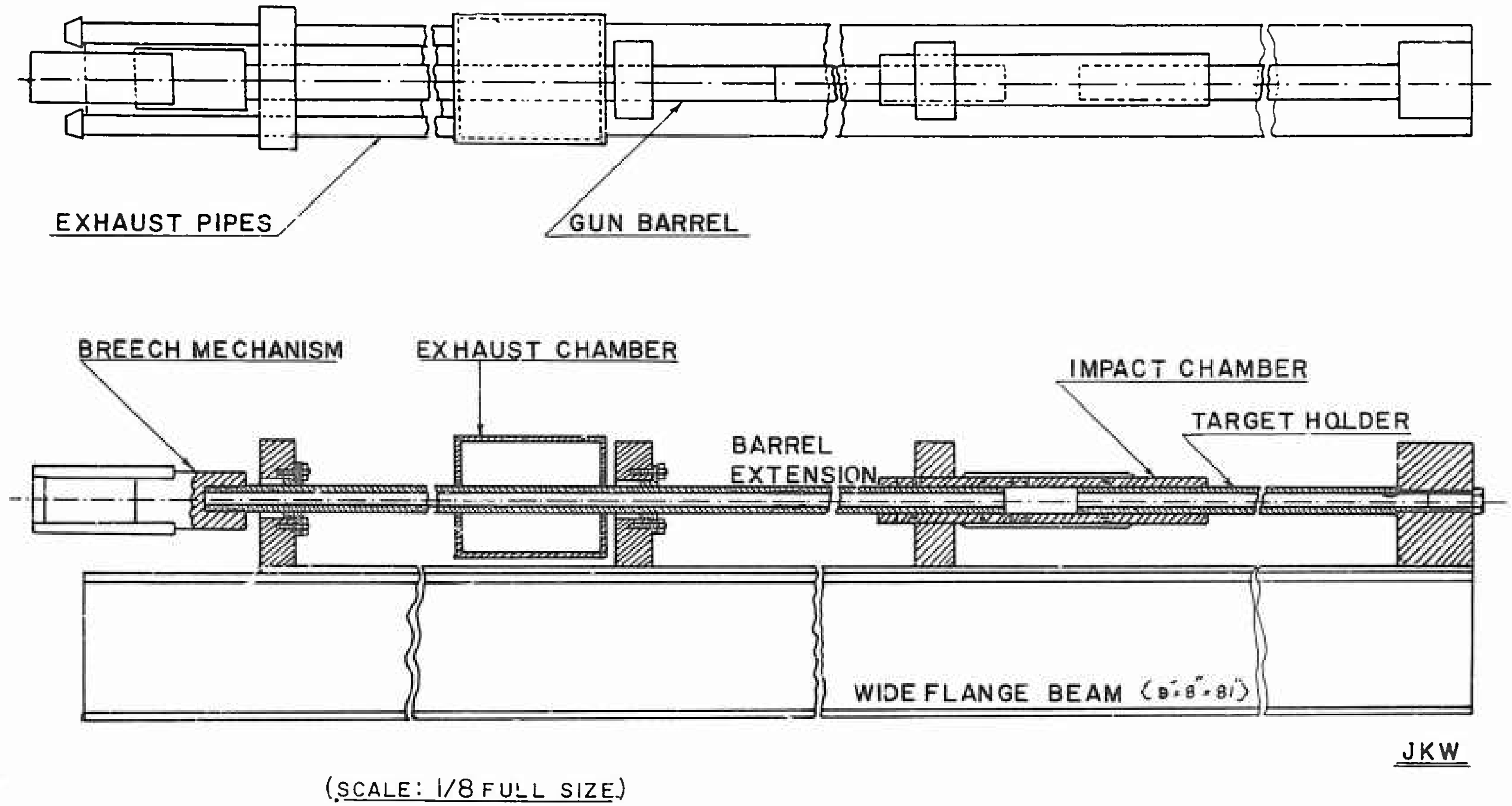


Figure 2. Assembled views of the 16mm Accelerator System.

the debris resulting from impact.

5. Vacuum System and Exhaust Chamber

The reasons for maintaining vacuum in the system and venting powder gases have already been mentioned in the design requirements of the accelerators. The vent holes are 5 feet from the breech end of the barrel. The diameter of these holes is large enough to allow most of the gases to escape. The exhaust chamber, as shown in Figure 2., surrounds the barrel and the exhaust ports. Based on a yield strength of 40,000 psi, the exhaust chamber can withstand an internal pressure of 30,000 psi, which is never approached at any powder load. The inner volume of the chamber is more than 1/8 $ft.^3$, while the volume of the powder gases is less than 1/11 $ft.^3$ for full powder charge. Thus the strength and size of the exhaust chamber are more than adequate. Two exhaust pipes are provided at the rear end of the chamber. When a vacuum is pulled, stop cocks are held against the ends of these pipes. The exhaust pipes and exhaust chamber also help in reducing the noise.

6. Supports and Recoil

The barrel is supported by two support blocks mounted on a wide flange beam as shown in Figure 2. When the accelerator is fired the barrel recoils and slides through brass collars. The clearance between the barrel and the collars is very small so that the entire recoil energy is dissipated in friction between the sliding surfaces. Special clamps are designed to support the impact chamber and the target holder. It has been observed that the recoil is not noticeable during firings.

7. Projectile and Target Specimen

A three ounce projectile is shown in Figure 3. It consists of a steel rod with Lexan sabots mounted to avoid metal to metal contact between the barrel and the projectile. Sabots are also provided so that the diameter of the projectile could be small enough to allow a suitable length. The rear end of the projectile is inserted in a loaded 20 gauge shell which is trimmed at the end and the lead shot removed.

The target specimen is identical to the projectile and is held in the target holder which is aligned with respect to the barrel so the target specimen is coaxial with the bore of the barrel in order to ensure axial impact. The impacting ends of the target and projectile are machined perpendicular to their axes for the same reason.

8. Theoretical and Experimental Curves

Prediction curves for the 16mm accelerator were plotted from the theoretical data obtained by using equations (4), (7) and (9). All computations were made on an IBM-1130 Computer. The program which is written in Fortran IV Language is shown in the Appendix (A) of reference [5]. The program was so written that the velocities and pressures were computed for projectile weight varying from one quarter ounce to five ounces with increments of one quarter of an ounce, and powder weights varying from two grains to twenty-six grains with increments of two grains. Sample calculations and tables are shown in Appendix (A) of Reference [5].

Figure 4. shows the velocity-travel curves for different projectile weights and full powder charge. These plots indicate that increasing the length of the barrel beyond five feet does not help significantly in increasing

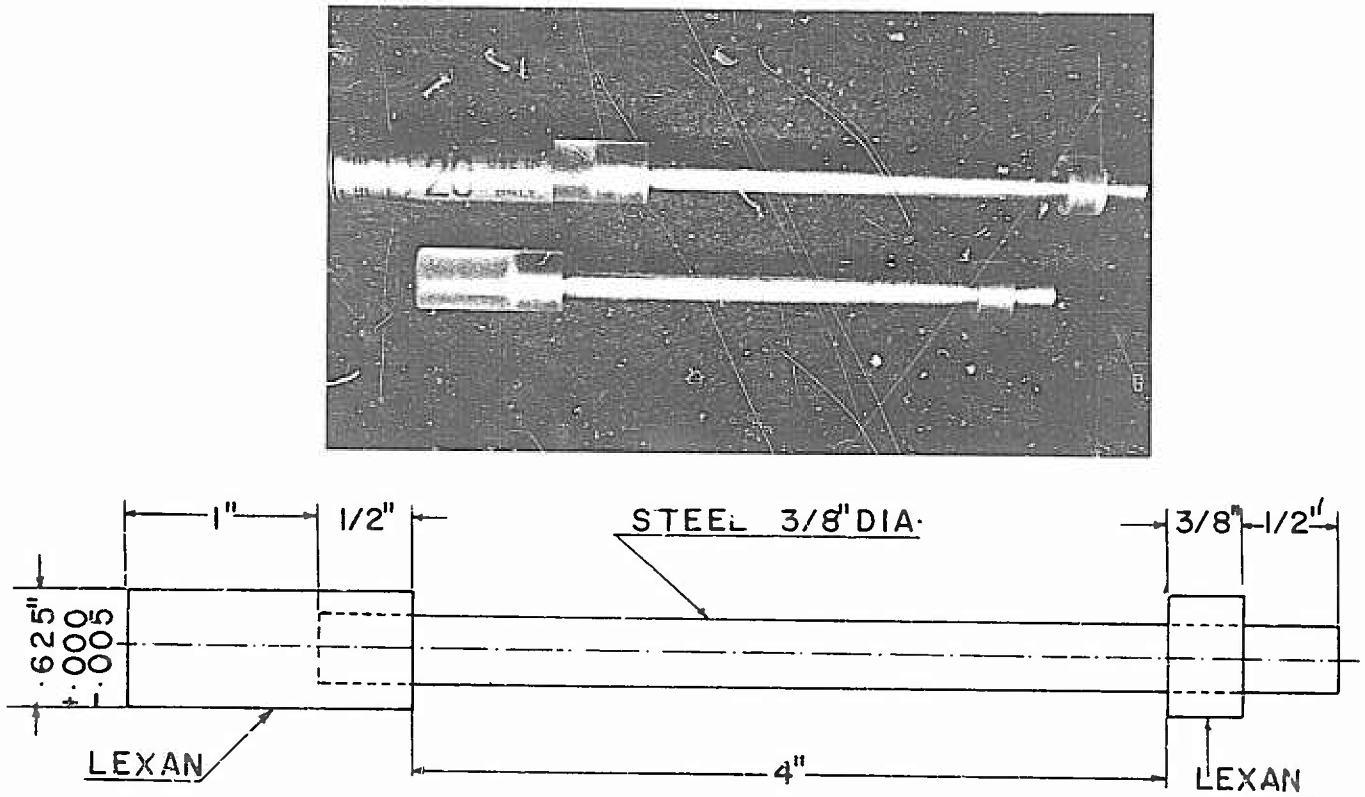


Figure 3. A Three ounce projectile for the 16mm accelerator.

the velocity of the projectile. On the contrary, the velocity might decrease with further barrel length if there is considerable friction between the barrel and the sabots. Figure 5. shows powder charge-muzzle velocity curves for different projectile weights. These curves indicate that for higher powder weights the muzzle velocity varies linearly with the powder charge. Curves showing the variation of muzzle velocity with projectile weight for constant powder charge are shown in Figure 6. It can be seen from the plots that muzzle velocity varies very rapidly with the projectile weight for lighter projectiles while the variation in the velocity is less for heavier projectiles. Pressure-travel curves for different projectile weights at full powder charge are shown in Figure 7. The curves indicate that maximum pressure is attained at a projectile position very close to the breech and, after which the pressure drops rapidly as the projectile travel increases.

Projectile velocities with 2-1.4 and 3-1.4 dram equivalent, 20 gauge magnum shells recorded by W. L. Liddell, one of the graduate assistants, during the test for the determination of strains and strain rates are shown in Figure 8.

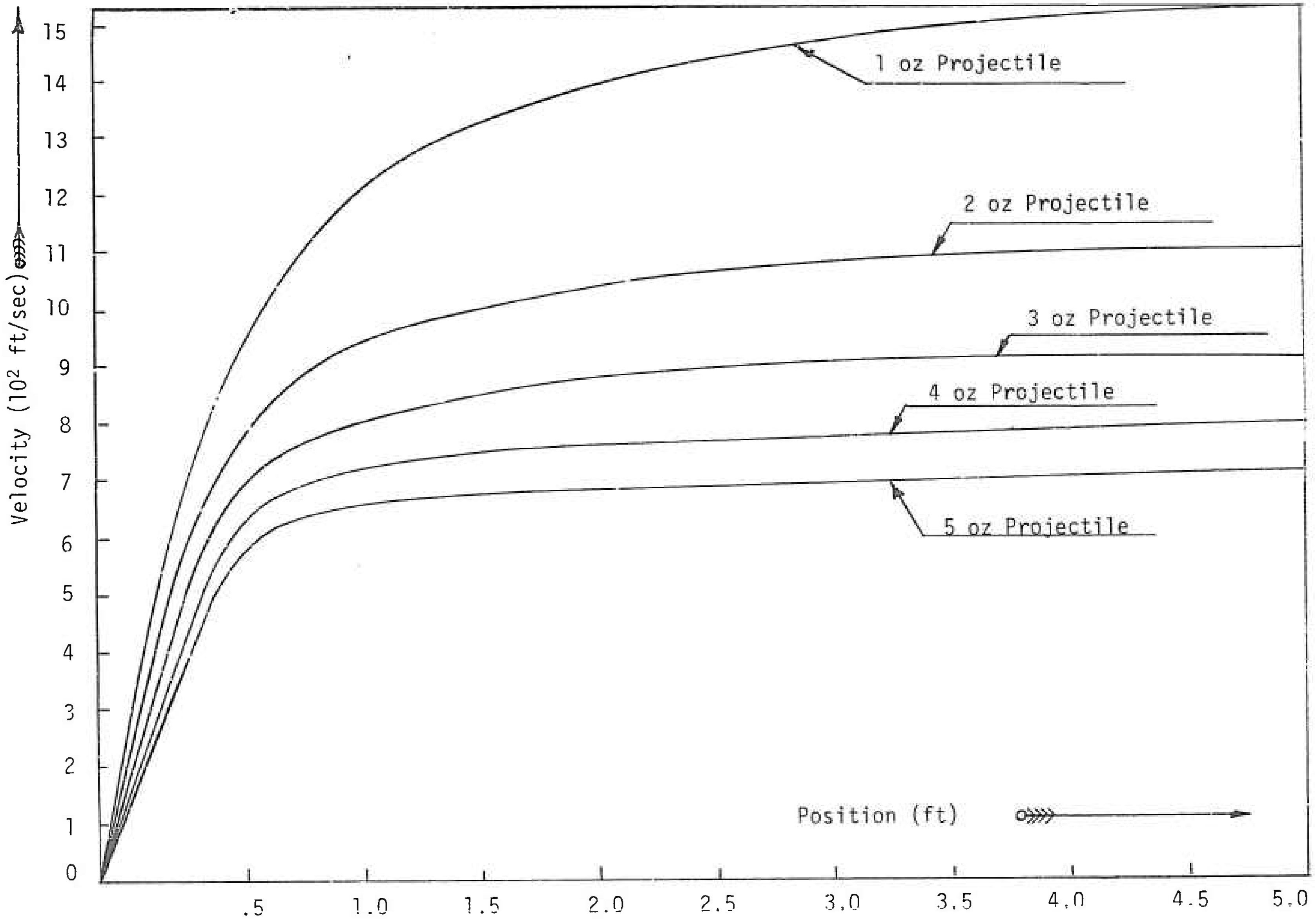


Figure 4. 16mm accelerator — Velocity Vs Projectile travel for full powder charge (25.7 grains).

