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TECHNICAL REPORT ARSCD-TR-84022

30-MM TUBULAR PROJECTILE

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OCTOBER 1984

U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
FIRE CONTROL AND SMALL CALIBER WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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The feasibility of tubular ammunition (sometimes referred to as STUP ammo) has been examined for both air-defense and air-to-air applications. The reduced time of flight, high kinetic energy at the target, low manufacturing costs and increased effectiveness have enticed weapon systems managers for half a decade. As a result, the Armament Division of the Fire Control and Small Caliber Weapon Systems Laboratory was asked to initiate the development of a 30-mm tubular cartridge for use in a weapon system feasibility demonstration called high impulse airborne demonstration (HIGAD). (cont)

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20. ABSTRACT (cont)

The effort consisted of: an analytical study to determine the optimum design for the tubular projectile, fabrication of tubular projectiles (both copper and plastic rotating bands were investigated), ballistic testing and reduction of the data.

The results of the effort are:

- The parametric analysis revealed that the benefit of the subcaliber tubular projectile in terms of time of flight was outweighed by the increase in kinetic energy which would be delivered to the target by the full bore projectile;

- The projectiles with plastic rotating bands remained intact and obturated well; and

- The projectile had reduced time of flight to a range of 2100 meters, where the projectile became high drag, causing the projectile to be range limited. This unique property makes a tubular projectile an ideal training round.

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INTRODUCTION

A tubular projectile is a cylindrical projectile with a large circular duct along the longitudinal axis. When launched from a gun, the projectile uses a pusher plate and an obturator to seal the propelling gases behind the projectile while in the gun tube. When the projectile exits from the muzzle, the pusher plate and obturator are completely separated from the projectile. The properly designed hollow projectile launched at or above the design Mach number will achieve the desired supersonic internal flow conditions. This flow condition produces the ideal low drag characteristics of the tubular projectile. As the velocity of the projectile decreases, the internal flow undergoes a change and becomes choked. In the choked flow condition, air continues to flow internally, but at subsonic velocity. In this mode, the drag is similar to a streamlined standard projectile.

Although, experimentation on tubular projectiles can be traced as far back as 1858 very little knowledge about supersonic flow, particularily in ducts, was known until after 1944. Use of this supersonic flow theory permitted a true scientific evaluation of tubular projectiles in the late 1960's by the Canadian Defense Research Establishment. During the early 1970's, the ARDC Weapon Systems Concept Team (WSCT) conducted experimentations on tubular shapes in a variable Mach number wind tunnel. Based on the findings from these experiments the WSCT developed a design methodology for tubular shapes for ballistic applications. Limited investigations of several tubular applications were conducted in several caliber sizes. The largest effort was the 20-mm program which resulted in the automatic firing of tubular projectiles from the vulcan air defense system. This firing yielded system dispersion for the tubular projectile in the M61 automatic gun and a measurement of velocity as a function of time which yielded drag coefficients as a function of Mach numbers.

The purpose of the effort described in this report is to determine single shot dispersion of a tubular projectile when fired from a hard mount and to verify the existing value of drag coefficients as a function of Mach numbers.

PARAMETRIC ANALYSIS

The foundation of any parametric analysis is a good understanding of the constraints placed on that analysis and the variables which are permitted. This program was funded by the Army Aviation Systems Command (AVSCOM) who directed that this ammunition effort be on tubular ammunition for air-to-air (helicopter-to-helicopter) engagements. Since this ammunition effort was to be compatible with the weapon for the high impulse gun airborne demonstration (HIGAD), the ammunition was constrained to function in the 30-mm, GAU-8 system. This constraint defined the gun caliber, gun tube length, peak chamber pressure, ammunition impulse and available case volume. The Weapon Systems Concept Team (WSCT) recommended the highest length to diameter ratio (L/D) possible without exceeding 3. The interior ballistics investigation was limited to conventional technology by the available funding. The projectile material selection was also limited by available funding. The parametric analysis was conducted on both steel and tungsten projectiles but actual hardware fabrication was limited to the steel projectiles only.

An effective analysis would strive to obtain the highest possible probability of kill. Such an analysis would be very complex and would require vulnerability testing and scenerio definition. It was decided to simplify the analysis by assuming that time-of-flight to the target would be the parameter to minimize. Time-of-flight would be computed for various projectiles as the caliber was varied from a subcaliber size of 12mm through the full bore size of 30mm. Once the caliber of the projectile was defined, the length was determined by the maximum length to diameter ratio of 3. To preclude exotic advances in the state of the art of internal ballistic technology the authors limited themselves to real and achievable muzzle velocities which were obtained using the projectile internal ballistics analysis (PIBA) program. This computer code in FORTAN uses the ballistic curves developed by Dr. H. P. Manning for calculating the velocity performance of small arms weapon systems.

COMPUTATION OF PROJECTILE WEIGHTS

In order to calculate the total launch weight of the tubular projectile assembly, the dimensions of two existing tubular projectile designs (20-mm and 30-mm) were analyzed. Three analytical equations to determine the weights of the projectile, the pusher plate and the obturator were generated. These equations listed below required only the outer diameter of the flight projectile and the density of the material being considered.

$$W_T = \pi \, R^3_{OD} \; P_T \qquad (2.541)$$

$$W_P = \pi \, R^3_{OD} \; P_P \qquad (0.4)$$

$$W_O = 8 \, \pi \; P_O \; R_{OD} \left[0.348 - R^2_{OD}\right]$$

Where:

W_T = Weight of tubular flight projectile (grains)

R_{OD} = Radius of tubular flight projectile (inches)

P_T = Density of tubular flight projectile material (grains/inch^3)

W_P = Weight of pusher plate (grains)

P = Density of pusher plate material (grains/inch^3)

W_O = Weight of obturator (grains)

P_O = Density of obturator material (grains/inch^3)

Using the above equations both the launch and flight weights of the tubular projectile in steel and tungsten were computed in 2-mm increments from 12-mm through 30-mm. The flight weights for the steel tubular projectiles are shown graphically as a function of diameter (see figure 1).

Those weights and the GAU-8 system constraints (see table 1) were then used as input to the interior ballistics program (PIBA) to compute both muzzle velocity and single shot impulse to the gun. The muzzle velocities of the steel projectiles are depicted as a function of subcaliber diameter in figure 2. Figure 3 shows single shot impulse for the steel tubular projectiles as a function of the subcaliber projectile diameter. Table 2 lists launch weight, flight weight, muzzle velocity and impulse for all of the steel subcaliber projectiles and table 3 lists the same parameters for all of the tungsten subcaliber projectiles. It is noted that all cases meet the impulse constraint which was 150 lb sec.

The flight weights and muzzle velocities of the various subcaliber tubular projectiles of tables 2 and 3 were then used as input to a two degree of freedom computer program to compute the time of flight to various ranges of interest. The program uses Newtonian mechanics to calculate the trajectory of projectiles. This program also requires the input of a drag coefficient vs Mach number curve to compute the time of flight. The best available drag coefficient which was determined from the 20-mm tests conducted at Ft. Bliss, TX was used. The computed data for the subcaliber steel tubular projectiles summarized in figure 4 graphically shows the time-of-flight to various ranges as a function of the diameter of the subcaliber steel tubular projectile. Examination of this data indicates that the optimum steel tubular projectile is somewhere in the range of 22-mm to 24-mm in diameter and that is only markedly noticeable at the longer ranges of 2500 meters to 3000 meters. At the more probable ranges of engagment below 1500 meters, the time-of-flight curve is almost flat, fielding a difference in time of-flight at 1500 meters between the 22-mm subcaliber projectile and the 30-mm full bore projectile of approximately 0.12 seconds. This modest gain in time of flight to 1500 meters is insignificant when compared to the decrease in kinetic energy delivered to the target at 1500 meters. The full bore 30-mm delivers more than 52,000 ft pounds as compared to the 24,000 ft pounds delivered by the subcaliber 22-mm. In addition, the full bore 30-mm will affect an area on the target that is 87 percent greater than the area affected by the subcaliber 22-mm tubular projectile. Using engineering logic in lieu of a detailed analysis one can see that the most effective projectile choice would be the full bore 30-mm tubular projectile.

DESIGN CHARCTERISTICS OF THE TUBULAR PROJECTILES

Flow Characteristics of the Tubular Projectiles

With increasing demand for high performance in projectiles, various means have been used to minimize the total drag of a shape. This decrease in drag has been brought about to a certain degree by streamlining the nose, boattailing the aft section, or by emission of gases at the base. These methods appear to be reaching an asymptotic limit on drag reduction for conventional shapes. The properly designed unconventional tubular shape shows excellent promise of performance superior to that of existing low drag conventional shapes.

To obtain an appreciation of the low drag potential of tubular shapes, the elements contributing to the total drag at supersonic speeds should be described. The major contributors to drag for conventional shapes are the frontal area (forebody) and the base. A tubular shape, correctly designed externally and internally will show an appreciable decrease in both frontal and base drag because of the presence of the internal passage and minimal losses due to the internal flow. The skin friction drag is higher than that of the conventional configuration, because in addition to external skin friction, there is internal skin friction present due to the internal flow. But the overall drag coefficient is decreased by a factor of two when compared to most conventional projectiles available to date.

Proper internal supersonic flow conditions must exist to allow the low drag performance of the tubular configuration. The internal flow becomes supersonic only when it is said to be swallowed. This is generally indicated when a lip or nose shock wave is generated externally as shown in figure 5. A choked flow condition which indicates a high drag mode is characterized by detached or bow shockwave as indicated in the same figure. It should be noted that the choked flow condition can result in one of two ways. Improper internal design of the tubular projectile will cause a choked flow condition at all velocities. A properly designed tubular projectile will experience a choked flow condition only when the projectile decelerates to a Mach number too low to sustain internal supersonic flow. The change from low drag condition to a high drag condition is instantaneous at this critical Mach number.

Configurational Design Requirements

The Aerodynamics Research and Concepts Assistance Section (ARCAS) Chemical System Laboratory, has been doing developmental work on tubular projectile shapes of various sizes since 1974. Experience has shown that there must be trade-offs in the design approach in order to obtain reasonable projectile weight and low drag characteristics.

The internal geometry was selected to allow the tubular projectile to decelerate to a Mach number of 1.8 before the high drag mode was reached. The internal portion of the projectile (see figure 6) consists of the convergence section, constant area section, and the divergence section. The length to diameter ratio of three has been considered a practical ratio.

The 30-mm tubular projectile shape used in these tests has the following design characteristics:

- Nose lip angle of 10°
- Boattail angle of 10°
- Internal divergence angle of 3° 15'
- A length to diameter ratio of three.
- Welded overlay rotating band or plastic rotating band.

Figure 6 shows the general contour and pertinent dimensions of the 30-mm tubular projectile tested in the program.

Internal Ballistics

The selection of an optimum propellant for the 30-mm tubular cartridges consisted of two steps. The first step entailed using analytical methods to select the propellant for the cartridge. The second step involved ballistic firings in order to verify that the propellant yielded the predicted muzzle velocity within the pressure constraints of the barrel.

The tubular projectile with sabot was predicted to be 250 grams. The length of projectile travel is 2.25 meters (88.58 inches), the barrel cross-sectional area is 7.35 square centimeters (1.139 square inches). The case volume available for propellant was estimated to be 162 cubic centimeters (9.9 cubic inches). Using the computer code, PIBA and propellant masses of 154 and 162 grams, the code predicted muzzle velocities of 1280 meters per second (mps) and 1310 meters per second (mps), respectively. Therefore, a minimum muzzle velocity of 1280 mps (4200 feet per second) will be obtainable.

Due to limited funding, conventional propellants were selected which would yield the greatest muzzle velocity but also conform to the operating pressures of the weapon. Three single base extruded propellants were selected, IMR 6962, CR8325, and IMR4996. The relative quickness values based on IMR4350 as a standard are 64, 58, and 51 respectively.

With propellants selected, internal ballistic testing was conducted on February 26, 1979. A 30-mm Hispano Suiza barrel and cartridge case were used as the test vehicle due to availability of components. The barrel was attached to a hydrorecoil bond mount. A lumiline screen was placed at a distance of 7.62 meters from the muzzle and another lumiline screen was placed at a distance of 3.05 meters beyond the first screen. A counter was attached to the lumiline screens to record the time interval for determination of velocity. Peak chamber pressure was recorded using a copper crusher gage. A total of 15 rounds of ammunition was fired during the test. Table 4 summarizes the results.

Three propellants were tested in order of increasing relative quickness. Propellants IMR4996 and IMR6962 were eliminated due to excess pressure. During testing, a graphical prediction showed that for IMR4996 a loading density of 100 percent would yield a peak pressure of 434 mega pascals (MPa) (63 kpsi). This pressure is above the 393MPa nominal operating pressure for the system. The 581 MPa reading for IMR6962 clearly eliminated this propellant, as well. The loading density of CR8325 was increased based on a revised prediction of tubular intrusion into the cartridge case. At a loading density of 105 percent, repeated firings yielded a velocity of 1277 meters per second (m/s) with a standard deviation of 6 m/s. The calculated muzzle velocity was 1286 m/s, which was satisfactory. The mean peak pressure of 430 MPa with a standard deviation of 10MPa was higher than the nominal pressure, but was within the maximum allowable pressure for the barrel. Since this effort was to demonstrate a concept, propellant CR8325 was used for ballistic testing.

Stress Analysis

The structural integrity of any new concept should be analyzed before fabrication. A finite element stress analysis was conducted at ARDC on the initial design (see figure 7). The results indicated a substantial amount of plastic deformation in the base of the projectile from the base to a distance of approximately 3.81mm from the base. This deformation can alter the configuration of the boattail of the projectile and could lead to in-bore problems with the projectile. In addition, the stresses in the bottom of the crimp groove were near the yield point. The stresses in the remainder of the projectile including the rotating band and its interface with the body were low and provided a large margin of safety.

With these results, several design modifications were made. After a few iterations, a final design emerged (see figure 8). The boattail angle was changed from 10° to 8°. The exit/diverging angle was changed from 3 degrees, 15 minutes to 3 degrees. This change increased the surface area on the base of the projectile, which in turn decreased the stress in the base of the projectile. The plastic deformation in the base of the projectile was eliminated.

The above changes in the projectile configuration changed the geometric properties of the projectile. Table 5 compares the initial design to the modified design. These slight differences in the geometric properties of the projectile designs were not expected to affect the flight characteristics. Therefore, the hardware was fabricated in accordance with the modified design.

FABRICATION

The tubular projectile consists of three parts: projectile, pusher plate, and obturator. Three different projectiles were fabricated for this effort: two configurations for air to air applications and one configuration for air defense application (see figure 9). A different procedure was used to fabricate each projectile component. The details of the processes are presented below.

Projectile

The projectile was machined from AISI-4340 steel bar stock. The bar stock was sectioned and machined for application of a copper rotating band, or a plastic rotating band. The details of the procedure for a copper banded projectile will be presented first, followed by the plastic banded projectile. For the copper banded projectile, a blank was sectioned from bar stock and machined (see figure 10) so as to be compatible for use in a copper overlay welding machine. A hole through the blank along its axis was required so water could be circulated for cooling of the blank during banding using the welded overlay machine. An iterative approach was required in order to define the proper wire thickness, current settings, rotating rates and number of revolutions required to band the projectile. The details of the banding procedure are discussed in appendix A. A total of 100 blanks were banded.

Forty of the 100 banded blanks were machined to the original tubular design. The remaining blanks were machined to the modified design. The banded blanks were machined close to final dimensions, then heat treated to obtain a hardness of 52 and 54 on the Rockwell C scale. Upon completion of heat treatment, the blanks were polished to final dimensions (see figure 11), yielding a tubular projectile.

With the recent advances made in the field of plastic rotating bands, 39 steel projectiles were machined from AISI 4340 steel bar stock. In order to accommadate a nylon rotating band, a slight band seat of 0.5 millimeters was machined into the projectile before heat treatment. The projectiles were polished to final dimensions. Two techniques investigated by the Air Force were considered for application of the rotating band onto the projectile.

The first technique consists of applying a coating of plasma sprayed material onto the band seat and then injection molding plastic onto this undercoating creating a rotating band (ref 1). The Air Force projectiles were fired in a GAU-8 barrel. Muzzle velocities of 1280 to 1370 mps were recorded. In flight photographs showed that the band obturated well, imparted spin to the projectile and remained in tact after launch. The second technique consisted of applying an adhesive to the band area and then injection molding the band to a tubular projectile body. The Air Force tubular projectile resembled the ARDC design. For this technique, no band seat is required. The results of the testing revealed that the rotating bands remained intact after launch, obturated well and imparted spin to the projectile. Muzzle velocities in excess of 1219 mps were recorded.

The second technique was chosen for application to the ARDC tubular projectiles. The banding process is described in Appendix B. Figure 12 shows the projectile at various steps in the fabrication process from bar stock through completion using the plastic injection molding technique.

Pusher Plate

The pusher plate was machined from AISI-4340 steel bar stock. The plates were heat treated to a hardness on the Rockwell C scale of 52 to 55. The plates were then machined to final dimensions.

Obturator

The obturator was machined from 31.75 millimeter bar stock. The material was nylon 6/12.

The next section of the report deals with the inspection, assembly and testing of the projectiles.

EVALUATION

The evaluation of the tubular projectiles consisted of three phases. First, an inspection of the components; second, indoor range testing to evaluate chamber pressure, muzzle velocity, sabot discard and integrity of the projectile; and third exterior ballistic testing to determine dispersion parameters, time of flight, velocity decay and a drag curve for each of the projectile designs.

Inspection

The plastic banded, copper banded, GAU-8 and Hispano Suiza tubular projectiles were inspected for critical dimensions. An extensive examination of the GAU-8 plastic banded tubular projectiles revealed dimensional uniformity within the manufactured lot (table 6). The copper banded projectiles (table 7) and the Hispano Suiza tubular projectiles (table 8) were inspected to a lesser degree; however, uniformity was met for these rounds as well. The pusher plate and the obturator (table 9) for the GAU-8 tubular projectiles were inspected for key dimensions. Only the mass was provided on the Hispano Suiza obturators and pusher plates (table 10). Examination of all data reveals uniformity throughout the lots.

Indoor Range Testing

The tubular projectiles were tested in the following order, Hispano Suiza, GAU-8 plastic banded; and, lastly, the GAU-8 copper banded tubular projectiles. Lumiline screens were placed at 8.5, 23.8, 39.0 meters from the muzzle of the gun. A micro-flash photography apparatus was placed at 8.5 meters from the muzzle of the gun. Armor plate was placed at 45.7 meters from the muzzle of the gun.

A total of 21 rounds was tested in an indoor range. The Hispano Suiza projectiles were fired from a Hispano Suiza field barrel. Plastic banded GAU-8 projectiles were fired from a GAU-8 Mann Barrel. The in-flight photographs (see figures 13 and 14) revealed that the rotating bands produced a good gas seal and that the projectiles are structurally sound. The chamber pressure and muzzle velocities (tables 11 and 12) for the Hispano Suiza and plastic banded GAU-8 projectiles confirmed the results that were obtained from the internal ballistic portion of the program. However, the high chamber pressures that were encountered during the initial testing of the GAU-8 tubular copper banded projectiles (see figure 15 and table 13) lead to a redesign of the copper rotating band. After several iterations, a relieved rotating band (figure 16) yielded a moderate pressure and muzzle velocity.

The penetration data gathered against the armor plate which was placed at 45.7 meters (150 feet) from the muzzle of the gun is shown in tables 11, 12 and 13. The projectile would not penetrate 5.08 centimeters of armor at 0 degrees obliquity (see figure 17, 18, 19, and 20) but will penetrate 5.08 centimeters of armor at 60 degrees obliquity (see figures 21 and 22). (Depth of penetration was measured normal to armor plate surface). At large angles of obliquity, the projectile digs itself into the armor plate (see figure 23). Due to its hardness, the projectile fragments upon impact. Further testing will be required to determine the ballistic limit of the tubular round of ammunition.

