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MODIFIED M505A3 FUZE WITH DELAY FUNCTION

AVCO CORPORATION
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The M505A3 point detonating fuze was modified to incorporate a time delay function. A mechanical delay was achieved by using a heavier firing pin and increasing the firing pin travel to the detonator. A series of 77 gun-launched tests were conducted to evaluate the modifications. Targets were 2024-T3 aluminum panels, 0.040, 0.063, and 0.090 inch thick. Impact velocities ranged from 1000 to 3650 feet per second and impact angles ranged from 90 degrees (vertical) to 10 degrees graze. Tests and analyses indicated that

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20. ABSTRACT (CONCLUDED)

the modifications for a time delay function are feasible and maintain a low cost fuze design.

The following target restrictions are recommended as a result of the tests:

1. Delay function can be achieved on 0.063-inch-thick aluminum targets up to a maximum obliquity angle of 55 degrees at 2500 ft/sec striking velocity. Obliquity angles higher than 55 degrees will produce superquick function.

2. Fuze function will occur on a 0.040-inch-thick aluminum target at a minimum muzzle velocity of 1800 ft/sec. At a muzzle velocity less than 1800 ft/sec the fuze is not sensitive enough to function on this target.

3. Delay function can be achieved on 0.090-inch-thick aluminum targets up to a maximum obliquity angle of 20 degrees at 2500 ft/sec striking velocity. Obliquity angles higher than 20 degrees will produce superquick function.

SUMMARY

The objective of the effort was to modify the M505A3 point detonating fuze to incorporate a time delay prior to detonating the 20mm M56 High Explosive Incendiary (HEI) projectiles.

The delay method selected for examination and test under this contract was a combination of a heavier firing pin and an increased distance from firing pin to detonator. Firing pins of aluminum, steel, and brass and fuze bodies of aluminum and steel were evaluated during the program.

A series of gun launched tests were conducted to evaluate the modifications. Target material was 2024-T3 aluminum sheets of three thicknesses: 0.040, 0.063, and 0.090 inch. Impact velocities ranged from 1000 to 3650 ft/sec and obliquity angles ranged from zero (vertical) to 80 degrees.

A total of 77 separate tests were conducted with standard and modified M505A3 fuze body designs. Sufficient hardware was fabricated to complete tests and provide contractual deliverables. Primary interest was directed toward a target thickness of 0.063 inch with an obliquity angle of 75 degrees. Such a condition was believed to be most representative of anticipated actual target conditions.

Following receipt of hardware to the latest design, tests were begun in early July 1974 on 0.063-inch targets, 0.017-inch-thick flange on brass firing pins, 75-degree obliquity, and 2500 ft/sec muzzle velocities, using a 20mm Mann barrel located 151 feet from the target.

A series of tests showed that target results appeared to be relatively independent of firing pin flange thicknesses of 0.017 to 0.035 inch or location of the firing pin, i.e., forward against the nose cap or rearward against the firing pin sleeve. Finally, Test 31 was conducted on 23 July 1974 when two rounds were fired without firing pins. Both functioned on target, and it was believed that the firing pin sleeve was causing initiation of the M57A1 detonator. This proved not to be true in Test 35, which resulted in two rounds functioning without sleeve or firing pin. The detonator was then triple staked into position to eliminate the possibility of detonator set forward initiation on the firing pin entrance hole to the rotor cavity. The triple staked detonator also functioned on the 0.063-inch target at 75-degree obliquity. The standard M505A3 fuze and GAU-7/A fuze were also tested against the same target condition to see if the observed function was peculiar only to the modified M505A3 fuze design. Both, however, functioned without firing pins. Of five GAU-7/A fuze designs fired without firing pin or sleeve, one resulted in a classic delay on target, i.e., good petalling rearward (toward the gun).

Test 41 (75° obliquity on a 0.063-inch target) was then conducted with an inert standard M505A3 fuze without firing pin. The round was allowed to pass through the target and was then soft recovered in Celotex®. Examination of the recovered round showed small aluminum pieces of the target imbedded

in the dummy detonator. In fact, the impact of the target material was sufficiently hard to drive the dummy detonator rearward leaving an indentation on the booster face.

Five inert modified M505A3 fuzes fired in the same manner showed that the firing pin, although striking the detonator first, was driven by a piece of target material. Thus, it was believed that the reason for no significant delay having been realized was because of a phenomenon of target mass flow into the fuze cavity. Further, it was believed that the condition occurred only at high obliquity angles because a proper delay had already been achieved on vertical, or less severe graze angle targets.

Several subsequent tests involved various attempts to slow the firing pin in spite of the additional target mass driving it rearward. These attempts included various energy absorbers in front of and around the pin. None of these showed improvement in delay.

A special steel firing pin (see Section 3.2, Figure 22) was made with breakaway undercut on the shank of the pin. At impact, the shank breaks and the upper portion of this firing pin is expected to cover the firing pin sleeve to impede the flow of target mass into the firing pin sleeve. In general, the design resulted in good target petalling rearward ("banana peel" showed on about 50 percent of the shots). The improvement reinforced the theory that the basic cause of no delay at high obliquities was because of target mass inflow, and efforts were begun to design a cap for that purpose alone.

Time remaining in the contract, however, was insufficient to redirect the overall fuze design, and it was decided to complete the program with target restrictions to be determined during final tests. Five of the protector cap items were fabricated and tested on the last day of firing, 22 August 1974. With the protector cap, a standard 0.017-inch-thick brass pin produced excellent delay shots on 0.063-inch targets set for 75-degree obliquity. One round on 0.090-inch-thick target at 75-degree obliquity produced partial delay. Finally, the last round fired on 0.063-inch vertical target produced an 8-inch delay.

In conclusion, it is believed that the overall objective of a mechanical delay fuze system utilizing a heavier mass firing pin with added stroke has been shown to be feasible. The addition of a steel protector cap, unfortunately found too late in the program to be incorporated into the deliverable rounds, could be simplified to maintain present low cost of the modified M505A3 fuze design.

For the fuze design that was prepared for shipment to the Air Force to achieve 80 to 90 percent good target delay functioning, certain target restrictions are recommended based on final tests conducted.

1. Delay function can be achieved on 0.063-inch-thick aluminum targets up to a maximum obliquity angle of 55 degrees at 2500 ft/sec striking velocity. Obliquity angles higher than 55 degrees will produce superquick function.

2. Fuze function will occur on a 0.040-inch-thick aluminum target at a minimum muzzle velocity of 1800 ft/sec. At a muzzle velocity less than 1800 ft/sec the fuze is not sensitive enough to function on this target.

3. Delay function can be achieved on 0.0900-inch-thick aluminum targets up to a maximum obliquity angle of 20 degrees at 2500 ft/sec striking velocity. Obliquity angles higher than 20 degrees will produce superquick function.

It should be noted that, in determining the recommended restrictions, all tests were conducted on targets rigidly supported on three sides with no more than one foot between supports. Tests on targets using a different type of support may result in greater or less distance delay.

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PREFACE

This report documents work performed during the period April 1974 through September 1974 by Avco Government Products Group, Avco Systems Division, 201 Lowell Street, Wilmington, Massachusetts, 01887, under contract F08635-74-C-0101. All of the fuze assembly and testing was performed at the Avco Ballistic Test Site, Connersville, Indiana. The program was sponsored by the Air Force Armament Laboratory with Major Stephen F. Moore and Mr. Allen H. Welle, Jr. (DLDG) as Project Engineers.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

A. D. Brown Jr

ALFRED D. BROWN, Jr., Colonel, USAF
Chief, Guns, Rockets & Explosives Division

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SECTION I

PROGRAM REQUIREMENTS

The present 20mm M505A3 point detonating fuze is used with the M56 HEI projectile for air-to-air combat. It is desired to improve the effectiveness of this projectile against aircraft targets by incorporating a time delay which enables the projectile to penetrate the aircraft skin prior to detonation.

This effort required the design of modifications to the M505A3 fuze to achieve a delay function without modifying the rotor ball and booster. Firing pin changes were appropriate, specifically changing the mass of the firing pin and increasing the distance the pin must travel prior to contacting the detonator. The shape of the resulting projectile must be compatible with the feed system of the M61 gun.

The effort also required an assessment of the feasibility of using zirconium as a booster holder material to increase the fire-start and fire-sustaining capabilities of the projectile.

Specific technical requirements were cited in regard to fuze length, arming distance, gyroscopic stability, and functioning. A maximum length of 1.2 inches between ogive point and interface shoulder was specified. An arming distance between 5 and 50 meters, and a gyroscopic stability factor of at least 1.2 under a given firing condition were stated. The functioning requirements were changed by contract amendment stipulating design goal to provide fuze function between 3 and 8 inches after penetration of an 0.063-inch aluminum plate at a 75-degree obliquity angle, and at 2500 $\pm$100 ft/sec. The amendment further stipulated that through testing the lower limit of impact velocity necessary for function against an 0.040-inch aluminum plate at 75 degrees (or less), obliquity angle would be derived. All planned environmental tests were deleted and substitute gun-launched tests were added to achieve the fuze function goals.

SECTION II

ANALYSIS

2.1 FUZE DESIGN

Figures 1 and 2 compare the standard M505A3 fuze and the new modified M505A3 fuze to illustrate interface relationships. The new fuze is about 0.3 inch longer and has a 24.5-degree conical ogive. When the new fuze is inserted in the standard M56 body, the common 0.671-inch diameter at the fuze base permits a relatively smooth contour blend. Although the length of the resulting cartridge would be too long for automatic gun firing, the cartridge can readily be tested in a Mann barrel.

The firing pin travel and fuze details are shown in Figure 2. The modified fuze has a metplat to shoulder distance of 1.2 inches compared to 0.894 inch for the standard M505A3. Using a standard ball rotor and firing pin, the firing pin travel increases from a normal 0.12 inch for the standard to 0.426 inch for the modified M505A3 fuze. The firing pin was modified (by use of brass material) to the same dimensions as the standard aluminum pin to permit higher weight for greater delay. The hardened steel firing pin sleeve and the indicated clearance between the firing pin and sleeve have been found to be essential under the GAU-7/A program to achieve reliable functioning. Details of the new parts of the modified M505A3 fuze are in Appendix A. The detonator and booster assemblies are the same as the standard M505A3 fuze.

2.2 FUZE ANALYSIS

The analysis in this section examines the fuze function on normal and oblique impacts, and the stability of the standard M56 HEI projectile when used with the modified fuze.

2.2.1 <u>Fuze Function</u>

The sequence of events occurring at impact is shown in Figure 3. The fuzing function analysis considers the mass of the nose cap, firing pin, and target and assumes the following:

1. The velocity reached by the firing pin is a result of a momentum exchange with the target, the energy to shear the firing pin is assumed to be zero.

2. The velocity of the firing pin will be constant after impact of the target is completed.

3. A portion of the mass of the nose cap will be considered as firing pin mass in the momentum exchange.

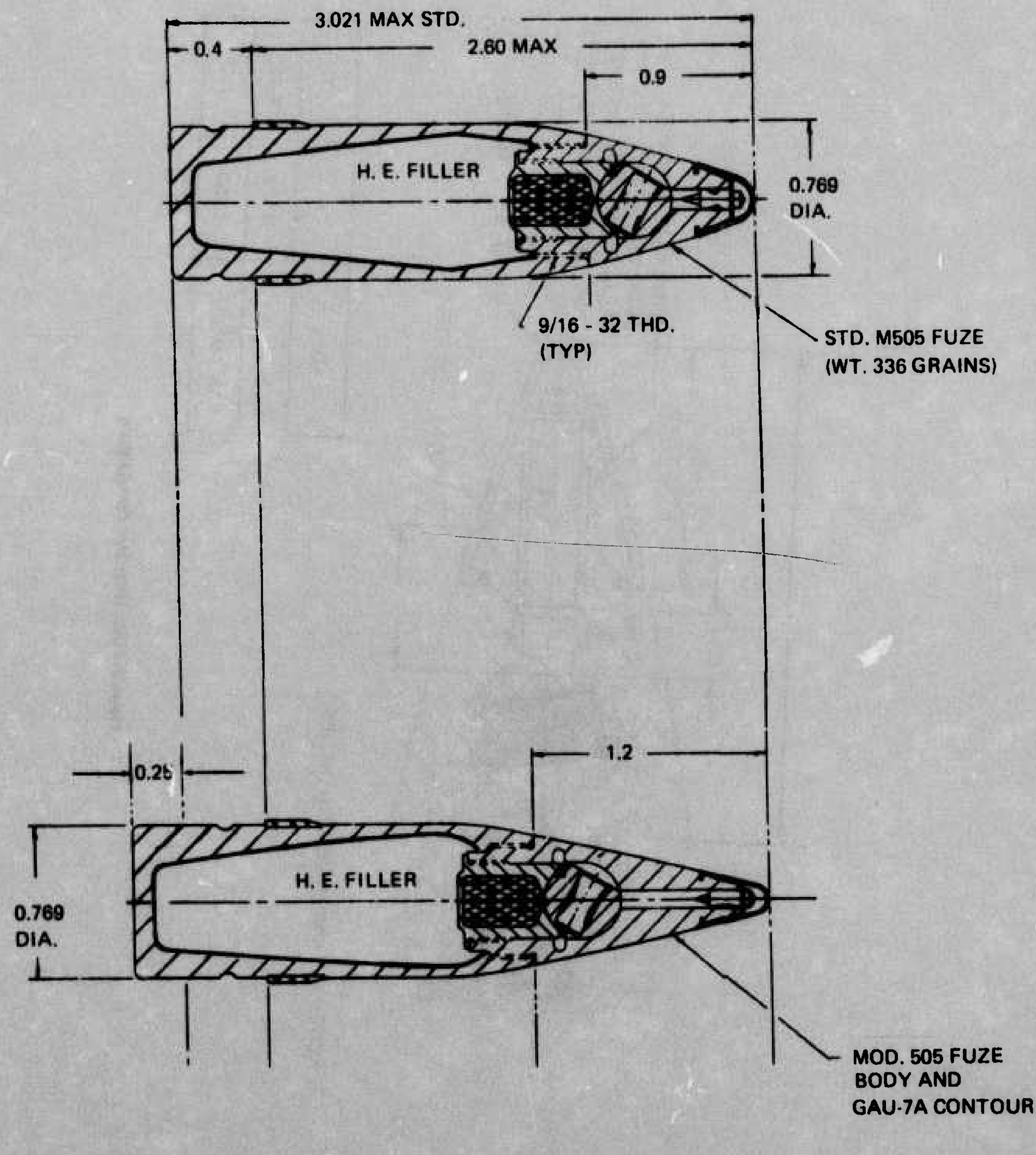
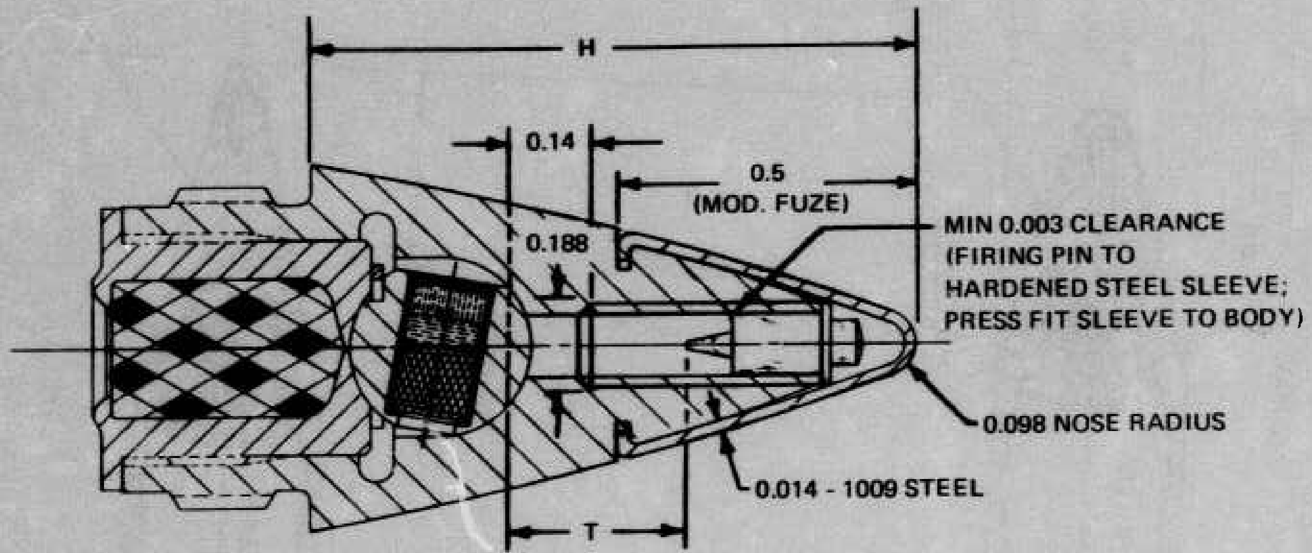