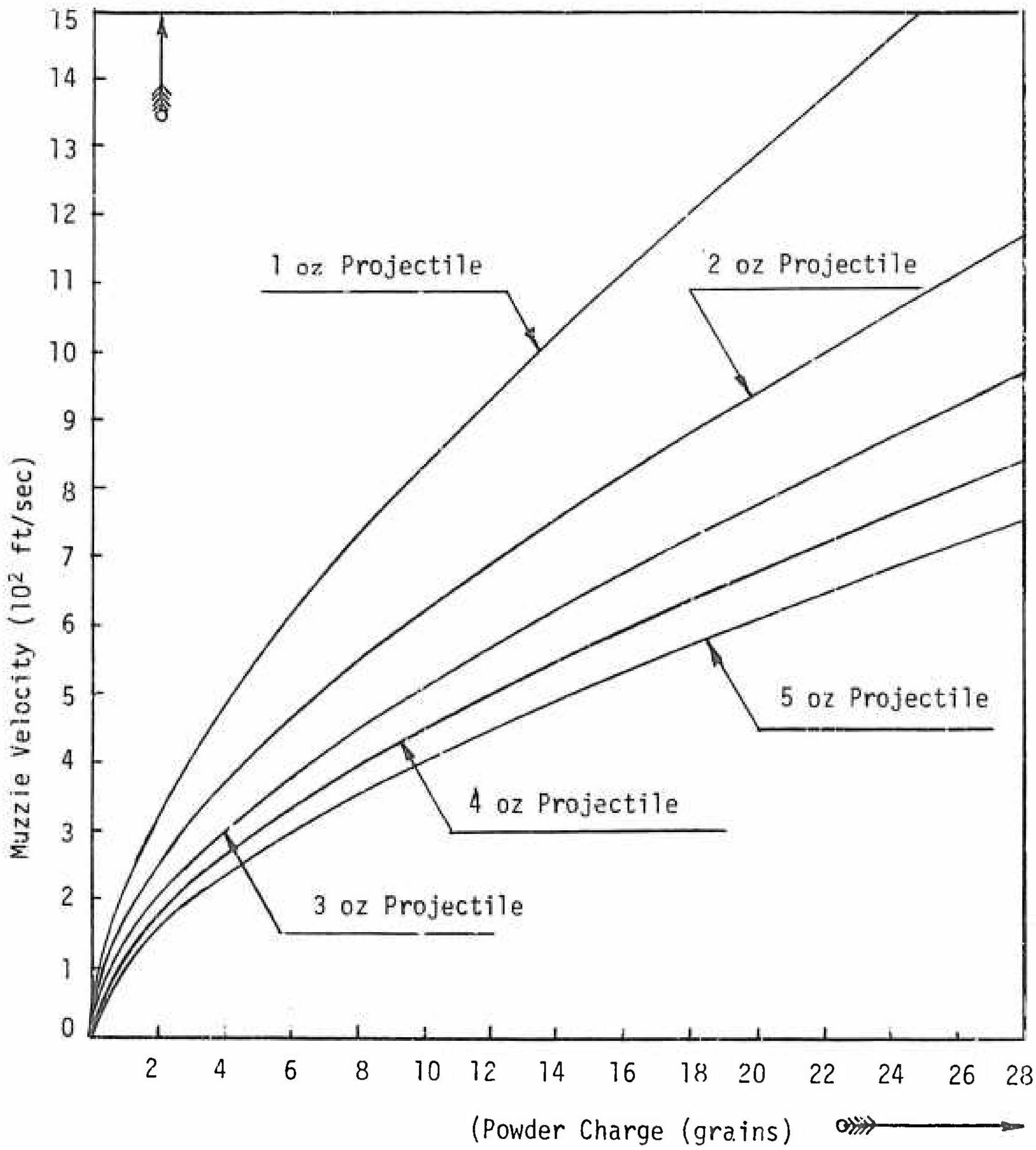


Figure 5. 16mm accelerator - Powder Charge Vs Muzzle Velocity.

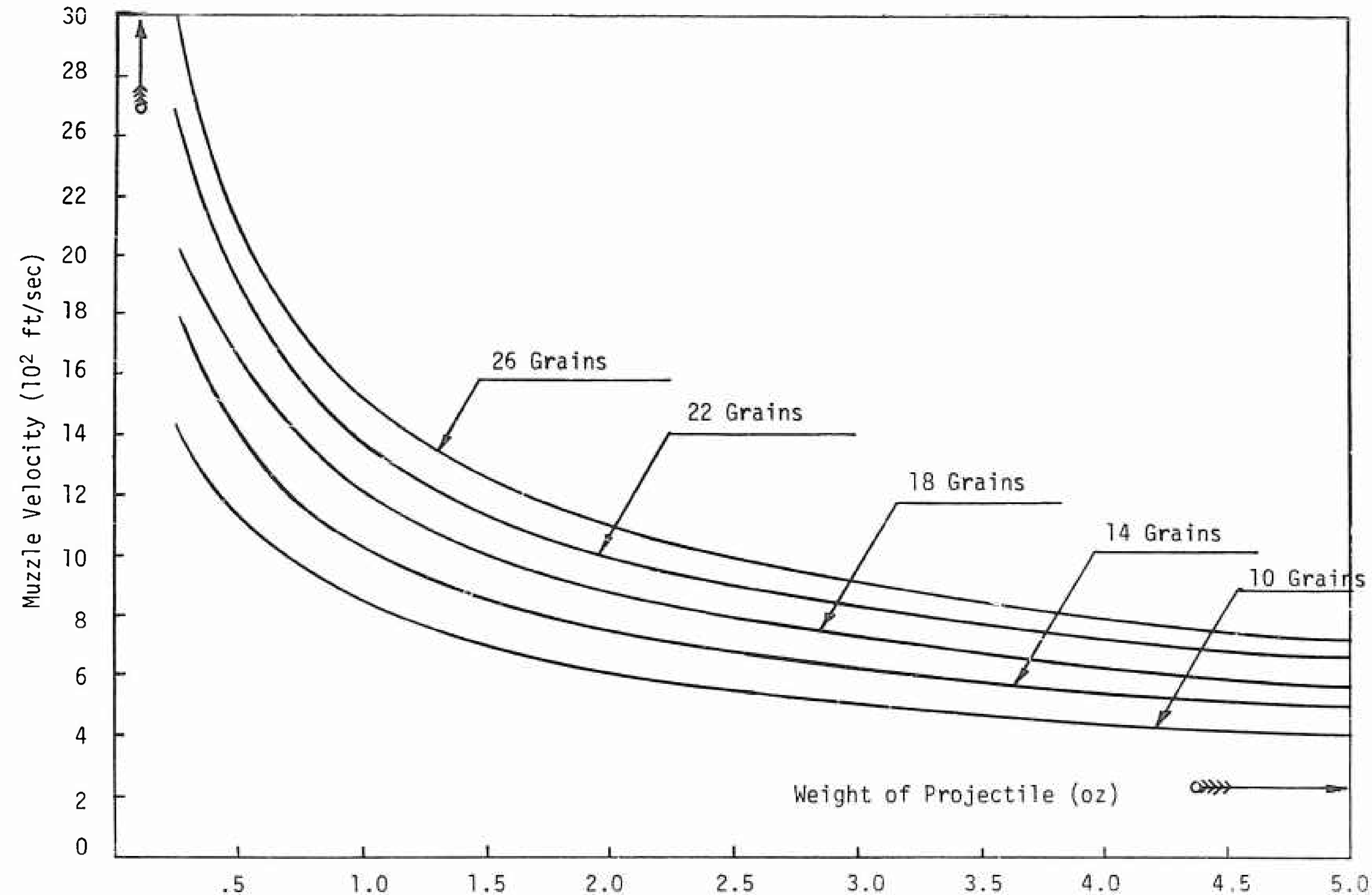


Figure 6. 16mm accelerator — Projectile weight Vs Muzzle Velocity.

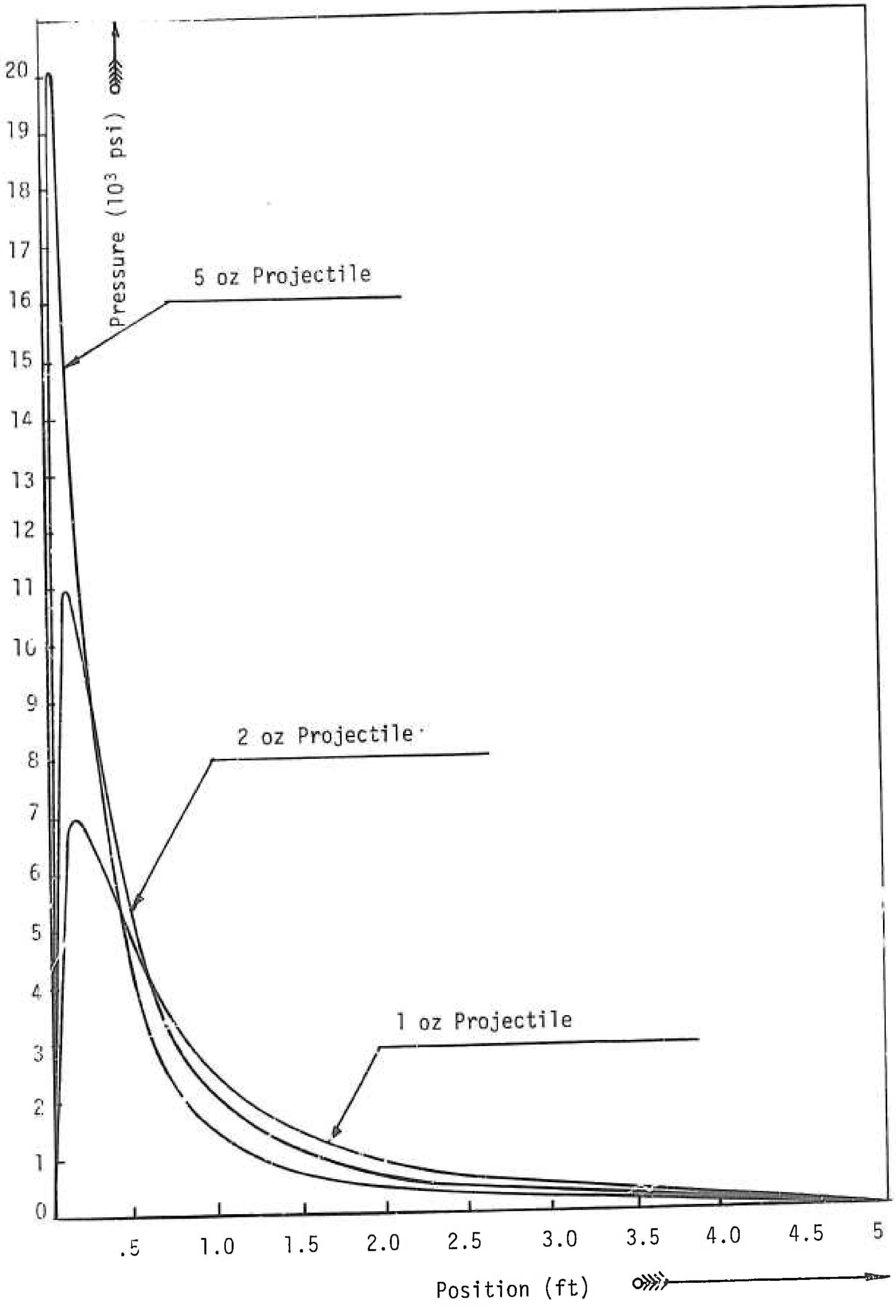


Figure 7. 16mm accelerator — Pressure Vs Projectile travel curves for full powder charge (25.7 grains).

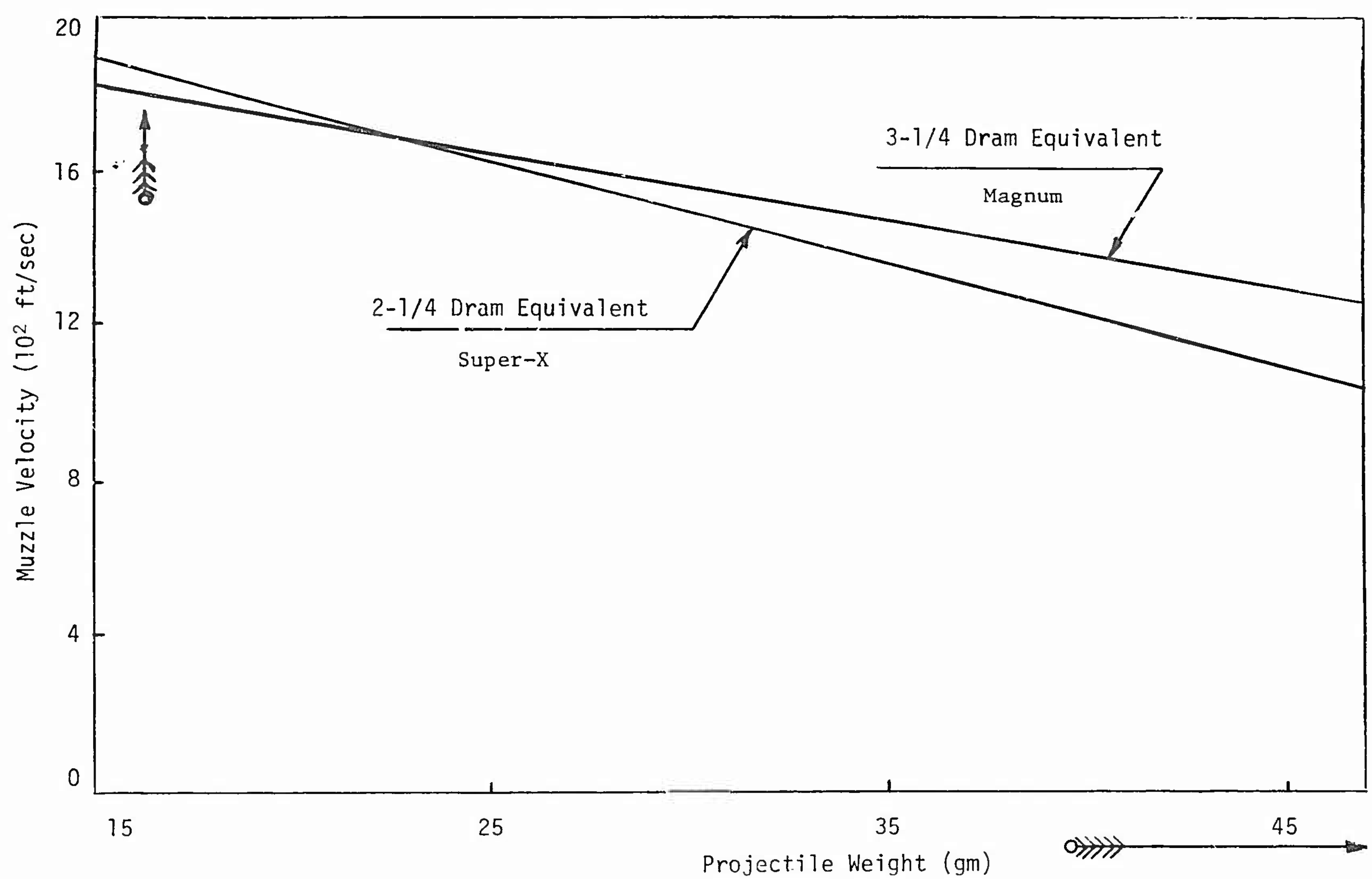


Figure 8. 16mm accelerator — Velocity Vs Projectile weight (experimental curves).

THE 19mm ACCELERATOR SYSTEM

A 19mm accelerator was designed to serve as a back-up system to the 16mm system and also to permit the measurement of circumferential strains and strain rates. This system differs from the 16mm system in the following ways.

1. The accelerator is designed to use 12 gauge shells, with shot removed, as propelling charge.

2. The accelerator barrel is enclosed in a concentric jacket.

3. The barrel and jacket assembly is mounted on v-block supports. The recoiling assembly slides freely on the supports.

4. Instead of venting the barrel into an exhaust chamber, O-ring sealed vent plugs are employed to vent directly to atmosphere.

5. Instead of using a concentric cylindrical tube as an impact chamber, a heavy walled rectangular tube is used.

6. Instead of stopping the projectile and the target in the target holder after impact, a heavy walled rectangular tube with energy absorbing material is used as a catcher.