Examination of yaw cards which were used for the first two rounds fired reveal that the pusher plate will depart from the projectile flight path within a 4 degree cone angle. The obturator will depart from the projectile flight path within a 2 degree cone angle.

Exterior Ballistics

The external ballistic testing of the three different projectiles consisted of two phases. The first phase conducted in March 1980 pertained to measuring the dispersion parameters of the projectiles and obtaining determination of the chamber pressure and muzzle velocity. The second phase conducted in May 1980 pertained to the Hawk radar tracking of the projectiles in order to determine the drag coefficients for the tubular projectile.

During the first phase, an accuracy target was placed at 1000 meters from the muzzle of the barrel. Chamber pressure (see figure 24) muzzle velocity, and the velocity of each round was recorded (table 14). The dispersion for the GAU-8 target practice projectiles manufactured by Aerojet, had a mean radius of 0.7 mils. The plastic banded GAU-8 tubular projectiles and copper banded GAU-8 tubular projectiles had a mean radius of 0.4 and 0.9 mils, respectively.

The dispersion is not available for the Hispano Suiza tubular projectiles. After several attempts to walk the projectiles onto the target, the test was concluded (ref 2). The problem did not lie with the ammunition but with the barrel. The Hispano Suiza barrel was not clamped in the proper places during the test firings. This was not discovered until after the test. The test was concluded in order to save the remaining projectiles for the Hawk Radar Test.

The Hawk Radar Test was conducted in May 1980. A total of 22 rounds of ammunition was tested (table 15). Of the 22 rounds of ammunition tested, 8 of the projectiles were target practice rounds, which were fired for reference. The Hawk Radar data was reduced to generate range and velocity as a function of time of flight. Appendix C contains time of flight and velocity decay data for each round of ammunition. The time of flight values were reduced to generate a drag curve for each of the rounds of ammunition presented in Appendix D. For each of the different types of projectiles, a mean drag table was generated. This mean table is simply the arithmetic mean of the individual rounds of ammunition. The mean values were then plotted to generate drag curves for each different type of projectile. Figure 25 compares the GAU-8 plastic banded and copper banded tubular projectiles with the 30-mm GAU-8 Aerojet target plastic projectiles. Figure 26 compares the Hispano Suiza tubular projectiles with the Hispano Suiza target practice projectiles. It is interesting to note that the drag curve for the Hispano Suiza tubular projectile fits between the drag curves for the two GAU-8 tubular projectiles.

CONCLUSIONS

The 30-mm tubular projectile program was a success. The results of the program worth noting are summarized below:

1. The parametric analysis revealed that the difference between the full bore and subcaliber tubular projectile in terms of time of flight was outweighed by the increase in kinetic energy which would be delivered to the target by the full bore projectile. Therefore, the full bore projectile was selected for the program.

2. The stress analysis conducted on the design of the projectile revealed possible structural problems could occur in the base of the projectile. Ballistic testing of the original design, Hispano Suiza tubular projectile, showed that the concern expressed was unnecessary.

3. The plastic rotating bands on the tubular projectiles remained intact and obturated well. The muzzle velocity and peak chamber pressure prediction were verified by the ballistic tests.

4. The tubular projectile has significant reduced drag coefficient as compared to conventional projectiles at high Mach number. This property of the tubular projectile yields reduced time of flight to a range of 2100 meters. Then, the projectile becomes high drag, causing the projecitle to be range limited. This unique property makes a tubular projectile an ideal training round.

5. The amount of reduction in the time of flight of a tubular projectile as compared to a conventional projectile at a distance of 2,000 meters is approximately 25%. The percent difference in the drag coefficient at Mach 2.5 between the tubular projectile as compared to the conventional projectile is approximately 50%. The dispersion of the tubular projectile is approximately ½ of the dispersion for the conventional projectile.

6. The purpose of the program did not entail determining the ballistic limit of the tubular projectile; therefore, no comment will be made on this point.

References

1. Stephen J. Price, Rotating Band for High Velocity Thin-Walled Projectiles, Report Number AFATL-TR-79-7, Florida, January 1979.

2. George B. Niewenhous, Feasibility Test of 20mm Tubular Projectile, Material Testing Directorate, Maryland, 1978.

Table 1. Constraints for parametric analysis

Parameter	Constraint	Source
Type projectile	Tubular	AVSCOM
Diameter of bore	30mm	HIGAD
Ratio of length to diameter	3max	WSCT
Length of projectile travel	84 inches	GAU-8
Peak nominal chamber pressure	59 Kpsi	GAU-8
Impulse	150 lb-sec max	HIGAD
Available case volume	8.9 in^3	GAU-8
Diameter of flight projectile	12 thru 30mm	Desired range
Materials	Steel & tungsten	Save time lower cost

Table 2. Steel

Projectile diameter (mm)	Launch weight (grains)	Flight weight (grains)	Muzzle velocity (ft/sec)	Impulse (lb/sec)
12	848	208	6687	73.2
14	1043	331	6409	77.7
16	1261	494	6114	82.2
18	1508	703	5811	86.9
20	1785	965	5513	91.7
22	2098	1284	5227	96.7
24	2449	1668	4971	102.0
26	2841	2120	4698	107.3
28	3279	2648	4458	112.8
30	3765	3256	4220	118.6

Table 3. Tungsten

Projectile diameter (mm)	Launch weight (grains)	Flight weight (grains)	Muzzle velocity (ft/sec)	Impulse (lb/sec)
12	1089	449	6345	78.7
14	1425	713	5909	85.4
16	1832	1065	5467	92.5
18	2320	1516	5053	100.00
20	2900	2080	4662	108.0
22	3582	2769	4305	116.5
24	4375	3594	3957	124.9
26	5291	4570	3618	133.0
28	6339	5708	3306	141.0
30	7529	7020	3030	149.3

Table 4. Internal ballistics summary*

Loading density Charge weight (grams)	Ratio of propellant charge weight to standard propellant charge weight	IMR4996 Pressure (MPa)	IMR4996 Velocity (m/s)	CR8325 Pressure (MPa)	CR8325 Velocity (m/s)	IMR6962 Pressure (MPa)	IMR6962 Velocity (m/s)
123	0.80	230	1030	221	1037	581	1215
139	0.90	357	1174	310	1148		
146	0.95	385	1215				
154	1.00			372	1233		
160	1.04			414	1288		
164	1.06			436	1264		
162	1.05			417	1275		
162	1.05			441	1288		
162	1.05			425	1268		
162	1.05			417	1271		
162	1.05			430	1277		
162	1.05			425	1277		

*Usable case volume 162 cubic centimeters

Table 5. Geometric properties

	Initial Design	Modification
Projectile (with sabot)		
Weight (grams)	241	254
Length (cm)	10.36	10.99
Penetrator		
Weight (grams)	106	211
Length (cm)	8.99	8.99
Diameter (cm)	2.98	3.00
C.G. from nose (cm)	4.83	4.88
Axial moment (g-cm^2)	338	346
Transverse moment (g-cm^2)	1104	1145

Table 6. Inspection of GAU-8 plastic banded tubular projectiles
(dimensions in millimeters, mass in grams)

ITEM	1	2	3	4	5	6	7	8	9	10
Length	89.853	89.853	89.840	89.840	89.853	89.865	89.840	89.853	89.853	89.840
Diameter	29.997	29.992	29.985	29.997	29.997	29.997	29.985	29.997	29.997	29.997
Mass Unbanded	195.5	195.3	195.6	195.3	195.4	195.3	195.3	195.5	195.6	195.4
Banded*	198.4	198.3	198.4	198.5	198.4	198.2	198.5	198.6	198.4	198.6
Band Diameter*	31.22	31.17	31.17	31.14	31.22	31.19	31.22	31.17	31.19	31.22
Band Length	19.05	18.99	18.92	19.07	18.95	18.92	18.90	19.02	19.02	18.97
Location of crimp groove from base	11.73	11.73	11.86	11.71	11.66	11.73	11.68	11.73	11.71	11.71
Inlet ID	23.70	23.70	23.70	23.67	23.70	23.70	23.70	23.70	23.70	23.70
OD	23.98	23.93	23.88	23.93	23.88	23.90	23.95	23.90	23.93	23.90
Exit ID	24.13	24.00	24.13	24.13	24.13	24.00	24.08	24.05	24.08	24.13
OD	27.389	27.358	27.351	27.381	27.356	27.386	27.379	27.399	27.391	27.417
Throat Diameter	22.66	22.66	22.67	22.67	22.66	22.66	22.66	22.66	22.66	22.66
Ogive Angle	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$	$5^{\circ}0'$
Boattail Angle	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$	$8^{\circ}10'$
Inlet Angle	$4^{\circ}47'$	$4^{\circ}46'$	$4^{\circ}46'$	$4^{\circ}47'$	$4^{\circ}46'$	$4^{\circ}46'$	$4^{\circ}46'$	$4^{\circ}46'$	$4^{\circ}46'$	$4^{\circ}46'$
Exit Angle	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$	$3^{\circ}13'$

*Measurements do not correspond to numbered projectile

Table 7. Inspection of GAU-8 copper banded tubular projectiles
(Dimensions in millimeters)

Item	1	2	3	4	5	6	7	8
Length	89.92	89.94	89.89	89.84	89.84	89.59	89.92	89.97
Diameter	29.97	29.97	29.97	29.97	29.95	29.95	29.95	29.95
Location of band from base	23.80	23.77	23.77	23.72	23.77	23.60	23.72	23.72
Band diameter	31.32	31.32	31.34	31.34	31.32	31.29	31.34	31.34
Throat diameter	20.04	20.14	20.04	20.02	20.07	20.02	20.02	20.12
Total indicator								
Runout								
At 1.62 in. from base	0.015	0.018	0.013	0.038	0.038	0.038	0.025	0.0076
At 2.62 in. from base	0.015	0.010	0.015	0.025	0.025	0.051	0.051	0.020
Inlet angle	within tolerance 7° 30' - 8° 0'							
Ogive angle	within tolerance 4° 30' - 5° 30'							
Exit angle	within tolerance 3° 0' - 3° 30'							
Boattail Angle	within tolerance 7° 30' - 8° 0'							

Table 8. Inspection of Hispano Suiza tubular projectile
(Dimension in millimeters, mass in grams)

Item	1	2	3	4	5	6	7	8
Length	89.66	89.74	89.87	89.89	89.69	89.79	89.81	89.76
Diameter	29.87	29.87	29.82	29.85	29.85	29.90	29.82	29.85
Band diameter	31.62	31.70	31.65	31.75	31.75	31.65	31.72	31.70
Throat diameter	20.65	20.65	20.62	20.68	20.65	20.65	20.65	20.62
Mass	203.5	202.9	202.0	202.1	202.5	202.4	203.6	203.5

Table 9. Inspection of GAU-8 sabot
(Dimensions in millimeters, mass in grams)

Item	1	2	3	4	5	6	7	8
				Pusher plate				
Overall thickness	7.57	7.62	7.60	7.62	7.60	7.57	7.60	7.65
Diameter	27.38	27.38	27.41	27.41	27.43	27.41	27.41	27.43
Web thickness	5.18	5.28	5.33	5.28	5.36	5.21	5.26	5.26
Minor diameter	23.88	23.93	23.93	23.88	23.90	23.90	23.90	23.93
Mass	28.3	28.2	28.1	28.1	28.2	28.4	27.8	28.2
				Obturator				
Overall length	29.74	29.82	29.82	29.77	29.79	29.77	29.82	29.74
Diameter	29.95	29.95	29.97	29.95	29.95	29.97	29.97	29.97
Web thickness	9.37	9.35	9.37	9.35	9.35	9.37	9.37	9.35
Inside diameter	27.41	27.48	27.51	27.43	27.46	27.46	27.46	27.48
Cup depth	13.82	14.30	14.25	14.27	13.82	14.33	14.30	14.30
Mass	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1

Table 10. Inspection of Hispano Suiza sabot (mass in grams)

Pusher plate

Item	1	2	3	4	5
Mass	29.8	30.0	30.1	29.9	29.8

Obturator

Item	1	2	3	4	5
Mass	6.1	6.1	6.1	6.1	6.1

Table 11. Firing data - 30-mm tubular projectile (Hispano Suiza copper banded)

Shot No.	Projectile Weight (grams)	Disc Weight (grams)	Obturator Weight (grams)	Propellant CR-8325 (grams)	Pressure (CUP)	Velocity over 50' @53'	Velocity over 50' @103'	Armor-Steel Thickness (in.)	Armor-Steel Obliquity (°)	Armor-Steel Penetration (in.)
1	201.0	29.8	6.1	129.6	37,400	NA*	NA*	NA	NA	NA
2	202.7	30.0	6.1	152.0	55,800	NA*	NA*	2	0	1.55
3	202.5	30.1	6.1	152.0	59,000	4219.4	4226.1	2	0	missed
4	202.1	29.9	6.1	152.0	56,100	NR	NR	2	0	1.59
5	202.1	29.8	6.1	152.0	56,500	4182.3	4187.9	2	0	1.47

*Paper panels at 28, 78 and 128 feet to confirm projectile stability prior to committing instrumentation.

Table 12. Firing data - 30-mm tubular projectile
(GAU-8 plastic banded)

Shot no.	Projectile weight (grams)	Disc weight (grams)	Obturator weight (grams)	Propellant CR-8325 (grams)	Pressure (PSI)	Velocity over 50' @53'	Velocity over 50' @103'	Armor-steel Thickness (in.)	Armor-steel Obliquity (°)	Armor-steel Penetration (in.)
6	197.2	28.1	9.8	145	NR	4034.2	4040.4	1.5	0	Complete
7	197.4	28.2	9.8	145	NR[a]	b	b	b	b	b
8	197.1	28.1	9.8	145	58,000	4029.9	4039.4	1.5	45	0.82
9	197.1	28.2	9.8	145	57,900	NR	4030.6	1.5	56	1.10
10	197.1	28.0	9.8	145	57,500	4038.7	4055.8	1.0	60	Complete
16	197.3	28.1	9.9	145	55,400	NR	4014.1	1.0	68	0.41
17	197.5	Combined weight 38		145	55,300	4051.5	4051.5	NA	NA	NA

a. Transducer apparently damanged on one of the first two firings. Plastic band material packed in pressure tap hole

b. Round grazed last shield and was deflected into floor of range

Table 13. Firing data - 30-mm tubular projectile (GAU-8 copper banded)

Shot no.[a]	Projectile weight (grams)	Disc weight (grams)	Obturator weight (grams)	Propellant CR-8325 (grams)	Pressure (PSI)	Velocity over 50' @53'	Velocity over 50' @103'	Armor-steel Thickness (in.)	Armor-steel Obliquity (°)	Penetration (in.)
11	Unknown	Unknown	Unknown	145.0	96,600	NR	4154.2	1.0	55	Complete
12	204.9	28.0	9.8	130.0	83,900	NR	3957.8	NA	NA	NA
13	207.3	28.3	9.8	130.0	74,400	3888.9	3888.9	NA	NA	NA
18[b]	206.0	28.2	9.6	130.0	76,000	3925.8	3927.4	NA	NA	NA
19[c]	200.0	28.1	9.9	130.0	36,800	3621.6	3620.8	NA	NA	NA
20[d]	200.4	28.2	9.8	130.0	45,800	3744.1	3740.5	NA	NA	NA
21[d]	203.9	28.4	9.8	145.0	54,000	4059.7	4056.1	NA	NA	NA
22[d]	203.7	27.9	9.8	145.0	51,000	4031.6	4023.8	NA	NA	NA
23[d]	201.6	27.8	9.9	145.0	53,500	4022.8	4012.8	NA	NA	NA

a. Projectile inserted into case until rear of band to case mouth measured
Shots 11, 12, 22, and 23: 0.250 inch and crimped
Shots 13, 18, 19, 20, and 21: 0.450 inch without crimping

b. Band diameter reduced from 1.235 in. to 1.226 in.

c. Band diameter reduced from 1.235 in. to 1.206 in. and middle portion reduced to 1.181

d. Band diameter reduced from 1.235 in. to 1.216 in. and middle portion reduced to 1.181

Table 14. 30-mm external ballistics results

Shot no.	Velocity no. 1	Velocity no. 2	Chamber pressure	Launch weight	Elevation of gun (mil.)	X (in.)	Y (in.)	Time
GAU-8, Target no. 1								
1	Warmer				5.5	Missed		1100
2	Warmer				8.0	Missed		1117
3	Warmer				9.0	Hit top center		1130
4	Warmer				8.4		6.5' Above top	1140
5	No instrumentation				8.0	24.5	17.0	1316
6	3280	3280	46,500		8.0	24.5	25.0	1410
7	3254	3247	45,200		8.0	4.5	8.5	1425
8	3270	3263	48,800		8.0	27.0	64.0	
9	3291	3277	47,700		8.0	-35.0	45.0	1440
GAU-8 Tubular (plastic band) target no. 2, aluminum cartridge case								
10	4195	4193	61,100	235.5	7	Missed		1450
11	4149	4143	55,600	235.8	7	30.0	55.5	1506
12	4174	4168	57,500	235.5	7	36.5	84.0	1520
13	4166	4165	55,900	234.9	7	Missed		
14	4143	4139	57,600	235.0	7	Missed		1535
15	4165	4160	65,300	235.2	6	Missed		

Time	Temperature (degrees)	Wind velocity (knots)	Wind direction (degrees)	Barometric pressure (in./Hg)	Relative humidity (percent)
1100	45	7	320	30:31	27
1200	48	9 G16	300	30:29	33
1300	50	9	260	30:28	37
1400	52	10	280	30:25	29

Tab'   Continued

Shot no.	Velocity no. 1	Velocity no. 2	Chambe pressure	Launch weight	Elevation of gun (mil.)	X (in.)	Y (in.)	Time
GAU-8 Tubular (plastic band) target no. 3								
16	——	——	——	235.0	5	- 6.5	42.5	0900
17	4157	4148	57,800	235.0	5	-17.0	39.5	0915
18	4136	4133	——	234.3	5	-17.75	43.5	0927
19	4155	4146	56,000	234.1	5	-23.75	25.5	0936
20	4152	4155	52,100	234.7	5	- 2.5	13.75	
21*	4156	4148	49,900	235.3	5	28.0	20.0	0950
22	4167	4159	58,500	234.7	5	5.56	37.5	
23	4167	4160	57,600	234.9	5	2.5	33.25	
24*	4158	4156	58,000	235.2	5	1.75	39.25	
25	4158	4156	56,400	235.2	5	27.25	29.6	1020
GAU-8 Tubular (copper band) target no. 4								
26*	3115?	——	55,000	246.0	5	7.5	73.0	Warmer
27*	4021	4009	50,500	243.3	4	21.6	-30.5	1045
28*	4146	4139	55,200	245.7	4	34.25	-48.5	
29*	4041	4035	51,700	244.7	4	5.5	-23.5	1053
30*	4121	4110	57,200	243.5	4	9.4	-53.25	
31*	4125	——	55,000	241.5	4	-38.2	-34.75	
32*	4045	——	53,300	245.1	4	19.8	- 2.25	1110
33*	4113	——	55,500	243.1	4	-22.0	19.4	
34*	4113	——	56,900	240.5	4	-13.75	19.5	1120
35*	4134	——	57,800	244.2	4	-13.0	-51.8	
36*	4100	——	55,700	242.1	4	-12.0	-65.4	

Time	Temperature (degrees)	Wind velocity (knots)	Wind direction (degrees)	Barometric pressure (in./Hg)	Relative humidity (percent)
0900	55	7	300	30:21	61
1000	58	5	310	30:20	38
1100	61	3	310	30:19	28
1200	62	9 G14	320	30:17	25