Figure 1. FUZE AND PROJECTILE ASSEMBLIES



NOTE: ALL DIMENSIONS IN INCHES

FUZE	H	T
STD.	0.894	0.120
LONG MOD.	1.200	0.426

Figure 2. FUZE DESIGN COMPARISON

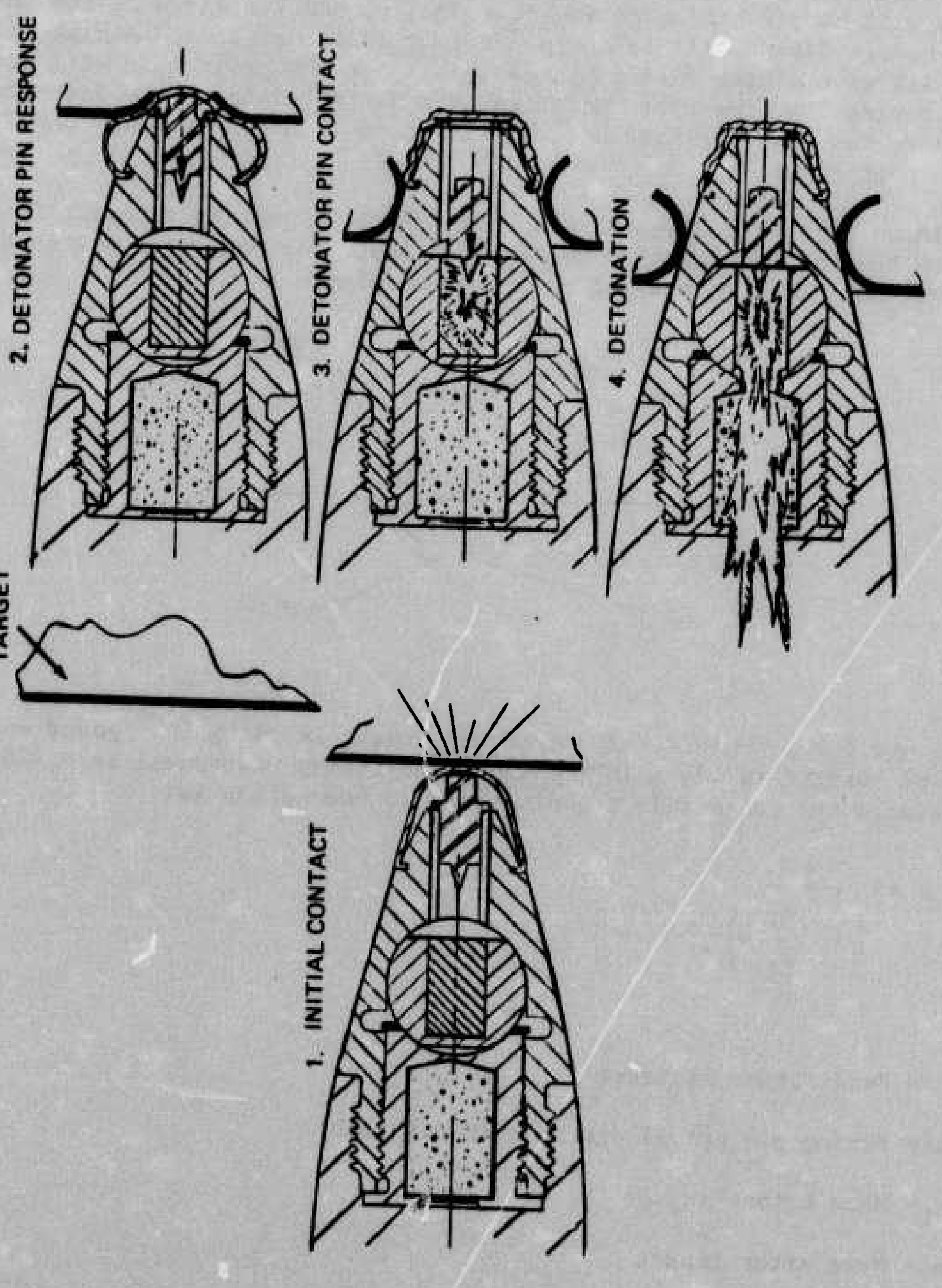
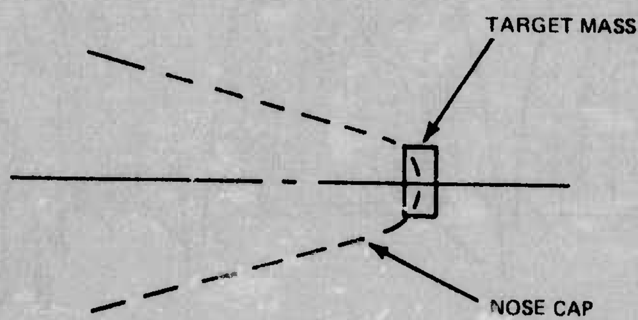


Figure 3. FUZE FUNCTIONING SEQUENCE

The masses to be considered during impact are constants -- firing pin, nose cap, and target mass intercepted during impact. When the masses are treated as constants, the firing pin velocity after impact will be determined by the ratio of the mass before impact to the mass after impact. The firing pin velocity will be a function of impact velocity, and the distance the shell travels before firing will be independent of shell velocity. A high velocity impact will give a high firing pin velocity, but the projectile will penetrate further during the time that the firing pin is traveling to the detonator. This theory has been verified by analysis shown in Appendix B and GAU-7/A test data shown in Figure 4.

During impact with a 0.040-inch aluminum target, a quality judgment is made to determine the mass intercepted by the nose cap. The following sketch shows the target mass that is assumed to be accelerated.



For the new fuze, the effective nose cap weight is 394×10^{-6} pound and the firing pin weight is 426×10^{-6} pound. The firing pin travel is 0.426 inch. The distance the projectile travels prior to detonation is:

$$S = \Delta S \frac{1}{\left(1 - \frac{m_1}{m_2}\right)}$$

Where:

S = Penetration distance

ΔS = Firing pin travel distance (0.426 inch)

m_1 = Mass before impact

m_2 = Mass after impact

$m_1 = 394 \times 10^{-6}$ lb (cap) $+ 168 \times 10^{-6}$ lb (alum pin) $= 562 \times 10^{-6}$ lb

$m_2 = m_1 + 31 \times 10^{-6}$ lb (target mass) $= 593 \times 10^{-6}$ lb

The derivation of this equation is provided in Appendix B.

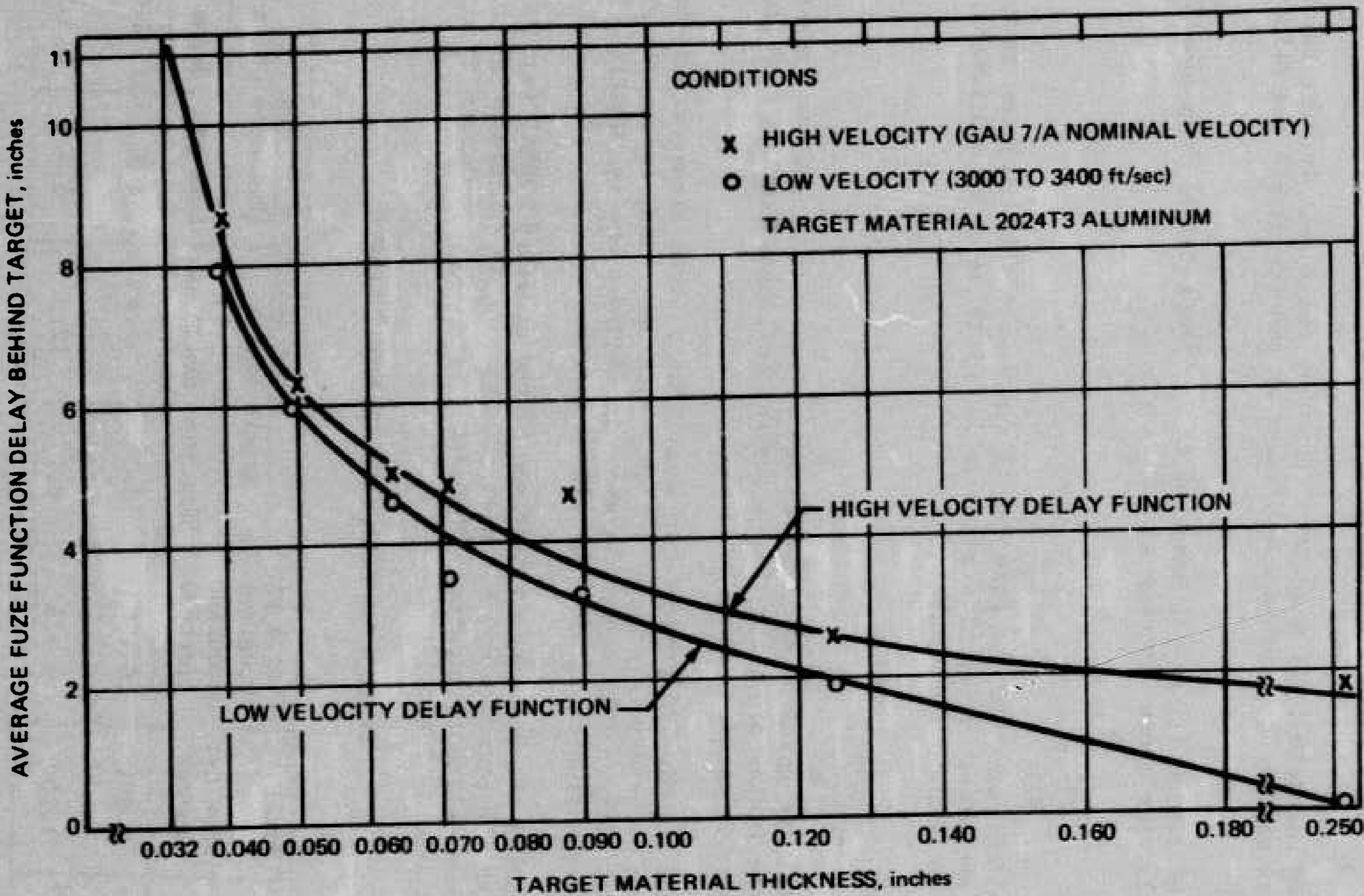


Figure 4. 25mm FUZE FUNCTION DELAY VERSUS TARGET THICKNESS

Then:

$$S = 0.426 \frac{1}{1 - \frac{562}{593}} = 8.1 \text{ in.}$$

As seen by the foregoing, the mass intercepted by the target is very critical because of its smallness compared to the mass of the firing pin and effective nose cap mass.

To show the effect of firing pin mass, we change the material from aluminum to brass and solve for a new distance to function:

$$S = 0.426 \frac{1}{1 - \frac{898}{929}} = 12.8 \text{ in.}$$

This calculation shows how the fuze can be tuned. In the foregoing example, we can make the brass firing pin longer to cut distance as we add length. By adding 0.09 inch to the length:

$$S = 0.336 \frac{1}{1 - \frac{1170}{1201}} = 10.1 \text{ in.}$$

Again, the fuze is tuned by making a change in mass and firing pin travel. In this case, the firing pin travel had a greater influence than mass to give a net reduction in function distance.

Experience in the GAU-7/A program has shown that a steel sleeve around the firing pin is necessary to promote reliable fuze operation, especially at high angles of obliquity. This sleeve is shown in Figure 2 and is identical to the GAU-7/A configuration except for the sleeve length.

Table 1 compares the penetration distance of the modified M505A3 fuze in Figure 2 with the standard M505A3 fuze. Penetration is calculated at normal and 60 degrees obliquity impacts. The effect of a light and heavy firing pin is also compared in Table 1.

TABLE 1. PROJECTILE PENETRATION DISTANCE

Fuze	Metplat to shoulder (inches)	Firing pin travel to detonator (inches)	Penetration in inches			
			Normal impact		60-degree Obliquity	
			Alum pin	Brass pin	Alum pin	Brass pin
M505A3	0.894	0.120	2.3	3.6	1.5	2.4
Modified fuze	1.200	0.426	8.1	12.8	5.4	8.5

The data indicates that for normal impact the modified M505A3 fuze with the standard aluminum firing pin will achieve the desired 8-inch travel after impact, but for targets at 60 degrees obliquity the firing pin of brass is required to achieve the 8-inch penetration.

At an 80-degree obliquity angle the mass of the target is difficult to predict; however, penetration is not required in this case. Experience has shown that this type analysis indicates trends only and that actual firing is necessary to identify penetration distance. For instance, Avco has performed this analysis and verified the penetration distance by actual test firings on the GAU-7/A program. The test data is shown in Figures 4 and 5.

Figure 4 illustrates the effect of target thickness and impact velocity on fuze function delay at 0-degree obliquity and indicates that a significant reduction in delay occurs as the target thickness or mass increases. As the obliquity angle increases, greater target mass is exposed to the fuze and the delay is further reduced. Figure 5 illustrates this effect of obliquity angle and target thickness on fuze function delay.

The actual test results of the 25mm tests were compared with theoretical predicted penetration and the ratio of actual/theoretical penetration was computed for target thickness. This is summarized in Table 2. The ratio was applied to the 20mm penetration predictions in Table 1, and corrected predictions were listed in Table 3. These predictions indicate about 1.3 inches improved penetration with the brass firing pin over the aluminum firing pin.

2.2.2 Fuze/Projectile Stability

This section examines the stability of the modified fuze when used with the standard M56 HEI projectile. Gyroscopic and dynamic stability factors were computed at the muzzle for the proposed modified fuze design for an aircraft velocity of 500 KTAS, a muzzle velocity of 3800 feet per second, a muzzle exit twist of 25 calibers per revolution, under -40° F sea level atmospheric conditions. The computed stability factors for this configuration are presented in Table 4. Values of the characteristics used in the computations are listed in Table 5.