1. Design of Barrel and Jacket

The barrel of the 19mm accelerator, which is designed to use 12 gauge shotgun shells as propellent, is shown in Figure 9. A 3 inch magnum shell with 38 grains of gun powder is used as propellent for all calculations in this section. The barrel is 7 ft. 2 in. long with exhaust ports at 3-1/2 ft. from the breech end. O-ring grooved exhaust port plugs are designed to close the exhaust ports while pulling vacuum. The outer diameter and thread specifications on both the 16mm and 19mm accelerators are the same, so that

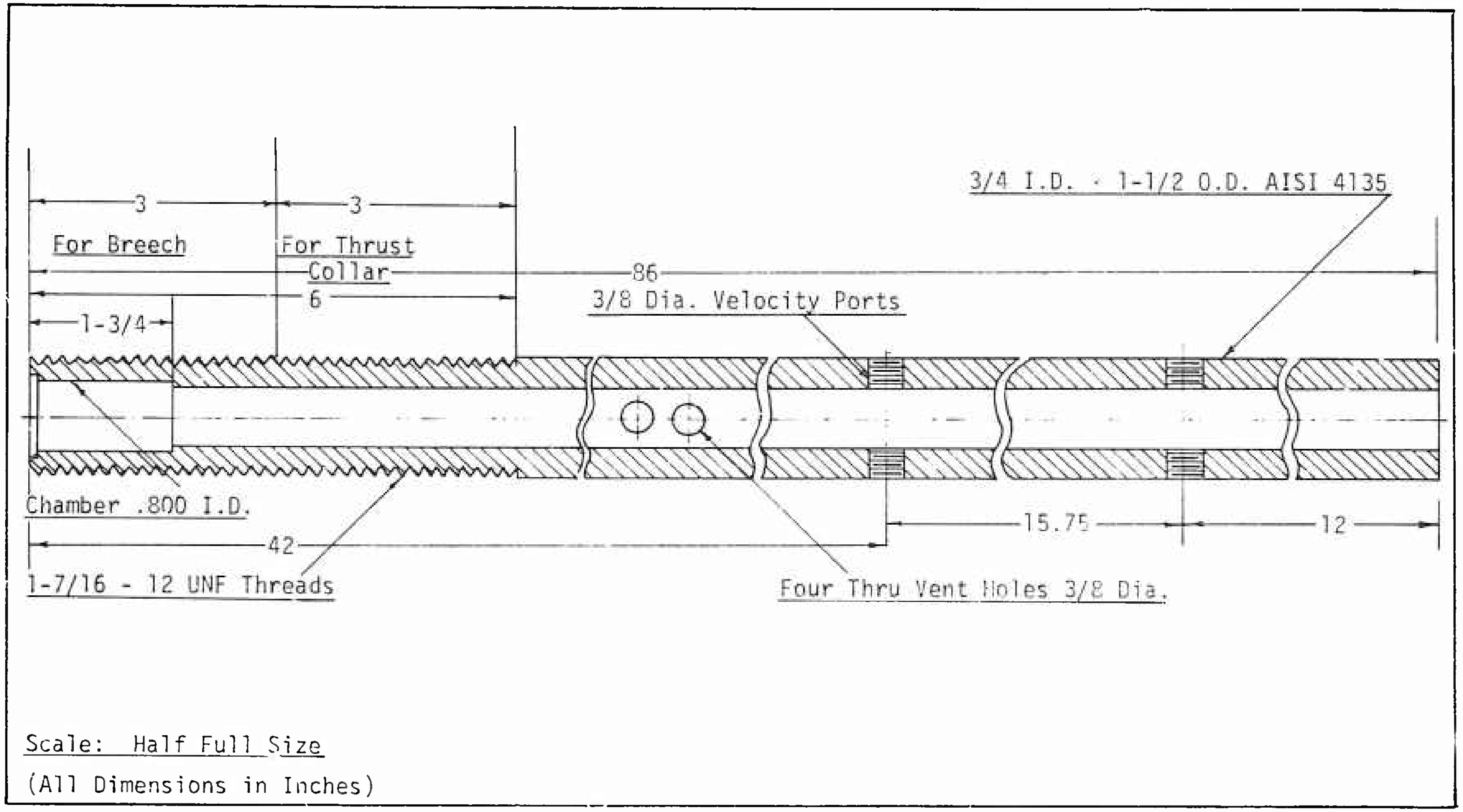


Figure 9. Accelerator Barrel for 19mm System.

the breech mechanism designed for the 16mm system can also be used for the 19mm system.

A mechanical tubing of 2-1/2 inch inner diameter and 3-1/2 inch outer diameter is used as a jacket. The jacket serves the following purposes.

1. Provides a means of bore alignment and alignment retention.

2. Acts as a safety protection in case of failure of the barrel.

3. Decreases the kinetic energy of recoil by increasing the mass of recoiling parts.

4. Any desired modes of lateral vibrations of the barrel can be eliminated by selecting proper locations and number of alignment screw stations.

The outer surface of the jacket is machined for about 15 inches from each end to provide a bearing surface, so that the barrel and jacket assembly may recoil freely on the v-blocks. The barrel is supported in the jacket by a thrust collar and alignment screws at five locations. The moment of inertia of the jacket cross-section is about twenty-three times that of the barrel, which ensures that the jacket will not deflect significantly while straightening the barrel. The muzzle end of the barrel-jacket assembly resting on a v-block is visible in Figure 10.

2. Impact Chamber and Catcher

The impact chamber, which also acts as a target holder, is shown in Figure 10. It consists of a thick walled rectangular tubing. Tapped holes are provided in the walls of the impact chamber for aligning the target. Cross slots are provided on the two sides of the impact chamber to provide optical path for the light beams for longitudinal and circumferential measurements. The slots are covered by optical flats.

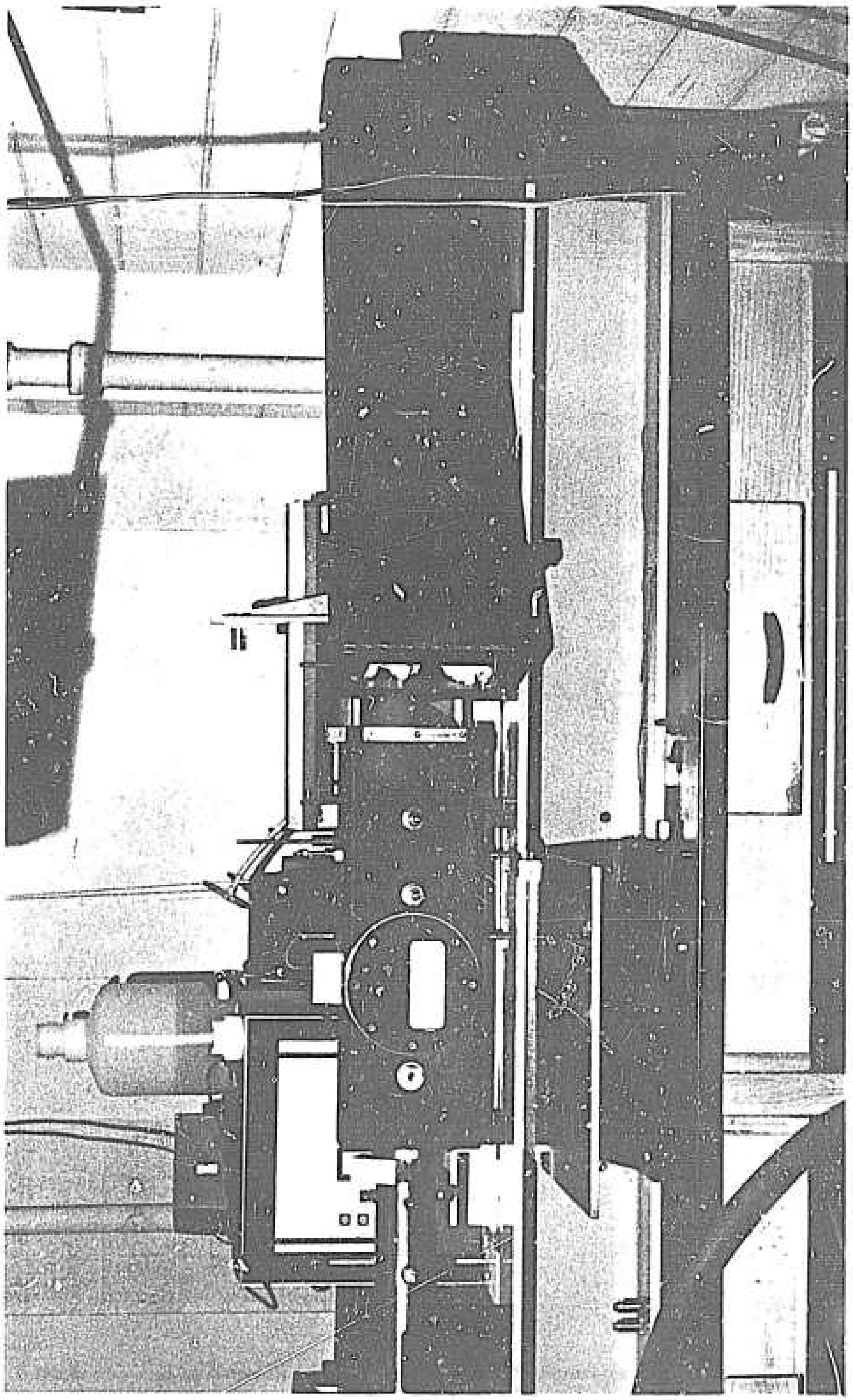


Figure 10. Muzzle end, impact chamber and catcher of the 19mm accelerator system.

The catcher, shown in Figure 10, is also constructed from a thick walled rectangular tubing. Parachute cloth is stuffed into the catcher in order to stop and retain the debris resulting from impact. O-rings are used to seal all the joints.

3. Projectile and Target

A three ounce projectile for the 19mm accelerator is shown in Figure 11. The design of this projectile is identical to that of the projectile for the 16mm system. The target is identical to the projectile and is aligned with respect to the bore of the barrel with the help of a mandrel and an expendable sleeve. The sleeve, which holds the target, is held in aligned position by eight expendable screws.

4. Supports and Recoil

The barrel and jacket assembly is supported on two v-blocks. The support blocks are rigidly mounted on an 8 in. x 8 in., 96 in. long wide flange beam, as shown in Figure 12. Oilite pads are embedded in the faces of the v-blocks where the jacket is going to rest. When the accelerator is fired, the barrel and jacket assembly recoils and slides on these Oilite facings. The impact chember is rigidly bolted to the wide flange. Spacers are used to align the impact chamber with respect to the barrel. The catcher is pivoted to the wide flange by a bolt in the center of its bottom and can be locked in alignment with the barrel and impact chamber whenever necessary by two shear pins. The pivot hole is an oblong slot, so that the catcher can slide forward and backward on the wide flange and can be pivoted in the horizontal plane in order to permit insertion of parachute cloth and removal

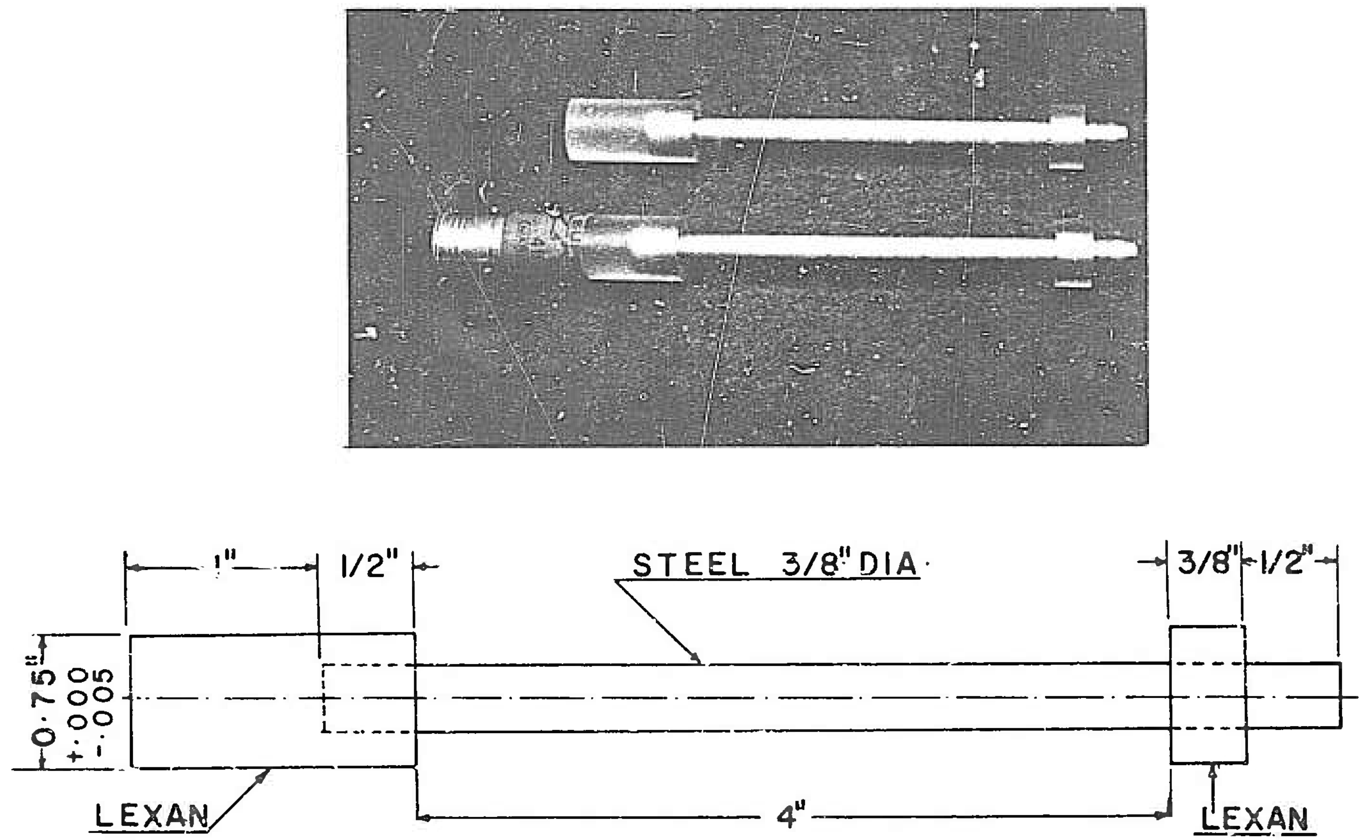


Figure 11. A Three ounce Projectile for the 19mm accelerator.

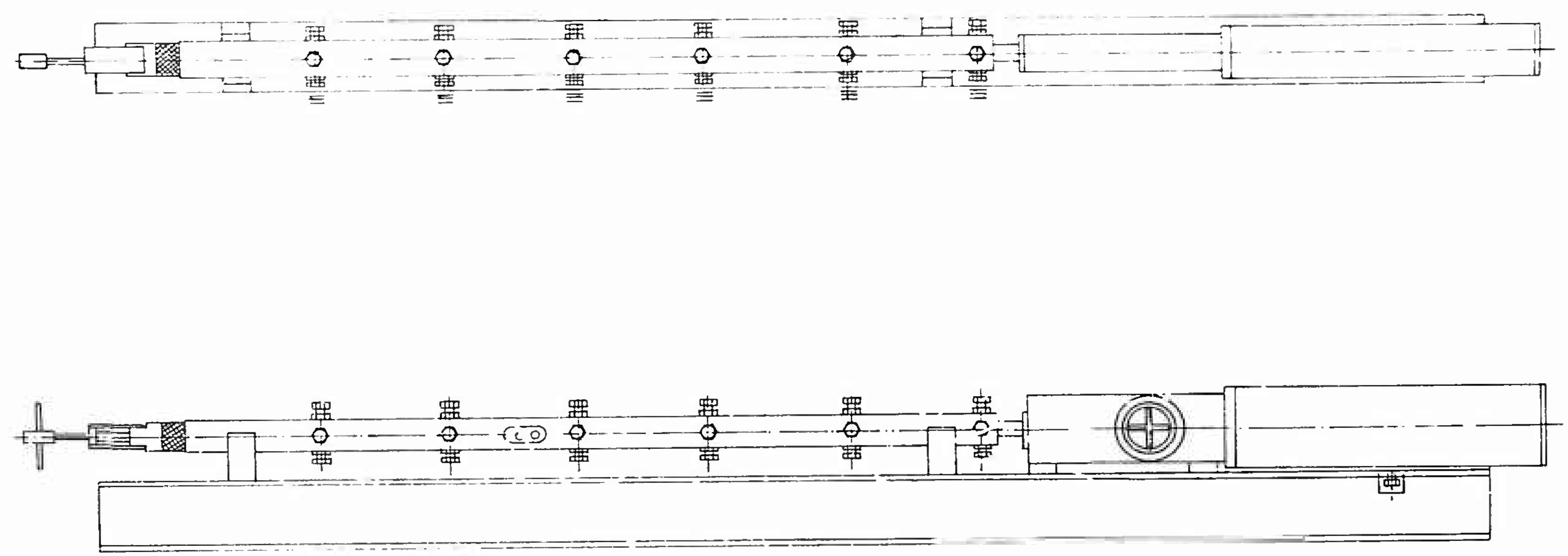


Figure 12. Assembled views of the 19mm accelerator system.

of cloth and debris resulting from impact. Two assembled views of the 19mm accelerator system are shown in Figure 12.

5. Prediction Curves for the 19mm Accelerator

A computer program similar to that for the 16mm system was written to compute the necessary data to plot the theoretical curves for the 19mm system. The powder weight varies from one to 40 grains in increments of two grains. The programs and sample calculations are shown in the Appendix B of Reference [5]. Velocity-travel curves for different projectile weights are shown in Figure 13. The velocity of the projectile increases very rapidly with the projectile travel up to one foot from the breech end, after which the increase in the velocity is not significant. It is observed that the projectile velocity remains practically unchanged beyond 3-1/2 ft. from the breech end of the barrel. Figure 14 shows the muzzle velocity-powder weight curves for constant projectile weight. The muzzle velocity varies almost linearly with the powder weight for more than twenty grains. Velocity-projectile weight curves for different powder weights are shown in Figure 15. Pressure-travel curves are shown in Figure 16. The conclusions drawn from Figures 15 and 16 are the same as those drawn from Figures 6 and 7 for the 16mm accelerator.