Table 14. Continued

Shot no.	Velocity no. 1	Velocity no. 2	Chamber pressure	Launch weight	Elevation of gun (mil.)	X (in.)	Y (in.)	Time
				HS 831 L TP, target no. 5				
37	3507	——	———		7	Missed		1330
38	3504	——	———		6	Hit		1350
39	3515	——	———		6			
40	3520	——	———		6	Missed		1407
41	3510	——	———		6	Missed		
				HS 831 Tubular (copper band), target no. 6				
42	4205	——	58,000	239.5	5	Low miss		1440
43	4195	——	60,500	239.1	5	Low		1445
44	4173	——	60,700	238.3	6	35.0	-27.0	1457
45	4200	——	62,300	238.3	6	Missed		1504
46	4199	——	66,600	238.7	6	59.0	-37.5	

Time	Temperature (degrees)	Wind velocity (knots)	Wind direction (degrees)	Barometric pressure (in./Hg)	Relative humidity (percent)
1200	62	9 G14	320	30:17	25
1300	62	11 G17	320	30:16	25
1400	64	7 G16	330	30:15	24

Table 15. Radar tracking and velocity

	General Electric barrel		Hispano Suiza barrel		
Shot	Target practice(TP)	Tubular	Target practice	Tubular	Time
1	TP				10:58
2	TP				11:00
3	TP				11:03
4		Plastic			
5		Plastic			11:07
6		Plastic			11:11
7		Plastic			11:15
8		Copper			11:17
9		Copper			11:20
10		Copper			11:24
11		Copper			11:29
12		Copper			13:46
13	TP				13:47
14			TP		14:33
15			TP		14:36
16				Copper	14:40
17				Copper	14:50
18				Copper	14:53
19				Copper	14:55
20				Copper	14:57
21			TP		15:01
22			TP		15:03