When the new fuze, which is about 0.3 inch longer than the standard M505A3 fuze, is inserted in the standard M56 body, the common 0.671-inch diameter at the fuze base permits a relatively smooth contour blend. The aerodynamic coefficients for this modified configuration were estimated using Reference 1.*

*Watt, R. M. and G. L. Winchenbach, Free Flight Range Tests of Blanked 4, 4-1/2 and 5 Caliber Bodies of Revolution with Secant Ogive, Tangent Ogive and Conical Nose Shapes, AEDC-TR-71-166.

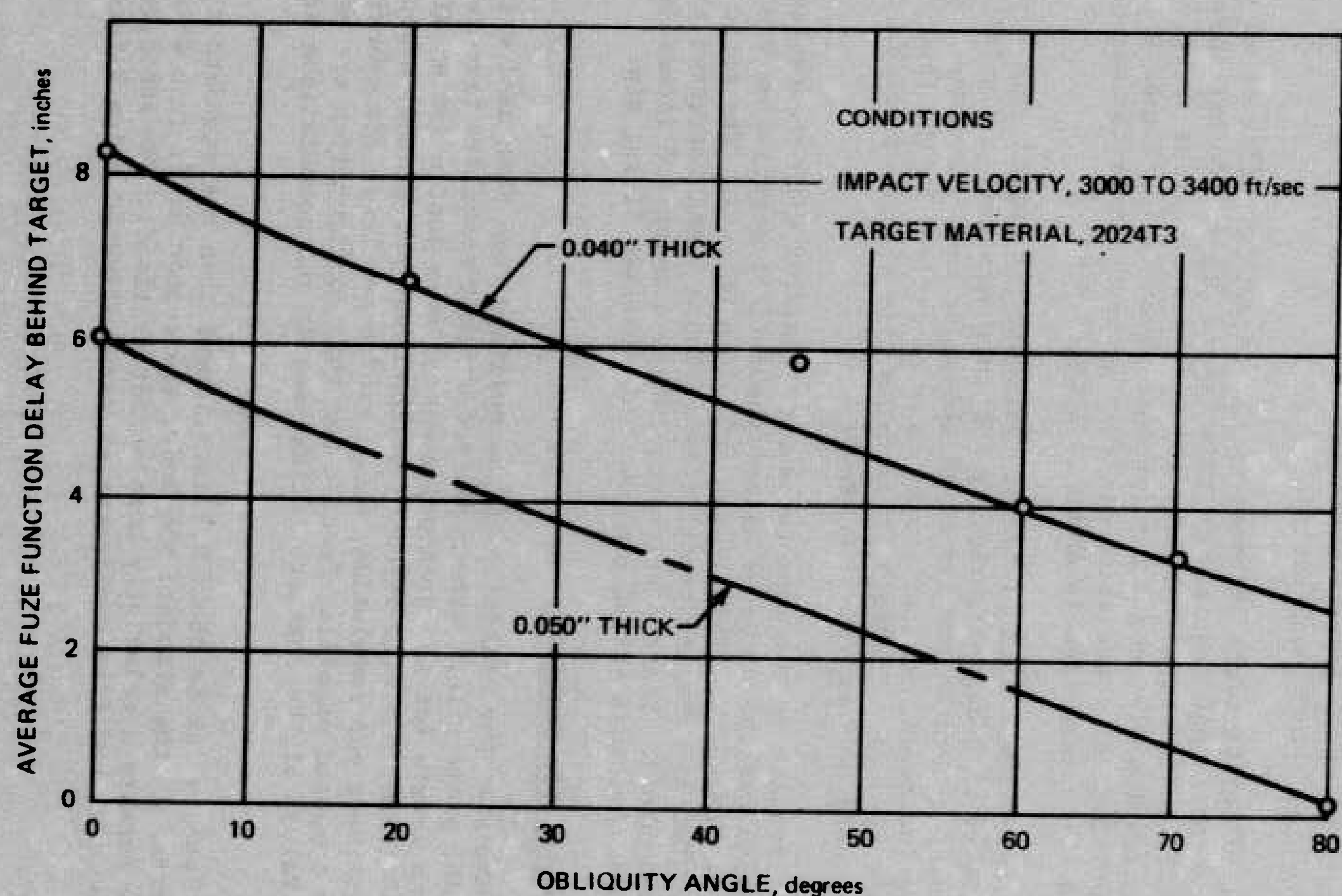


Figure 5. 25mm FUZE FUNCTION DELAY VERSUS TARGET ANGLE

TABLE 2. GAU-7/A ACTUAL VERSUS THEORETICAL PENETRATION DISTANCE

Impact velocity (ft/sec)	Target thickness (inch)	Angle of obliquity (degrees)	Theoretical penetration (inch)	Actual penetration (inch)	Ratio Actual/theoretical penetration (percent)
3900	0.040	0	12.3	8.2	67
3900	0.08	0	6.5	4.0	60
3900	0.120	0	4.5	2.8	62
3900	0.040	30	10.7	5.0	47
3900	0.040	60	6.5	2.8	43

TABLE 3. CORRECTED 20mm FUZE PENETRATION DISTANCE

Firing pin material	Aluminum target	Theoretical penetration	Corrected predicted penetration
Aluminum	0.040/0°	8.1	5.4
Brass	0.040/0°	12.8	8.6
Aluminum	0.040/65°	5.4	2.3
Brass	0.040/65°	8.5	3.6

TABLE 4. ESTIMATED STABILITY FACTORS OF MODIFIED FUZE DESIGN

Gyroscopic stability factor, Sg	Dynamic stability factor, Sd	Gyroscopic stability factor required Sg required
1.50	0.57	1.23

TABLE 5. VALUES OF CHARACTERISTICS USED IN STABILITY COMPUTATIONS

Characteristic	
C_{M_α}, ^{1}/radian	2.77
C_{N_α}, ^{1}/radian	2.82
C_D	0.23
C_{MP_β} ^{1}radian^2	0.3
$(Cmq + Cm'_\alpha)$, ^{1}/radian	-15.
C_{l_p}, ^{1}/radian	-0.01
A, lb-in^2	0.0174283
B, lb-in^2	0.1156870
ρ, lb/ft^3	0.0994
d, in.	0.784
V, ft/sec	4650
N, radian/sec	14,620
k_a, caliber	0.363
k_t, caliber	0.936
m, lb	0.215

The gyroscopic stability factor was computed as 1.50. The dynamic stability factor was estimated as 0.57. These estimates indicate that the proposed fuze design coupled with the standard M56 body will have adequate stability. The equations used to determine the stability factors are as follows:

$$S_g = \frac{24 A^2 N^2}{\pi B \rho d^3 V^2 C_{m_\alpha}}; \quad S_g > 1 \tag{1}$$

$$S_d = \frac{2(C_{N_\alpha} - C_D) + (\frac{1}{2} k_a^{-2} \quad C_{mp_\beta}); \qquad 0 < S_d < 2}{C_{N_\alpha} - C_D - \frac{1}{2} k_b^{-2} \quad (C_{m_q} + C_{m_{\dot\alpha}}) + k_a^{-2} \quad C_{l_p}} \tag{2}$$

$$C_{N_a} - C_D - \frac{1}{2} k_b^{-2} (C_{m_q} + C_{m_{\dot{\alpha}}}) + k_a^{-2} C_{l_p} > 0 \qquad (3)$$

$$S_g \geq \frac{1}{S_d(2 - S_d)} \qquad (4)$$

where

S_g	= Gyroscopic stability factor	
S_d	= Dynamic stability factor	
S_g Req'd	= Gyroscopic stability factor required for dynamic stability	
C_{m_α}	= Pitching moment derivative	1/radian
C_{N_α}	= Normal force derivative	1/radian
C_D	= Drag coefficient	
C_{mp_β}	= Magnus moment derivative based on (d/2V)	$1/\text{radian}^2$
$C_{m_q} + C_{m_{\dot{\alpha}}}$	= Pitch damping derivative based on (d/2V)	1/radian
C_{l_p}	= Roll damping derivative	1/radian
A	= Polar moment of inertia	lb-in^2
B	= Transverse moment of inertia	lb-in^2
ρ	= Air density	lb/ft^3
d	= Reference diameter	in.
V	= Velocity	ft/sec
N	= Spin rate	radian/sec
k_a	= Polar radius of gyration, $\sqrt{A/md^2}$	caliber
k_b	= Transverse radius of gyration, $\sqrt{G/md^2}$	caliber
m	= Projectile weight	lb

During the analysis of the modified M505A3 fuze some of the parameters were measured or determined by detailed study. The following weights were measured for the modified M505A3 fuze design:

a. Total in-flight weight of fuze and projectile:

Aluminum fuze body with brass firing pin, sample of five:

1. 93.72 grams
2. 94.33 grams
3. 93.84 grams
4. 93.96 grams
5. 94.25 grams

Steel fuze body with brass firing pin, sample of five:

1. 105.38 grams
2. 105.67 grams
3. 106.07 grams
4. 105.30 grams
5. 105.84 grams

b. The following average individual component weights in grams are given from a sample of ten each:

Steel fuze body	19.67
Aluminum fuze body	8.28
Steel sleeve	0.98
Nose cap	0.73
Brass firing pin	0.25
Aluminum firing pin	0.08

The comparative drag and normal force coefficients in Table 6 were determined by analysis for the standard and two modified fuze shapes.

TABLE 6. AERODYNAMIC COEFFICIENT COMPARISON

	C_D	C_N
Standard M505A3	0.316	0.048
Modified M505A3 with conical shape	0.232	0.047
Modified M505A3 with ogive configuration	0.223	0.046

The analysis was conducted by the three-dimensional method of characteristics with a digital computer program. The comparison study was made to evaluate the aerodynamic performance that would result by increasing the fuze length from 0.9 inch to 1.2 inches and decreasing the nose radius to 0.098 inch. The standard M505A3 fuze was modeled as a sphere-cone followed by an ogive and thin conical sections. The two modified M505A3 fuze configurations were straight cone and secant ogive. The straight cone configuration had a

13-degree half-cone angle from the 0.098-inch nose radius back to a point 1.2 inches from the nose tip. An 11-degree half-cone angle then blended into the projectile body. The secant ogive was similar except the 13- and 11-degree cones were blended with a 20-inch radius.

The data in Table 6 indicate that the modified fuze configurations offer significant improvement over the standard M505A3 configuration. The conical design was selected for the modified fuze because it was very much like the ogive and it was easier to fabricate. Test hardware was made with a half-cone angle of 12.25 degrees rather than the 13- and 11-degree angles.

The computed characteristics and mass properties of the conical ogive fuze design are listed in Table 5. The roll moment of inertia, I_{xx}, is the same as A in the table. The yaw and pitch moment of inertia, I_{yy} and I_{zz}, are equal and are listed as B in Table 5.

SECTION III

TESTS

3.1 STATIC TESTS

3.1.1 Load Test on Threaded Joint

A total of 12 fuze bodies, six steel and six aluminum, were subjected to breakoff tests. These tests were conducted to determine the sensitivity of the threaded joint between the fuze and the projectile on the delay action of the fuze during oblique impacts. A measurement of the side force required to separate the fuze from the projectile body was used to determine this sensitivity. The first test consisted of three each steel and aluminum without epoxy on the threads. Results are given in Table 7.

TABLE 7. PEAK BREAKOFF FORCE STEEL ALUMINUM

Test	Description	Peak force (pounds)		
		Item 1	Item 2	Item 3
1	Epoxied threads			
	Steel	3700	4450	4100
	Aluminum	3700	3850	4100
2	Bare threads			
	Steel	3125	2675	4000
	Aluminum	3000	2500	1600

As a result of these static tests, it was concluded that:

a. Aluminum generally required a lower breakoff force than steel although this difference is negligible when the threads are epoxied.

b. Although the epoxied threads required a higher peak breakoff force than the bare threads, it was decided to conduct all tests with bare threads because present and planned 20mm projectile assemblies use bare threads.

3.1.2 Load Tests on Firing Pins and Nose Cap

A series of static tests were conducted prior to the gun firing tests to compile basic data on the actuator mechanism of the modified M505A3 fuze. The basic data included the compressive strength of the nose cap and the shear strength of the shoulder on the firing pin. This information was needed to determine the contribution of these components to the fuze delay and to observe the differences between the modified and standard components. The mechanisms included new brass firing pins, M505A3 aluminum firing pins, modified nose caps, and M505A3 nose caps. The brass and the M505A3 aluminum firing pins were identical except for weight.

The results of these tests are shown in Figures 6 through 15.

In general, the static tests showed the following:

a. The force necessary to shear either the brass or M505A3 aluminum firing pins is basically the same. (See Figures 14 and 15.) In all cases, the firing pin shoulder sheared off clean allowing the firing pin to drop through the steel support sleeve.

b. A higher force is required to shear the firing pin installed in the modified M505A3 fuze than in the standard fuze. (See Figures 6 and 7.) The force rate curve was found to be slightly lower, which means that the brass pin requires more time to shear.

c. Annealing the modified M505A3 fuze nose caps reduces the force rate to a level below that of the standard fuze. (See Figures 6 and 9.) This point may prove useful at some later date if it is determined that sensitivity to thin targets is as important as achieving an actual delay detonation.

3.1.3 Zirconium Booster Detonator Safety Tests

During the month of August 1974 four fuzes were modified to allow initiation of the M57A1 detonator in the out-of-line position. The purpose of the tests was to determine if the modified M505A3 fuze with zirconium booster cup presented any safety problems. The standard M505A3 fuze was also tested at the same time as a basis of comparison with the test hardware. Two standard M505A3 fuzes and two modified M505A3 fuzes with a zirconium booster were preassembled without rotor and booster to drill a firing pin access hole in the side of the fuze body. All fuzes were then assembled with live components. Each was then held in a firing fixture to initiate the detonator in the out-of-line position.

Results of this test are shown in Figure 16. Out-of-line initiation of the standard M505A3 fuze results in separation of the fuze body. Although badly distorted, the booster failed to initiate. The modified M505A3 fuze with zirconium cup did not separate and showed little distortion of the zirconium booster.

Based on this limited test, the detonator safety of the modified M505A3 fuze with zirconium booster is comparable to the standard M505A3 fuze.

3.2 GUN TESTS

3.2.1 Description of Test Setup

The setup selected for all firing tests is shown in general form in Figure 17.