The experimental data, recorded by Dr. H. W. Blake in connection with the calibration of the 19mm accelerator, is shown in Table 12 in the Appendix B of Reference [5]. The experimental curves, which are in close agreement with the theoretical curves of Figure 15, are shown in Figure 17.

Experience with the 16mm and 19mm accelerators has shown that reloading shells with smaller powder charges than those for which they are designed gives unpredictable velocities. For producing low velocities with good reproducibility a conversion mechanism was designed by W. L. Liddell [3] to operate the 19mm powder accelerator as a compressed-gas accelerator. In the gas version of the 19mm accelerator the breech mechanism is replaced by the conversion unit. Projectile velocities up to 500 feet per second have been produced by the compressed-gas accelerator using Nitrogen as the propelling gas.

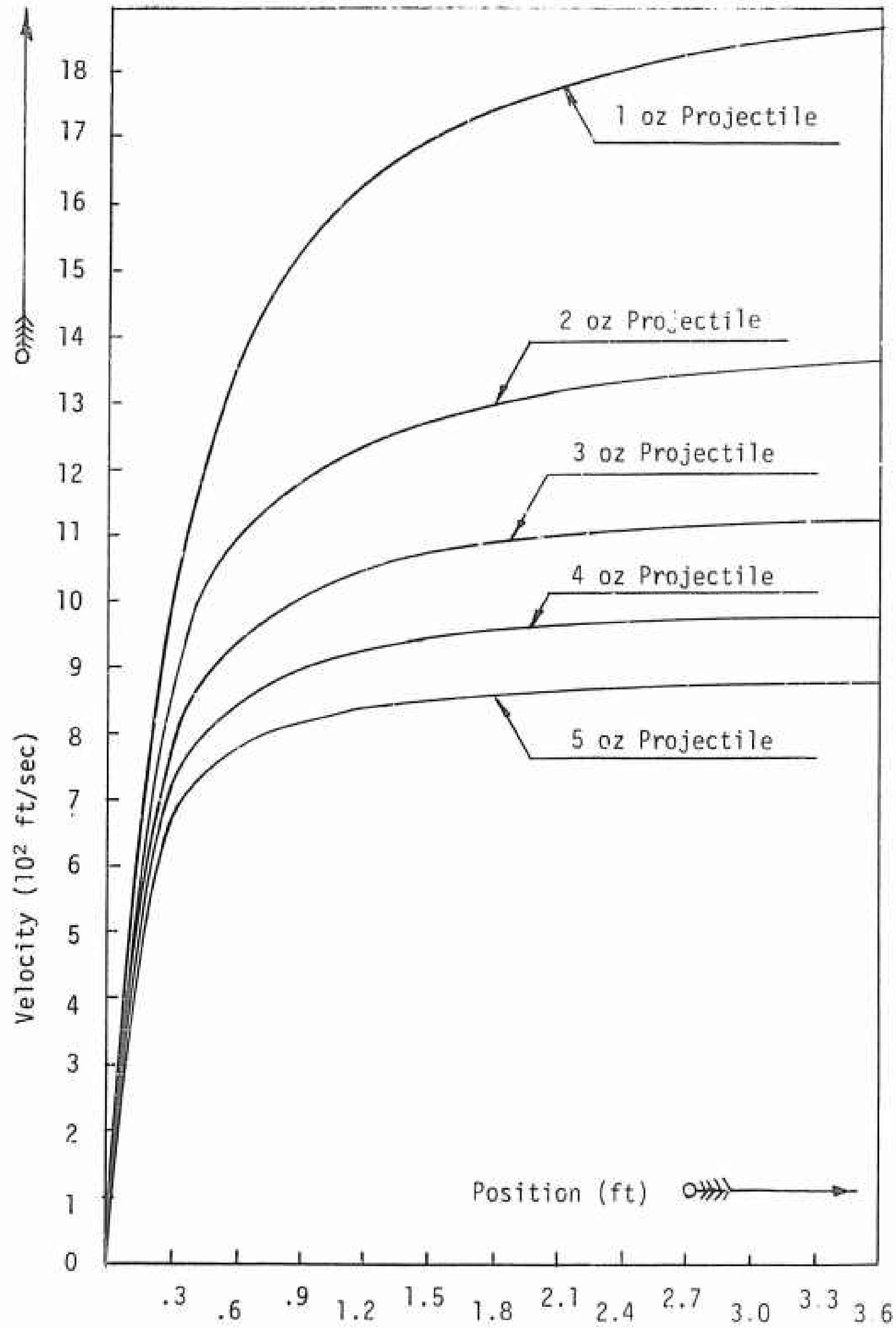


Figure 13. 19mm accelerator -- Velocity Vs Projectile travel curves for full powder charge (38 grains).

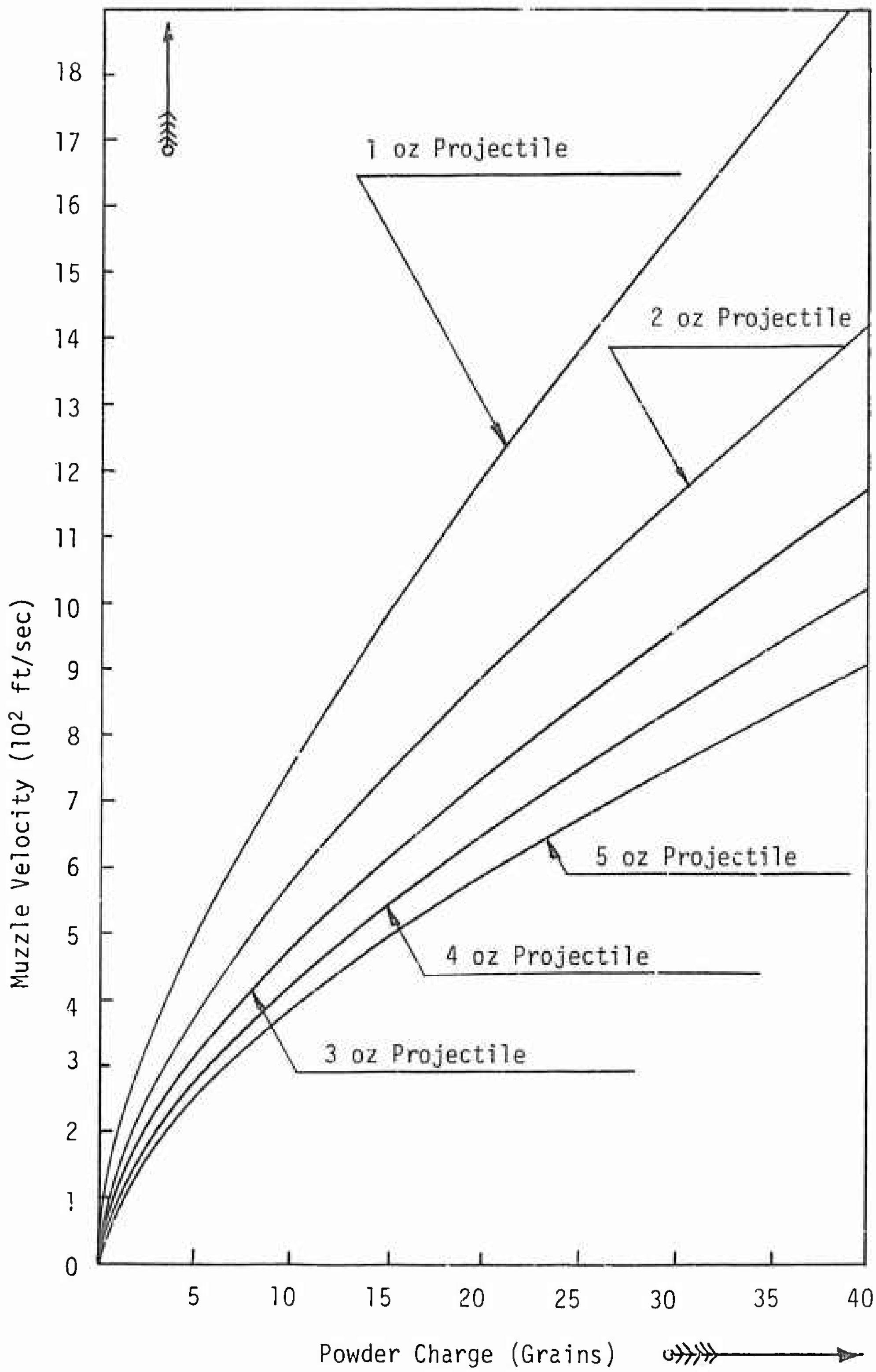


Figure 14. 19mm accelerator — Powder charge Vs Muzzle velocity.

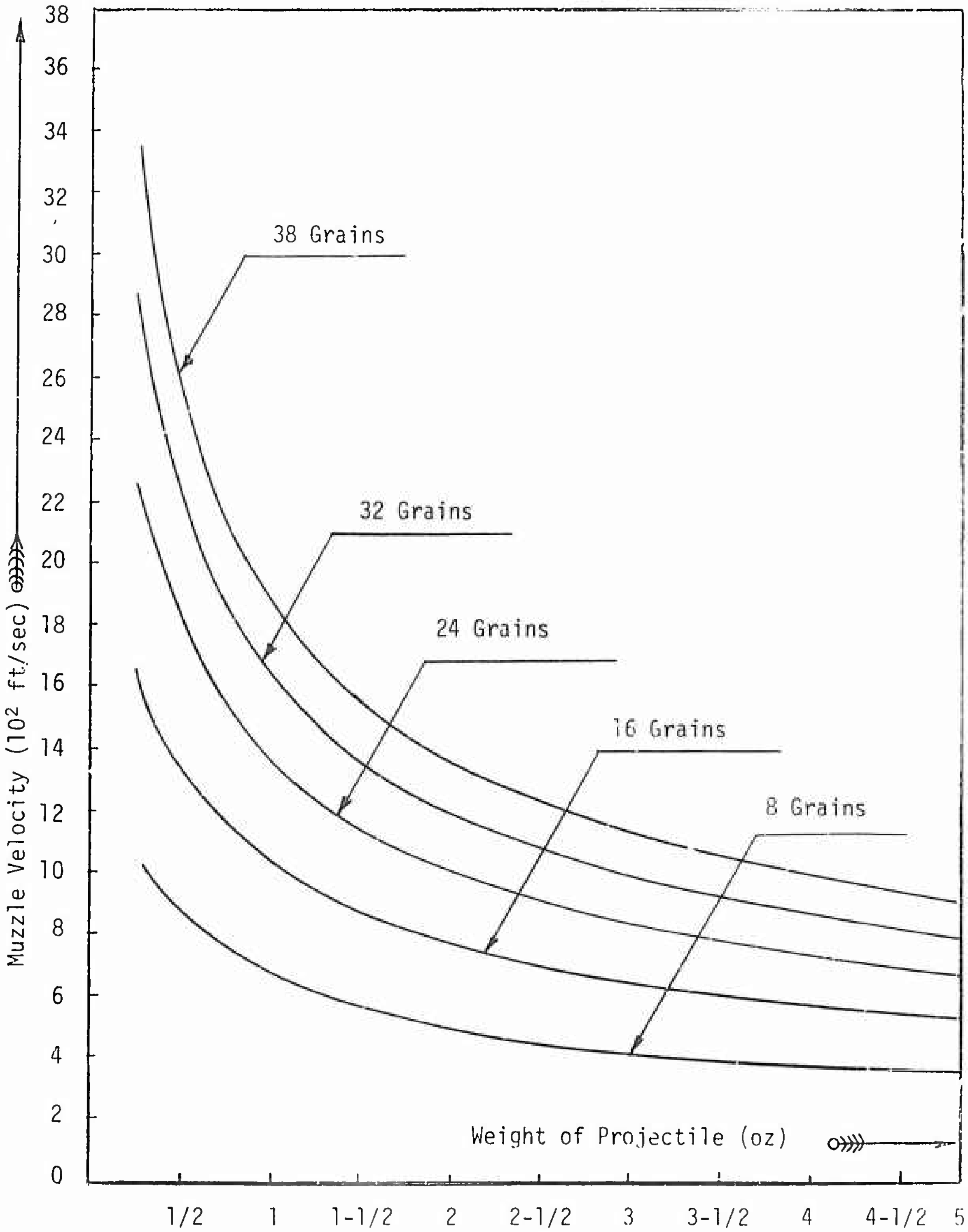


Figure 15. 19mm accelerator — Projectile weight Vs Muzzle velocity curves.

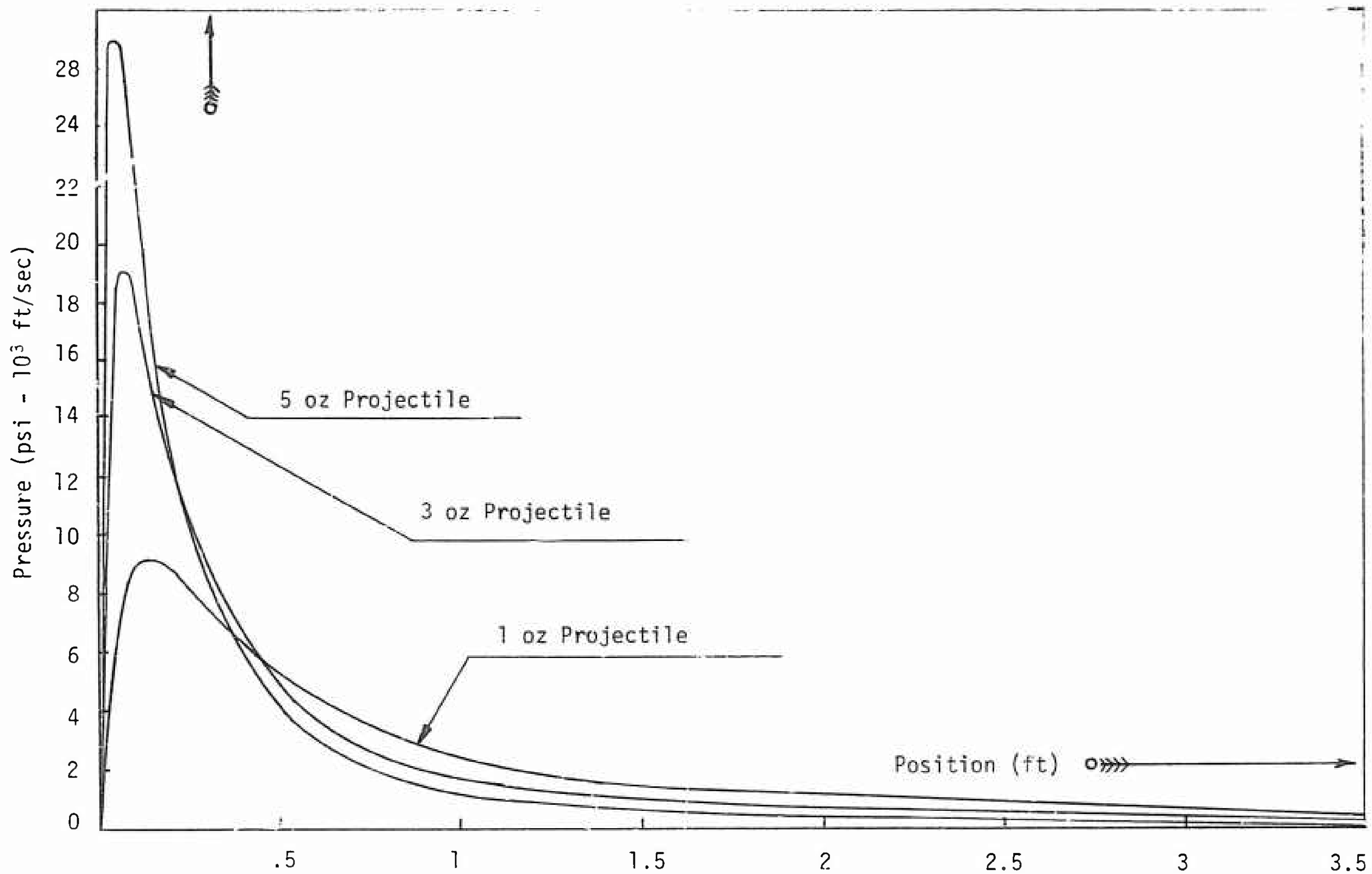


Figure 16. 19mm accelerator. Pressure Vs projectile travel curves for full powder charge (38 grains).