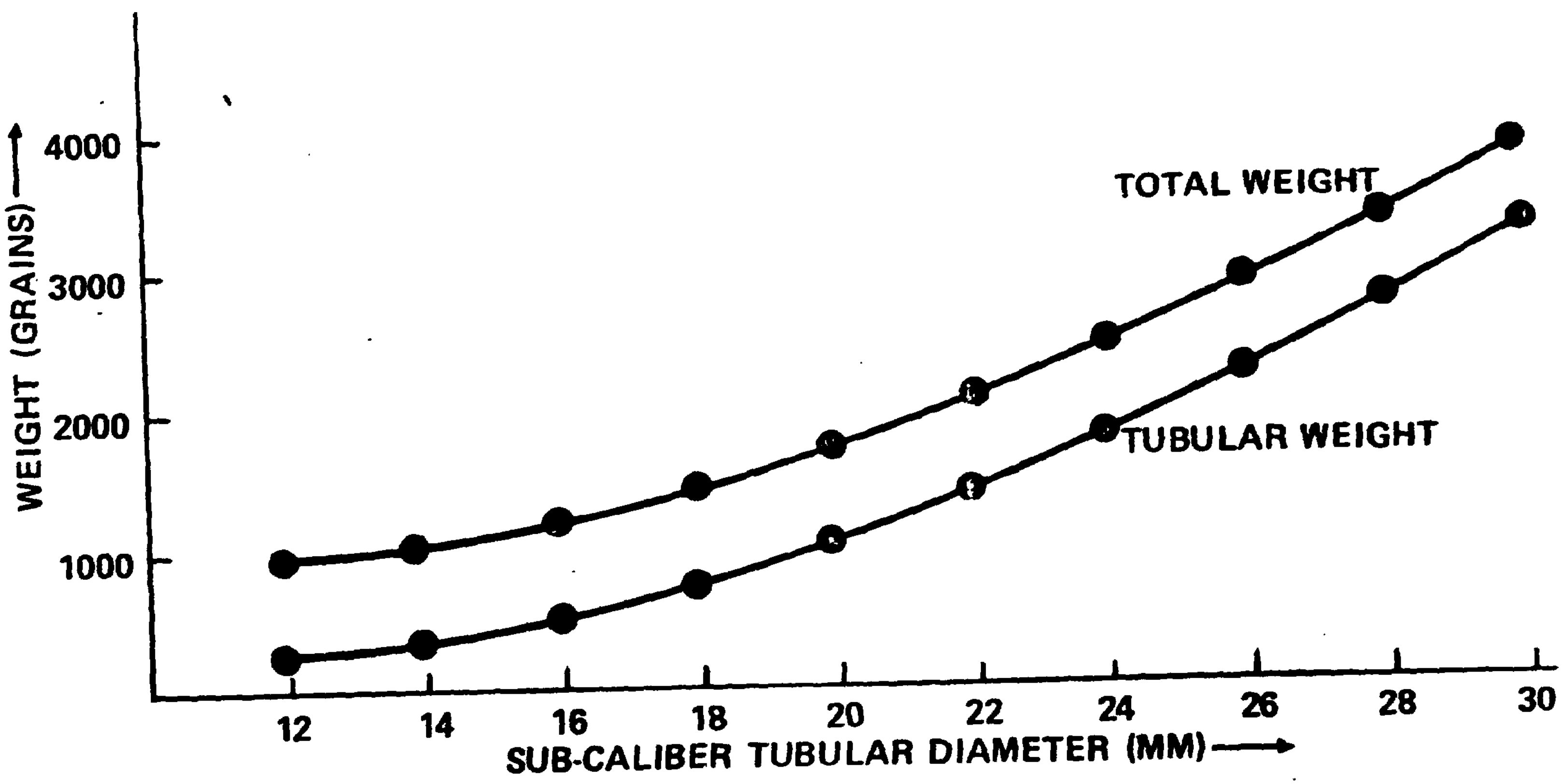


Figure 1. Subcaliber tubular diameter

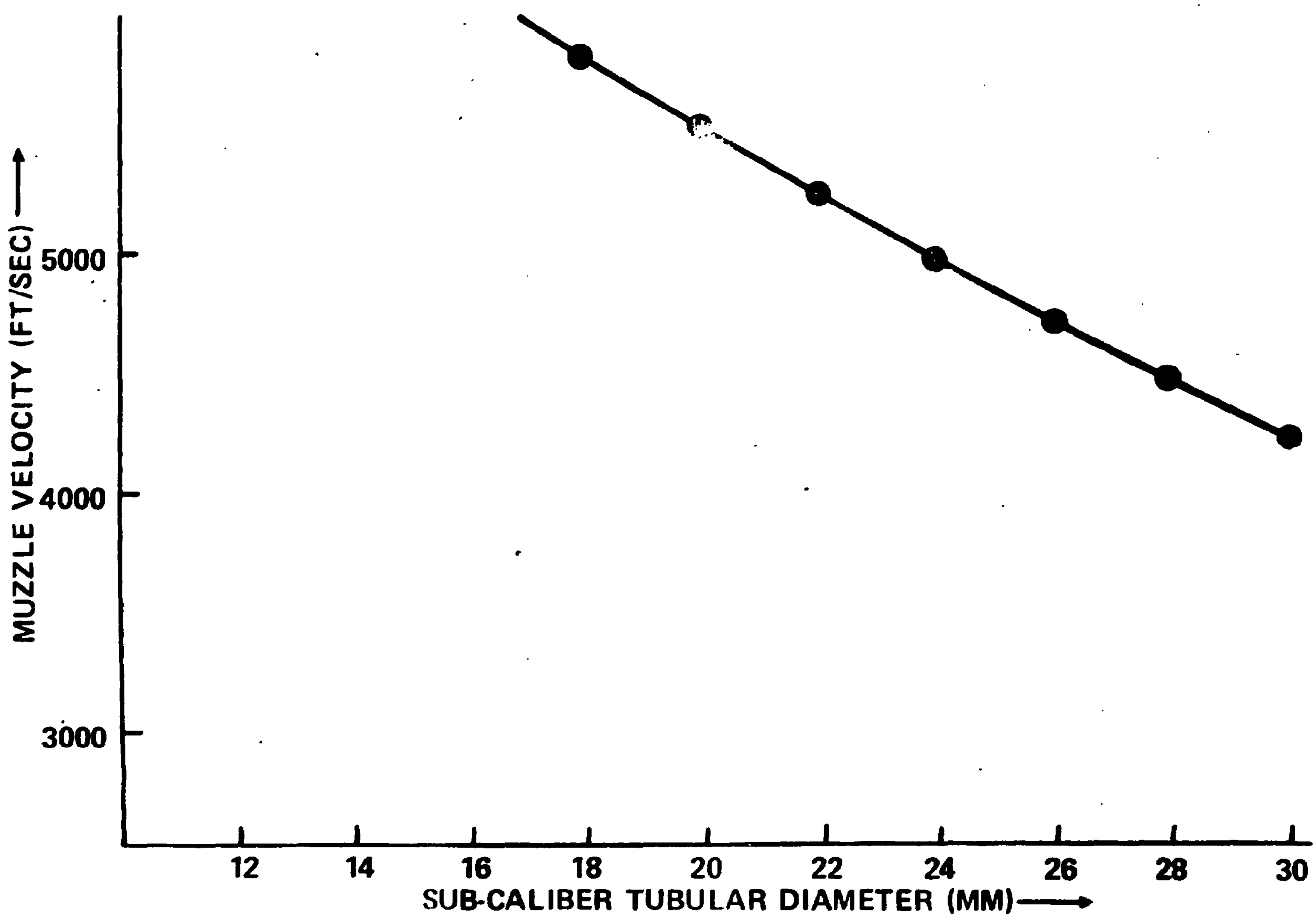


Figure 2. Subcaliber tubular muzzle velocity

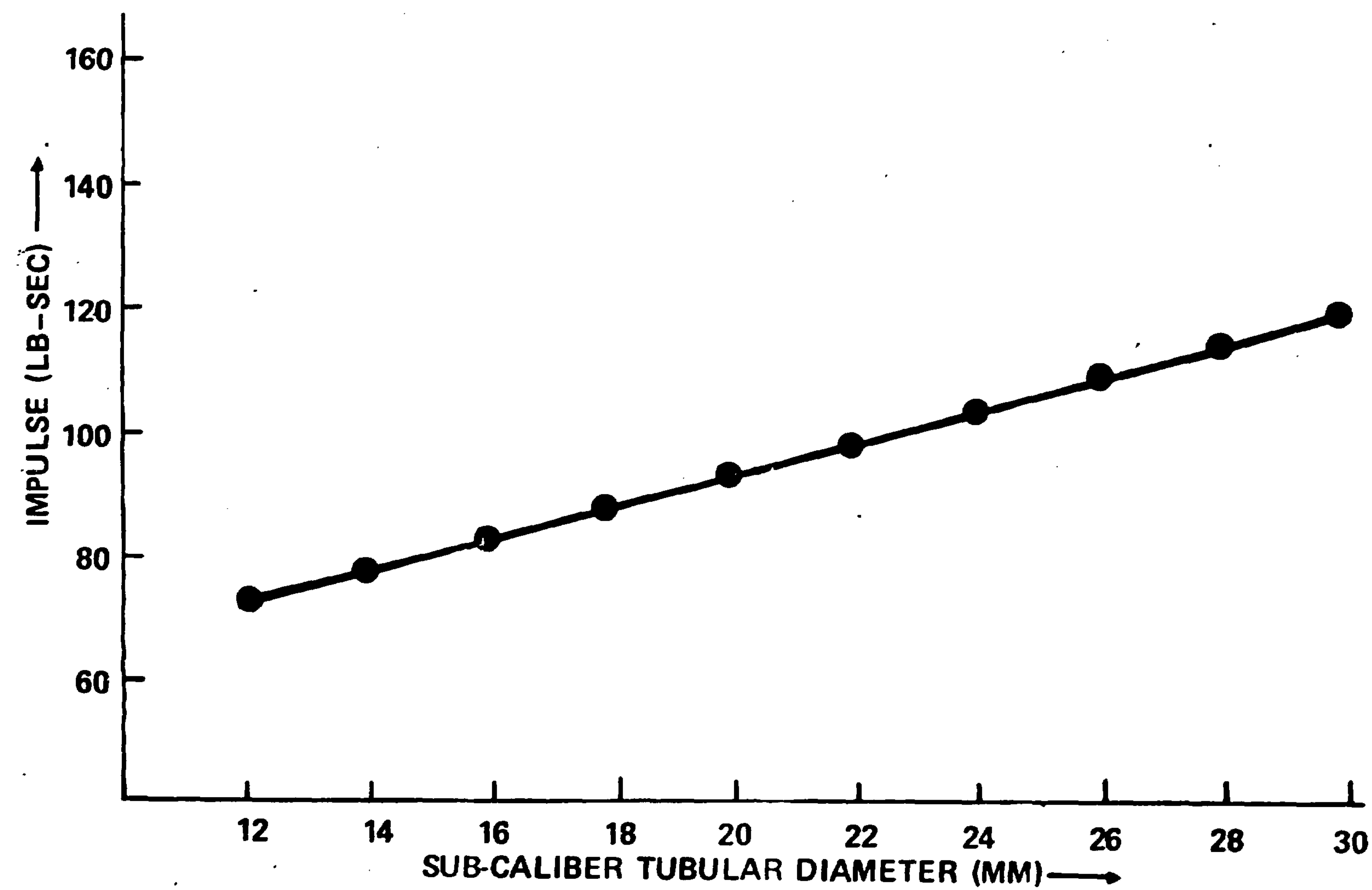


Figure 3. Subcaliber tubular impulse

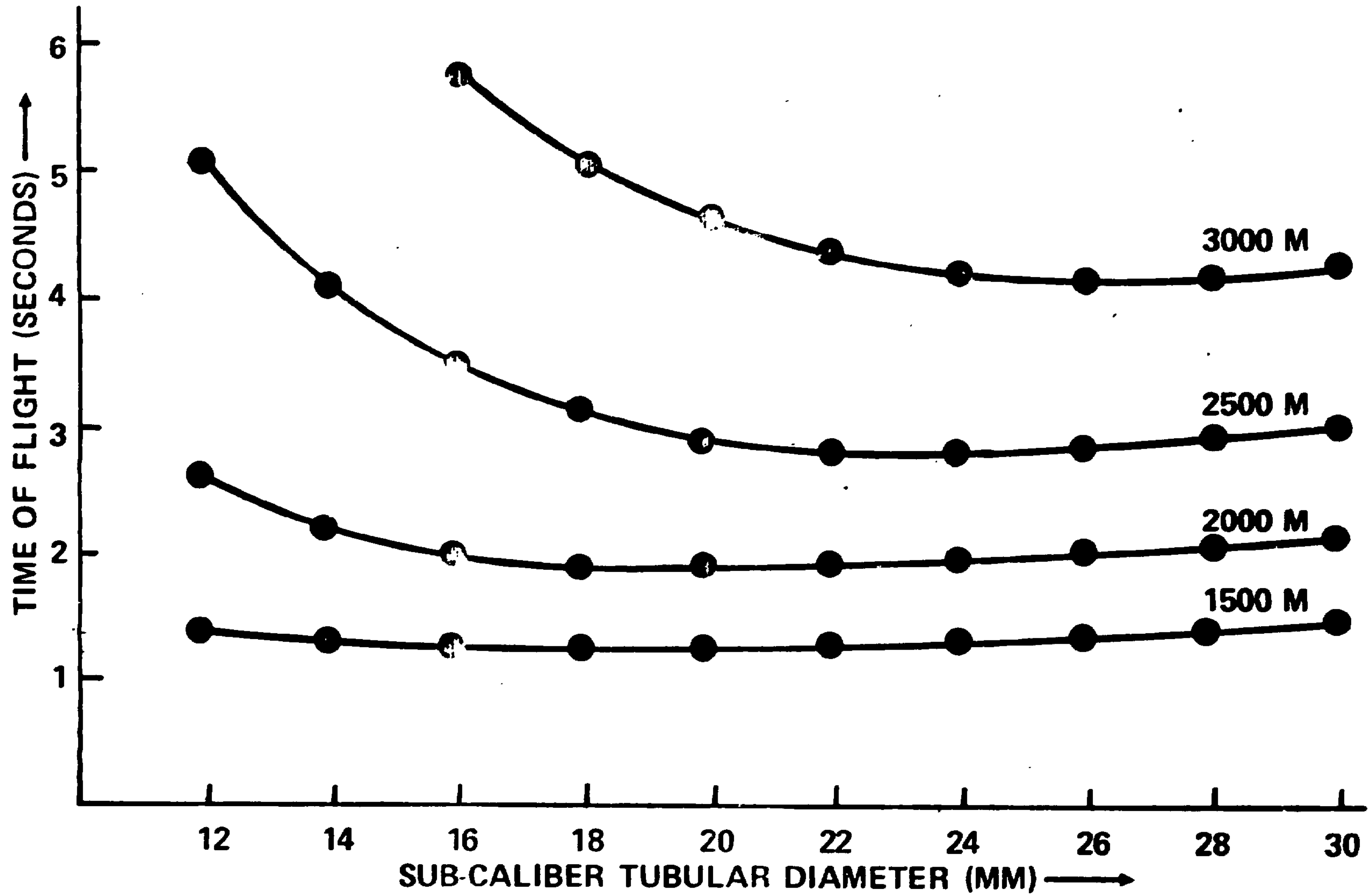


Figure 4. Subcaliber tubular time of flight

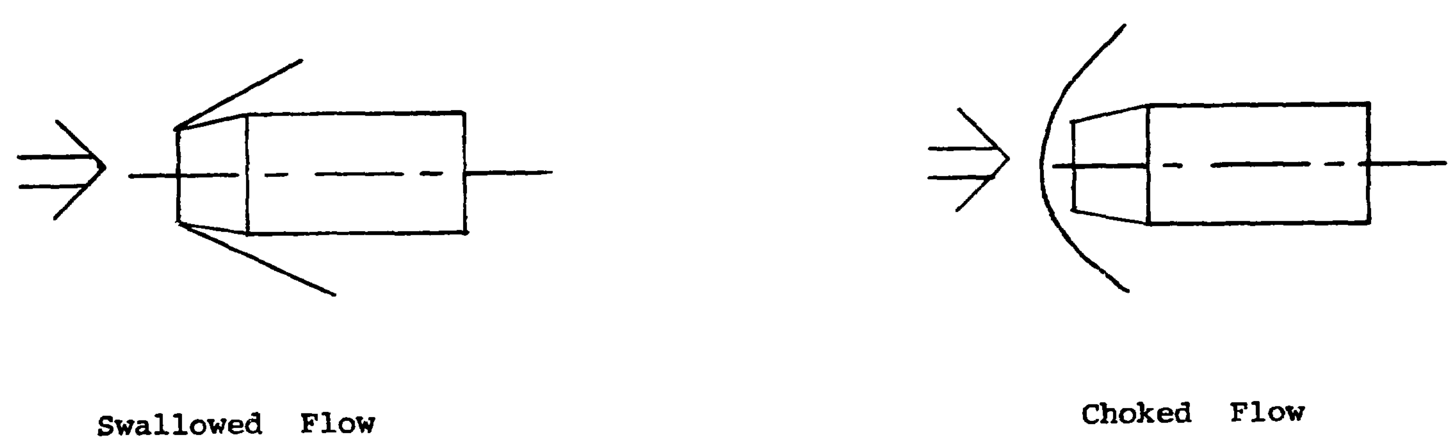


Figure 5. Flow condition of tubular projectile

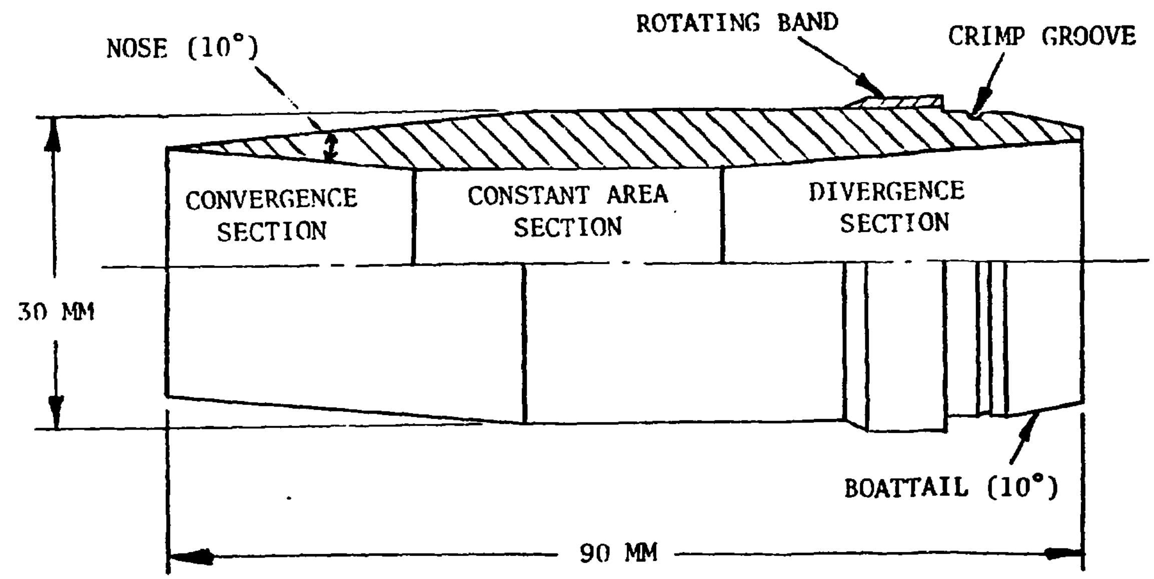


Figure 6. Tubular projectile

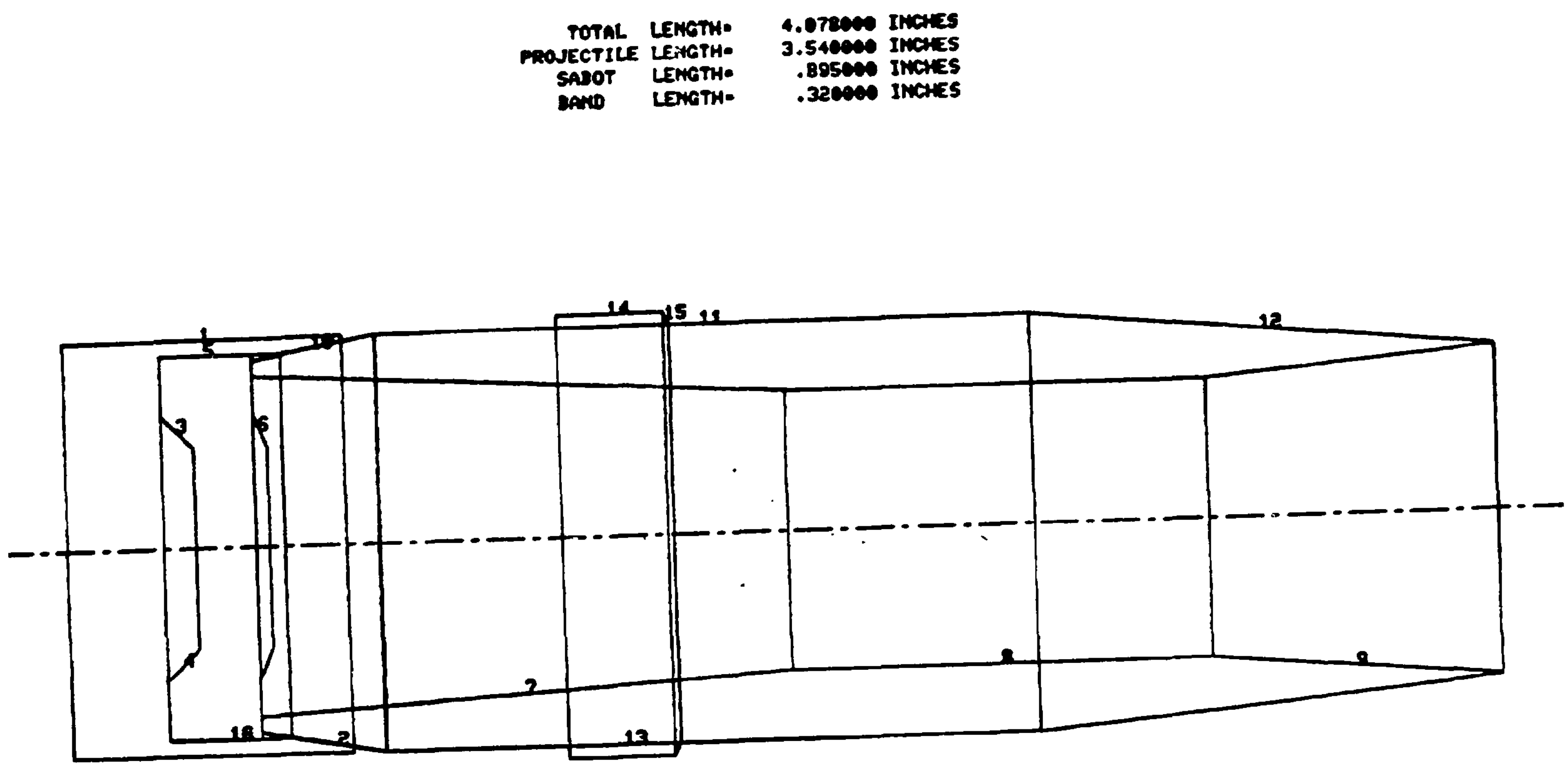


Figure 7. Original design of 30-mm tubular projectile

TOTAL LENGTH= 4.333000 INCHES
PROJECTILE LENGTH= 3.540000 INCHES
SABOT LENGTH= 1.172000 INCHES
BAND LENGTH= .320000 INCHES

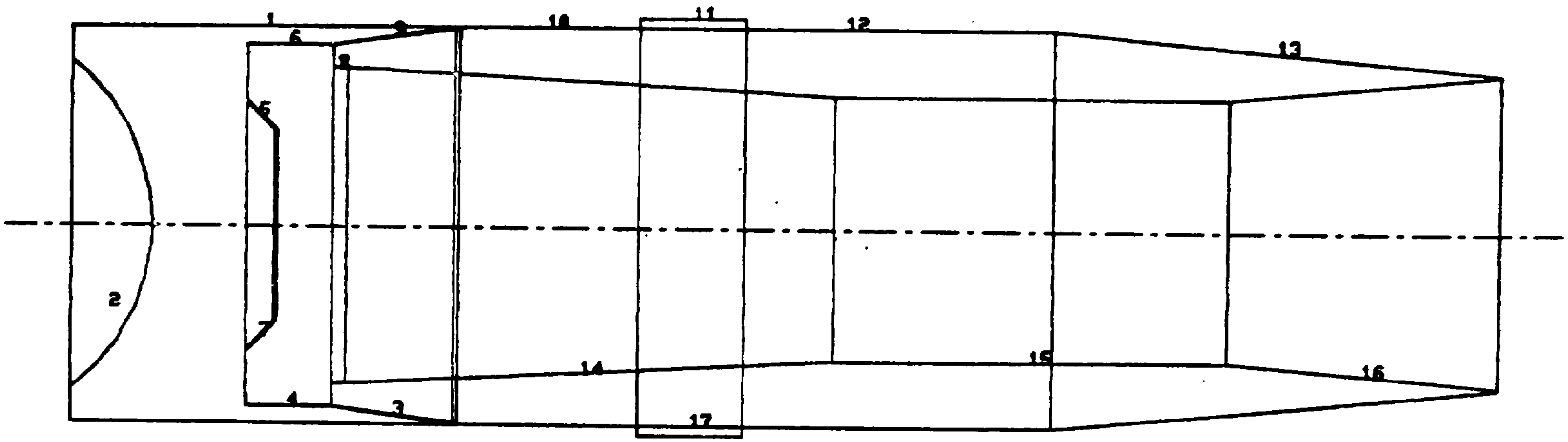
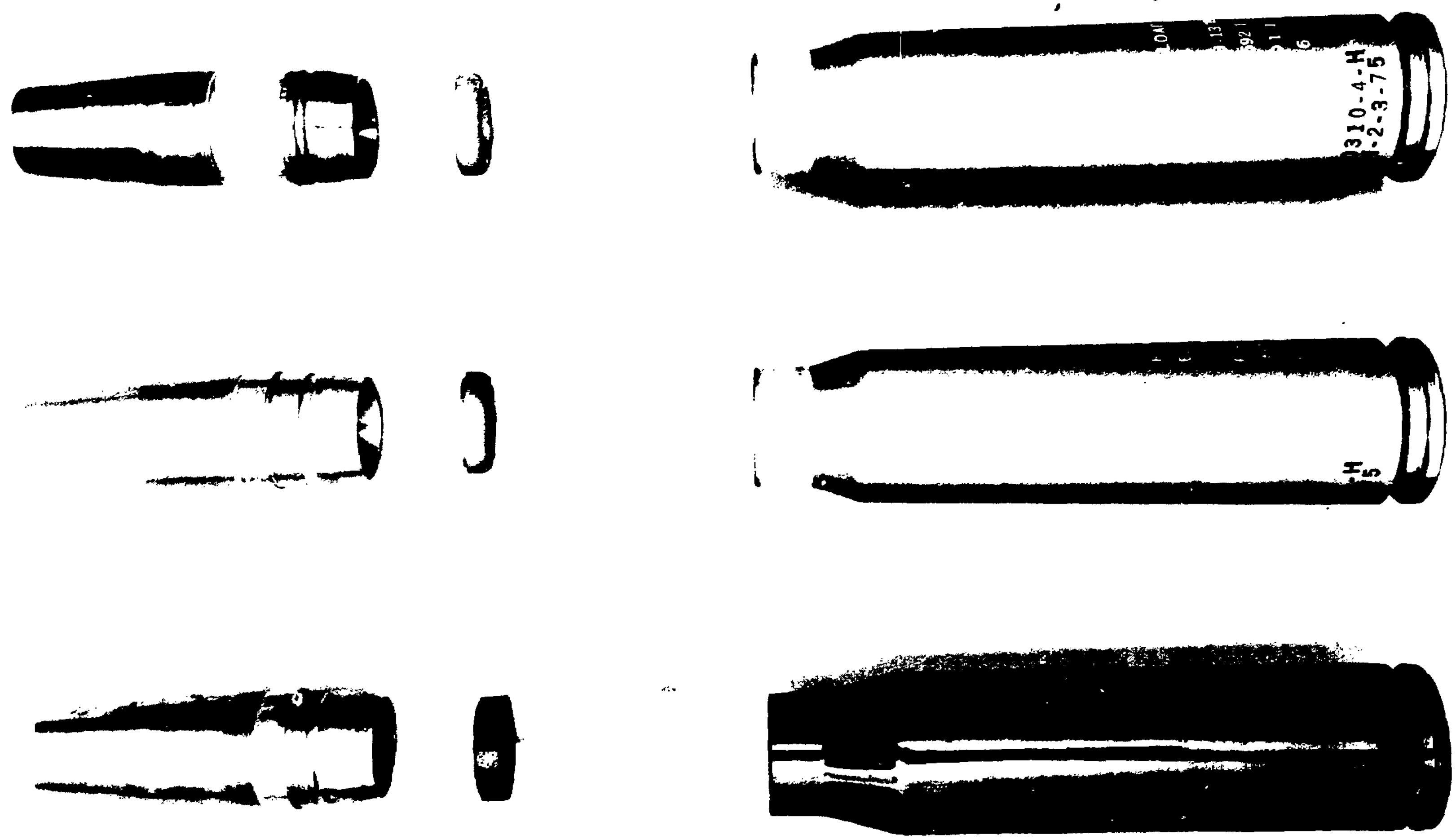


Figure 8. Modified design of 30-mm tubular projectile



Top - Plastic banded
Middle - Copper banded modified design
Bottom - Copper banded original design

Figure 9. Tubular projectiles, original and modified designs

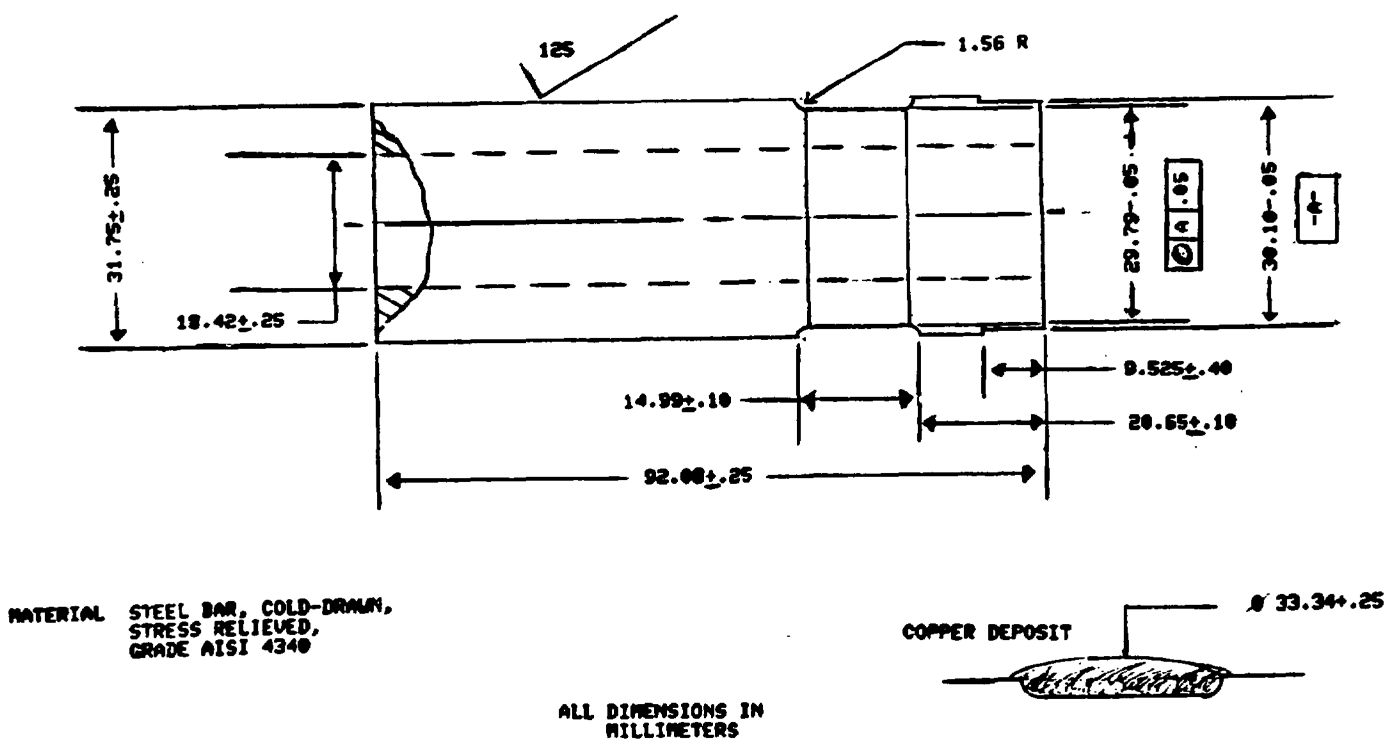
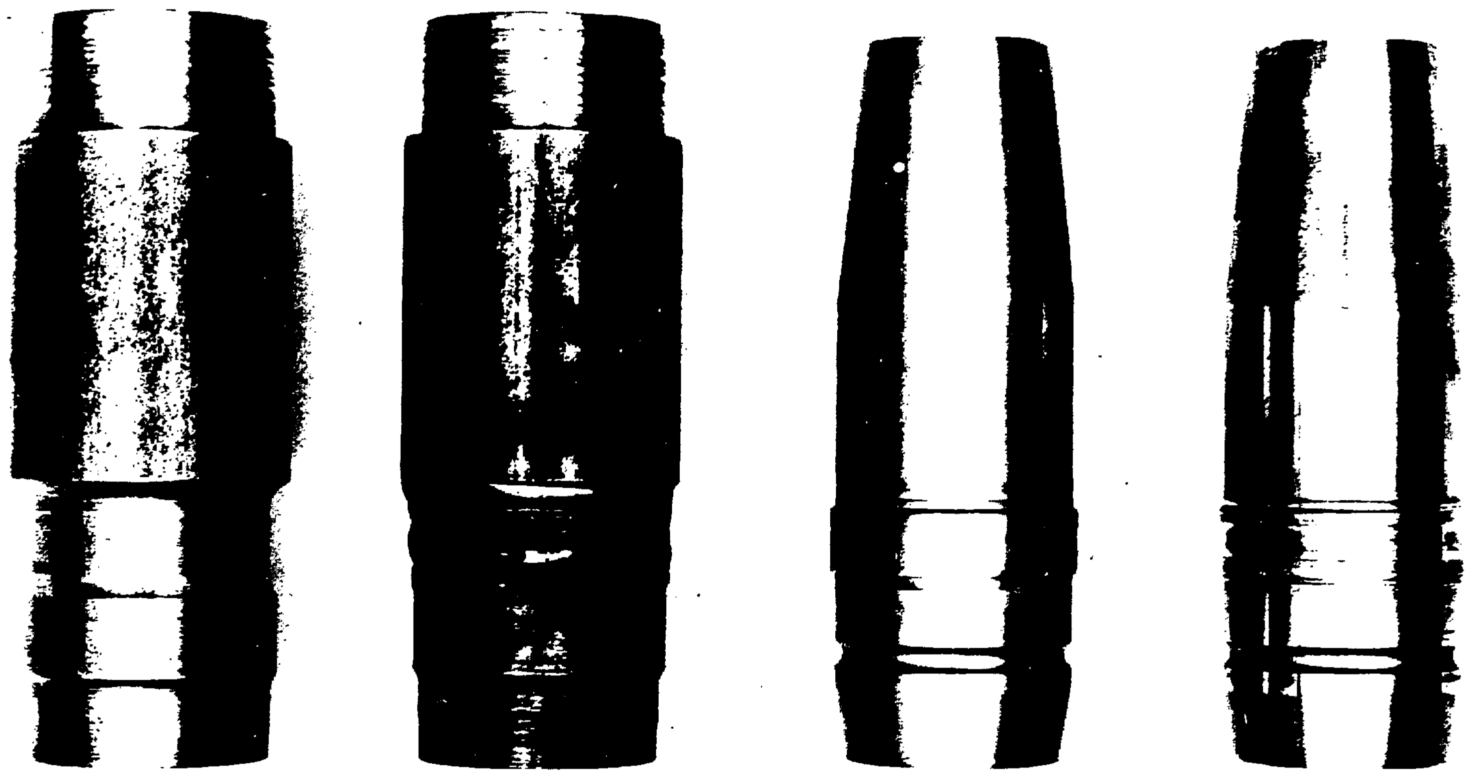