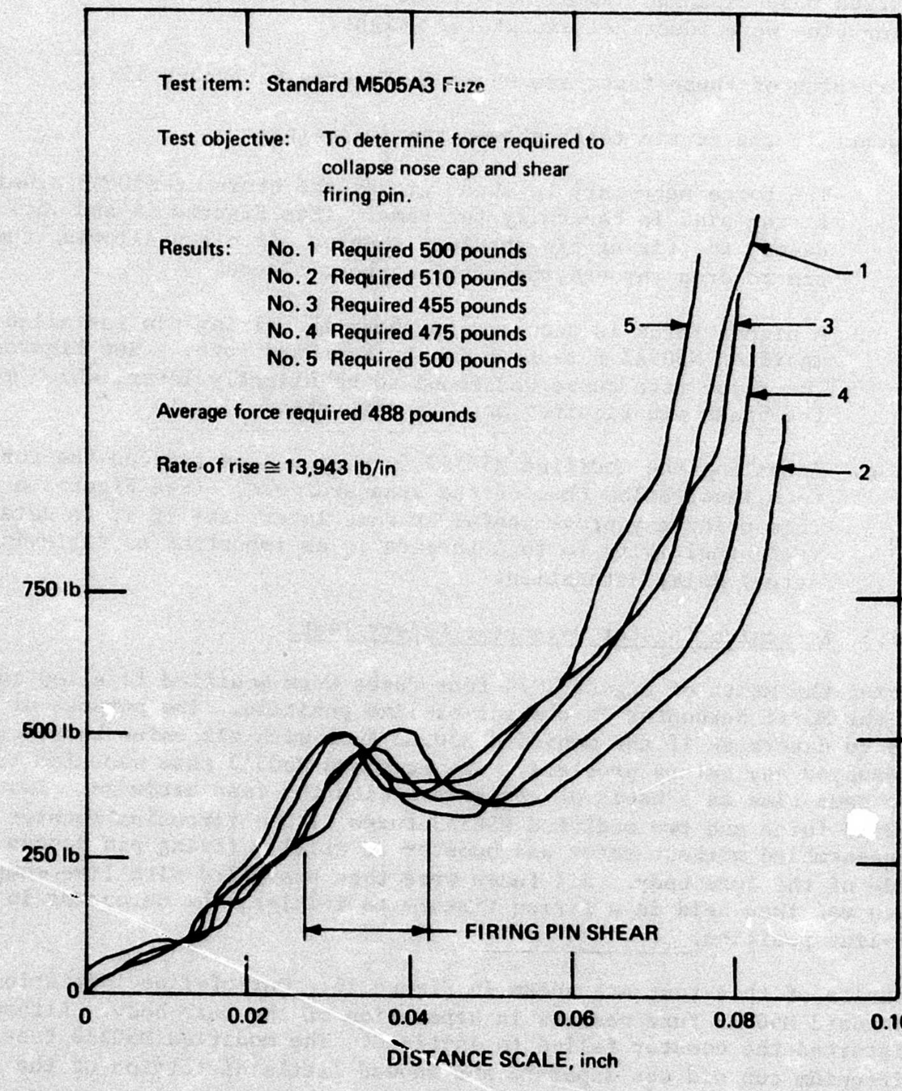


Figure 6. FORCE REQUIRED TO COLLAPSE NOSE CAP AND SHEAR FIRING PIN -- STANDARD M505A3

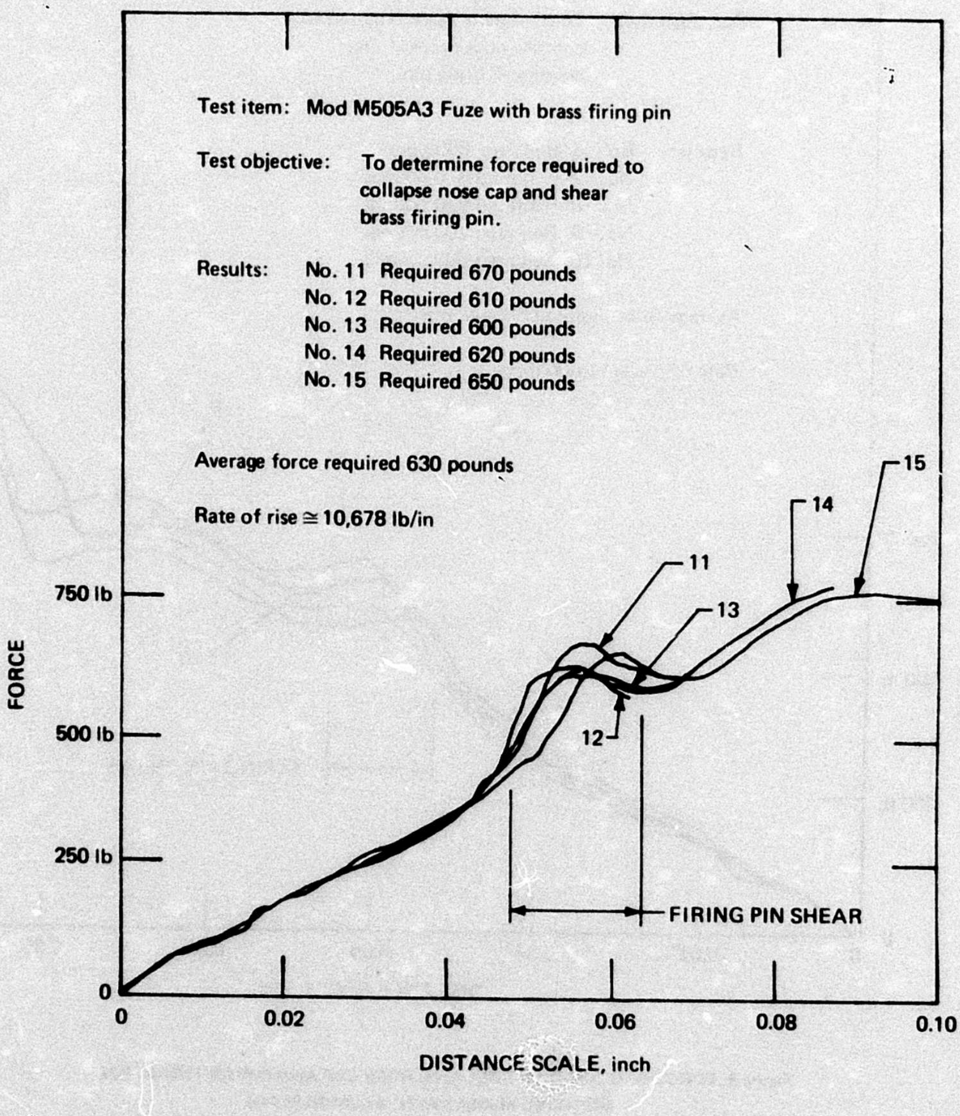


Figure 7. FORCE REQUIRED TO COLLAPSE NOSE CAP AND SHEAR FIRING PIN -- MODIFIED M505A3 WITH BRASS PIN

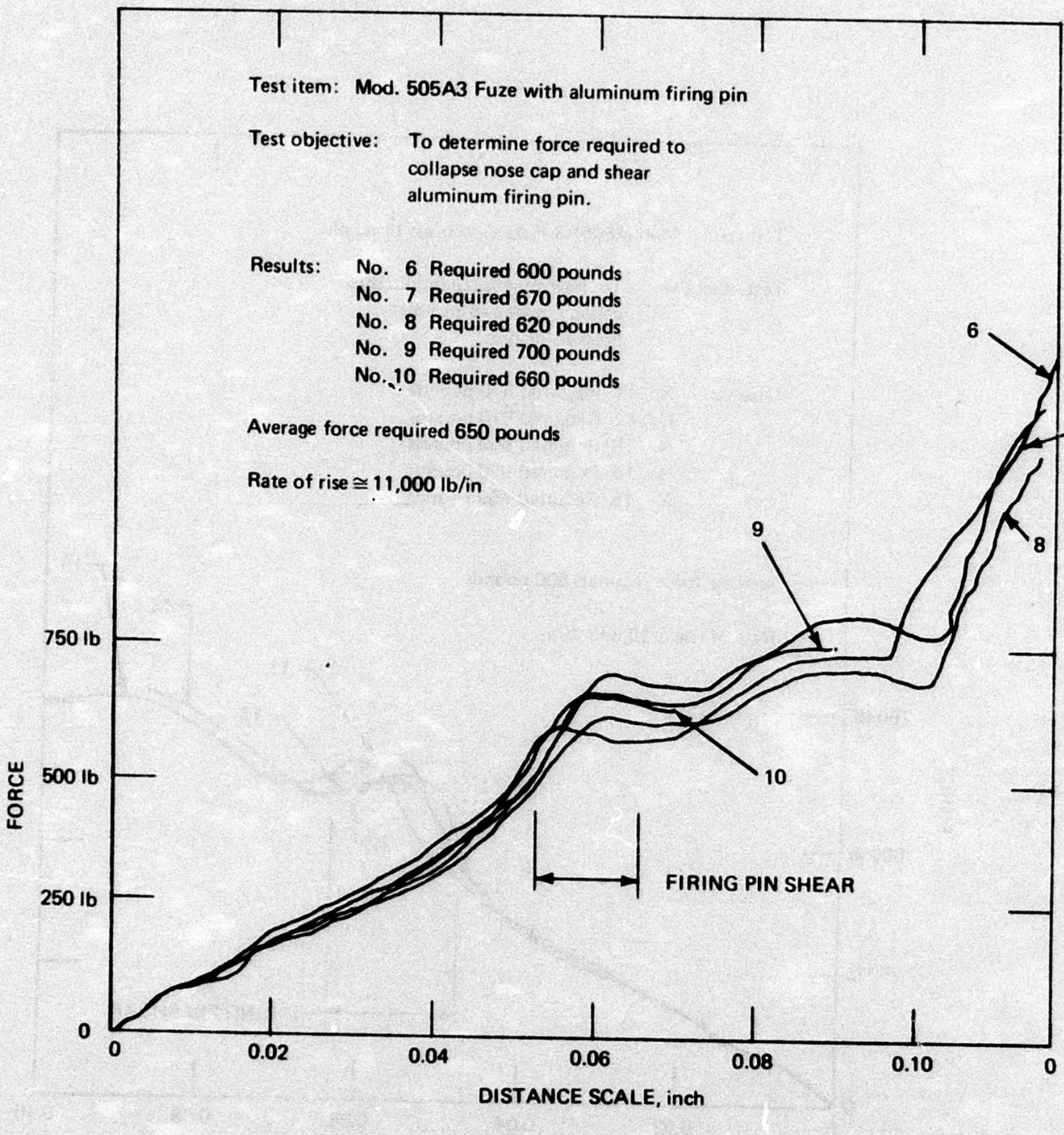


Figure 8. FORCE REQUIRED TO COLLAPSE NOSE CAP AND SHEAR FIRING PIN -- MODIFIED M505A3 WITH ALUMINUM PIN

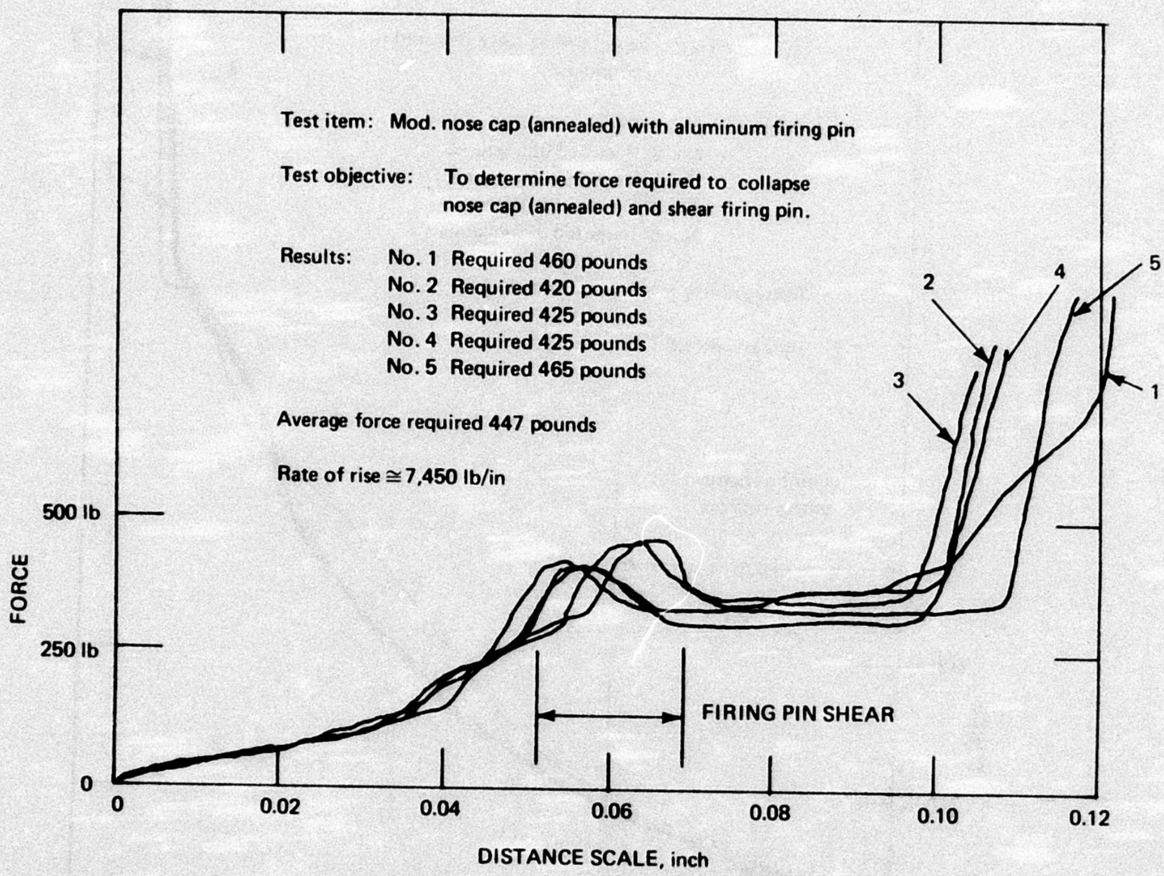


Figure 9. FORCE REQUIRED TO COLLAPSE NOSE CAP AND SHEAR FIRING PIN -- MODIFIED M505A3 WITH ANNEALED NOSE CAP

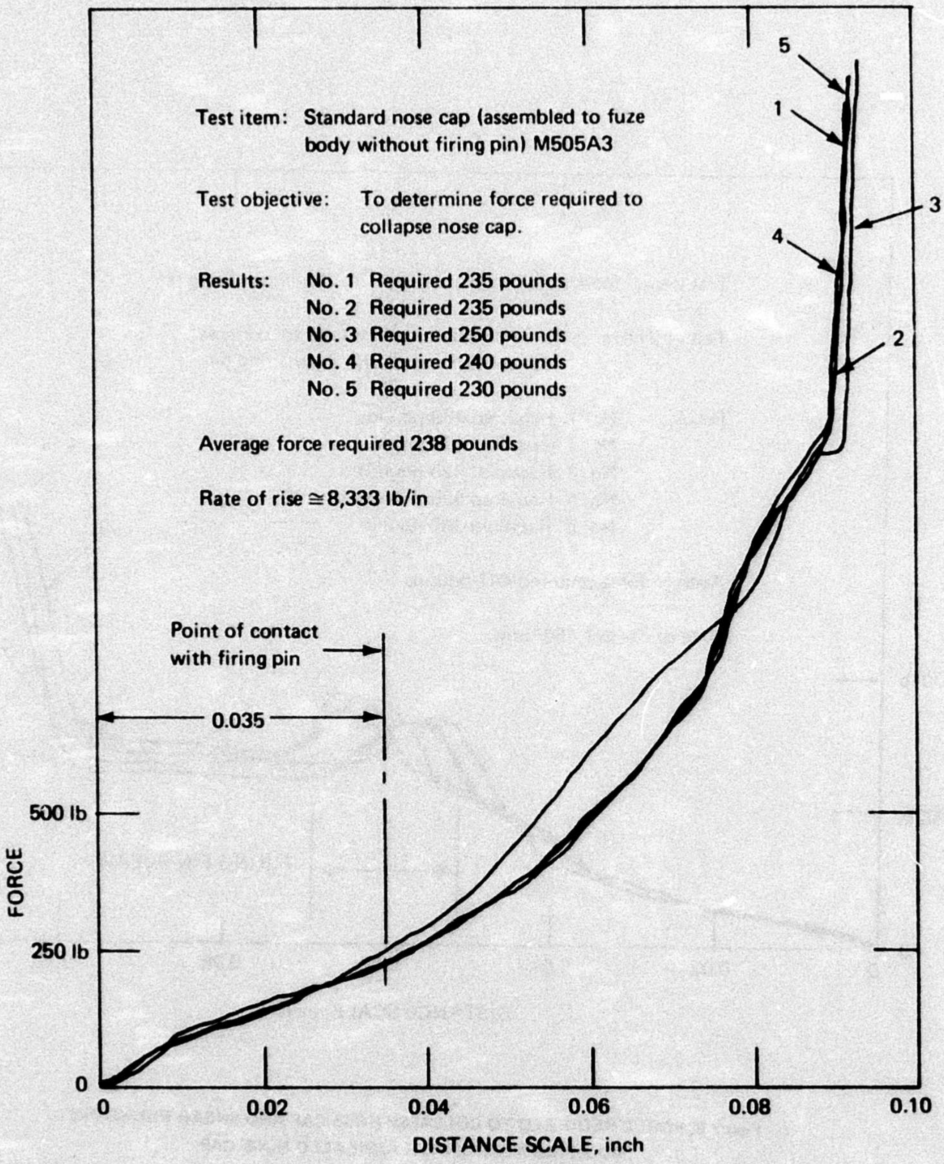


Figure 10. FORCE REQUIRED TO COLLAPSE NOSE CAP ASSEMBLED TO FUZE BODY -- STANDARD M505A3

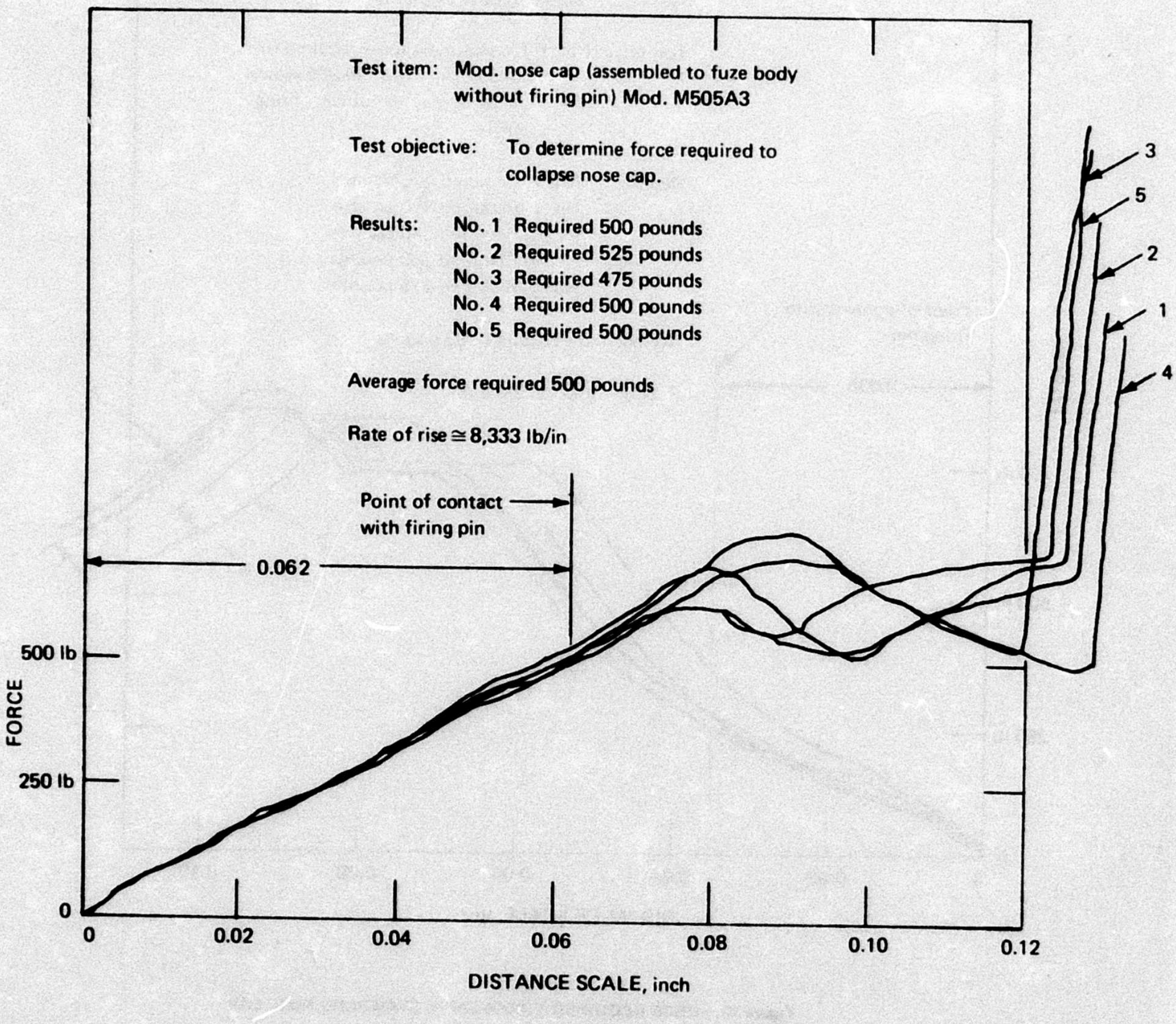


Figure 11. FORCE REQUIRED TO COLLAPSE NOSE CAP ASSEMBLED TO FUZE BODY -- MODIFIED M505A3

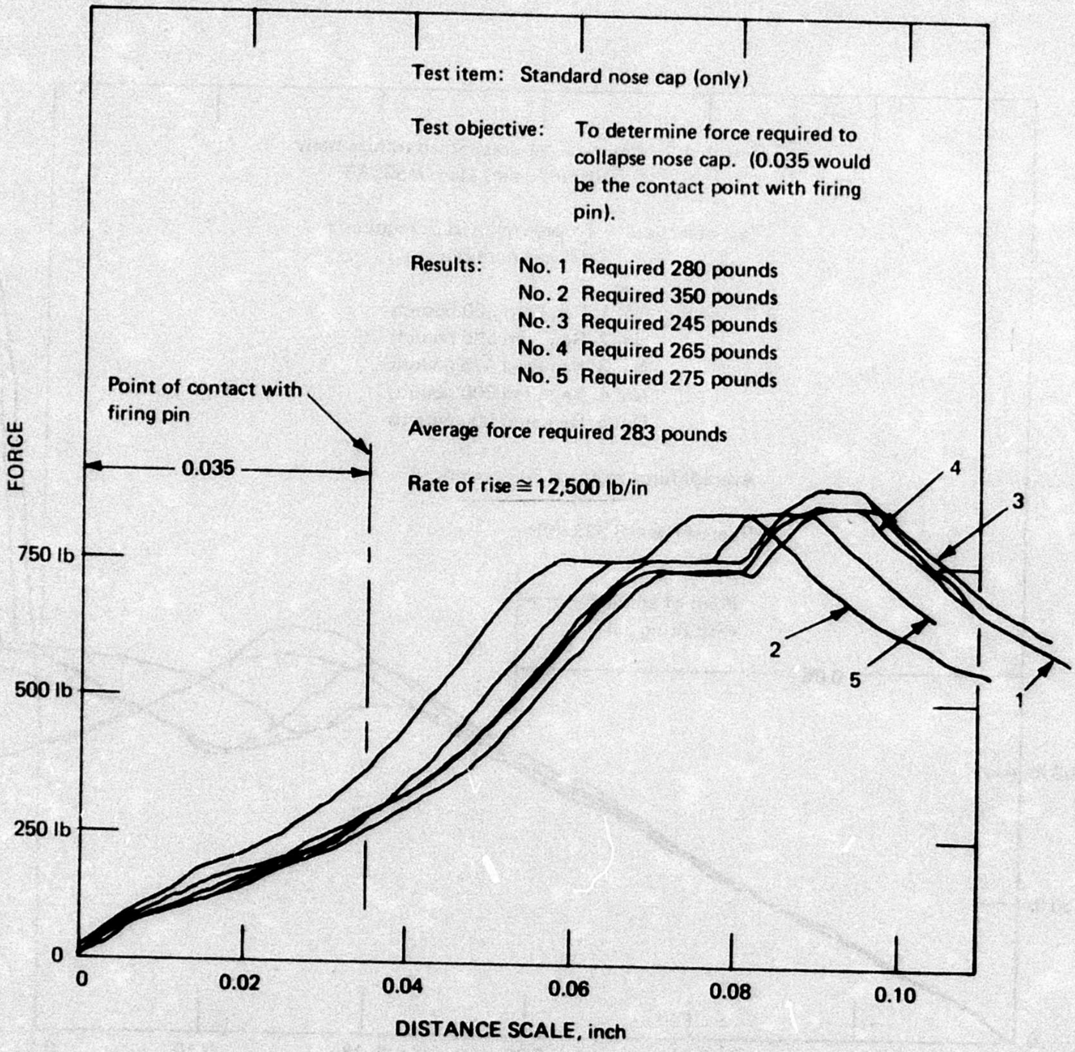


Figure 12. FORCE REQUIRED TO COLLAPSE STANDARD NOSE CAP

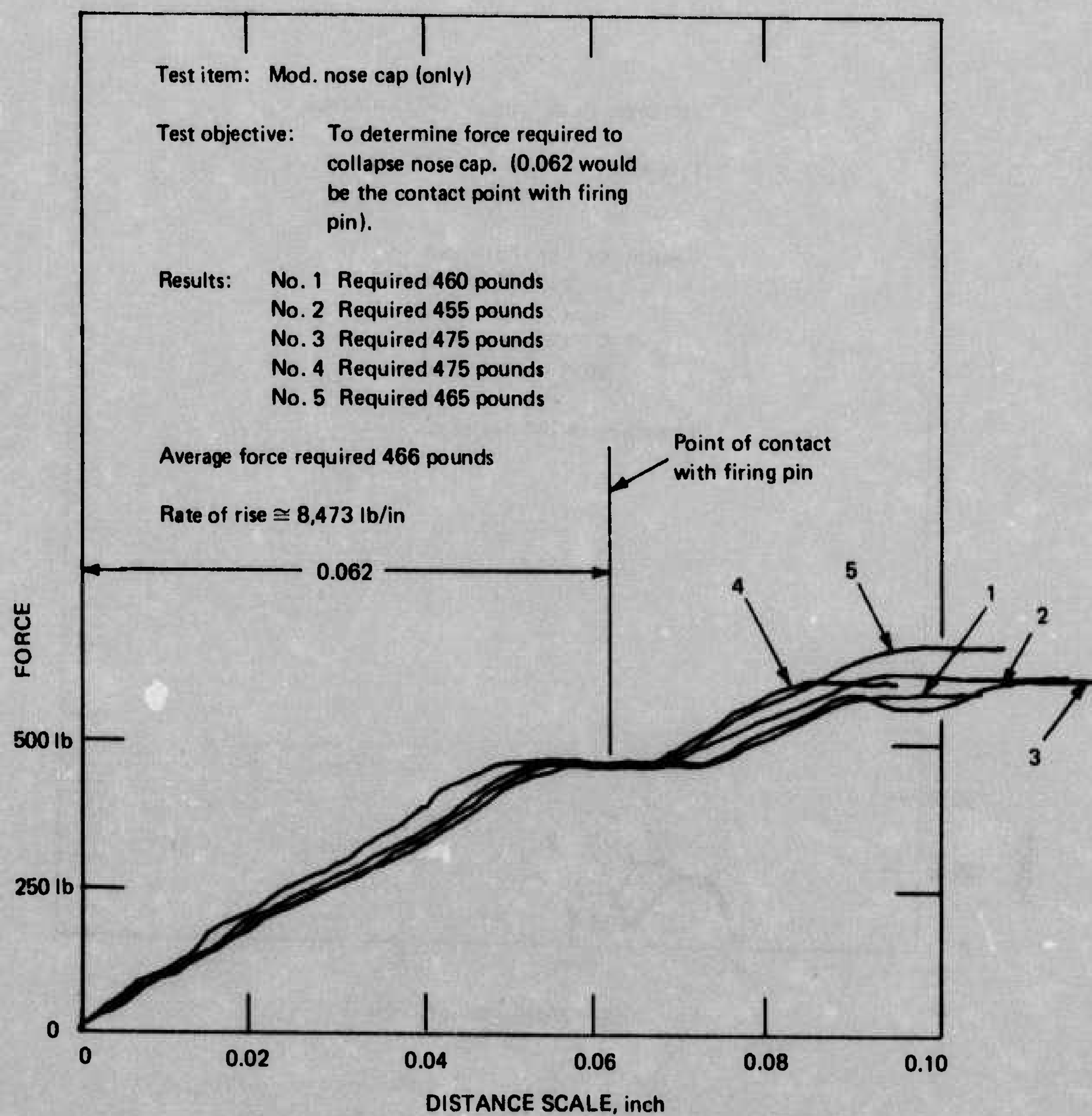


Figure 13. FORCE REQUIRED TO COLLAPSE MODIFIED NOSE CAP

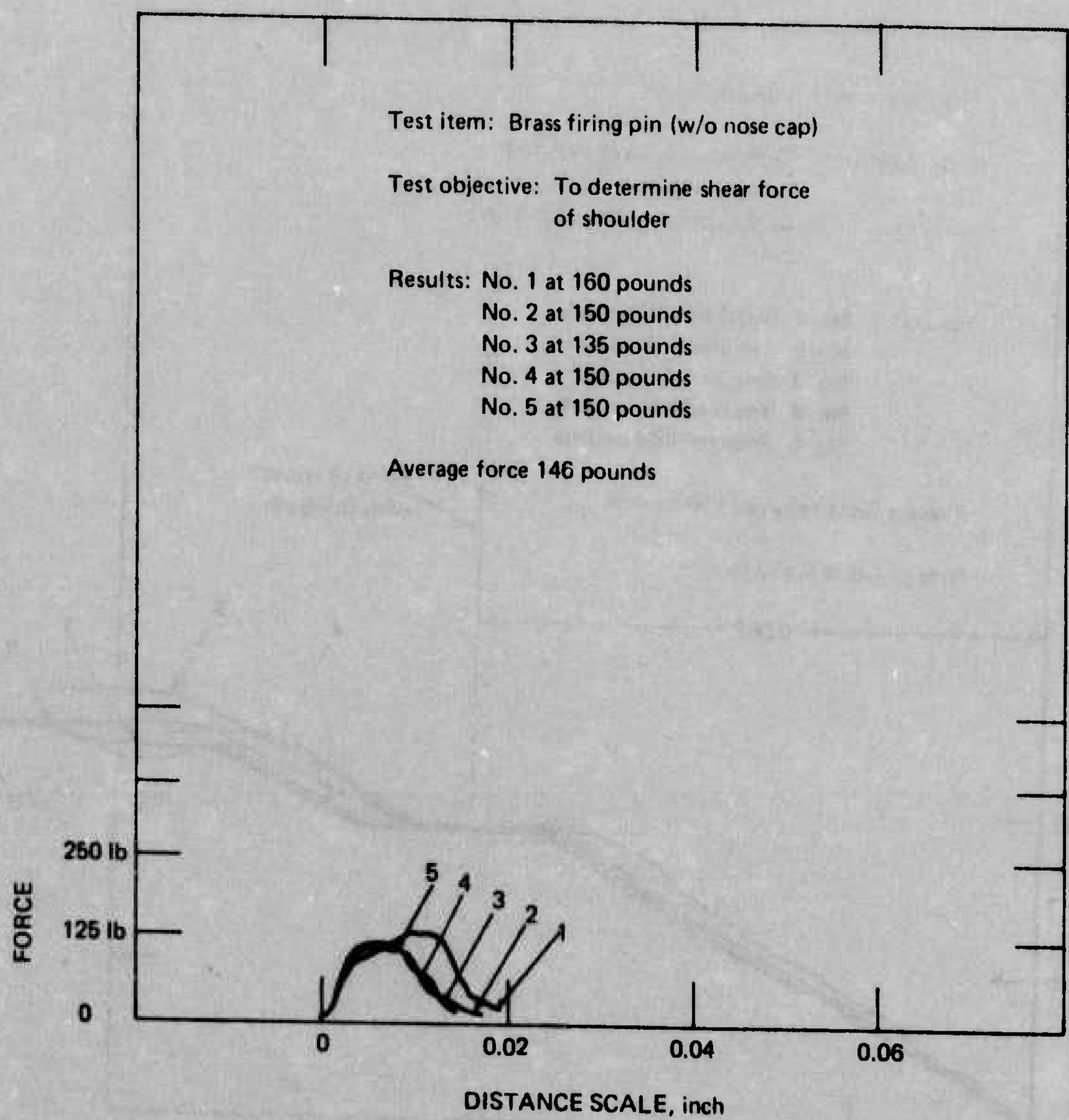


Figure 14. FORCE TO SHEAR SHOULDER OF BRASS FIRING PIN

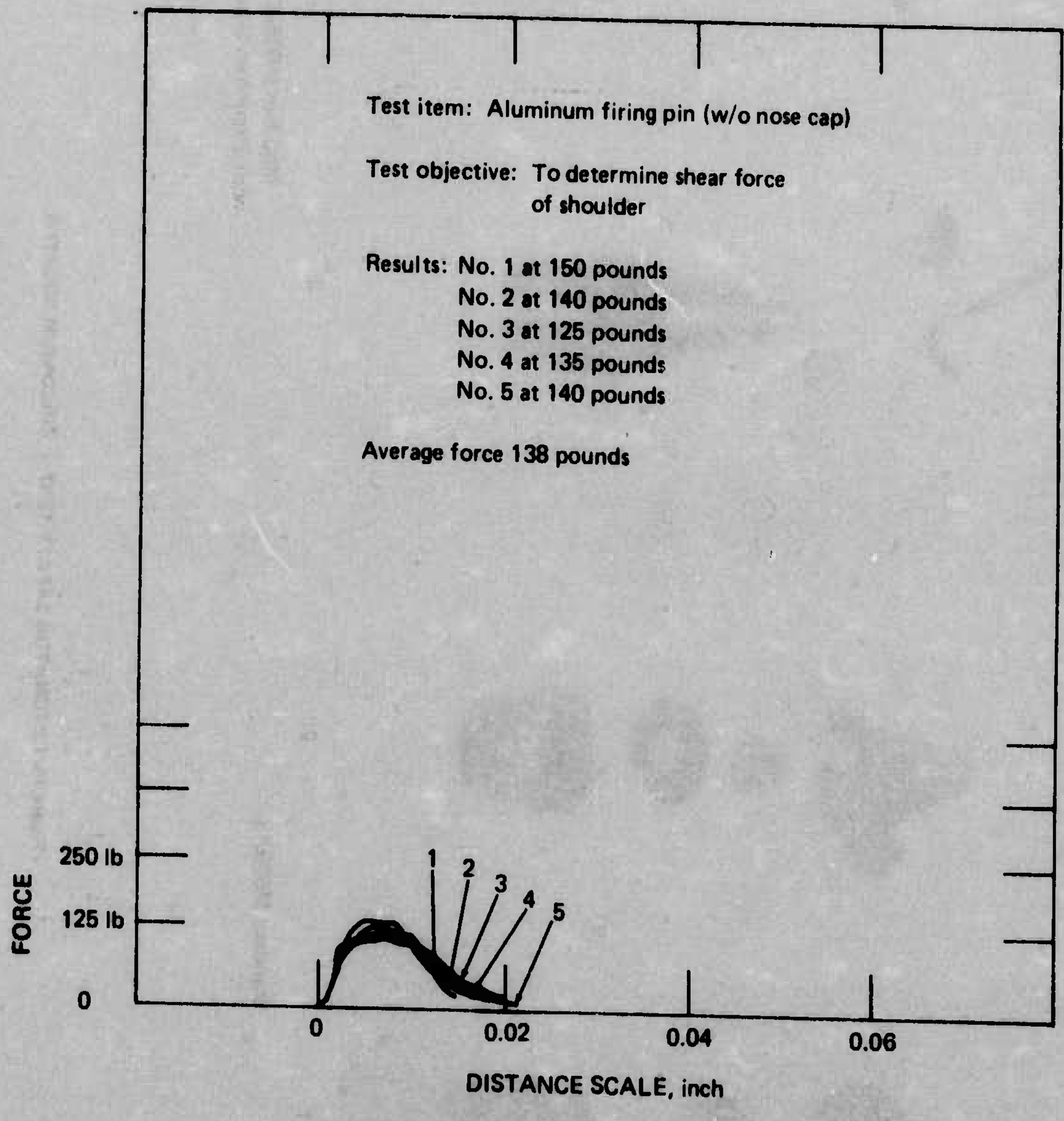
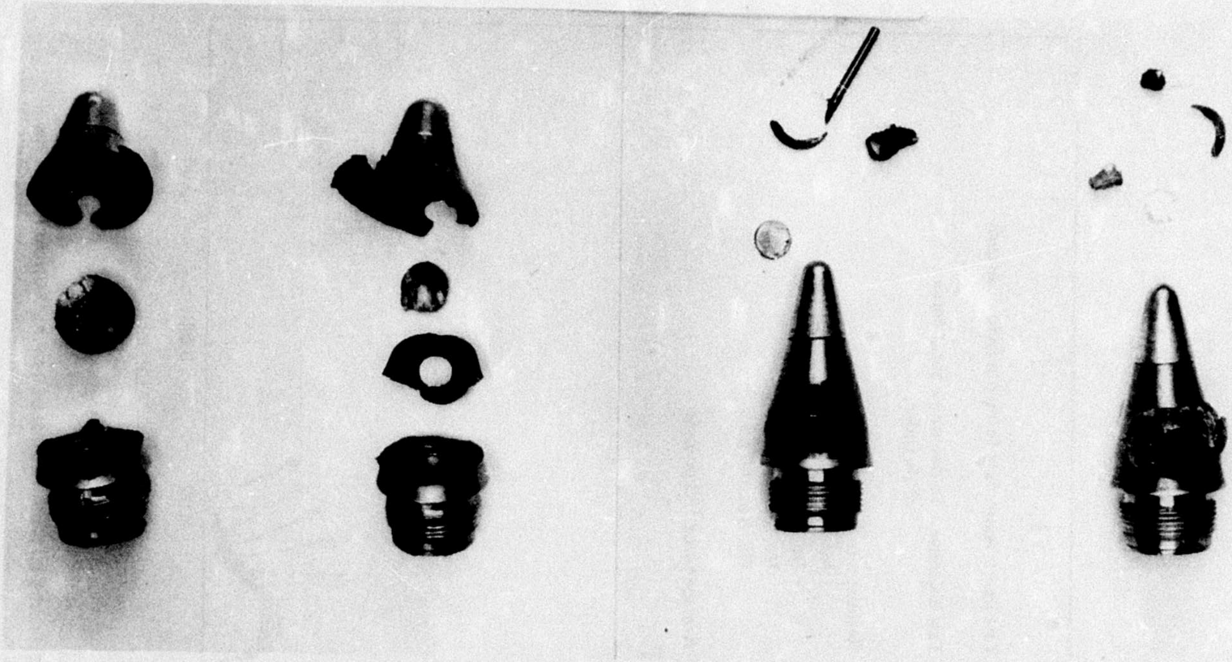


Figure 15. FORCE TO SHEAR SHOULDER OF ALUMINUM FIRING PIN



1 2

Standard M505A3

3 4

Modified M505A3
with Zirconium Booster

Figure 16. DETONATOR SAFETY TEST -- ZIRCONIUM BOOSTER

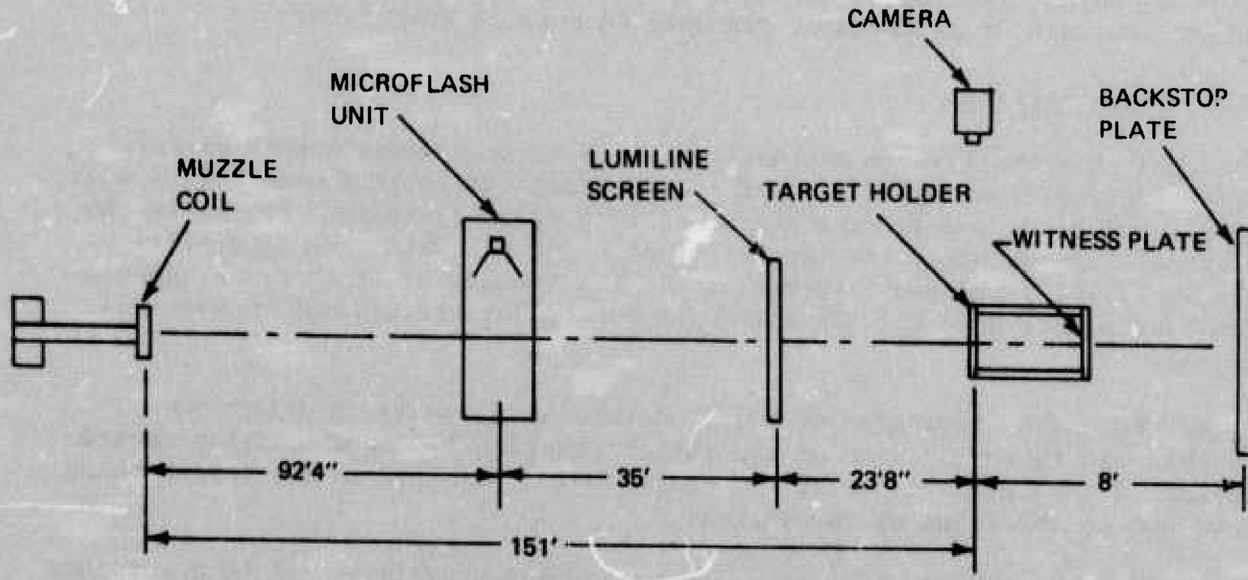


Figure 17. TYPICAL TEST SETUP

All targets were 2024-T3 aluminum cut to a 1-foot-square size and rigidly clamped to a target holder located 151 feet from the muzzle.

Muzzle velocities were measured by means of a muzzle coil and one or more lumiline screens. All rounds were magnetized just before firing. Time intervals were measured with a Hewlett-Packard digital counter between the muzzle coil and lumiline screens.