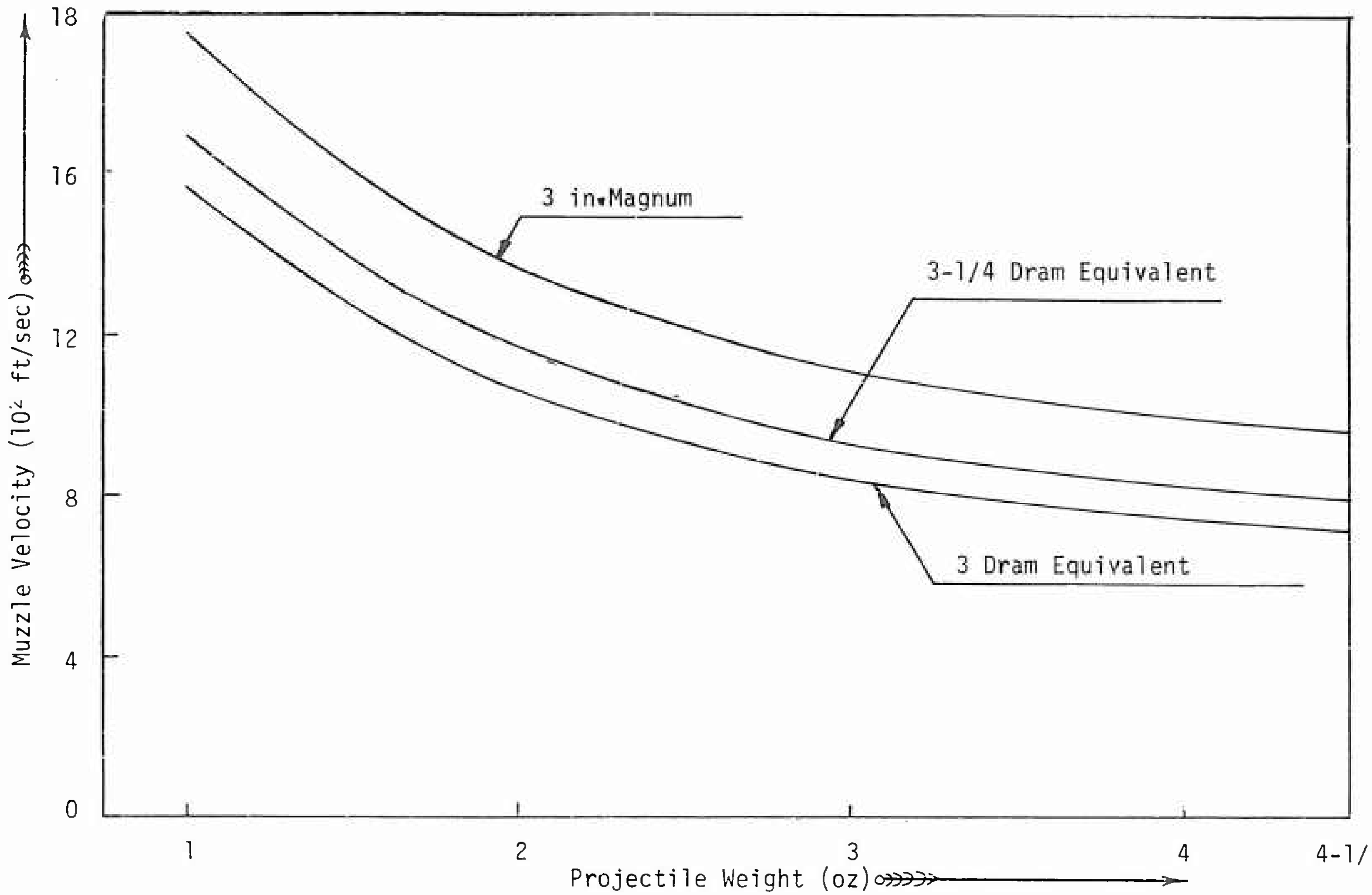


Figure 17. 19mm accelerator — Velocity Vs Projectile weight (experimental curves).

THE 50mm ACCELERATOR SYSTEM

The 16mm and 19mm accelerator systems are limited in specimen size to weights in ounces. A 50mm accelerator system was developed to accelerate projectiles weighing up to 3 pounds to muzzle velocities as high as 3000 ft/sec, producing a maximum kinetic energy of the order of 500,000 ft-lbs. This system is of the same basic design as the 16mm and 19mm systems so that instrumentation systems developed with the two smaller systems can be used directly with the 50mm system. The breech mechanism and barrel were designed and fabricated by the Utah Research and Development Company at Salt Lake City, Utah.

1. Barrel and Sleeve

The barrel of this system is 15 ft. long with 2 in. inner diameter and 5 in. outer diameter. External threads are provided on one end of the barrel to mount the breech on it while the outer diameter of the other end is reduced to 3 in. over one ft. length from the muzzle. Eight blast holes of one in. diameter were provided as shown in Figure 18, for venting the barrel. The barrel is supported in a 13-1/2 ft. long thick walled sleeve of 7 inc. I.D. and 11 in. O.D. by alignment capscrews and an internal spacer as shown in Figure 18. Two 15 in. long, 2 in. wide slots opposite to each other are provided in the sleeve in order to have access to the blast holes. The outer surface of the sleeve is machined for about 28 in. from each end to provide a smooth contact surface for the supporting rollers and recoiling assembly.

2. Breech Mechanism

The breech mechanism of the 50 mm accelerator is designed for a maximum load of 850 grams of gun powder. Spacers are provided to be used for

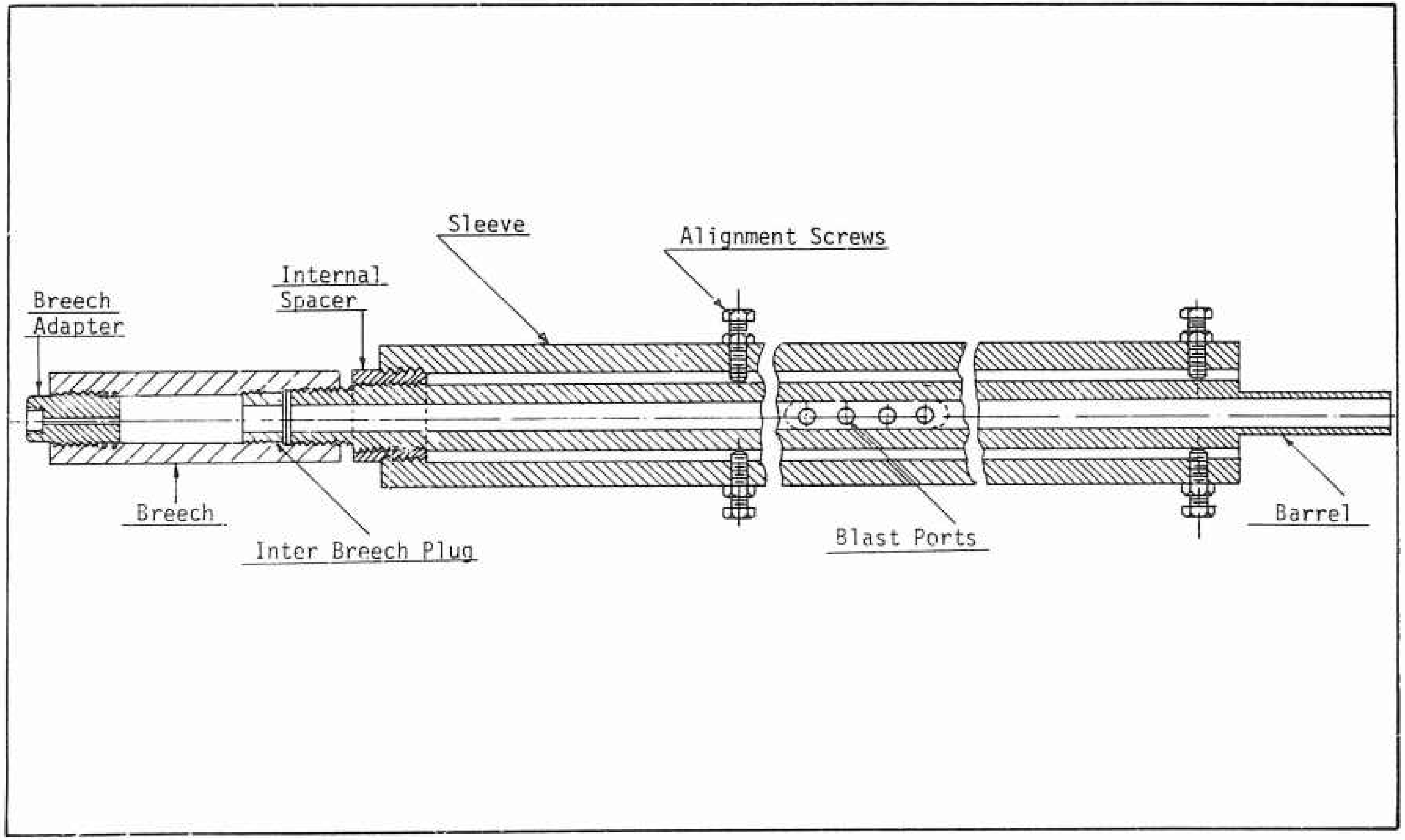


Figure 18. 50mm accelerator — barrel, breech and jacket assembly.

smaller powder charges. When the spacers are used, the amount of powder that can safely be used decreases linearly as the spacers increase. The following chart gives the proper spacers to provide a usable volume in the breech:

640 - 850 grams	No spacer
440 - 640 grams	1/4 breech volume spacer
240 - 440 grams	1/2 breech volume spacer
0 - 240 grams	3/4 breech volume spacer

3. Theoretical Curves

Since each accelerator, usually, has unique firing characteristics, it is necessary to establish the powder and projectile weight versus velocity curves for the particular accelerator. A relationship to calculate approximate values, however, was provided as

$$0.2\ M_p E_p = 1/2\ m V^2 \tag{14}$$

where, M_p = mass of powder,

E_p = specific energy of powder,

M = mass of projectile,

V = muzzle velocity.

The above equation, which is based on the assumption that 20 percent of the potential energy of the propelling gases is converted into the kinetic energy of the projectile, was furnished by the Utah Research and Development Company. Equation (14) can also be written as

$$V = \left(0.4\ M_p E_p/M\right)^{1/2}. \tag{15}$$

Muzzle velocities for projectile weights varying from 1/4 lb. to 3 lbs. and powder weights varying from 50 grams to 850 grams were calculated, using equation (15) for a typical gun powder (IMR 4064) of specific energy of

4400 Joules per gram. The results and specimen calculations are shown in the Appendix C of Reference [5]. The theoretical curves are shown in Figures 19 and 20. Figure 19 shows Muzzle velocity - Powder weight curves for constant projectile weights. It is observed that the velocity of the projectile increases with the powder weight. The velocity increases almost linearly with powder weight more than 400 grams. Muzzle velocity - Projectile weight curves for 850, 650, 450, 250 and 50 grams of powder charge are shown in Figure 20.

4. Accelerator Supports

The barrel and jacket assembly was designed to recoil freely on two frictionless roller support blocks (Figure 21) which were mounted on an 18 ft. long 36 in. standard wide flange beam. The instrumentation systems developed for 16mm and 19mm systems were designed to work in a plane 51 in. above the floor level. Therefore, spacers were used under the support blocks for 50mm accelerator to raise the axis of the accelerator to 51 in. above the floor.

5. Mufflers

The reasons for evacuating the barrel and the impact chamber and for venting the barrel have already been mentioned in the introduction. Eight blast holes, four on each side of the barrel of 50mm accelerator, are provided at 10 ft. from the breech end. The axes of the holes are horizontal and 3 in. apart. Two mufflers were designed as shown in Figure 22. The mufflers are mounted on 4 in. I-beams. The function of these mufflers is to reduce the noise and reduce the pressure of the powder gases behind the projectile in order to create a condition of free flight of the projectile. Muffler extensions were designed to guide the gases into the mufflers. The free ends

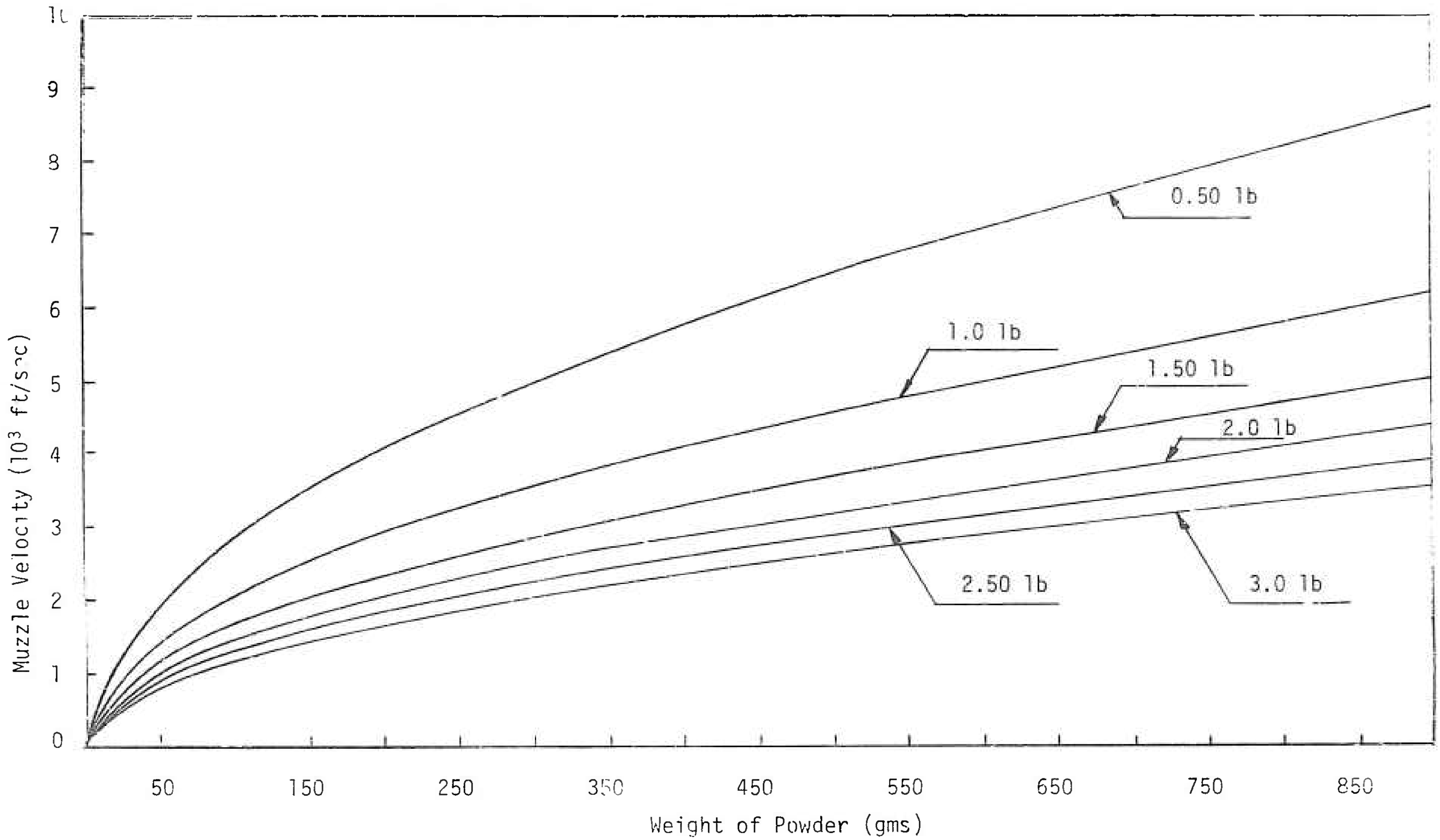


Figure 19. 50mm accelerator — Muzzle velocity Vs powder weight (Theoretical curves).