Figure 10. Bar stock prepared for banding



Blank

Blank after banding

Machined before heat treatment

Heat treated final machined

Figure 11. Fabrication of copper banded projectiles

Fibure 12. Fabrication of plastic banded projectiles

Figure 13. In-flight Hispano Suiza tubular projectile

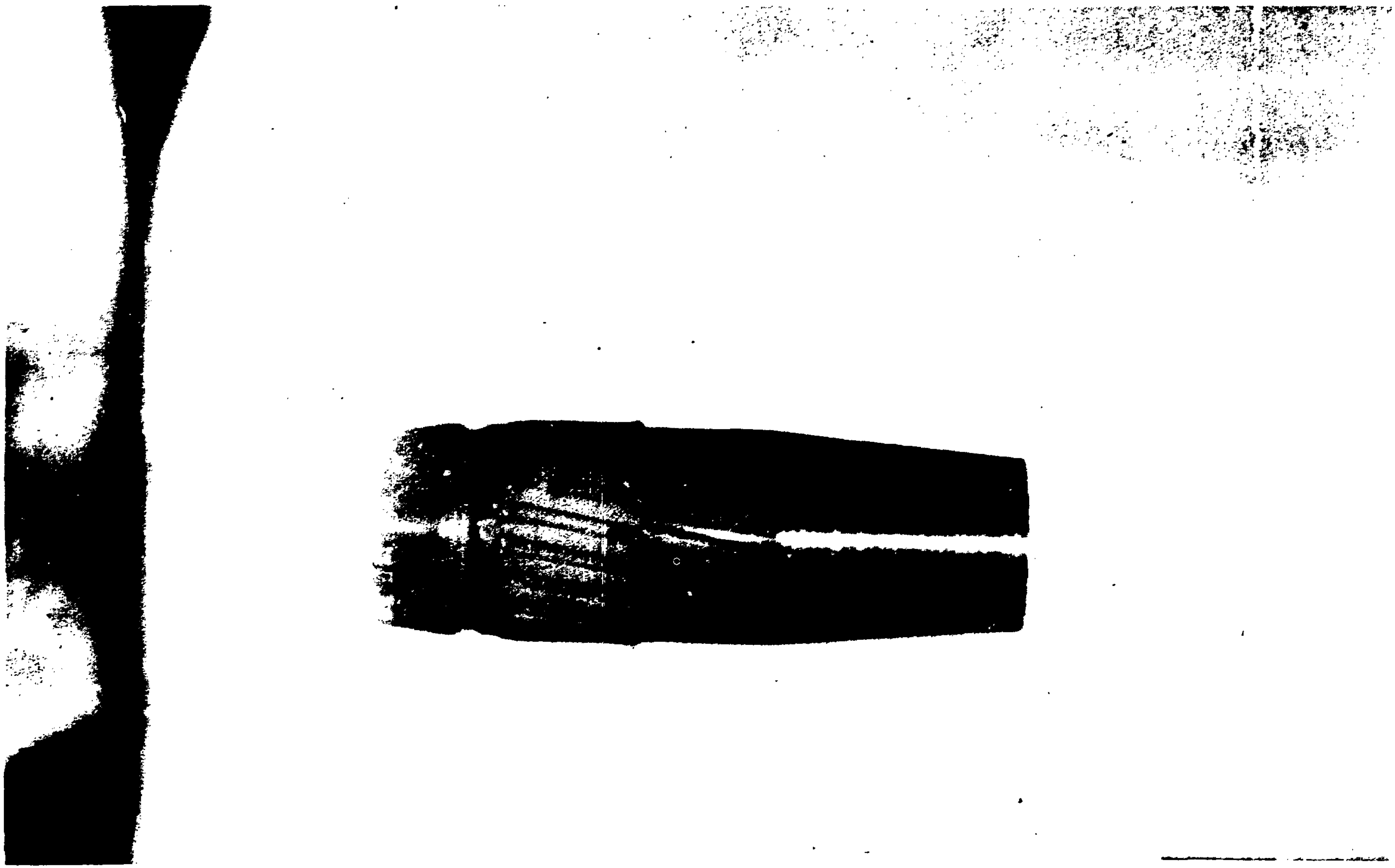


Figure 14. In-flight GAU-8 (plastic) tubular projectile

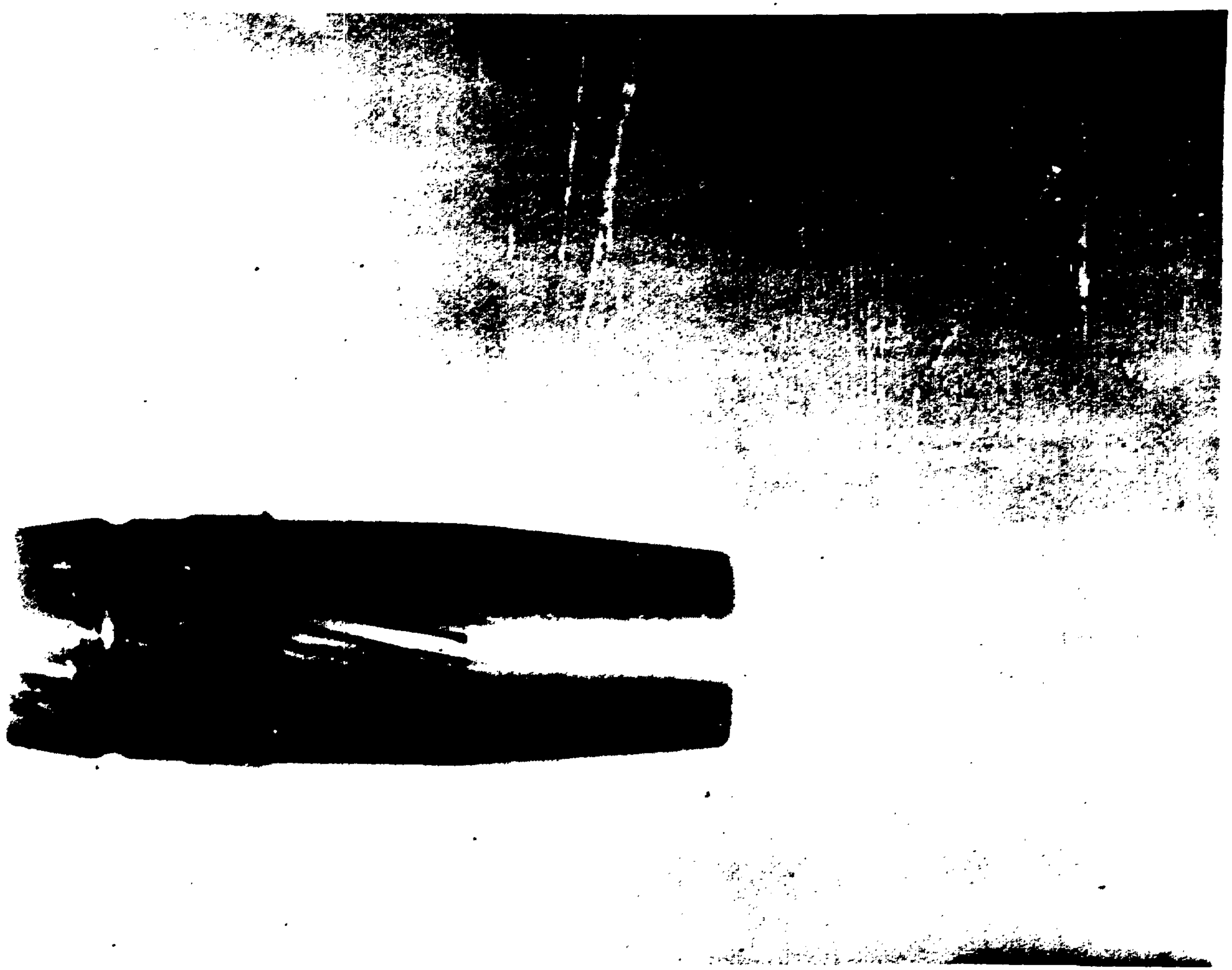


Figure 15. In-flight GAU-8 (copper) tubular projectile

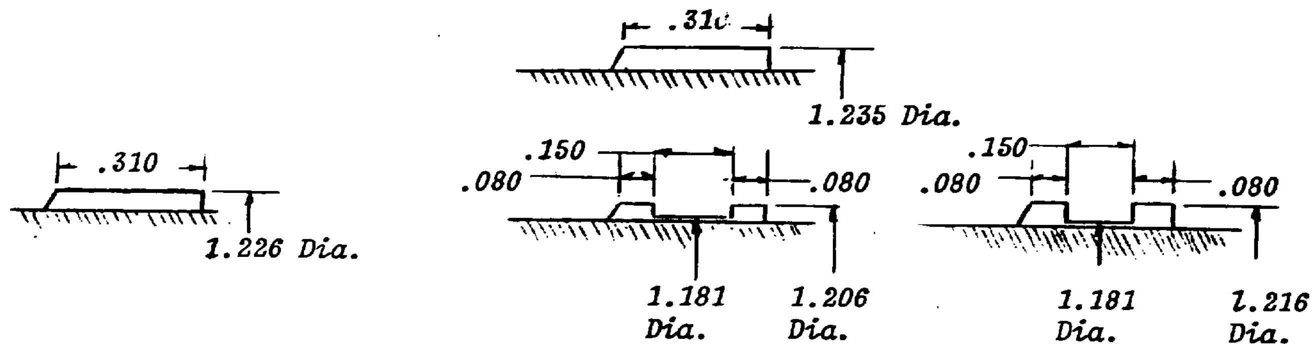


Figure 16. Modification of copper banded GAU-8 projectile

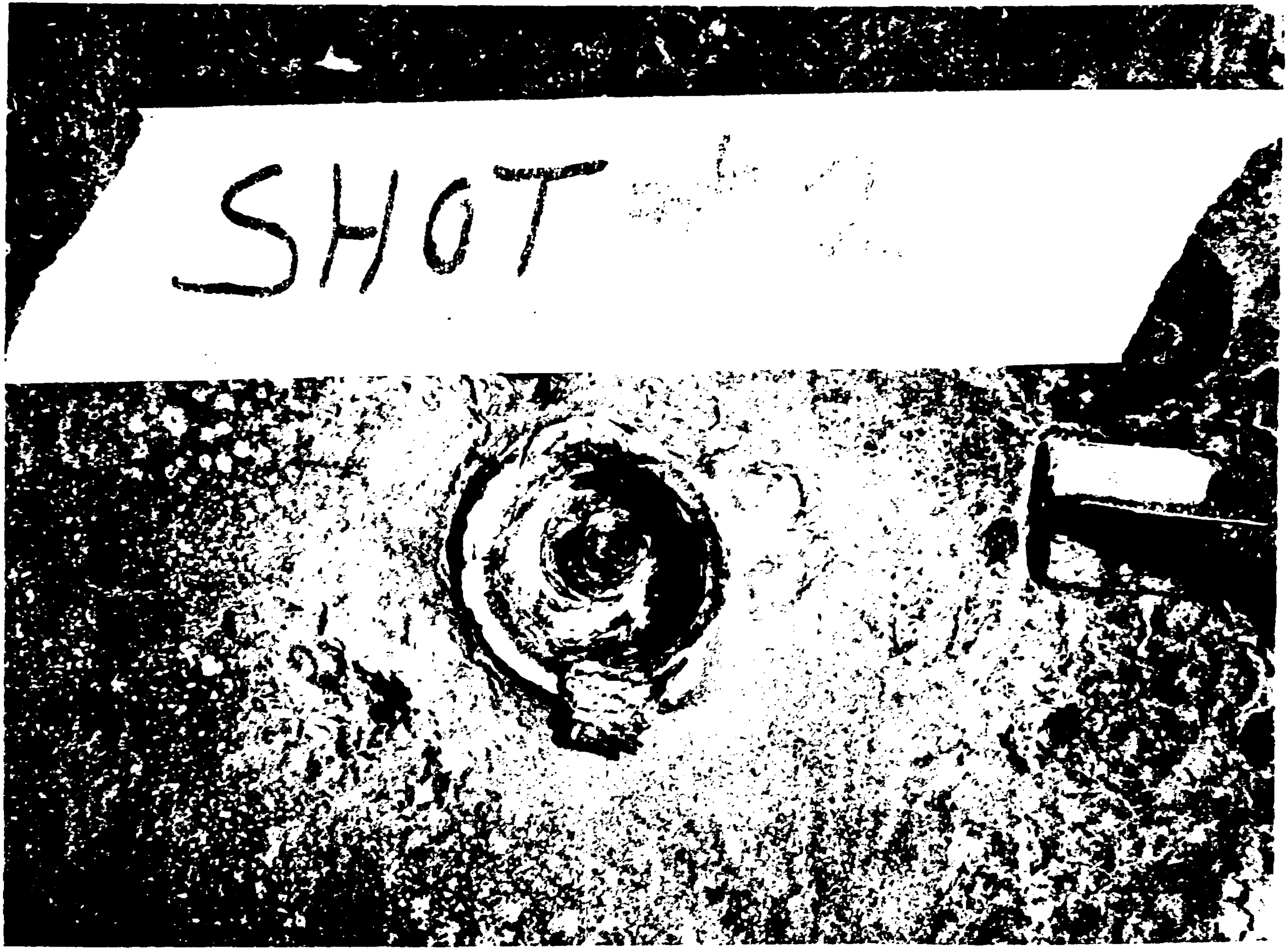


Figure 17. Zero degree impact of shot 2 on 2-in. armor 1.55 in. penetration

Figure 18. Back of armor of shot 2

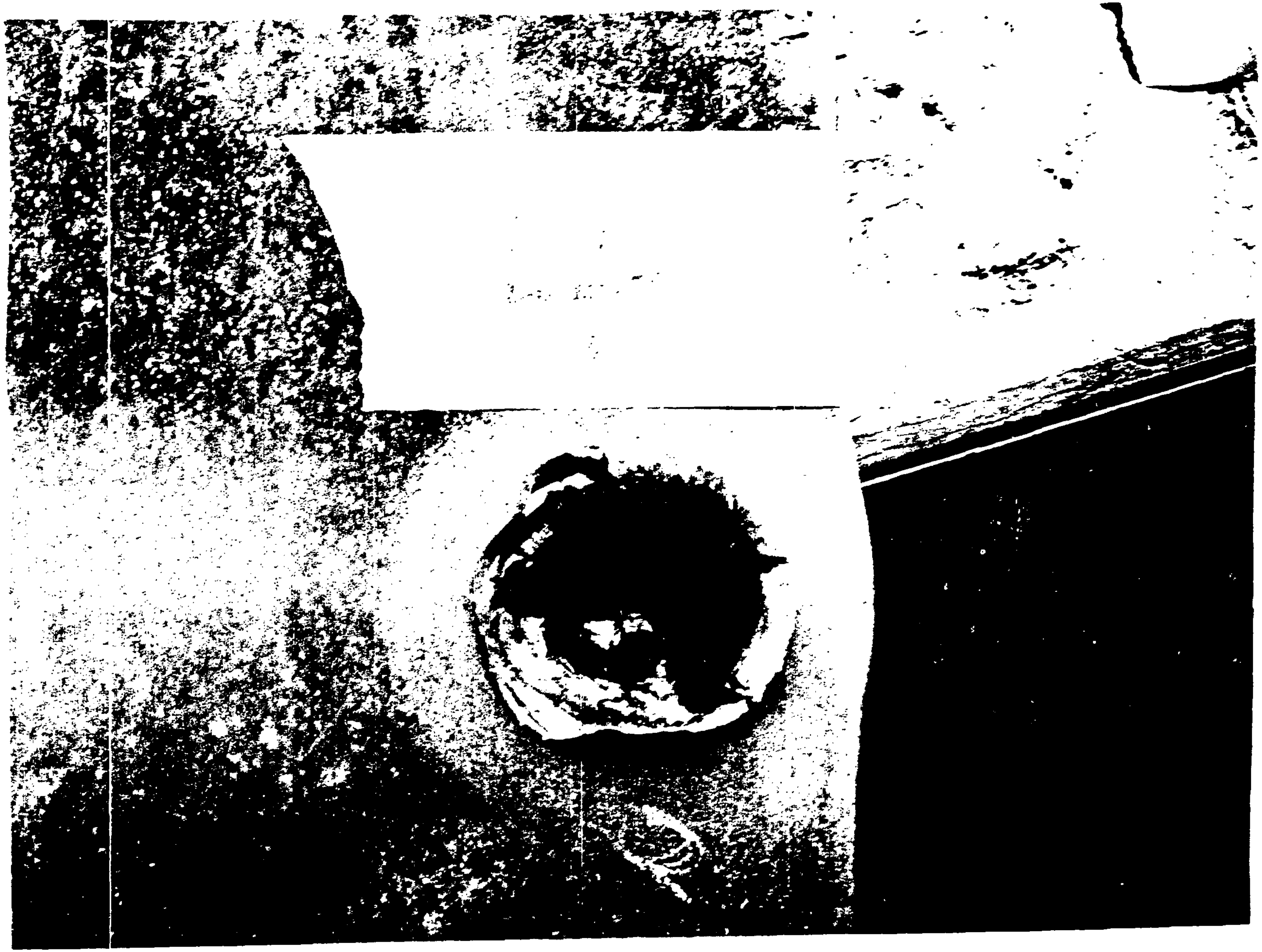


Figure 19. Zero degree impact of shot 4 on 2 in. armor 1.59 in. penetration

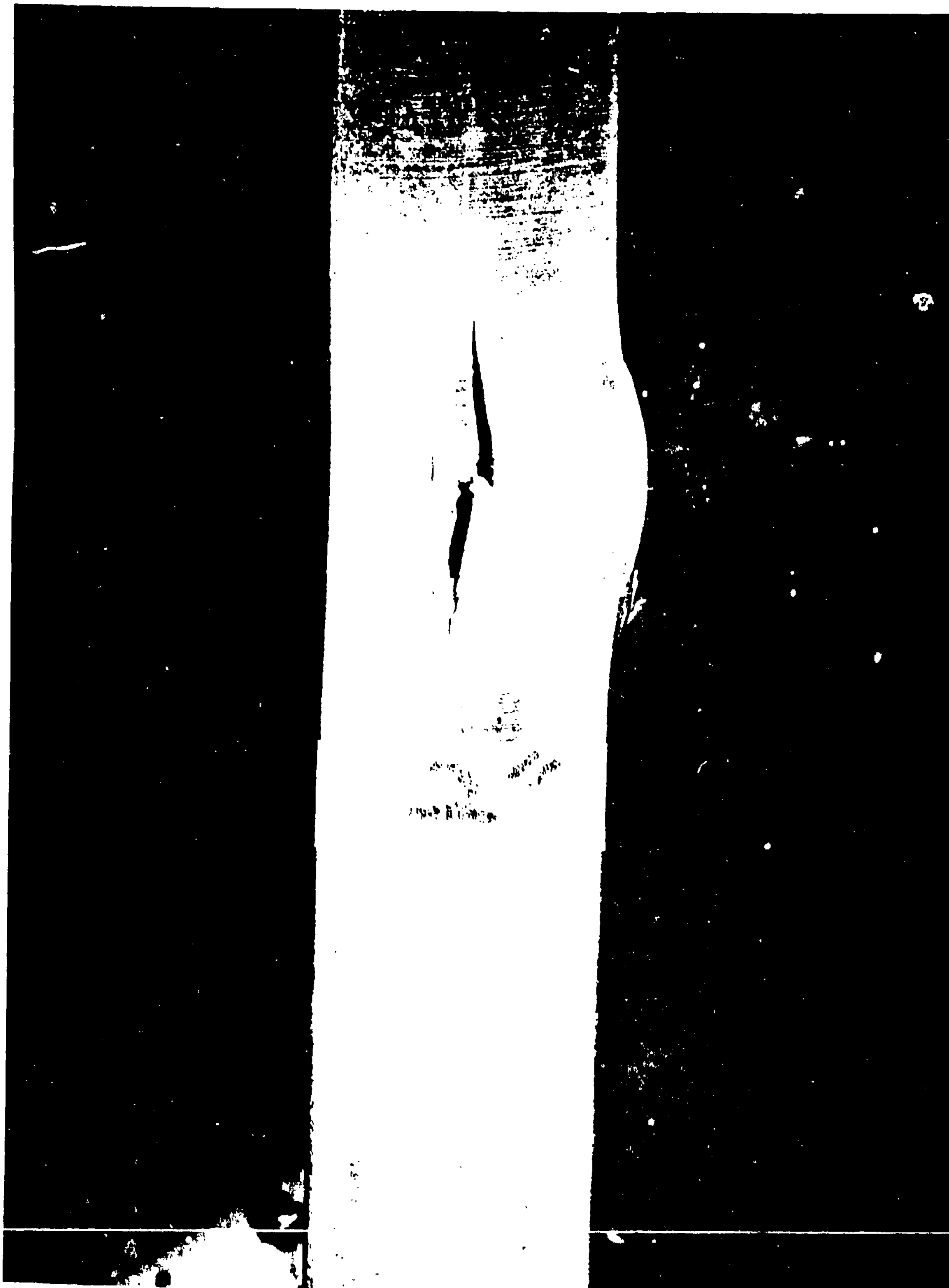


Figure 20. Side of armor from shot 4

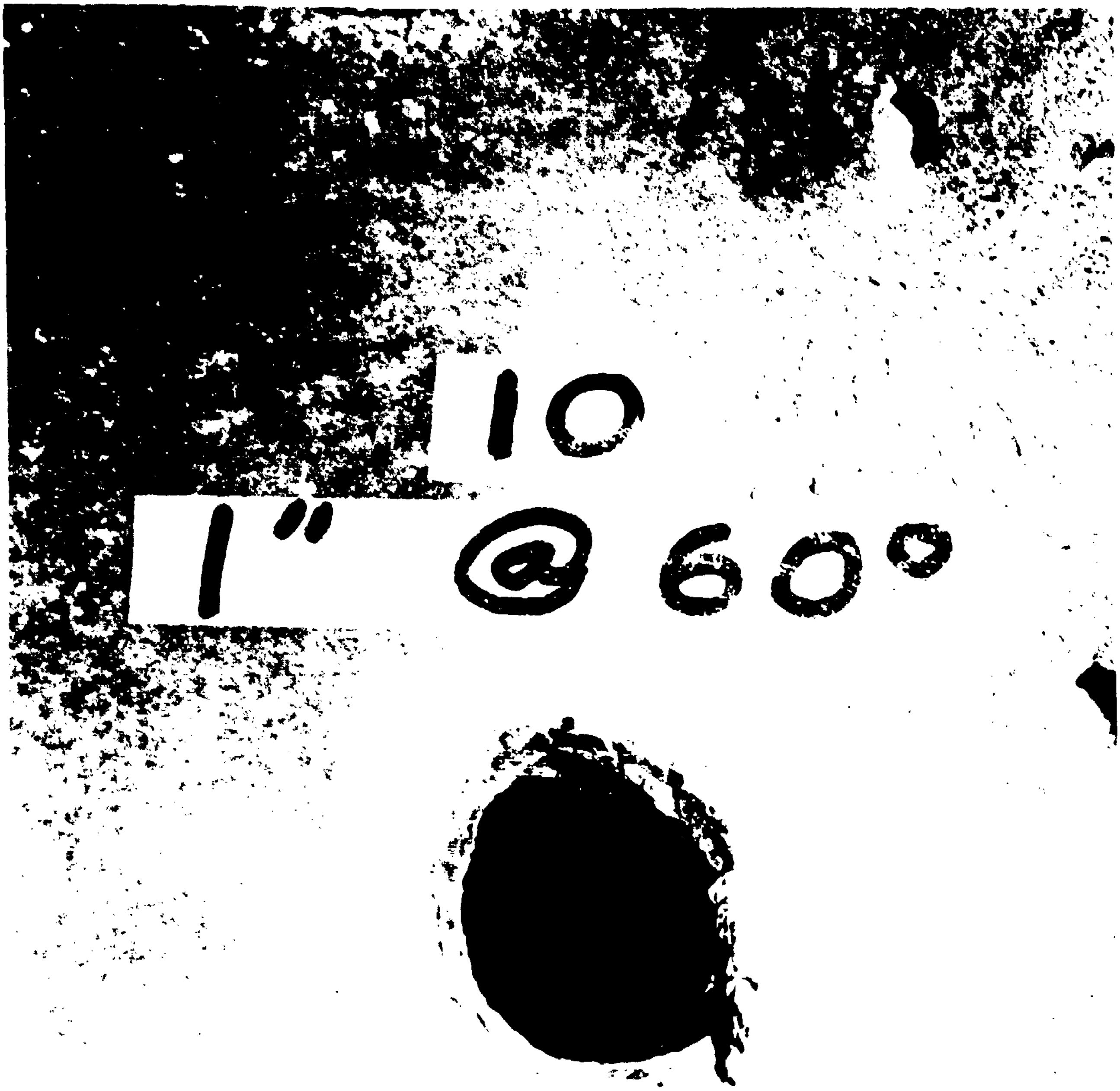


Figure 21. Impact at 60^0 obliquity of shot 10 on 1.05 in. armor-complete penetration

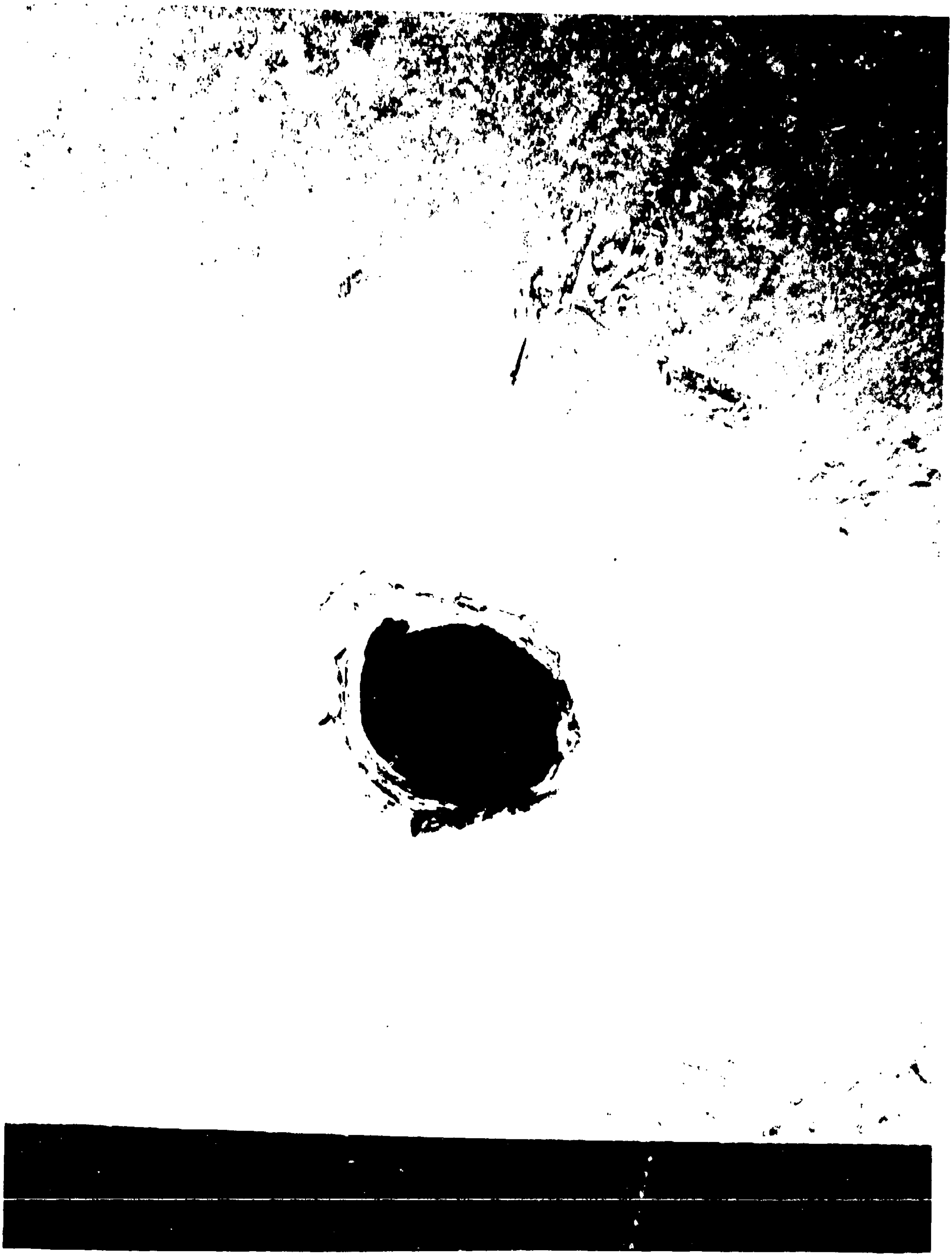


Figure 22. Back of armor of shot 10