The microflash unit was used during early tests to photograph the projectile in flight to prove that the projectile had not functioned in the gun barrel. (See paragraph 3.2.4 for further discussion.)

The first five tests were conducted at a range of 97.5 feet with the ball rotor epoxied in the armed position to ensure proper arming of the fuze. When it was ascertained that the fuze and projectile body were holding a true trajectory over all test velocities, the range was increased to 151 feet. At this range the rotor was armed during flight and did not require any epoxy or staking in the armed position.

Each round was directed toward a 2-inch-thick plate backstop set at an angle to direct fragments toward the ground as a safety measure.

Function on the target was recorded by means of a 4 x 5 color Polaroid® picture that included a calibration scale to determine distance behind the target at which the initiation event occurred.

The projectiles, in the initial series of tests, were loaded with inert warhead charges and live RDX booster charges. Functioning distances reported in the first 18 test results were actually a calibrated distance between target impact and a point where flash produced by booster initiation was observed in photographs. After Test 18 it was decided to eliminate any possible delay errors by using live rounds rather than inert rounds. The center of the projectile flash or photographs was used to measure fuze delay.

3.2.2 Test Criteria

Throughout the tests three methods were used to make measurements on fuze delay achieved from round to round. High speed camera film resulted in what is believed to be a fair measurement of fuze delay distance. Figure 18 shows a typical film sequence for two different targets. Distances determined by film were listed whenever appropriate in the summary of Table 8. Fragmentation boards were used occasionally with good delay measurement on vertical targets.