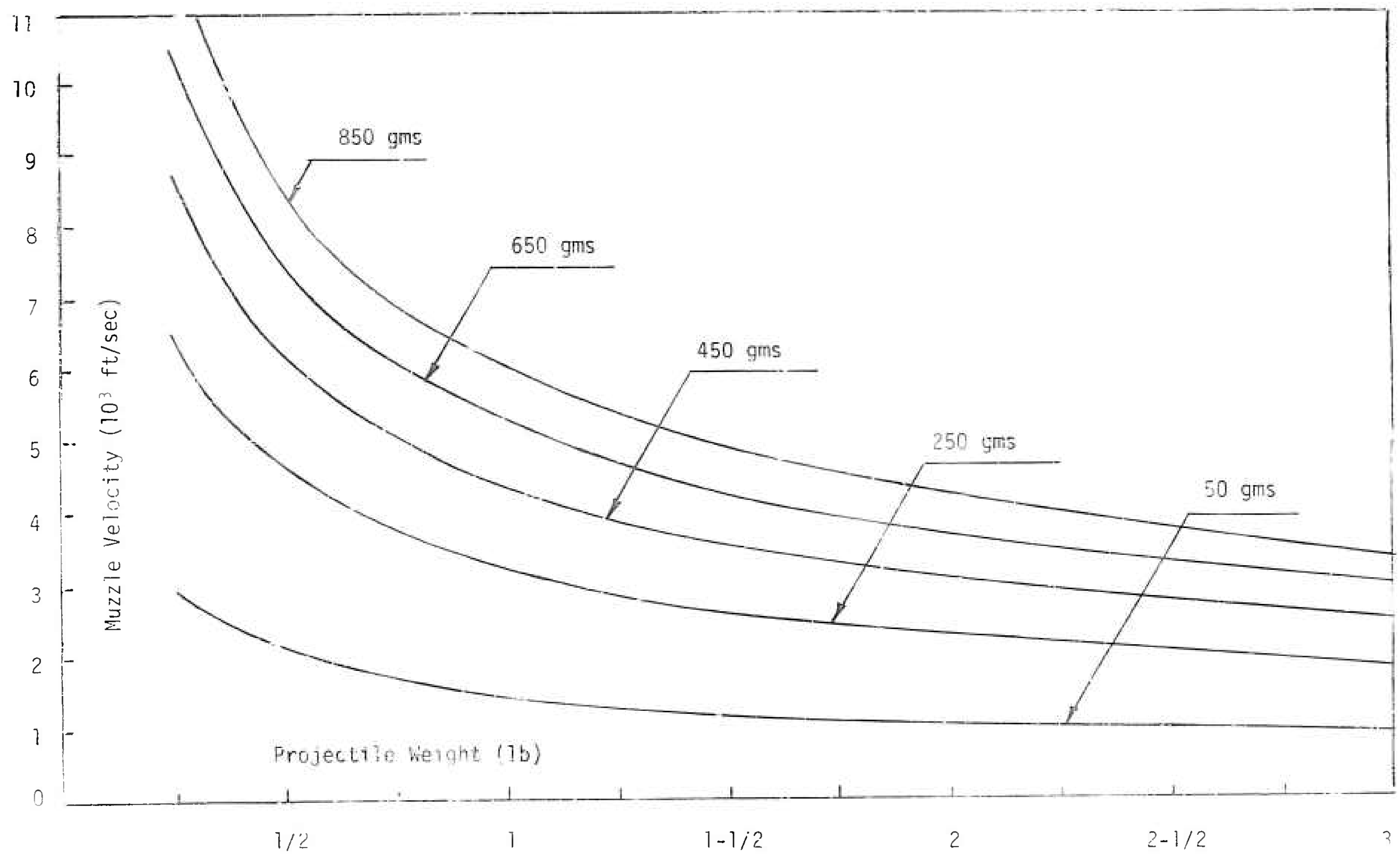
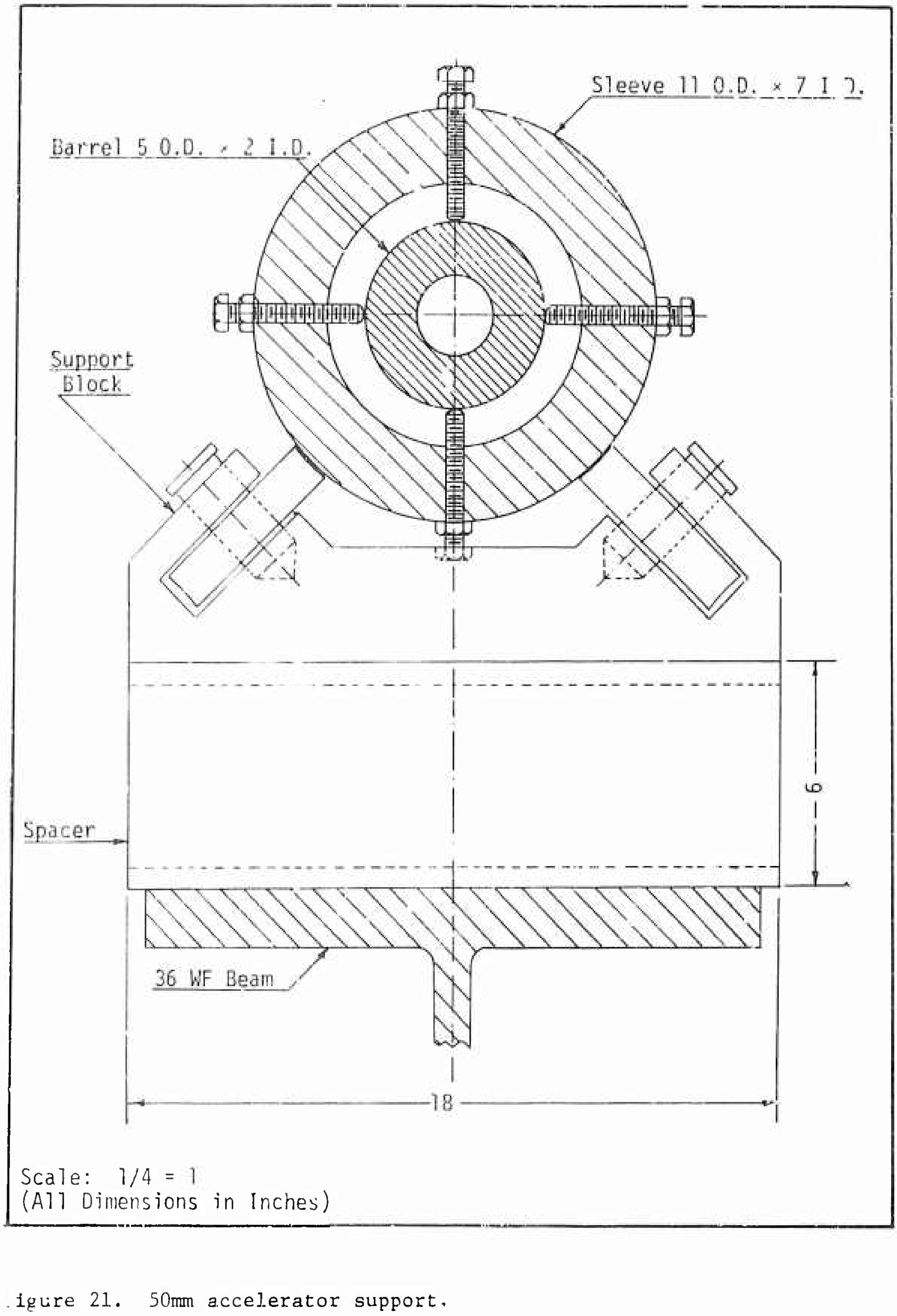


Figure 20. 50mm accelerator — Muzzle velocity Vs projectile weight (Theoretical curves).



igure 21. 50mm accelerator support.

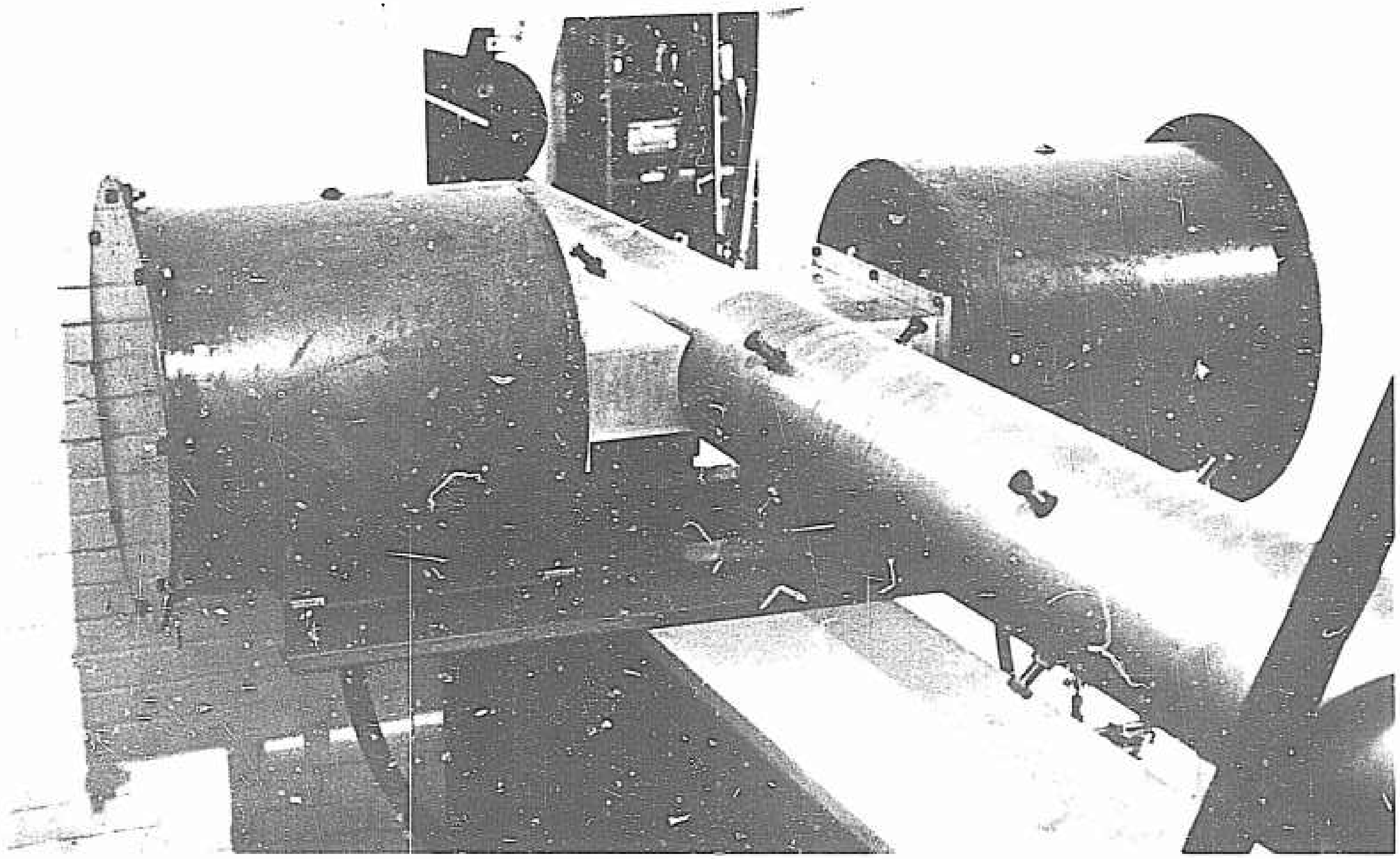
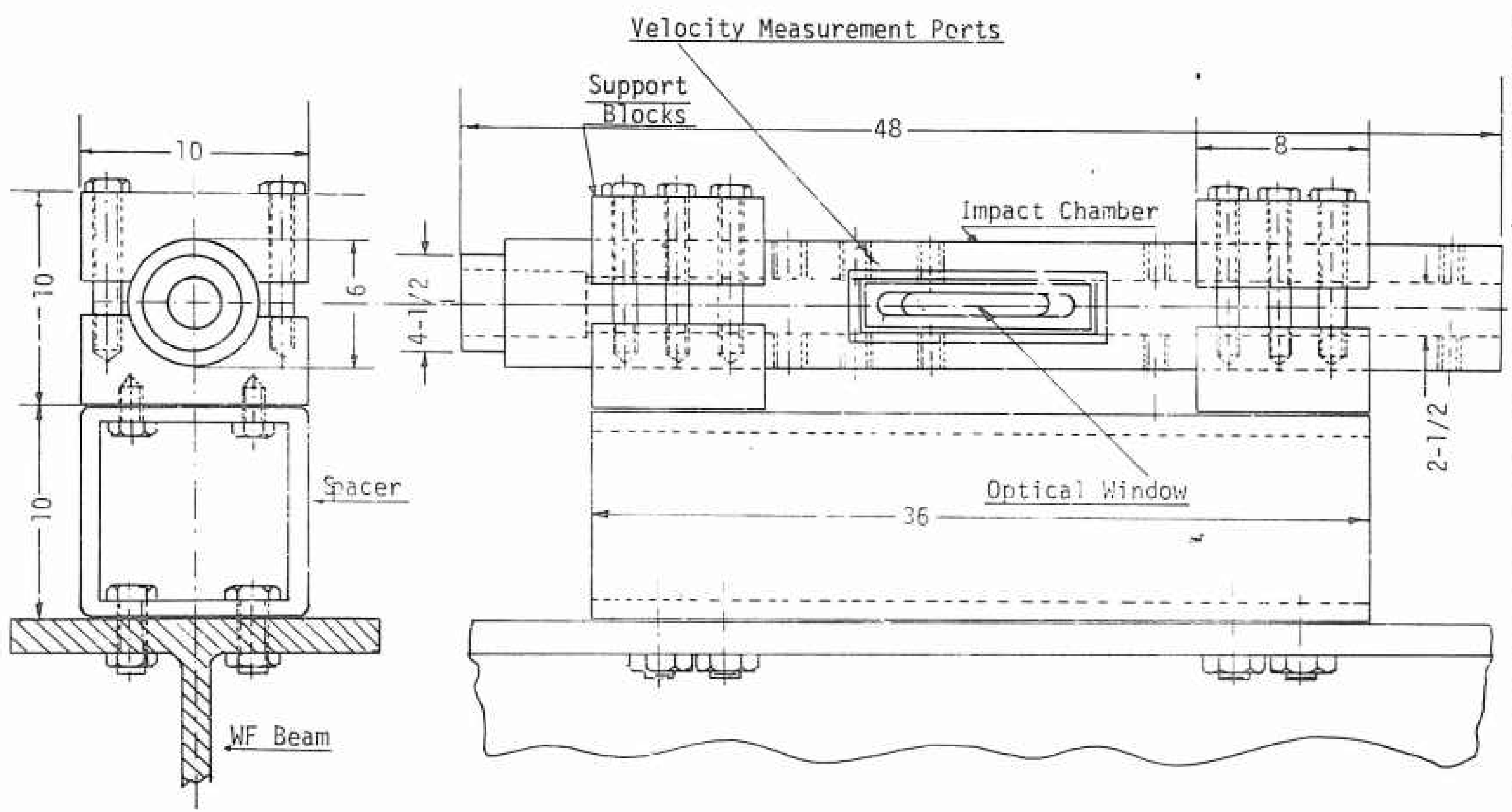


Figure 22. Mufflers for the 50mm accelerator system.

of the extensions are set very close to the outer surface of the accelerator sleeve. Rectangular openings, 6 in. x 18 in., were provided at the front ends of the mufflers facing the barrel. The extensions are mounted on these openings with aluminum diaphrams to close them. Rubber gaskets are used to make the joints air tight. The rear ends of the mufflers are closed by cover plates with bolts and gaskets. The blast holes are blocked by an air conditioner tape and the mufflers are evacuated while firing the accelerator. When the projectile passes the blast holes, the gases behind the projectile break the tape and enter the mufflers bursting the diaphrams.

6. Impact Chamber

The impact chamber for the 50mm accelerator system consists of a 4 ft. long mechanical tubing machined as shown in Figure 23. The end of the impact chamber which lies towards the accelerator was reduced on the outer diameter to 4-1/2 in. over a 2 in. length. A rubber boot, which connects the accelerator barrel and the impact chamber to provide a vacuum seal, is mounted on this reduced section. The inner diameter of the same end of the impact chamber was enlarged to 3-1/4 in. over a 6 in. length of the tube, so that the barrel could be moved into it in order to stop the rubber boot from collapsing. Before firing the accelerator the barrel is moved forward to rest against the 1/8 in. shoulder in the impact chamber. Two sets of tapped holes are provided 3 in. apart to house the velocity measurement plugs. Tapped holes are also provided at three other stations, as shown in Figure 23, for the alignment of the target. There are four alignment holes at each station. A rectangular optical window is provided in the middle of the impact chamber. The window is 3 in.long and 1/2 in.