Figure 23. Impact at 56^0 obliquity of shot 9 on 1.5 in. armor 1.10 in. penetration

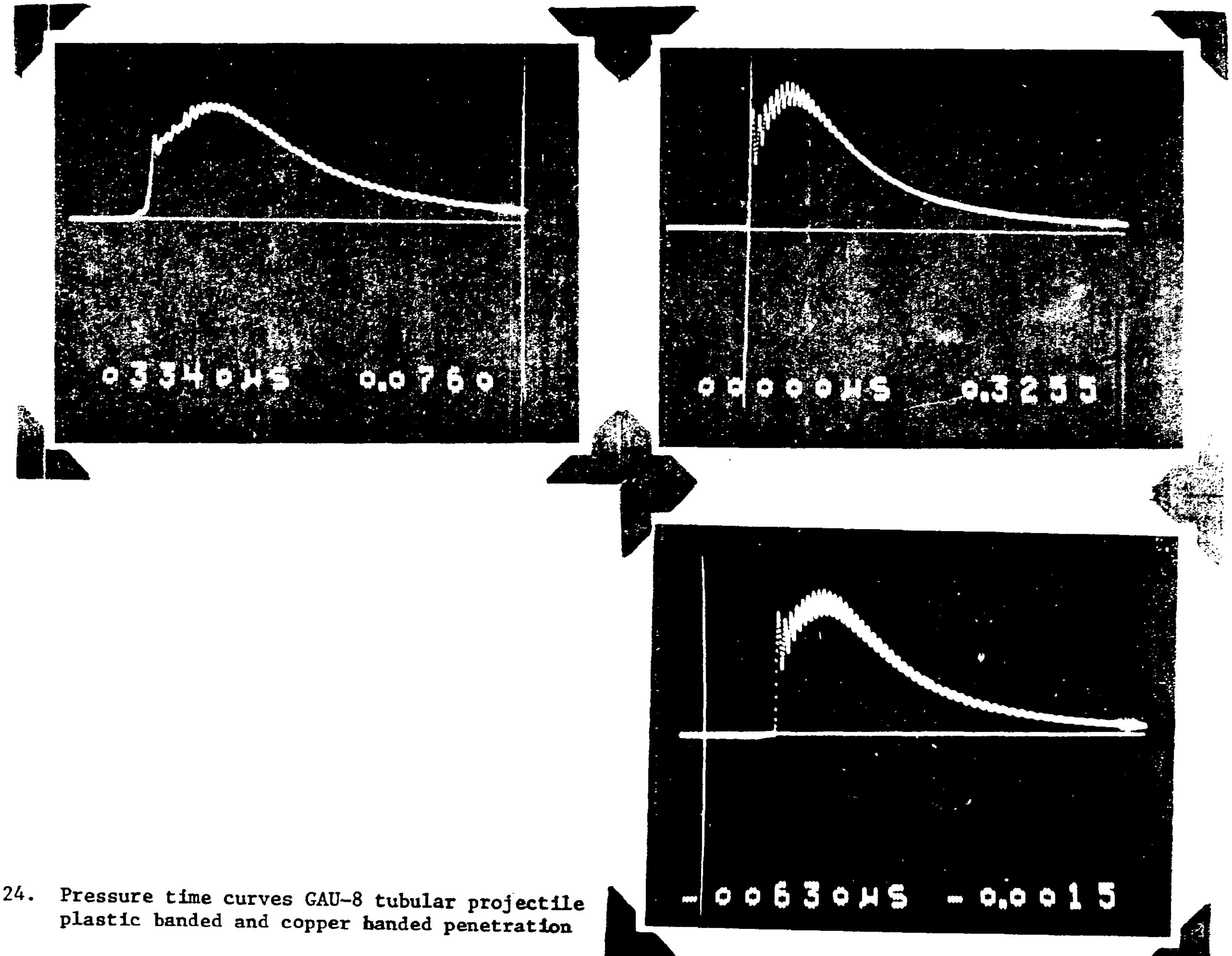


Figure 24. Pressure time curves GAU-8 tubular projectile plastic banded and copper banded penetration

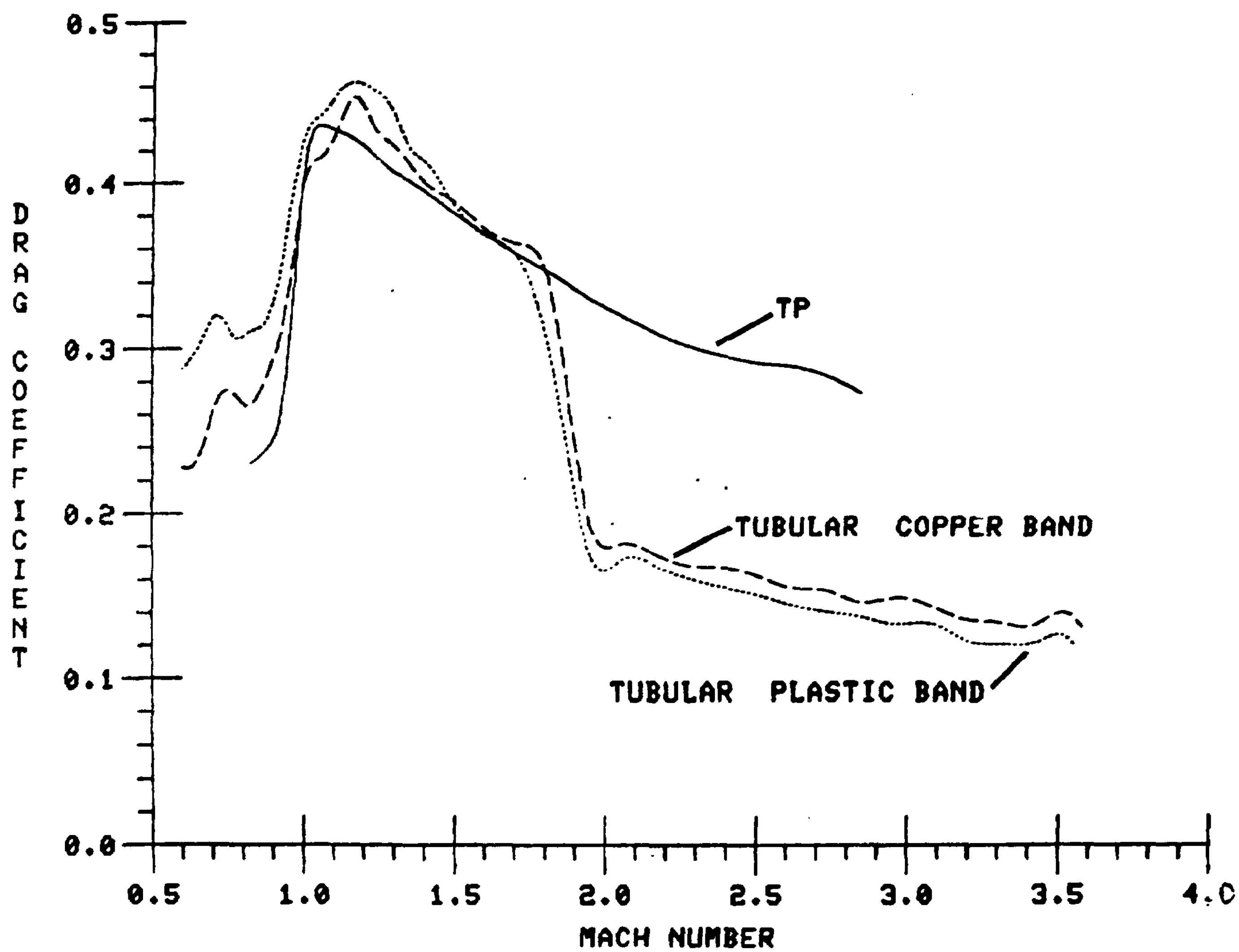


Figure 25. 30-mm GAU-8 projectiles C_D vs Mach numbers

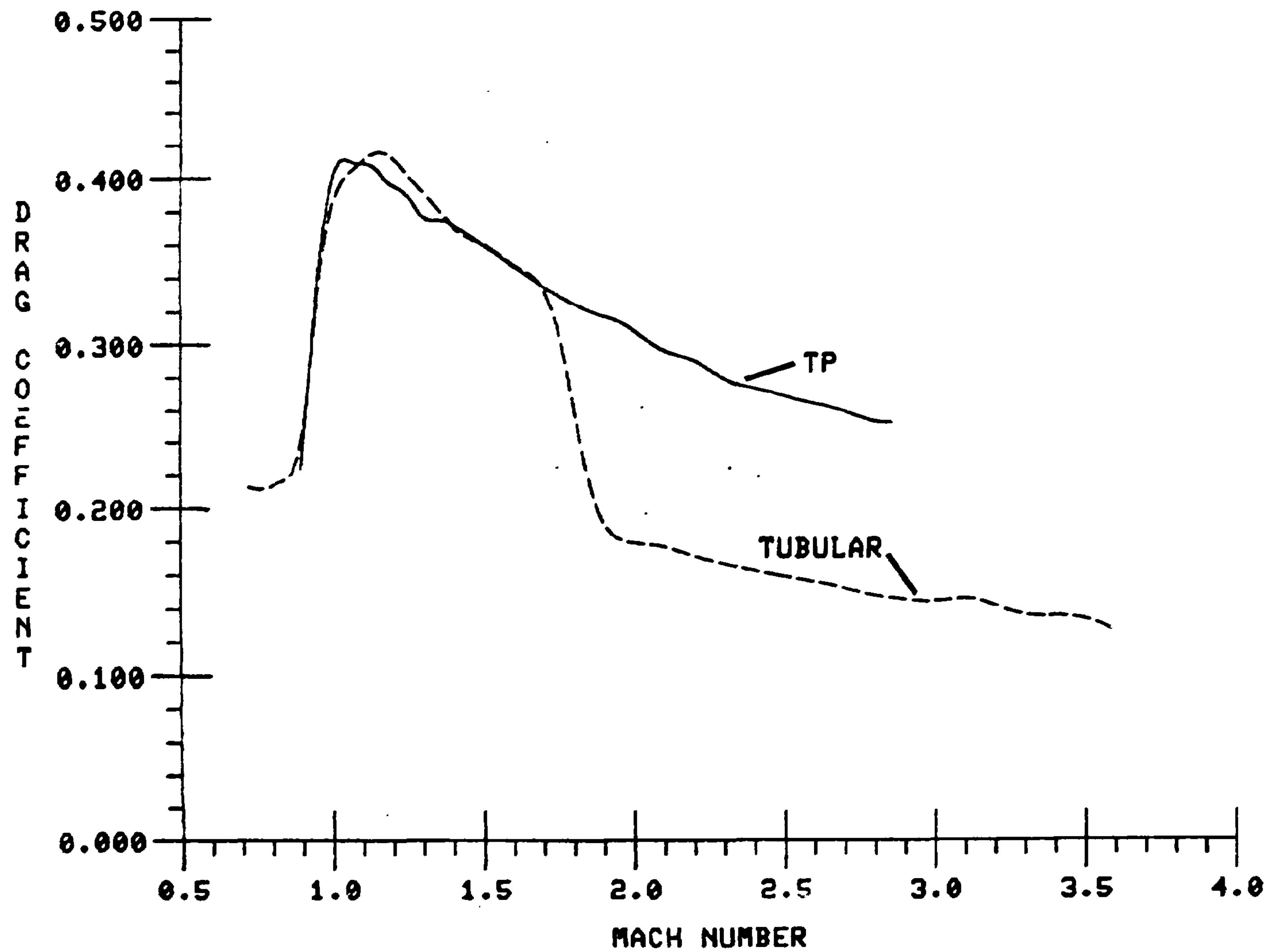


Figure 26. 30-mm Hispano Suiza projectile C_D vs Mach numbers

APPENDIX A

COPPER BANDED PROJECTILE

The banding of the steel projectiles was a manual procedure. The equipment required for the process consisted of a tungsten inert gas (TIG) welder, rotating table, and CDA-189 copper wire of various diameters. A total of 10 bar stock sections, blanks, (see figure 10 in body of report) from the 100 blank lot was used to determine the procedure for applying the bands to the blanks. The procedure consisted of placing a blank into the rotating table, and applying a weld bead in a tightly wound helix onto the band seat area. Initially, wire of 2.38-mm diameter was selected. Eleven revolutions were required of the blank to apply sufficient copper to the bank seat area for the rotating band. (No water was circulated through the projectile using this manual procedure.)