By far, the most meaningful method of determining whether a delay was achieved was in examination of the target itself. A fuze with delay caused a blast on the back surface of the target which resulted in the target being blown out to the front of the target.

The entrance and blast holes produced in the target were graded in accordance with the degree and type of damage. Good delay produced a large blast hole on low graze targets with most of the torn edges pointing back toward the gun. Such a result was listed as "good petalling" or, if very prominent, "banana peel." Superquick fuze -- meaning no delay -- was correlated with a target hole having all edges pointing away from the gun. A typical example of these extremes is shown in Figure 19.

Polaroid® film was also found to be useful in determining whether a proper delay was achieved.

"Banana peel" target results invariably showed a prominent fireball below the target in the case of low graze tests. Detection of a marginal delay, however, is not believed to be practical with Polaroid® camera setup.

3.2.3 Tests Conducted -- Summary Chart

A total of 273 rounds were assembled and tested in a series of 77 different tests. These tests are listed by number with pertinent data in Table 8.

Most rounds fired were photographed by a Hycam 16mm camera with a framing rate between 12,500 and 15,000 frames per second. In addition, a Polaroid® camera was used to photograph the fireball on target. Setup for all tests was identical to that described in paragraph 3.2.1 except in the case of soft recovery tests, which required moving the target a few feet closer to the gun to allow for a depth of Celotex®. Standard lumiline screens recorded muzzle velocities.