Scale: 1/8 = 1 (All Dimensions in Inches)

Figure 23. Impact chamber and Support System.

wide at the inner surface and diverges to 6 in. long and 1 in. wide at the outer surface of the tube. An aluminum frame (not shown in the figure) was designed to hold an optical flat against the optical window. An O-ring groove is provided to seal the joint. The other end of the impact chamber which lies towards the catcher was machined so that an aluminum disc with a thin coating of vacuum grease could be used to close the end while evacuating the system. Two heavy support blocks were designed, as shown in Figure 23, to hold the impact chamber in position. The support blocks are fastened to a heavy walled square structural tubing which is bolted to the wide flange I-beam.

7. Catcher

The maximum predicted amount of kinetic energy of the 50mm system is 500,000 foot-pounds. If an identical target is used, then as a result of impact the kinetic energy is reduced to one half of the above value. The problem of stopping the target and projectile, which leave the impact chamber with a kinetic energy of 250,000 foot-pounds, was solved by designing a catcher as shown in Figures 24 and 25.

The external jacket of the catcher consists of an 11 ft. long mechanical tubing with 14 in. outer diameter and 1-1/2 in. wall. The catcher tube is supported by a rigid frame, made out of heavy walled structural steel tubing (as shown in Figures 25 and 29) which rests on four swivel casters through fine threaded rods. The height of the catcher can be adjusted by hex-nuts under the frame. The casters are equipped with four-position swivel locks and wheel brakes.

The internal portion of the catcher was designed based on the principle of stepping down the kinetic energy of the target and projectile entering

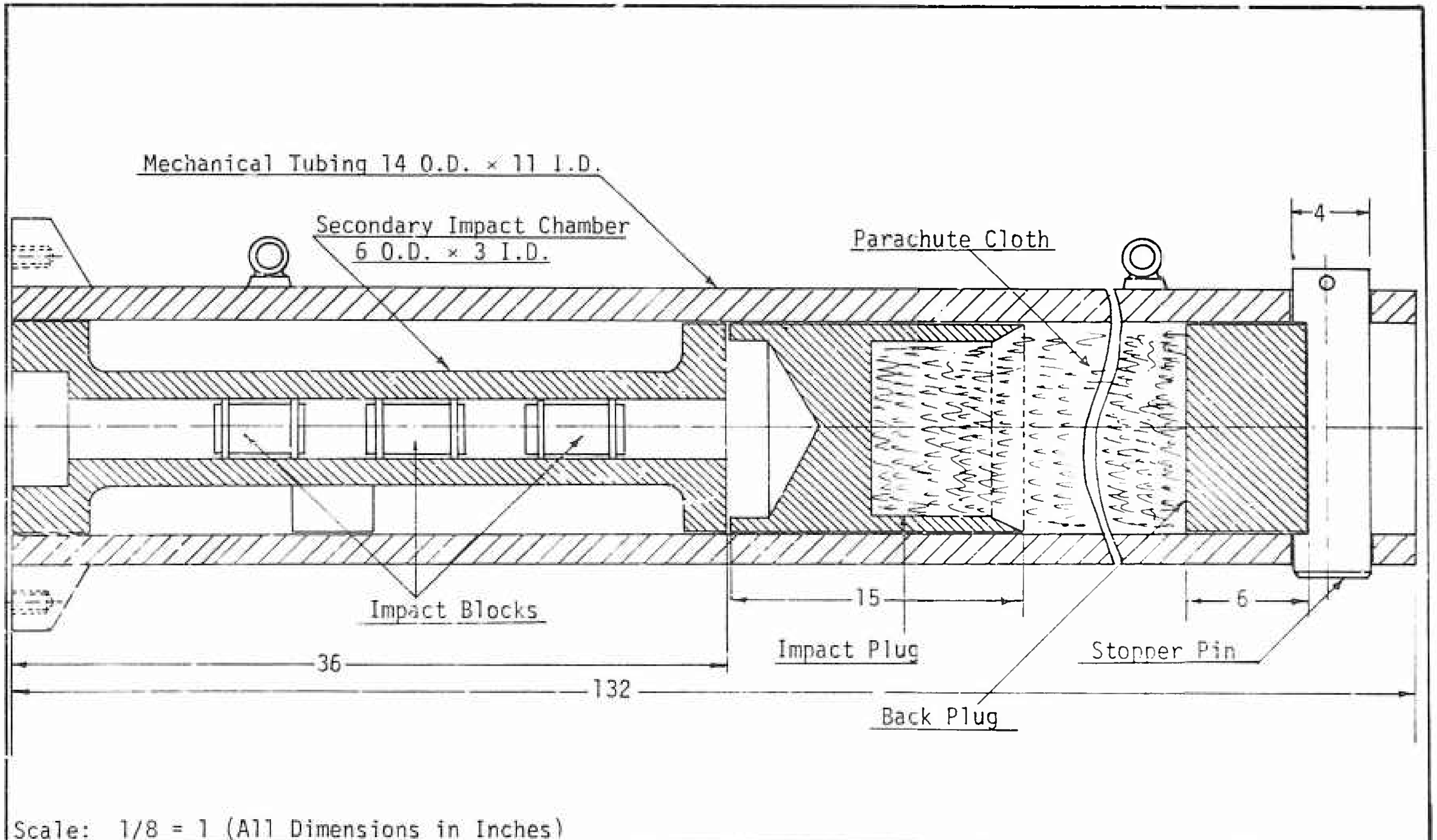


Figure 24. Internal of the catcher.

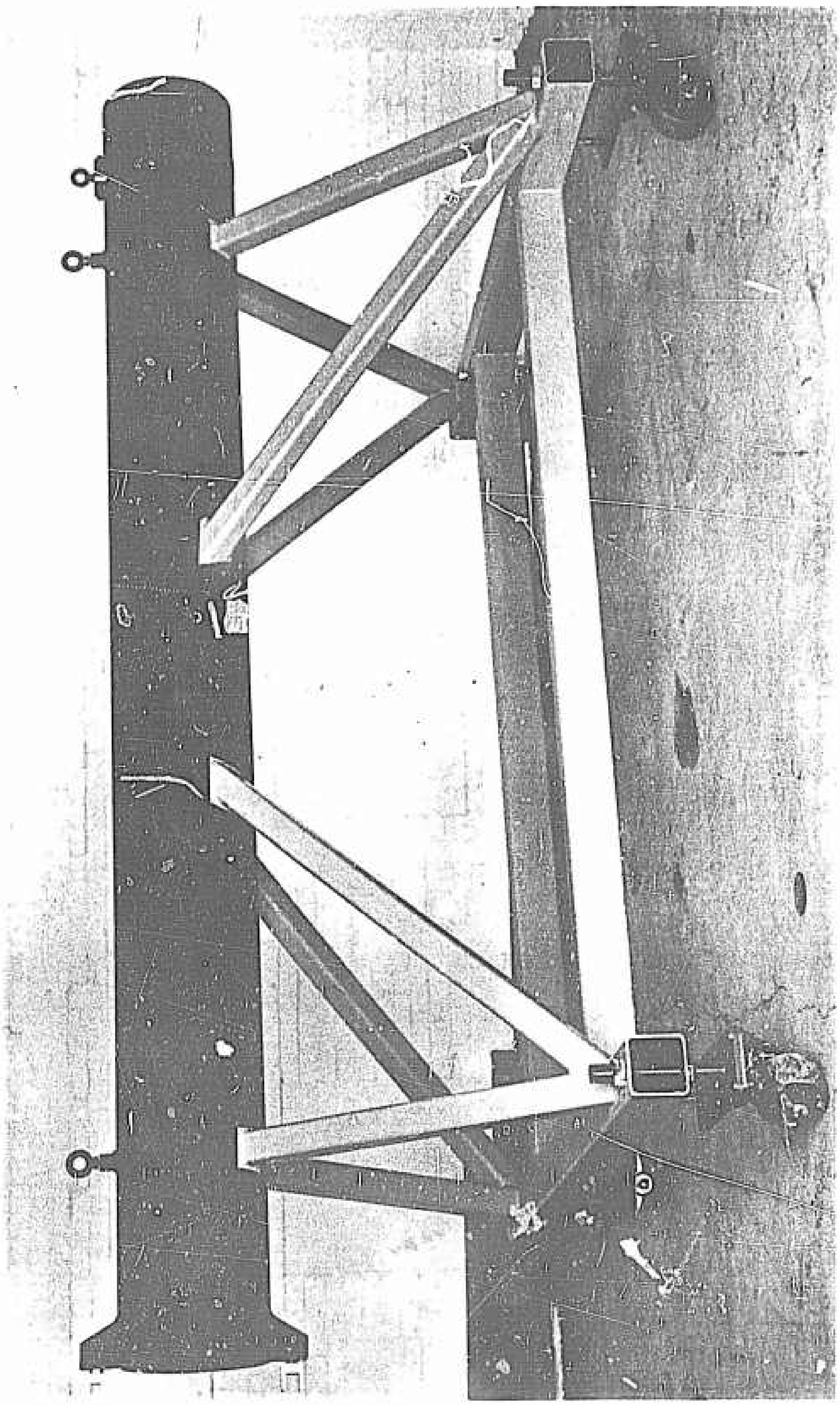


Figure 25. Catcher assembly for 50mm System.

the catcher gradually to a reasonably low value before stopping them. It consists of a heavy walled secondary impact chamber in which there are two or three impact blocks. The target and projectile strike these blocks, which are so designed that the resultant total kinetic energy is halved after each impact. An impact plug weighing 189 pounds was designed as shown in Figure 24. The debris resulting from impact hits the impact plug which in turn moves forward compressing parachute cloth which is held against a heavy back plug.

The following calculations demonstrate the energy absorption processes that take place in the catcher.

Weight of powder charge for producing maximum kinetic energy	= 850 grams
Weight of the projectile (w_1)	= 3 lbs.
Muzzle velocity (from Figure 19) (v_1)	= 3445.3 ft./sec.
Velocity of target and projectile after impact (It is assumed that the target and projectile move as one mass after impact)	= v_2
Weight of target specimen (w_2)	= 3 lbs.

$$\frac{w_1 v_1}{g} = \frac{(w_1 + w_2)}{g} v_2$$

$$\therefore v_2 = 1722.7 \text{ ft./sec.}$$

Weight of 1st impact block (w_3)	= 6 lbs.
Velocity of target, projectile and 1st impact block after impact	= v_3

$$\frac{(w_1 + w_2)}{g} v_2 = \frac{(w_1+w_2+w_3)}{g} v_3$$

$$\therefore v_3 = 861.35 \text{ ft./sec.}$$

Weight of 2nd impact block (w_4) = 12 lbs.

Velocity of target, projectile, 1st and 2nd impact block after impact = v_4

$$\frac{(w_1+w_2+w_3)}{g}\, v_3 = \frac{(w_1+w_2+w_3+w_4)}{g}\, v_4$$

$$\therefore \quad v_4 = 430.7 \text{ ft./sec.}$$

Weight of the 3rd impact block (w_5) = 24 lbs.

Velocity of projectile, target and 3 impact blocks = v_5

$$v_5 = \frac{(w_1+w_2+w_3+w_4)\ (430.7)}{(w_1+w_2+w_4+w_5)}$$

$$= 215.4 \text{ ft./sec.}$$

Weight of impact plug (w_6) = 189 lbs.

Velocity of impact plug after impact = v_6

$$v_6 = \frac{(w_1+w_2+w_3+w_4+w_5)\quad 215.4}{(w_1+w_2+w_3+w_4+w_5+w_6)}$$

$$= \frac{48 \times 215.4}{237} = 43.5 \text{ ft./sec.}$$

Kinetic energy of impact plug + debris of impact after impact

$$= 1/2\ \frac{(48 + 189)}{32.2}\ (v_6)^2$$

$$= \frac{237}{64.4} \times (43.5)^2$$

= 7000 foot-pounds

The parachute material in front of the impact plug is capable of absorbing kinetic energy much greater than 7000 ft.-lbs. This is based on experience with the catcher of the 19mm system. The 19mm system catcher readily absorbs a kinetic energy of 3000 ft.-lbs. using a projectile with a 3/4 in. diameter sabot which penetrates 36 in. through the parachute material before stopping. In the case of the 50mm system the diameter of the impact plug is fourteen times the sabot diameter of the 19mm accelerators' projectile, thus presenting a considerably greater frontal area.

8. Shock Absorbing Mechanism

The shock absorbing mechanism was designed to connect the barrel assembly and the catcher through shock absorbers in order to make the whole system a closed one as far as energy dissipation is concerned. The mechanism was designed taking the worst condition into consideration, i.e., a case where there was no target specimen in the impact chamber to reduce the kinetic energy of the masses entering the catcher and the internal components of the catcher failed to function as predicted. In such a case the entire kinetic energy of the projectile is directly imparted to the catcher, which as a consequence starts rolling away from the accelerator assembly. The velocity of the catcher was calculated as follows.

Weight of the catcher assembly	= 3615 lbs.
Weight of the projectile	= 3 lbs.
Maximum velocity of 3 lb. projectile	= 3445 ft./sec.

$\therefore$ Velocity of the catcher =

$$\frac{\text{Weight of projectile x velocity of projectile}}{\text{Weight of the catcher}}$$

$$= \frac{3 \times 3445}{3615} = 2.86 \text{ ft./sec.}$$

$$\text{Kinetic energy of the catcher} = 1/2 \quad \frac{3615 + 3}{32.2} \quad (2.86)^2$$

$$= 460 \text{ ft.-lbs.}$$

The recoil energy of the accelerator assembly which rolls on frictionless roller supports was calculated as follows.

Weight of accelerator assembly = 3800 lbs.

Maximum recoil velocity of the accelerator =

$$\frac{\text{Maximum weight of projectile x maximum velocity}}{\text{Weight of the accelerator assembly}},$$

$$= \frac{3 \times 3445}{3800} = 2.72 \text{ ft./sec.}$$

$$\text{Recoil energy} = 1/2 \quad \frac{3800}{32.2} \quad (2.72)^2,$$

$$= 440 \text{ ft.-lbs.}$$

Total K.E. to be absorbed = 440 + 460 = 900 ft.-lbs.

Two 8 in. travel shock absorbers, as shown in Figure 26, were selected which can absorb the entire kinetic energy in 6 in. travel. The remaining 2 in. travel provides a safety margin.

9. Breech Support and Protection

To handle the breech which weighs 200 lbs. a support system was designed as shown in Figure 27. It consists of a horizontal roller supported by a hoist mounted on a rigid frame welded to the wide flange beam. Two flat belts run around the roller and the breech and permit the breech to be rotated easily.