Examination of the band seat after chemically etching the copper from the steel body revealed a smooth surface, indicating little absorption of the substrate material into the band. It was determined that only 0.25 percent of the steel diffused into the copper band. The time required to perform the task was approximately 30 minutes per blank. The amount of copper applied to the blank exceeded the maximum dimension for the rotating band. In order to reduce the time required to band the projectile, the wire was changed to a diameter of 3.18 millimeters. Four revolutions were required, for a total of eight minutes. However, etching revealed cracks in the band indicating an unacceptable weld. After numerous attempts to weld the band onto the blanks failed, a decision was made to return to the 2.38 millimeter diameter wire for the banding of the stock.

The process requires a considerable period of time to apply the copper to each bar stock section, but this procedure resulted in an acceptable copper rotating band. The TIG weld process using 2.38-mm wire was used to apply the copper to the bar stock sections.

APPENDIX B

PLASTIC BANDED PROJECTILE

The procedure used to prepare the projectiles for banding and the materials used are described in this section.

The tubular projectiles were placed in a bath of trichlorethylene and soaked until the surfaces were free from oil. The projectiles were then centered in a lathe and rotated. The band seat was cleaned with emery paper to remove the oxidized surface. The outside surfaces were wiped and lint was removed by compressed air. After all the projectiles were prepared, the projectiles were placed in a lathe for the second time. Using a small paint brush, a coating of 253-P adhesive was applied to the band seat area, from the crimp groove to the boattail. The projectiles were air dried overnight. The following day, the projectiles were placed in a 232° oven for 45 minutes. The temperature of the projectile, the nylon 12 and the 3 piece insert for the single cavity mold (see figure B-1.) were checked periodically until all three items were the same temperature. The projectiles were inserted one by one into the mold. In a period of 45 minutes the 42 projectiles were banded. During the banding process, a projectile was tested for structural integrity of the rotating band. The projectile was placed into a fixture to simulate the lands and grooves of a barrel. A 9 kilogram mass was dropped 1.8 meters onto the band. This simulated the approximately 81 joules the projectile would experience in the launch environment. No cracking or separation of the band from the projectile body was observed.

After the projectiles cooled to room temperature, they were placed in the lathe for the third time. The band was turned to a diameter of 31.14 + 0.05mm. The diameter is based on the groove diameter of the barrel of 31.19 + 0.05mm. A leading and trailing angle of 15 + 2 degrees was placed on the band to eliminate plastic filaments as the band is engraved. It was thought that these filaments increase drag during flight.

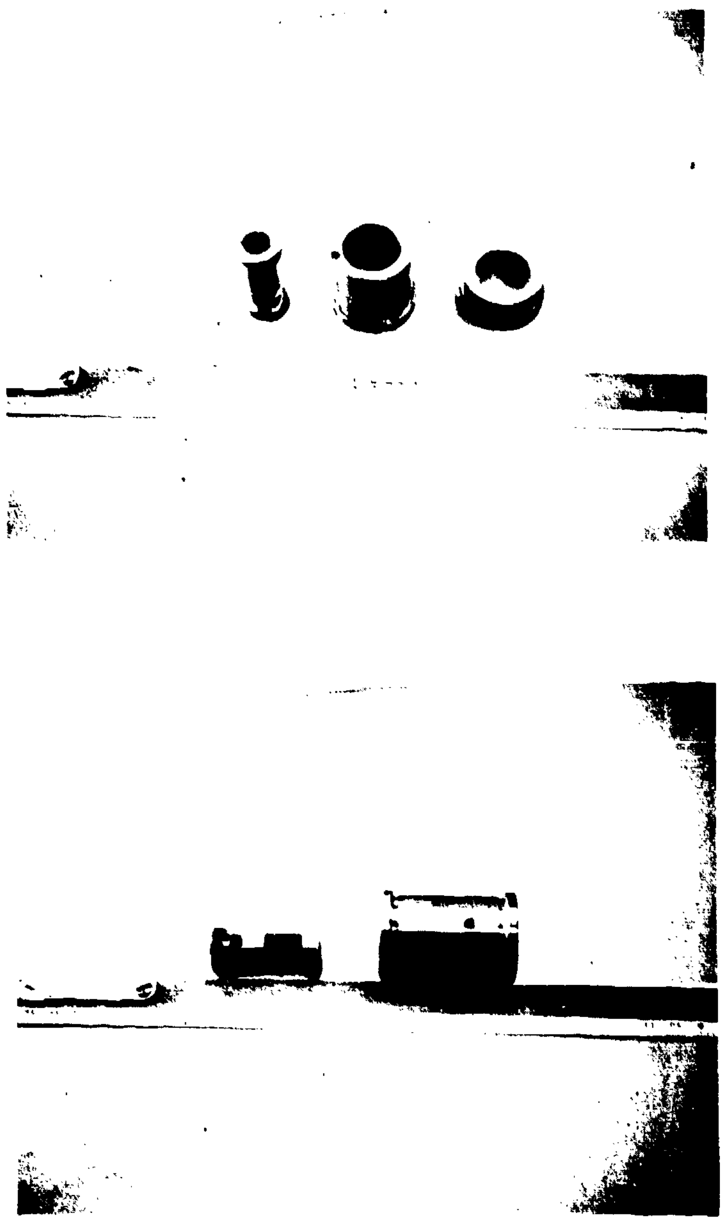


Figure B-1. Mold insert

APPENDIX C

RADAR TEST RESULTS

TIME OF FLIGHT
VELOCITY DECAY

A total of 22 projectiles were tracked by the Hawk Radar. Target practice projectiles were fired as well as the tubular projectiles. The key parameters for the projectiles are presented in Table C-1. The meterological data which is required to reduce the radar data is contained in Table C-2. Tables C-3 through C-7 contain the time of flight and the velocity of the projectiles as a function of range.

The numbering of the projectiles 1 through 22 in the tables in appendix C correspond to the values presented in Table 15 of the report. Target practice projectiles were fired before and after the GAU-8 tubular projectiles and the Hispano Suiza tubular projectile . The target practice projectiles serve as a reference round so that comparison can be made between a conventional projectile and the tubular projectile. The radar data was reduced at 0.02 seconds time of flight intervals. Tables C-3 through C-7 summarize the reduction of the radar data.

The choking of the air flow through the tubular projectile is evident in the velocity decay plot for the tubular projectile. For example, figure C-1 is the velocity decay plot for the GAU-8 target practice projectile. The curve has a gradual change in slope. Figure C-2 is the velocity decay plot for the plastic banded GAU-8 tubular projectile. The velocity decay curve has a sharp discontinuity at 2.5 seconds of flight. This discontinuity represents the unique property of the tubular projectile.

To the left of the discontinuity, the air flows through the center of the projectile. To the right of the discontinuity the flow is choked. This discontinuity is observed for each of the tubular projectiles.

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Table C-1. Tubular Projecitle Properties

	Mass (grams)	Length/Diameter
GAU-8		
TP	369	4.6
Plastic Banded Tubular	198	3
Copper Banded Tubular	204	3
Hispano Suiza		
TP	362	5.3
Tubular	203	3

Table C-2. Meterological data.

Hawk Radar Test on 29 May 1981

Location - Ft. Dix, New Jersey

Time	Temperature ($^{\circ}C$)	Wind direction	Wind velocity (knots)	Barametric pressure	Relative humidity %
1100	22.8	040	4	761.4	35
1200	23.3	050	6	761.1	35
1300	23.8	360	5	760.9	35
1400	24.4	020	4	760.9	34
1500	25.6	060	6	760.6	37

Speed of sound 345 m/s (1132 f/s)

45° N latitude for July

US Standard atmosphere

Table C-3. GAU-8 Tubular projectile

Range (m)	Time of flight (seconds)				Velocity (mps)			
	1	2	3	13	1	2	3	13
0	0	0	0	0	977	1006	1010	1008
500	0.57	0.55	0.55	0.55	811	842	844	841
1000	1.25	1.20	1.20	1.20	663	698	697	696
1500	2.10	2.00	2.00	2.00	519	566	564	563
2000	3.17	2.99	3.00	3.00	409	477	444	444
2500	4.57	4.27	4.28	4.29	322	345	342	342
3000		5.84	5.88	5.88		294	292	292

Table C-4. GAU-8 plastic banded tubular projectile

	Time of flight (seconds)				Velocity (mps)			
Range (m)	4	5	6	7	4	5	6	7
0	0	0	0	0	1278	1283	1285	1270
500	0.43	0.43	0.42	0.43	1117	1100	1138	1112
1000	0.91	0.92	0.88	0.92	961	997	987	942
1500	1.48	1.51	1.44	1.49	811	777	841	794
2000	2.13	2.22	2.09	2.19	666	618	697	650
2500	3.06	3.24	2.92	3.14	444	387	503	417
3000	4.51	4.86	4.20	4.67	282	259	313	270
3500	6.64		6.13	6.90	198		219	189

Table C-5. GAU-8 copper banded tubular projectile

	Time of flight (seconds)					Velocity (mps)				
Range (m)	8	9	10	11	12	8	9	10	11	12
0	0	0	0	0	0	1273	1249	1279	1280	1251
500	0.43	0.44	0.43	0.42	0.44	1111	1065	1086	1122	1087
1000	0.91	0.96	0.94	0.90	0.93	954	886	901	966	927
1500	1.48	1.58	1.55	1.46	1.52	806	721	736	820	777
2000	2.16	2.38	2.35	2.13	2.23	669	517	517	683	625
2500	3.06	3.62	3.60	3.00	3.23	456	325	321	479	402
3000	4.44	5.42	5.44	4.31	4.77	302	240	231	315	276
3500	6.36			6.14	6.87	227			239	207

Table C-6. Hispano Suiza target practice

	Time of flight (seconds)				Velocity (mps)			
Range (m)	14	15	21	22	14	15	21	22
0	0	0	0	0	1078	1089	1093	1107
500	0.51	0.51	0.50	0.50	922	924	935	939
1000	1.10	1.10	1.08	1.08	775	778	790	794
1500	1.81	1.80	1.78	1.77	639	641	654	657
2000	2.68	2.67	2.63	2.62	516	518	530	533
2500	3.78	3.76	3.69	3.68	406	409	419	420
3000	5.17	5.14	5.04	5.03	323	326	326	327

Table C-7. Hispano Suiza tubular projectile

Range (m)	Time of flight (seconds)					Velocity (mps)				
	16	17	18	19	20	16	17	18	19	20
0	0	0	0	0	0	1305	1299	1130	1301	1293
500	0.42	0.42	0.42	0.42	0.43	1124	1119	1134	1129	1112
1000	0.90	0.90	0.89	0.90	0.91	952	954	964	962	947
1500	1.48	1.48	1.46	1.45	1.49	793	803	805	807	791
2000	2.18	2.16	2.15	2.15	2.19	795	662	658	664	649
2500	3.12	3.05	3.05	3.03	3.12	430	469	460	469	440
3000	4.56	4.38	4.41	4.37	4.54	301	314	307	311	300
3500	6.42	6.18	6.26	6.20	6.42	240	256	255	190	239

Figure C-1. Velocity Decay GAU-8 TP

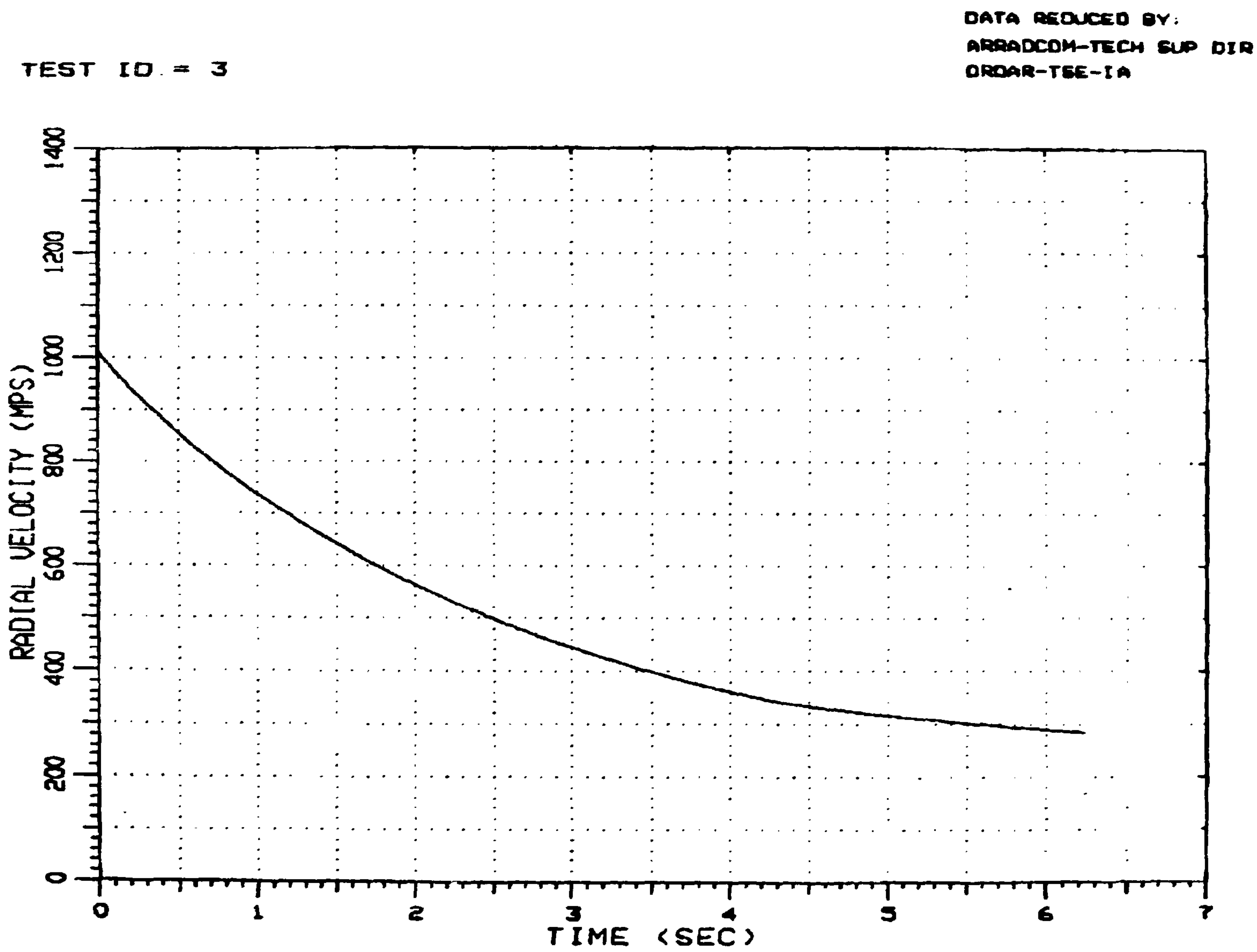

Figure C-2. Velocity Decay Tubular

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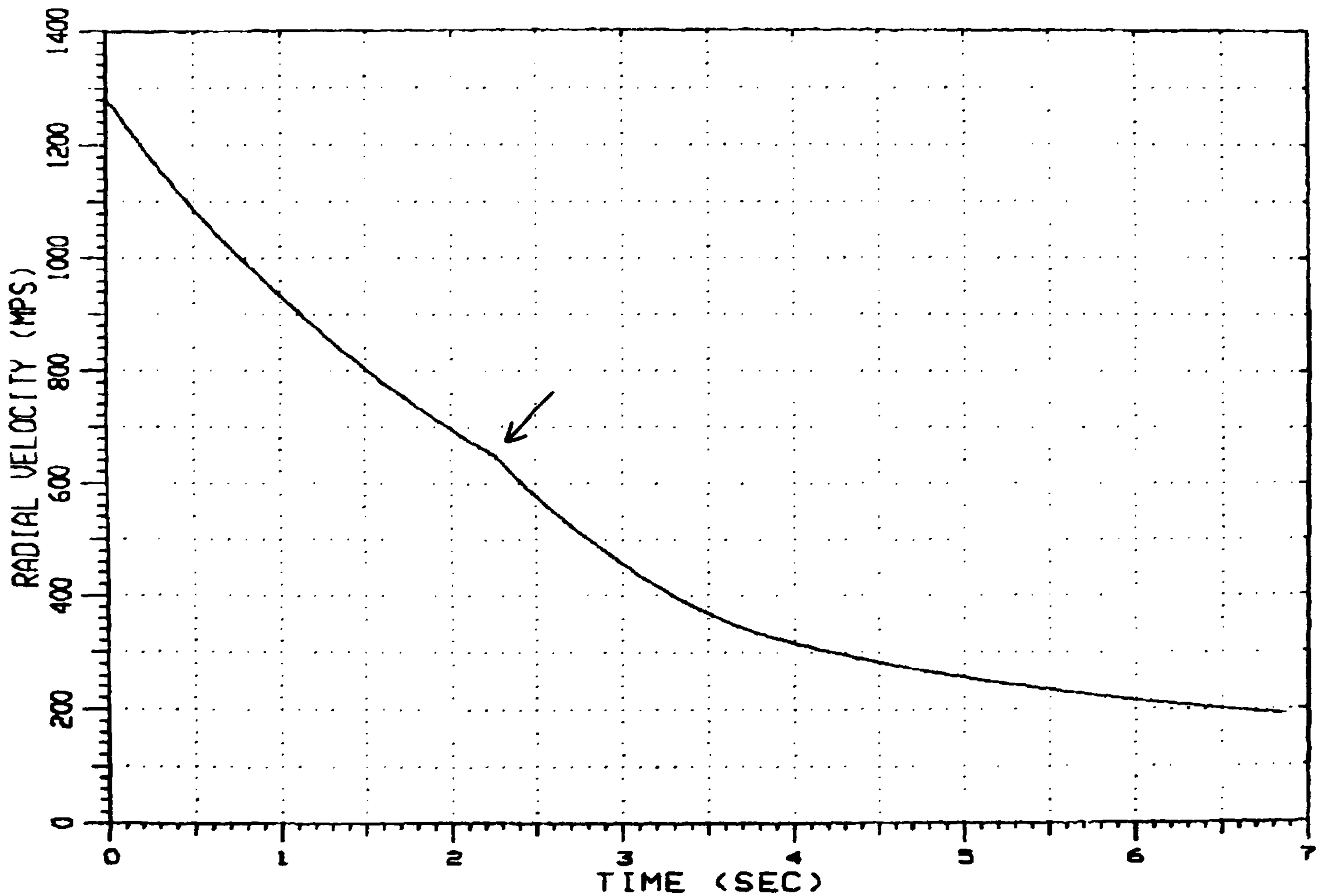

APPENDIX D

DRAG COEFFICIENTS

The time of flight values were used to generate by computer methods the drag coefficients, C_D as a function of the projectile velocity. Tables D-1 through D-10 contain the drag coefficients for each of the 5 different types of projectiles. The numbers in the column headings of the tables refer to the firing sequence of the projectiles.

For each of the different projectile types, a mean drag table was generated. Tables D-2, D-4, D-6, D-8, D-10, refer to the GAU-8 target practice, GAU-8 plastic banded tubular projectiles, GAU-8 copper banded tubular projectiles, Hispano Suiza target practice, and Hispano Suiza tubular projectiles respectively. The C_D values in the above tables are the arithmetic mean of the individual values for each projectile. The mean values are plotted as Figures 22 and 23 in the report. The mean values of C_D should be used to generate ballistic trajectories.