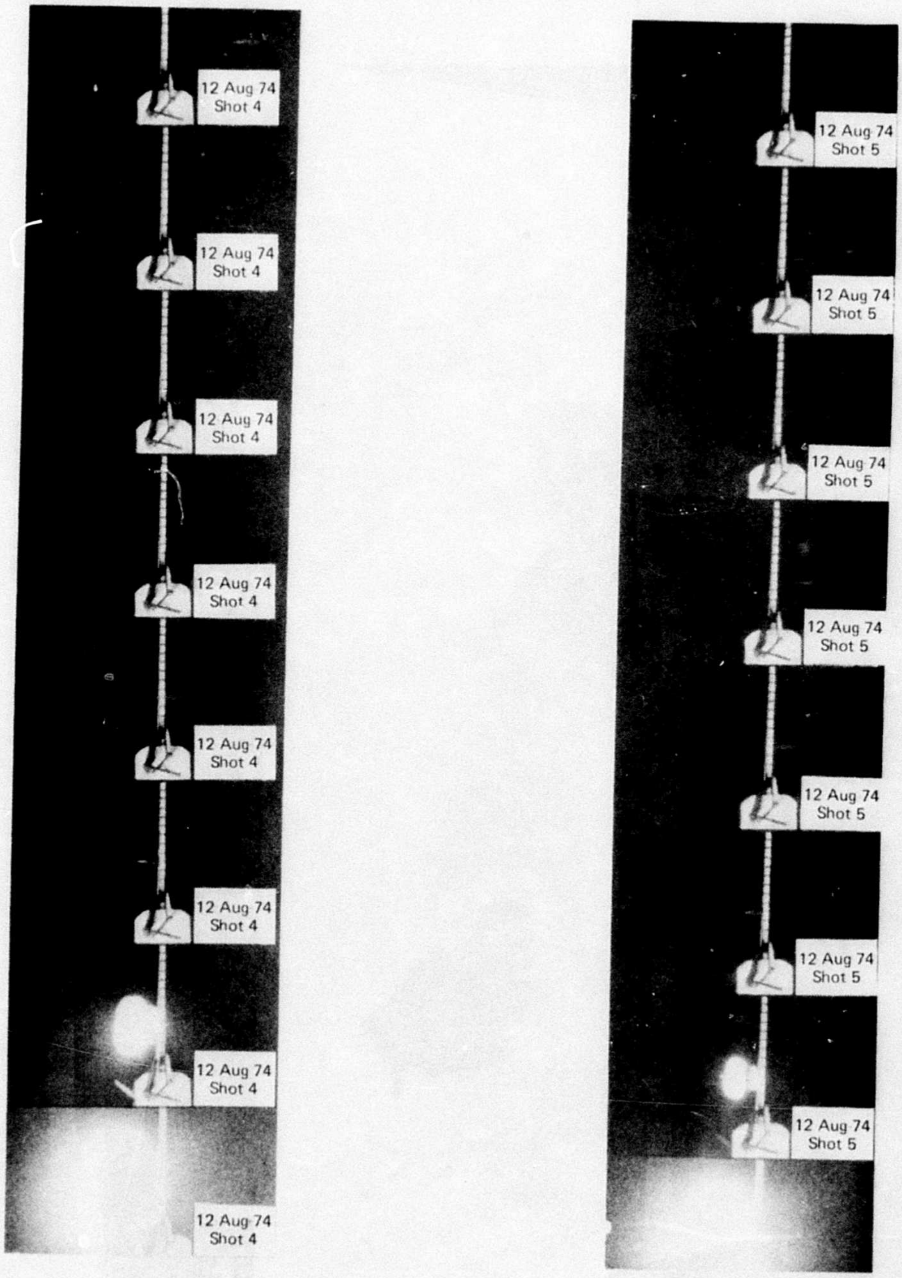


Figure 18. HIGH SPEED FILM SEQUENCE

Figure 19. TYPICAL TARGET RESULT EXTREMES

TABLE 8. MODIFIED M505A3 FUZE TEST RECORD SUMMARY

Date 1974	Test	Rounds fired	Fuze condition	Target		Velocity (ft/sec)	Remarks
				Type	Position		
18 May	1	10	Brass/aluminum	Celotex® 10 Ft.	Vertical Soft Recov.	3601-3653	Mat accel on new brass firing pin-pin held OK.
21 May	2	1	Brass/steel	0.040	80° oblique	1944	Charge too high.
		1	Brass/steel	0.040	80° oblique	1590	Charge too high.
		1	Brass/steel	0.040	80° oblique	1030	Round hit upper part of test, chg. OK.
		2	Brass/steel	0.040	80° oblique	989-1061	Good hits-did not function.
21 May	3	2	Brass/aluminum	0.040	80° oblique	1029-1076	Good hits- no function.
		3	Brass/aluminum	0.040	Vertical	967-1087	2-No function.
28 May	4	5	Brass/aluminum	Celotex®	Vert. Soft Recovery	3604-3649	All rounds functioned in Celotex®. Brass pin OK on setback. M47 detonator.
28 May	5	5	Brass/steel	0.040	80° oblique	983-1018	1 round hit low-discounted, 4 rounds failed to function on target. M47 detonator.
28 May	6	10	Standard M505A3 Fuze	Celotex®	---	3507-3557	Standard fuze functions in less Celotex® depth.
31 May	7	2	Brass/steel	0.090	80° oblique	2560-2570	Other round hit top edge-discounted.
		5	Brass/steel	0.090	80° oblique	2550-2570	1 hit too high on target. Possible slight delay.
31 May	8	5	Brass/steel	0.040	Vertical	2550-2570	5 good hits-no function.
4 Jun	9	5	Brass/aluminum	0.040	Vertical	2527-2548	M47 detonator.
4 Jun	10	5	Aluminum/aluminum	0.040	Vertical	2519-2535	No picture of 5th round, probable function. M47 detonator.
4 Jun	11	5	Brass/aluminum	0.090	Vertical	2521-2574	All good hits, 2 no function. Possible slight delay.
4 Jun	12	5	Brass/steel	0.040	80° oblique	2483-2496	2 missed target.
6 Jun	13	5	Standard M505A3 Fuze	0.040	Vertical	2513-2546	
6 Jun	14	5	Aluminum/aluminum	0.040	Vertical	2559-2579	Consistent function.
6 Jun	15	5	Standard M505A3 Fuze	0.090	Vertical	2499-2537	No significant delay.
6 Jun	16	5	Aluminum/aluminum	0.090	Vertical	2533-2577	No significant delay.
7 Jun	17	5	Aluminum/aluminum	0.090	80° oblique	2425-2460	#5 probable also on plate-may have struck target holder.
7 Jun	18	5	Aluminum/aluminum	0.040	Vertical	922-1026	No function on target or backup plate-doubtful results- should have functioned on plate.
10 Jul	19	4	0.017 brass pin shoulder.	0.090	Vertical	2500	Delay OK 3", 4", 11", 4".
10 Jul	20	4	0.017 brass pin shoulder.	0.063	Vertical	2500	1 no function 3 excellent delay, 6", 7", 10".
10 Jul	21	4	0.017 brass pin shoulder.	0.063	75° oblique	2500	On target, no significant delay.
10 Jul	22	4	0.021 brass pin shoulder.	0.063	75° oblique	2500	Partial petal rearward, 1 round missed target.
10 Jul	23	2	0.017 brass pin shoulder.	0.063	75° oblique	2500	Partial petal rearward, 4" x 4' target.
18 Jul	24	3	0.017 brass pin, epoxied rearward.	0.063	75° oblique	2500	Partial petal, no change.
18 Jul	25	3	0.017 brass, sleeve cutoff, epoxy rearward	0.063	75° oblique	2500	No significant difference.
22 Jul	26	2	0.017 brass, 0.040 longer sleeve.	0.063	75° oblique	2500	No significant difference.
22 Jul	27	2	0.025 brass, 0.040 longer sleeve.	0.063	75° oblique	2500	No change.
22 Jul	28	2	0.035 brass, 0.040 longer sleeve.	0.063	75° oblique	2500	No change.
22 Jul	29	2	0.035 brass, standard length sleeve.	0.063	75° oblique	2500	No change.
22 Jul	30	2	Brass nub cutoff.	0.063	75° oblique	2500	No change.
23 Jul	31	2	No firing pin.	0.063	75° oblique	2500	Function on target.
23 Jul	32	1	No sleeve, no firing pin.	0.063	75° oblique	2500	Did not function.
23 Jul	33	1	No firing pin, sleeve squared off on seat.	0.063	75° oblique	2500	Function on target.
23 Jul	34	1	No firing pin, sleeve cut-off flush with body.	0.063	75° oblique	2500	Function on target.
23 Jul	35	4	No sleeve, no firing pin.	0.063	75° oblique	2500	2 no function, 2 function on target, classic delay on one.
23 Jul	36	1	No sleeve, no firing pin. Triple stake detonator.	0.063	75° oblique	2500	Function on target.
24 Jul	37	5	Standard M505A3 no firing pins.	0.063	75° oblique	2500	All function on target.
24 Jul	38	5	GAU-7/A without firing pins.	0.063	75° oblique	2500	All function on target - one classic delay.
24 Jul	39	4	GAU-7/A without firing pin and sleeve - dummy detonator.	0.063	75° oblique	2500	No function on target - problem is not booster.

TABLE 8. MODIFIED M505A3 FUZE TEST RECORD SUMMARY (Concl'd)

Date 1974	Test	Rounds fired	Fuze condition	Target Type	Target Position	Velocity (ft/sec)	Remarks
24 Jul	40	5	GAU-7/A with 0.025 thick brass pins.	0.063	75° oblique	2500	3 good delay, 2 no delay.
25 Jul	41	2	Inert M505A3 standard, no firing pin.	0.063 then soft recovery	75° oblique	2500	Both rounds show target material hit detonator.
29 Jul	42	5	Inert modified M505A3 fuze fully assembled.	0.063 then soft recovery	75° oblique	2500	Showed brass pins hit first driven by slug of aluminum.
29 Jul	43	3	Modified M505 grooved firing pin.	0.063	75° oblique	2500	No significant delay.
30 Jul	44	2	Special steel firing pin.	0.063	75° oblique	2500	1 banana peel, 1 round missed target.
30 Jul	45	2	0.025 brass pin shoulder.	0.063	45° oblique	2500	Definite function behind target.
30 Jul	46	2	0.017 brass pin shoulder.	0.063	45° oblique	2500	Definite behind target, 1 banana peel.
30 Jul	47	2	0.017 brass pin shoulder.	0.063	70° oblique	2500	1 banana peel, 1 no delay.
30 Jul	48	2	Special steel firing pin.	0.063	75° oblique	2500	1 banana peel, 1 no function.
30 Jul	49	1	Warped brass pin	0.063	75° oblique	2500	Superquick.
31 Jul	50	2	Steel pin, 0.010 undercut.	0.063	75° oblique	2500	1 banana peel, 1 no significant delay.
31 Jul	51	1	Steel pin 0.005 undercut.	0.063	75° oblique	2500	Banana peel.
31 Jul	52	1	Steel pin - no undercut.	0.063	75° oblique	2500	Failed to function on target.
31 Jul	53	5	0.017 brass modified M505A3 (standard).	0.063	70° oblique	2500	1 round missed target, 4 no significant delay.
1 Aug	54	3	Steel pin - no flat.	0.063	75° oblique	2500	1 fair banana peel - 2 partial - not significant.
1 Aug	55	5	Steel pins - 0.030 flat.	0.063	75° oblique	2500	2 prominent banana peel. 2 partial delay. 1 round missed target.
1 Aug	56	2	0.017 brass pin shoulder.	0.063	65° oblique	2500	1 superquick. 1 no significant delay.
1 Aug	57	3	0.017 brass pin shoulder.	0.063	60° oblique	2500	1 banana peel - excellent. 1 good delay. 1 no significant delay.
2 Aug	58	3	Steel pin - 0.005 undercut, 0.030 flat.	0.090	75° oblique	2509-2549	1 miss, 2 no function.
2 Aug	59	1	Steel pin.	0.063	75° oblique	2551	Good delay and petal.
2 Aug	60	1	Steel pin.	0.040	Vertical	2544	No function.
6 Aug	61	5	0.025 brass pin shoulder.	0.063	70° oblique	2500-2525	1 round missed target. 4 rounds - no significant delay.
6 Aug	62	2	0.035 brass pin shoulder.	0.063	70° oblique	2491, 2531	Superquick.
6 Aug	63	2	0.025 brass pin shoulder.	0.063	60° oblique	2511, 2529	No delay.
FINAL TESTS							
9 Aug	64	5	0.017 brass pin shoulder.	0.040	Vertical	2522-2562	8" to 12" delay.
9 Aug	65	5	0.017 brass pin shoulder.	0.063	Vertical	2511-2540	6" to 8" delay.
12 Aug	66	5	0.017 brass pin shoulder.	0.090	Vertical	2496-2520	1/2" to 2" delay.
12 Aug	67	2	0.017 brass pin shoulder.	0.040	Vertical	1282, 1356	No function, 8 grams.
12 Aug	68	3	0.017 brass pin shoulder.	0.040	Vertical	1450, 1465, 1510	No function, 11-1/2 grams.
12 Aug	69	5	0.017 brass pin shoulder.	0.063	55° oblique	2496-2527	Good delay.
12 Aug	70	OBJECTIVE: Determine minimum reliable graze angle on 0.090 target.					
		1	0.017 brass pin shoulder.	0.090	45° oblique	2502	No delay.
		1	0.017 brass pin shoulder.	0.090	30° oblique	2507	No significant delay.
		1	0.017 brass pin shoulder.	0.090	75° oblique	2545	Good delay.
		1	0.017 brass pin shoulder.	0.090	32½° oblique	No velocity	Good delay.
13 Aug	71	5	0.017 brass pin shoulder.	0.063	60° oblique	2496-2533	4 delay, 1 no delay.
13 Aug	72	OBJECTIVE: Check minimum reliable velocity on 0.040 vertical.					
		1	0.017 brass pin shoulder.	0.040	Vertical	1880	3" delay - approx
		1	0.017 brass pin shoulder.	0.040	Vertical	1855	3" delay.
		1	0.017 brass pin shoulder.	0.040	Vertical	1745	No function.
		1	0.017 brass pin shoulder.	0.040	Vertical	1763	3" delay - approx
		1	0.017 brass pin shoulder.	0.040	Vertical	1670	No function.
22 Aug	73	5	0.017 brass pin shoulder.	0.040	75° graze	2515-2535	Good delay - 2" to 3".
22 Aug	74	2	Round steel cap on 0.030 brass pin shoulder.	0.063	75° graze	2510, 2535	Superquick
22 Aug	75	3	Cone steel cap on 0.017 brass pin shoulder.	0.063	75° graze	2510, 2520, 2535	Excellent delay - banana peel.
22 Aug	76	1	Cone steel cap on 0.017 brass pin shoulder.	0.090	75° graze	2500	Partial delay - target blown to side.
22 Aug	77	1	Cone steel cap on 0.017 brass pin shoulder.	0.063	Vertical	2500	8" delay.

In Tests 1 through 18 fuze delays were indicated by booster detonation. All subsequent tests used detonation of HEI M56A3 projectiles to indicate delay behind the target. All fuze configurations used the M57A1 detonator except as noted in the Remarks column of Table 8.

3.2.4 Brass Firing Pin -- Maximum Acceleration

Fifteen rounds were fired in Tests 1 and 4 to subject the new brass firing pins to maximum acceleration in the gun barrel. Ten rounds were fired in Test 1 using M57A1 detonators and five rounds were fired in Test 4 using the more sensitive M47 detonator. All rounds were assembled with aluminum fuze bodies and empty M56A3 warhead bodies to provide a minimum in-flight or maximum acceleration in the gun barrel. A cartridge charge of 40 grams of WC870 propellant produced muzzle velocities that varied between 3601 and 3653 ft/sec.

Microflash photographs of each projectile in both tests were taken as the projectile passed over a photocell trigger at a range of 35 feet from the gun barrel. The resulting Polaroid® pictures proved that the projectiles were intact and that the brass firing pin shoulder had not failed under setback loads. To prove that each round was capable of functioning, a Celotex® target was positioned 93 feet downrange. Depth of penetration into the Celotex® before initiation of the booster was noted to vary between 2 and 3-1/2 inches. All rounds functioned.

Test 6 was conducted to provide a comparison in Celotex® penetration of the standard M505A3 fuze with the modified fuze of Test 4. Depth of penetration of the standard fuze was noted to vary between 1/2 and 1-1/2 inches before initiation of the booster. The modified fuze had an improved delay equivalent to an additional 1-1/2 to 2 inches in Celotex®.