To protect the surroundings in case of breech failure, a breech protection device, as shown in Figure 28 was designed. It consists of a 4 ft. long mechanical tubing supported by a frame of structural tubing. Casters are provided under the frame so that the breech protection device can be moved easily. The rear end of the mechanical tubing is closed by a heavy plug. At the time of firing the breech protection unit surrounds

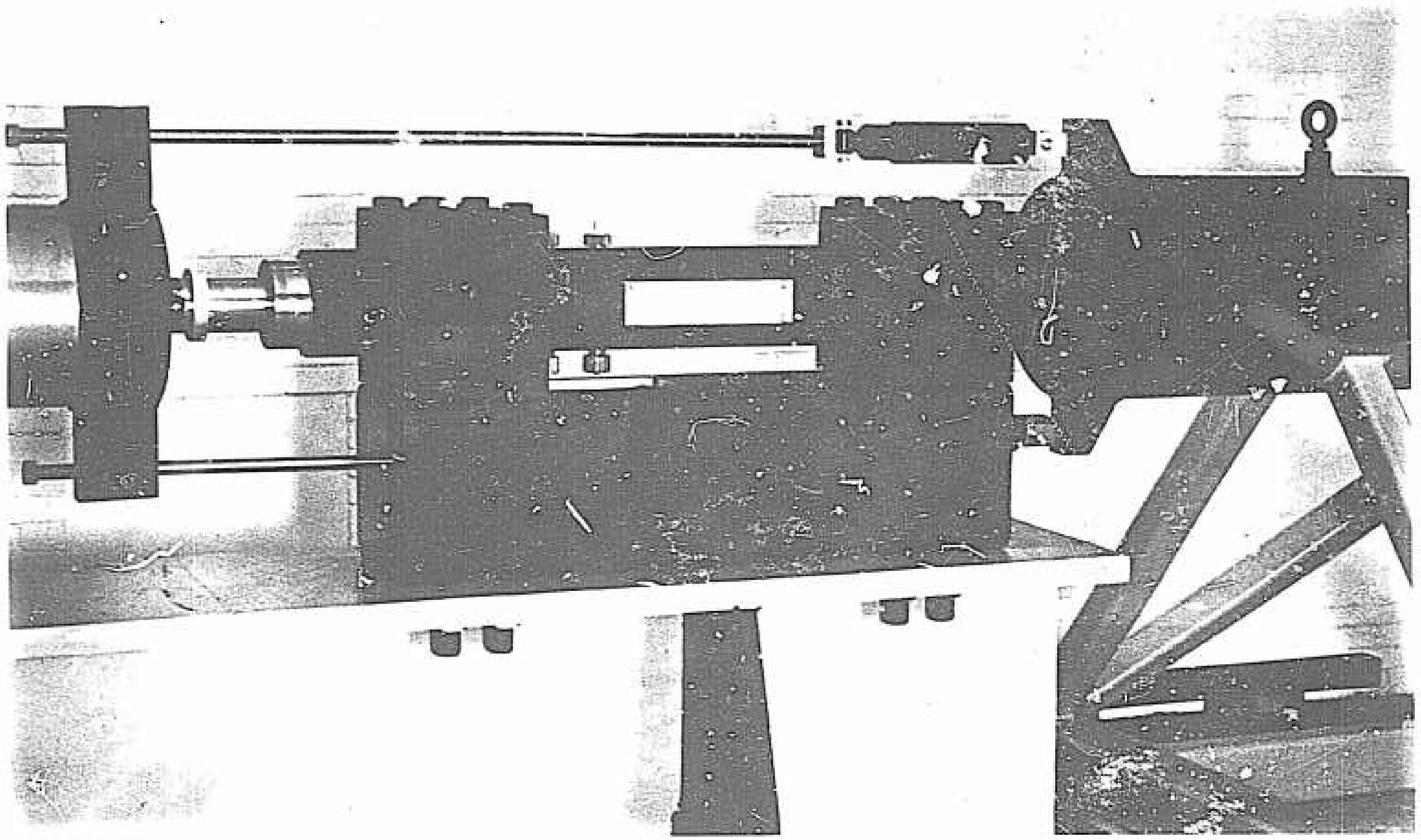


Figure 26. Impact chamber and shock absorbing mechanism.

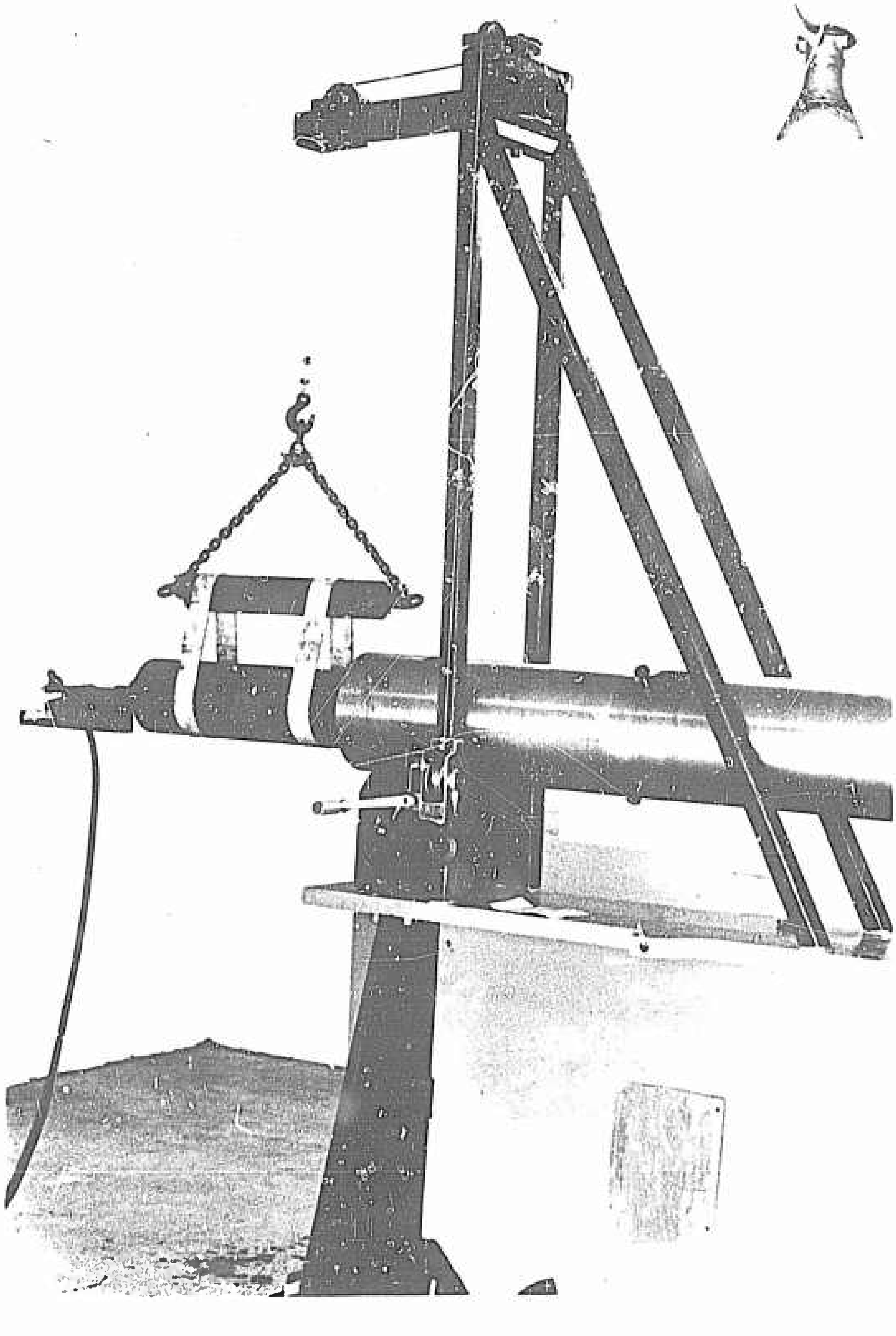


Figure 27. Breech and Breech support.

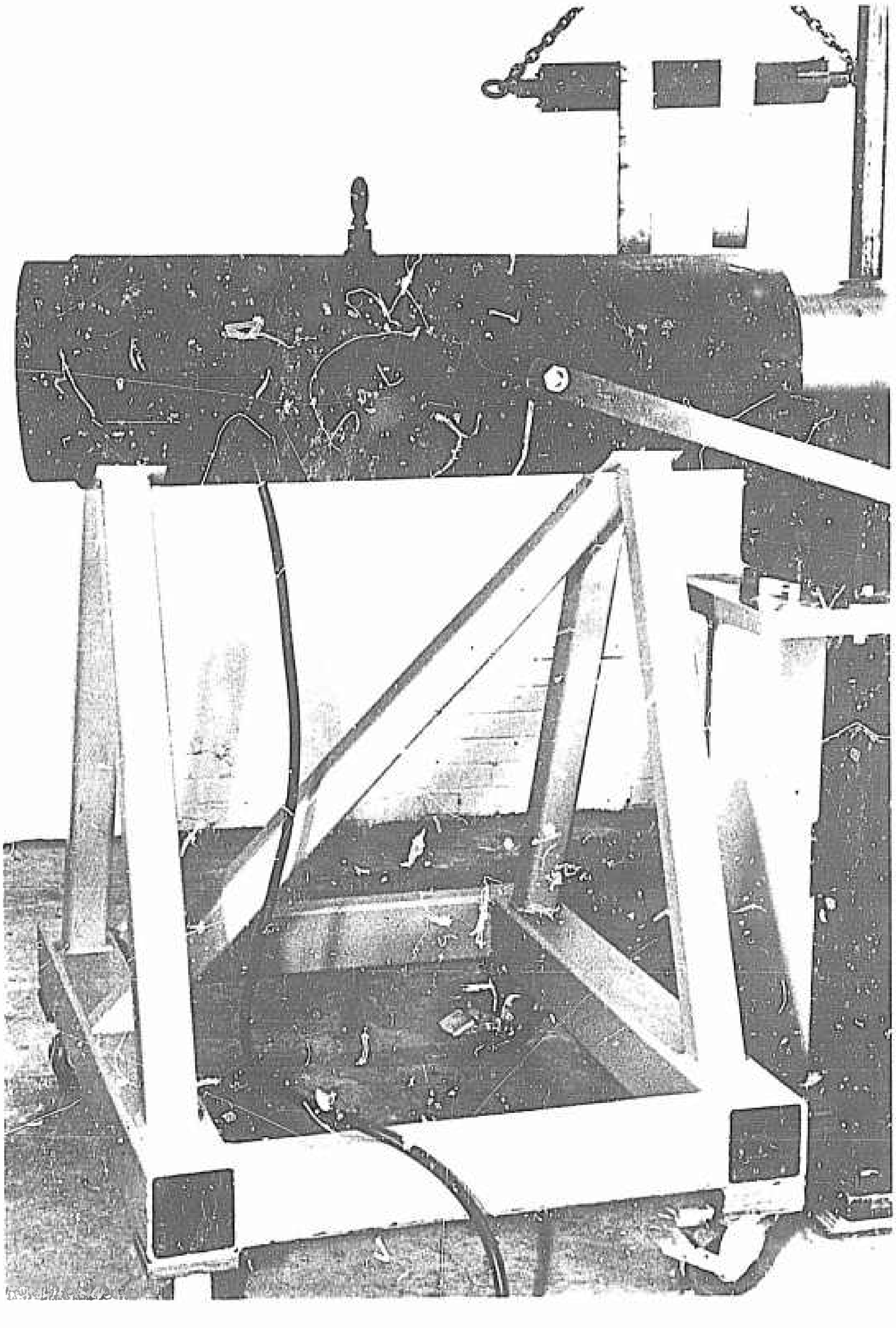


Figure 28. Breech Protection Surrounding the breech.

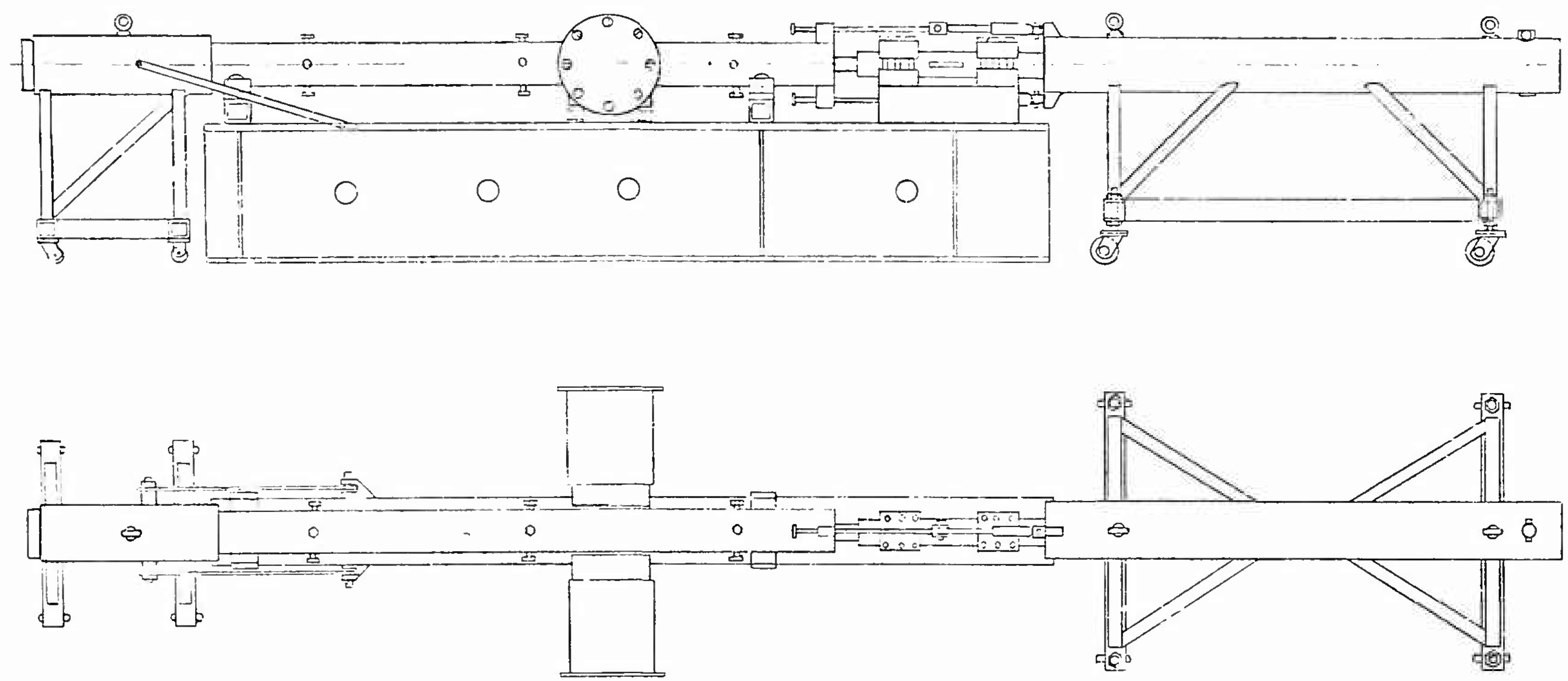


Figure 29. Assembled views of the 50mm accelerator system.

the breech and is connected to the wide flange beam by tie rods.

10. Firing and Cleaning

Firing and cleaning of the 50mm accelerator system involves handling of explosives and heavy weights. A considerable amount of time can be saved if the operations are performed in a logical sequence. The sequence of operations, however, depends upon the type of experiment. In order to illustrate the steps involved in operating the accelerator, a procedure is given in Appendix D of Reference [5].

SUMMARY

This report describes three powder accelerator systems which have been designed and installed and are currently being used for the measurement of strains, strain rates and wave velocities in metallic and non-metallic materials.

Analytical expressions for predicting the pressures of the powder gases in the barrel and velocities of the projectiles are given in terms of weight of projectile, physical properties of the propellent (weight, specific gravity and rate of burning constant) and bore and chamber dimensions of the accelerator. These equations enable a designer to calculate pressures and velocities without going to steps such as calculation of gun constants, etc. These relationships can also be used to design the dimensions of an accelerator for producing a required amount of kinetic energy using a known weight of projectile and a powder propellent of known physical properties. Application of the distortion energy theory coupled with a static yield stress for predicting the failure of the accelerator barrel and breech has resulted in a conservative design which is not objectionable since weight of the accelerator is not a critical factor. The heavy mass of the accelerator assembly, in fact, has helped in reducing the recoil energy. However, in cases where the weight of the accelerator is a critical factor application of the maximum distortion energy theory coupled with an appropriate (dynamic) yield stress of the material should yield a design which is more consistent with experimental results.

The 16mm accelerator has been used successfully for producing projectile velocities from 650 ft./sec. to 2000 ft. per second. Projectiles weighing from 0.625 oz. to 4 oz. have been accelerated. A kinetic energy of 2000 ft.-lbs.

has been produced from this accelerator.

The 19mm accelerator system, which is a modified version of the 16mm system, has been used for producing kinetic energies up to 3000 ft. lbs. The catcher of this system has readily absorbed the largest amount of energy produced by the accelerator. This accelerator has been used to produce projectile velocities up to 1760 ft. per second and projectiles weighing up to 4-1/2 oz. have been accelerated.

The 50mm accelerator system, which is functionally similar to the 16mm and 19mm systems, although somewhat different in appearance, has been installed and is ready for use. This accelerator is designed to produce a kinetic energy of 500,000 ft. lbs. and has been fired only a few times to date. In the second firing a projectile velocity of 900 ft. per second was measured for a one lb. projectile.

The design of blast chambers (mufflers) and evacuation of the barrel has resulted in a firing noise level which is barely noticeable in adjoining rooms.

All of the three accelerators described in this report have proved to be suitable for impact studies because of their simplicity and unobjectionable behavior in proximity to other research and academic activities. For impact studies and similar research programs, where funds and shop facilities are limited, powder accelerators can be easily designed and fabricated without great difficulty because, unlike reservoir-type guns, these accelerators have shorter barrels and can be readily fabricated. Powder accelerators are simple in construction and do not require the high pressure reservoirs, quick opening valves and long barrels, which are the main drawbacks of compressed-gas guns.

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ERRATA – Technical Report 71-2

Page	Correction
37	Equation (14) should be $0.2\ Mp\ Ep = 1/2\ M\ V^2$
37	Equation (15) should be $V = \left(0.4\ Mp\ Ep/M\right)^{1/2}$