Table D-1. GAU-8TP

VELOCITY (MPS)	CD TP 1	TP 2	TP 3
986.8		.261	.273
967.0		.273	.280
947.3	.274	.281	.284
927.6	.283	.285	.286
907.8	.290	.285	.287
888.1	.295	.284	.288
868.4	.299	.283	.289
848.6	.303	.285	.290
828.9	.305	.288	.293
809.2	.309	.291	.296
789.4	.312	.294	.300
769.7	.315	.298	.304
749.9	.319	.304	.309
730.2	.324	.310	.314
710.5	.330	.314	.319
690.7	.336	.319	.325
671.0	.343	.323	.331
651.3	.349	.330	.336
631.5	.355	.337	.342
611.8	.360	.343	.349
592.1	.366	.348	.354
572.3	.373	.356	.360
552.6	.379	.363	.366
532.9	.386	.368	.374
513.1	.393	.378	.381
493.4	.400	.386	.388
483.5	.403	.389	.392
473.7	.407	.392	.395
463.8	.411	.395	.398
453.9	.415	.399	.401
444.0	.420	.401	.404
434.2	.425	.404	.407
424.3	.429	.411	.413
414.4	.433	.418	.417
404.6	.437	.426	.420
394.7	.441	.428	.423
384.8	.445	.428	.428
375.0	.447	.428	.431
365.1	.445	.430	.433
355.2	.433	.430	.426
345.4	.407	.411	.401
335.5	.359	.357	.348
325.6	.296	.280	.280
315.8	.251	.246	.247
305.9	.241	.235	.239
296.0	.236	.238	.231
286.2	.220	.225	.239

GAU8 TP 13

VEL (MPS)	CD
984.0	.284
964.3	.290
944.6	.293
925.0	.294
905.3	.293
885.6	.292
865.9	.292
846.2	.292
826.6	.293
806.9	.296
787.2	.298
767.5	.301
747.8	.306
728.2	.312
708.5	.317
688.8	.322
669.1	.327
649.4	.333
629.8	.340
610.1	.346
590.4	.353
570.7	.360
551.0	.369
531.4	.376
511.7	.384
492.0	.391
482.2	.395
472.3	.400
462.5	.403
452.6	.406
442.8	.411
433.0	.415
423.1	.419
413.3	.423
403.4	.426
393.6	.428
383.8	.433
373.9	.437
364.1	.436
354.2	.429
344.4	.401
334.6	.336
324.7	.270
314.9	.255
305.0	.247
295.2	.238
285.4	.238

Table D-2. GAU-8 TP Mean Values

LOT GAU-8 TP VELOCITY(MPS)	CD ,	VELOCITY	CD
984.0	.273	344.4	.405
964.3	.281	334.6	.350
944.6	.283	324.7	.281
925.0	.287	314.9	.250
905.3	.289	305.0	.240
885.6	.290	295.2	.236
865.9	.291	285.4	.230
846.2	.292		
826.6	.295		
806.9	.298		
787.2	.301		
767.5	.305		
747.8	.309		
728.2	.315		
708.5	.320		
688.8	.326		
669.1	.331		
649.4	.337		
629.8	.344		
610.1	.350		
590.4	.356		
570.7	.362		
551.0	.369		
531.4	.376		
511.7	.384		
492.0	.391		
482.2	.395		
472.3	.398		
462.5	.402		
452.6	.405		
442.8	.409		
433.0	.413		
423.1	.418		
413.3	.423		
403.4	.427		
393.6	.430		
383.8	.433		
373.9	.436		
364.1	.436		
354.2	.430		

Table D-3. GAU-8 Tubular Projectiles
Plastic Rotating Band

VELOCITY (MPS)	CD · GAU8 TUP 4	GAU8 TUP 5	GAU8 TUP 6	GAU8 TUP 7
1263.1		.082	.056	
1243.3	.099	.128	.105	.082
1223.6	.118	.143	.110	.118
1203.9	.122	.141	.111	.121
1184.1	.122	.136	.111	.118
1164.4	.120	.132	.114	.119
1144.7	.120	.135	.112	.118
1124.9	.119	.134	.115	.117
1105.2	.121	.131	.121	.121
1085.4	.129	.134	.128	.126
1065.7	.133	.145	.118	.135
1046.0	.128	.147	.118	.144
1026.2	.127	.139	.121	.147
1006.5	.128	.140	.125	.144
986.8	.132	.139	.130	.147
967.0	.135	.144	.130	.147
947.3	.138	.145	.130	.148
927.6	.141	.147	.138	.141
907.8	.143	.150	.139	.143
888.1	.146	.155	.143	.148
868.4	.151	.157	.143	.151
848.6	.152	.157	.151	.151
828.9	.154	.160	.154	.153
809.2	.157	.164	.154	.161
789.4	.162	.166	.155	.159
769.7	.164	.169	.162	.163
749.9	.165	.172	.163	.171
730.2	.170	.175	.168	.168
710.5	.173	.175	.167	.174
690.7	.175	.175	.176	.170
671.0	.173	.177	.171	.178
651.3	.188	.195	.173	.181
631.5	.286	.311	.267	.279
611.8	.343	.356	.339	.352
592.1	.357	.355	.343	.355
572.3	.362	.366	.351	.370
552.6	.366	.371	.367	.368
532.9	.381	.379	.367	.378
513.1	.390	.395	.379	.393
493.4	.405	.399	.393	.409
483.5	.412	.414	.408	.419

Table D-3. (cont)

CD

VELOCITY (MPS)	TUP4	TUP5	TUP6	TUP7
473.7	.415	.414	.417	.424
463.8	.420	.419	.414	.434
453.9	.433	.429	.416	.438
444.0	.450	.445	.441	.452
434.2	.461	.447	.443	.466
424.3	.461	.455	.442	.471
414.4	.461	.463	.450	.467
404.6	.459	.472	.455	.466
394.7	.459	.474	.453	.467
384.8	.452	.480	.438	.461
375.0	.450	.468	.436	.456
365.1	.447	.452	.436	.437
355.2	.435	.438	.426	.437
345.4	.434	.442	.412	.424
335.5	.416	.420	.425	.419
325.6	.367	.378	.355	.388
315.8	.342	.332	.328	.330
305.9	.328	.320	.316	.317
296.0	.317	.287	.313	.324
286.2	.325	.309	.301	.311
276.3	.323	.317	.312	.301
266.4	.311	.297	.311	.308
256.6	.319	.293	.322	.314
246.7	.326	.294	.324	.342
236.8	.317	.286	.305	.331
227.0	.310	.273	.310	.318
217.1	.314	.295	.303	.312
207.2	.310	.267	.294	.282
197.4	.282	.276	.266	.311

Table D-4. GAU-8 Tubular Projectiles
Plastic Rotating Band
Mean Values

LOT GAU8 TU PL

VELOCITY(MPS)	CD	VELOCITY	CD
1263.1	.069	513.1	.389
1243.3	.103	493.4	.401
1223.6	.122	483.5	.413
1203.9	.124	473.7	.417
1184.1	.122	463.8	.422
1164.4	.121	453.9	.429
1144.7	.121	444.0	.447
1124.9	.121	434.2	.454
1105.2	.123	424.3	.458
1085.4	.129	414.4	.460
1065.7	.133	404.6	.463
1046.0	.134	394.7	.463
1026.2	.133	384.8	.458
1006.5	.134	375.0	.453
986.8	.137	365.1	.443
967.0	.139	355.2	.434
947.3	.140	345.4	.428
927.6	.142	335.5	.420
907.8	.144	325.6	.372
888.1	.148	315.8	.333
868.4	.150	305.9	.320
848.6	.153	296.0	.310
828.9	.155	286.2	.311
809.2	.159	276.3	.313
789.4	.160	266.4	.307
769.7	.165	256.6	.312
749.9	.168	246.7	.321
730.2	.170	236.8	.310
710.5	.172	227.0	.303
690.7	.174	217.1	.306
671.0	.175	207.2	.288
651.3	.184	197.4	.284
631.5	.286		
611.8	.347		
592.1	.352		
572.3	.362		
552.6	.368		
532.9	.376		

Table D-5. GAU-8 Tubular Projectiles
Copper Rotating Band

VELOCITY (MPS)	GAU8 TUC 8 CD ,	GAU8 TUC 9	GAU8 TUC 10	GAU8 TUC 11	GAU8 TUC 12
1263.1				.109	
1243.3	.094		.147	.109	
1223.6	.114	.100	.147	.239	
1203.9	.122	.143	.144	.137	.095
1184.1	.123	.141	.150	.120	.117
1164.4	.124	.144	.148	.136	.127
1144.7	.124	.149	.152	.116	.129
1124.9	.126	.147	.149	.137	.130
1105.2	.128	.146	.155	.119	.129
1085.4	.134	.149	.152	.136	.131
1065.7	.139	.151	.154	.138	.132
1046.0	.135	.158	.175	.141	.138
1026.2	.132	.170	.169	.133	.145
1006.5	.134	.165	.162	.138	.143
986.8	.137	.157	.158	.137	.140
967.0	.136	.159	.167	.128	.140
947.3	.139	.163	.167	.147	.142
927.6	.142	.168	.168	.138	.146
907.8	.145	.169	.171	.137	.149
888.1	.148	.169	.175	.136	.151
868.4	.150	.174	.172	.158	.150
848.6	.153	.179	.180	.152	.154
828.9	.157	.180	.180	.156	.159
809.2	.160	.182	.172	.148	.164
789.4	.160	.184	.189	.145	.164
769.7	.158	.184	.183	.163	.164
749.9	.166	.187	.188	.160	.165
730.2	.168	.187	.180	.145	.172
710.5	.165	.197	.196	.172	.171
690.7	.172	.195	.189	.182	.173
671.0	.173	.200	.290	.167	.181
651.3	.195	.240	.362	.172	.177
631.5	.295	.347	.355	.329	.211
611.8	.350	.357	.381	.350	.306
592.1	.362	.372	.375	.340	.353
572.3	.356	.365	.376	.346	.363
552.6	.361	.381	.391	.357	.365
532.9	.372	.387	.389	.363	.369
513.1	.379	.399	.404	.385	.379

Table D-5. (cont)

CD

Velocity (MPS)	TUC 8	TUC 9	TUC 10	TUC 11	TUC 12
493.4	.391	.400	.420	.379	.388
483.5	.393	.400	.417	.384	.401
473.7	.394	.412	.415	.382	.408
463.8	.397	.422	.429	.420	.406
453.9	.402	.442	.440	.392	.403
444.0	.412	.431	.466	.394	.411
434.2	.423	.434	.467	.403	.427
424.3	.431	.443	.442	.424	.434
414.4	.437	.450	.463	.399	.440
404.6	.437	.454	.471	.462	.444
394.7	.439	.458	.451	.416	.446
384.8	.430	.437	.455	.411	.450
375.0	.418	.421	.459	.414	.439
365.1	.417	.422	.436	.384	.425
355.2	.416	.414	.460	.352	.421
345.4	.392	.416	.419	.362	.417
335.5	.353	.397	.399	.389	.413
325.6	.306	.335	.354	.303	.389
315.8	.276	.306	.308	.241	.326
305.9	.272	.262	.321	.297	.299
296.0	.257	.292	.289	.249	.283
286.2	.266	.270	.293	.232	.276
276.3	.258	.256	.300	.218	.269
266.4	.264	.268	.286	.274	.262
256.6	.265	.279	.305	.223	.273
246.7	.257	.275	.280	.264	.268
236.8	.261	.267	.288	.216	.262
227.0	.254	.253	.278	.122	.260
217.1		.240	.258		.261
207.2			.228		.240

Table D-6. GAU-8 Tubular Projectiles
Copper Rotating Band
Mean Values

LOT GAU8 TU C

VELOCITY(MPS)	CD •	VELOCITY	CD
1259.5	.109		
1239.8	.116	511.7	.391
1220.2	.139	492.0	.398
1200.5	.133	482.2	.400
1180.8	.132	472.3	.402
1161.1	.136	462.5	.414
1141.4	.134	452.6	.418
1121.8	.138	442.8	.426
1102.1	.136	433.0	.432
1082.4	.141	423.1	.436
1062.7	.144	413.3	.438
1043.0	.151	403.4	.454
1023.4	.149	393.6	.443
1003.7	.148	383.8	.434
984.0	.146	373.9	.427
964.3	.146	364.1	.416
944.6	.153	354.2	.412
925.0	.153	344.4	.400
905.3	.155	334.6	.386
885.6	.156	324.7	.325
865.9	.162	314.9	.286
846.2	.165	305.0	.287
826.6	.167	295.2	.273
806.9	.165	285.4	.266
787.2	.168	275.5	.259
767.5	.170	265.7	.273
747.8	.175	255.8	.268
728.2	.170	246.0	.268
708.5	.181	236.2	.258
688.8	.184	226.3	.234
669.1	.201	216.5	.246
649.4	.236	206.6	.228
629.8	.327		
610.1	.358		
590.4	.363		
570.7	.362		
551.0	.372		
531.4	.378		

Table D-7. Hispano Suiza TP

VELOCITY(MPS)	HS TP 14	HS TP 15	HS TP 21	HS TP 22
1080.0	CD .	.246	.094	.248
1060.0	.215	.254	.257	.281
1040.0	.225	.259	.267	.241
1020.0	.235	.260	.247	.256
1000.0	.243	.257	.257	.230
980.0	.248	.255	.253	.232
960.0	.252	.255	.251	.260
940.0	.255	.257	.252	.234
920.0	.258	.260	.263	.272
900.0	.262	.263	.260	.267
880.0	.267	.266	.262	.258
860.0	.272	.268	.275	.286
840.0	.275	.272	.264	.236
820.0	.277	.277	.287	.251
800.0	.281	.281	.268	.294
780.0	.287	.285	.291	.285
760.0	.292	.289	.283	.300
740.0	.297	.295	.293	.286
720.0	.301	.301	.285	.343
700.0	.304	.307	.305	.286
680.0	.310	.311	.313	.339
660.0	.318	.315	.321	.308
640.0	.324	.321	.309	.330
620.0	.327	.326	.326	.348
600.0	.332	.330	.330	.326

Table D-7. (cont)

CD

VELOCITY (MPS)	HSTT14	HSTPI5	HSTP21	HSTP22
580.0	.337	.333	.334	.367
560.0	.343	.341	.349	.310
540.0	.349	.349	.343	.349
520.0	.355	.356	.362	.403
500.0	.364	.363	.346	.366
490.0	.367	.366	.376	.400
480.0	.370	.368	.369	.361
470.0	.373	.371	.376	.363
460.0	.376	.374	.379	.364
450.0	.381	.375	.365	.380
440.0	.385	.377	.379	.399
430.0	.388	.381	.398	.355
420.0	.392	.386	.405	.361
410.0	.398	.390	.397	.376
400.0	.405	.392	.391	.408
390.0	.410	.395	.415	.417
380.0	.414	.398	.407	.414
370.0	.417	.400	.405	.419
360.0	.415	.399	.456	.399
350.0	.403	.390	.409	.423
340.0	.372	.363	.437	.407
330.0	.310	.302	.410	.442
320.0	.245	.239	.284	.263
310.0	.210	.203	.254	.206
300.0		.185	.233	.300

Table D-8. Hispano Suiza TP
Mean Values

LOT HS TP

VELOCITY(MPS)	CD
1080.0	.197
1060.0	.247
1040.0	.253
1020.0	.250
1000.0	.253
980.0	.252
960.0	.253
940.0	.255
920.0	.260
900.0	.261
880.0	.265
860.0	.271
840.0	.271
820.0	.279
800.0	.277
780.0	.287
760.0	.289
740.0	.295
720.0	.296
700.0	.304
680.0	.311
660.0	.317
640.0	.319
620.0	.326
600.0	.330
580.0	.336
560.0	.344
540.0	.348
520.0	.358
500.0	.360
490.0	.369
480.0	.369
470.0	.374
460.0	.378
450.0	.376
440.0	.382
430.0	.389
420.0	.394

VELOCITY	CD
410.0	.396
400.0	.398
390.0	.407
380.0	.408
370.0	.409
360.0	.422
350.0	.405
340.0	.396
330.0	.347
320.0	.260
310.0	.223
300.0	.210
290.0	.287

Table D-9. Hispano Suiza Tubular Projectiles

VELOCITY(MPS)	HS TU 16 CD	HS TU 17	HS TU 18	HS TU 19	HS TU 20
1280.0	.115	.117	.102	.092	.107
1260.0	.120	.121	.114	.110	.115
1240.0	.126	.124	.126	.125	.130
1220.0	.131	.127	.133	.132	.138
1200.0	.134	.130	.136	.134	.139
1180.0	.137	.132	.137	.133	.136
1160.0	.138	.133	.137	.133	.132
1140.0	.140	.135	.137	.132	.133
1120.0	.142	.136	.139	.135	.137
1100.0	.144	.138	.143	.141	.140
1080.0	.146	.140	.147	.146	.145
1060.0	.148	.141	.148	.145	.150
1040.0	.149	.142	.147	.142	.142
1020.0	.149	.142	.146	.141	.140
1000.0	.149	.142	.147	.142	.144
980.0	.149	.143	.149	.144	.145
960.0	.151	.144	.150	.147	.147
940.0	.153	.146	.153	.149	.152
920.0	.156	.148	.155	.151	.153
900.0	.159	.150	.157	.154	.153
880.0	.161	.152	.159	.156	.157
860.0	.163	.154	.160	.156	.159
840.0	.166	.156	.162	.160	.160
820.0	.168	.159	.165	.162	.162
800.0	.170	.162	.168	.164	.167
780.0	.172	.165	.172	.166	.166
760.0	.175	.167	.174	.169	.170
740.0	.178	.170	.176	.174	.173
720.0	.180	.171	.181	.176	.178
700.0	.181	.172	.182	.177	.180
680.0	.182	.174	.186	.181	.177
660.0	.197	.184	.185	.178	.177
640.0	.237	.209	.193	.185	.228
620.0	.287	.247	.242	.255	.312
600.0	.323	.285	.308	.322	.330
580.0	.343	.315	.341	.340	.341
560.0	.351	.334	.352	.345	.342

Table D-9. (cont)

CD

VELOCITY (MPS)	HSTU16	HSTU17	HSTU18	HSTU19	HSTU20
540.0	.356	.347	.358	.352	.346
520.0	.361	.355	.363	.360	.355
500.0	.368	.363	.365	.359	.362
490.0	.373	.366	.367	.363	.367
480.0	.379	.369	.373	.373	.371
470.0	.386	.373	.379	.383	.376
460.0	.392	.377	.385	.392	.381
450.0	.398	.383	.390	.394	.390
440.0	.405	.388	.398	.393	.397
430.0	.409	.394	.408	.396	.399
420.0	.412	.399	.416	.406	.405
410.0	.412	.403	.420	.414	.418
400.0	.410	.405	.422	.418	.423
390.0	.406	.406	.418	.419	.422
380.0	.401	.404	.413	.416	.417
370.0	.396	.399	.407	.409	.413
360.0	.390	.390	.402	.404	.397
350.0	.376	.377	.397	.403	.391
340.0	.349	.356	.386	.389	.397
330.0	.300	.322	.354	.361	.352
320.0	.250	.282	.288	.283	.264
310.0	.227	.249	.249	.241	.236
300.0	.214	.230	.230	.227	.216
290.0	.207	.223	.231	.217	.206
280.0	.206	.215	.221	.219	.217
270.0	.201	.212	.225	.221	.202
260.0	.206	.213	.232	.226	.201
250.0	.203	.226	.214	.216	.204
240.0			.222		.410

Table D-10. Hispano Suiza Tubular
Projectiles
Mean Values

LOT HS TU

VELOCITY(MPS)	CD	VELOCITY	CD
1280.0	.107		
1260.0	.116	560.0	.345
1240.0	.126	540.0	.352
1220.0	.132	520.0	.359
1200.0	.135	500.0	.363
1180.0	.135	490.0	.367
1160.0	.135	480.0	.373
1140.0	.135	470.0	.379
1120.0	.138	460.0	.385
1100.0	.141	450.0	.391
1080.0	.145	440.0	.396
1060.0	.147	430.0	.401
1040.0	.144	420.0	.407
1020.0	.144	410.0	.413
1000.0	.145	400.0	.415
980.0	.146	390.0	.414
960.0	.148	380.0	.410
940.0	.151	370.0	.405
920.0	.153	360.0	.396
900.0	.155	350.0	.389
880.0	.157	340.0	.375
860.0	.159	330.0	.338
840.0	.161	320.0	.273
820.0	.163	310.0	.241
800.0	.166	300.0	.223
780.0	.168	290.0	.217
760.0	.171	280.0	.216
740.0	.174	270.0	.212
720.0	.177	260.0	.216
700.0	.178	250.0	.213
680.0	.180	240.0	.316
660.0	.184		
640.0	.210		
620.0	.269		
600.0	.314		
580.0	.336		

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