3.2.5 Function on 0.040-Inch-Thick Target at 0-degree Obliquity

Tests 3, 8, 9, 10, 13, 14, and 18 were conducted to measure functional characteristics of the new fuze design against a thin vertical target at both 1000 and 2500 ft/sec velocity levels. Inert rounds were used for these and all tests through Test 18. Results of these initial tests are summarized by the following statements:

a. At 1000 ft/sec, the modified fuze design, as shown in Figure 2, failed to sense a 0.040-inch-thick target.

b. At 2500 ft/sec the design functioned consistently with an aluminum firing pin on 0.040-inch-thick targets. It provided a functioning delay between 6 and 13 inches.

c. The brass firing pin did not function on 0.040-inch-thick vertical targets even at a velocity of 2500 ft/sec. (Later tests with brass firing pins under these conditions, e.g., Test 64, displayed very good delay.)

d. The standard M505A3 fuze functioned consistently on 0.040-inch-thick targets at a velocity of 2500 ft/sec. The delay in function, as measured with the same test setup previously described was practically negligible.

3.2.6 Function on 0.040-inch-Thick Target at 80-degree Obliquity

Tests 2, 3, 5 and 12 showed that the modified fuze design at 80-degree obliquity angle requires a velocity of 2500 ft/sec using the brass firing pin to function between 3-1/2 and 4 inches behind a 0.040-inch aluminum target. As at 0 degree obliquity and at a velocity of 1000 ft/sec, the fuze did not adequately sense the target.

3.2.7 Function on 0.090-inch-Thick Target at 0-degree Obliquity

Tests 11, 15 and 16 were conducted against vertical 0.090-inch-thick targets. Five test rounds using the brass firing pin showed an apparent delay at a velocity of 2500 ft/sec. Two of the five rounds failed to function, however.

Tests 15 and 16 showed that neither the standard M505A3 fuze nor the modified design with an aluminum firing pin resulted in a significant delay. Thus, the added stroke of the firing pin in the new design is not sufficient by itself to produce a warhead initiation delay after passing through a 0.090-inch-thick target.

3.2.8 Function on 0.090-inch-Thick Target at 80-degree Obliquity

Tests 7 and 17 showed that the modified M505A3 fuze design is capable of both penetration and function on 80-degree obliquity, 0.090-inch-thick targets. The tests clearly indicated that the brass and aluminum firing pins have sufficient energy to cause booster function. The amount of delay was obscured because booster function was the only criterion during these tests.

3.2.9 Fuze Delay and Steel and Aluminum Fuze Bodies

During the first 18 tests, data was accumulated for a comparison of variables other than target thickness, impact velocity and obliquity angles and their effect on fuze delay. The data from the initial tests was sorted and re-assembled in Table 9. The effect of fuze body material on fuze delay was noted in tests on 0.040-inch-thick aluminum at 2500 ft/sec, 0-degree obliquity and 1000 ft/sec, 80-degree obliquity. In this small segment of the tests the fuze body material did not appear to have any effect on the fuze delay. All tests subsequent to Test 18 were conducted with fuze bodies using the same steel material of the standard M505A3 fuze.

3.2.10 Fuze Delay and Brass and Aluminum Firing Pins

The data in Table 9 also provided an examination of the influence of brass and aluminum firing pins on fuze delay. Because the modified fuzes had the same dimensions, the heavier brass pin provided more delay, as expected. This was clearly demonstrated against 0.090-inch-thick target. In Tests 7 and 11 the brass pin resulted in an apparent delay causing detonation behind the target, whereas the aluminum pin in Tests 16 and 17 had no delay at all with detonation on the front surface. This indicated that the brass pin traveled slower than the aluminum pin. This same trend was noted against the 0.040-inch target.

TABLE 9. SUMMARY OF FUZE RESPONSE DURING INITIAL TESTS OF MODIFIED M505A3 FUZE

Test No.	Aluminum Target	Velocity (ft/sec)	Obliquity (degrees)	Detonator	Aluminum Body		Steel Body	
					Alum. Pin	Brass Pin	Alum. Pin	Brass Pin
11, 16	0.090	2500	0	M57	5 quick	3 delay* 2 dud		
7, 17	0.090	2500	80	M57	4 quick			4 delay* 1 quick
14, 18	0.040	2500	0	M57	5 delay			5 duds
9, 10	0.040	2500	0	M47	4 delay	5 dud		
12	0.040	2500	80	M57				3 delay
3, 18	0.040	1000	0	M57	5 dud	1 delay 2 dud		
2, 3	0.040	1000	80	M57		2 dud		2 dud
5	0.040	1000	80	M47				4 dud

*Detonation immediately behind target indicated by initiation of booster.

3.2.11 Fuze Delay and Detonators

Most of the initial tests were conducted with the M57A1 detonators. A few tests were also made with the M47 detonator which has an all fire level of 12 in-oz compared to the M57A1 all fire of 112 in-oz. Because the M47 detonator requires less energy for initiation, the firing pin should be able to travel slower, thus giving the fuze more delay. Comparison tests were conducted with 0.040-inch aluminum. (See Table 9.) With an aluminum firing pin at a velocity of 2500 ft/sec and an obliquity of 0 degrees, both detonators initiated and the fuze provided sufficient delay. At a very low velocity and high obliquity angle (1000 ft/sec and 80°) with a brass firing pin, the detonators did not initiate. In this latter case, the impact energy imparted to the firing pin was insufficient to shear the shoulder and then to provide the necessary firing energy for the M47 detonator. The M57A1 detonator could not initiate under these conditions either.

At this point in the program, attention was directed to achieving sufficient fuze delay with the brass firing pin at 2500 ft/sec on thick targets (greater than 0.040 inch) for all angles of obliquity. This investigation introduced several new parameters of the fuze design which were evaluated by test. Further evaluation of M47 detonators was not undertaken because the M57A1 appeared to behave in the same manner in the tested environments, and the M57A1 is standard on the present M505A3 fuze. However, because use of the M47 detonator offers more opportunities for introducing delay into the fuze, it should not be eliminated from further consideration in any ensuing fuze efforts.

3.2.12 Investigation on 0.063- and 0.090-inch-Thick Target

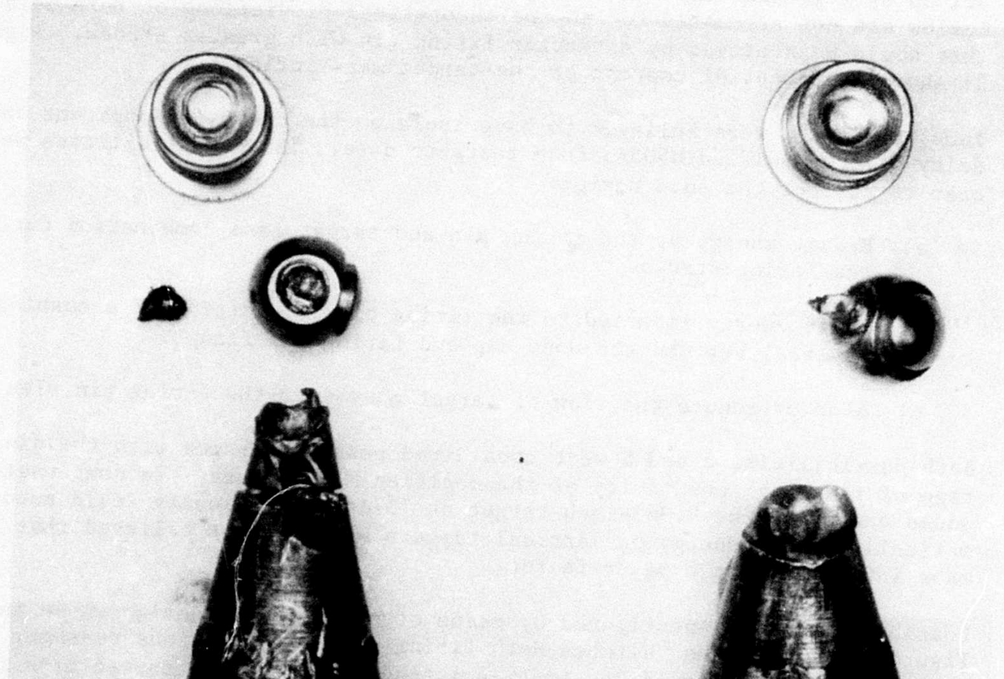
In July a series of tests were conducted to evaluate delay of the modified M505A3 fuze on targets thicker than 0.040 inch. The series was started with vertical impacts at 2500 ft/sec against 0.090- and 0.063-inch thicknesses (Tests 19 and 20). These and subsequent tests were conducted with live rounds. Four rounds were fired in each test. One of the rounds against 0.063-inch-thick did not function. The next test at 75-degree obliquity resulted in no significant fuze delay. The following series of tests were conducted with configuration changes to the firing pin in an attempt to achieve a fuze delay. The shoulder thickness was increased. The pin travel to the detonator was increased and the crushup distance between the nose cap and the pin was increased. None of these changes in the limitations of the modified fuze envelope appeared to introduce delay to the fuze.

An exploratory investigation was begun by testing the modified fuze without firing pins at 75-degree obliquity. Seven out of 10 rounds functioned on impact with the target. Five standard M505A3 fuzes without firing pins and five GAU-7/A fuzes without firing pins were also tested with live rounds at 75-degree obliquity. All of these rounds functioned on impact.

Premature detonation of the booster was suspected, but a test of four rounds with only boosters (Test 39) resulted in duds. In Test 40 a brass firing pin with a thick shoulder was tested in a GAU-7/A fuze. No delay was observed in two of the five rounds.

3.2.13 Target Mass in the Fuze Cavity

Soft recovery tests were conducted to determine the cause of detonator initiation when the fuzes had no firing pins. Standard and modified M505A3 fuzes were assembled with dummy detonators. The standard fuze had no firing pin, but the modified fuze had a firing pin. Figure 20 is a photograph of both fuzes after soft recovery following impact on a 0.063-inch target at 75-degree



Mod. 505A3
with dummy det.
& brass firing pin
.017 shoulder

Std. M505A3
with dummy det.
& no firing pin.

Figure 20, RECOVERED HARDWARE -- TARGET MASS INFLOW obliquity. In the case of the standard fuze, a slug of target aluminum is shown imbedded in the dummy detonator -- sufficient to cause initiation of the M57A1 detonator. In the case of the modified M505A3 hardware, a similar slug of target aluminum was found on the firing pin which was imbedded into the dummy detonator. This was a significant recovery on the modified fuze because it proved that the firing pin reached the detonator first although driven by a greater mass than originally predicted. In fact, target mass inflow was not accounted for in the theoretical predictions of fuze delay that would be achieved by a heavier firing pin with greater stroke. Figure 21 shows a sequential concept of the target mass inflow.

Thus, the tests were believed to have isolated the cause for apparent non-delay of the modified M505A3 fuze tests to date. Three possibilities were open to correct the fuze design:

a. Reduce energy of the firing pin and target mass combination during the firing stroke.

b. Limit energy imparted to the firing pin by addition of a cushioning material between the nose cap and firing pin flange.

c. Stop or reduce the flow of target mass into the firing pin sleeve.

Both possibilities a and b were considered passive changes with the disadvantage of reducing sensitivity of the modified M505A3 fuze. To compensate for added energy on the 0.063-inch target at 75-degree obliquity would automatically reduce energy on vertical targets where it was believed that target mass inflow was not a major factor.

Possibility c was investigated by means of a firing pin design shown in Figure 22, dubbed the "Witches Hat" firing pin -- for obvious reasons. The upper portion of this firing pin was intended to restrict target mass inflow after separation of the firing pin shank. Several tests were conducted with the design resulting in an overall "good delay" score of approximately 50 percent on 0.063-inch targets at 75-degree obliquity. Comparing these results with the previous score of almost 100 percent superquick action, continuation of development effort for a design that would improve the "witches hat" firing pin seemed worthwhile. Time remaining in the contract, however, was insufficient to allow further engineering investigation. It was decided that target limitations should be determined during final tests using the original 0.017-inch-thick brass firing pin flange. Further effort toward a firing pin protector design would be accomplished only on a non-interferring basis. On this basis some work was accomplished, the results of which are discussed in paragraph 3.2.15.

3.2.14 Target Limitations and Final Tests

As noted above, it was decided to complete final tests without further design changes to achieve penetration of the 0.063-inch target at 75-degree obliquity. Thus, final tests and deliverable hardware consisted of a brass firing pin

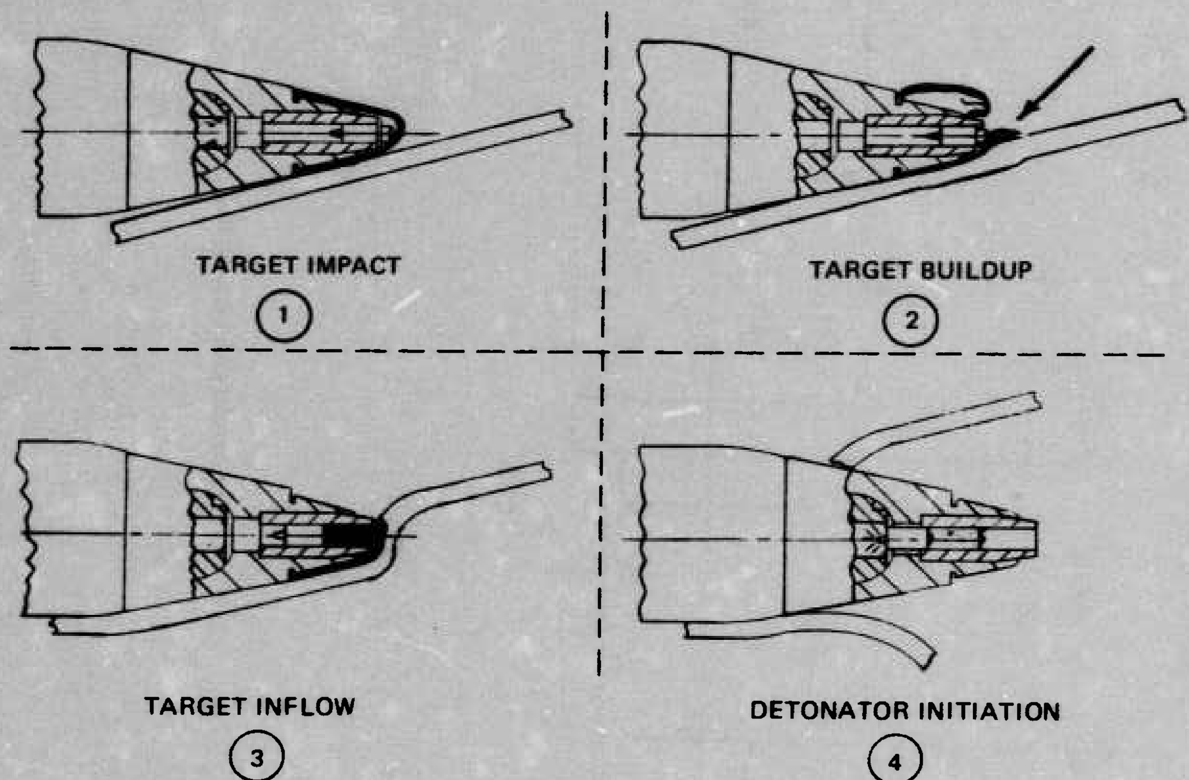


Figure 21. TARGET MASS INFLOW

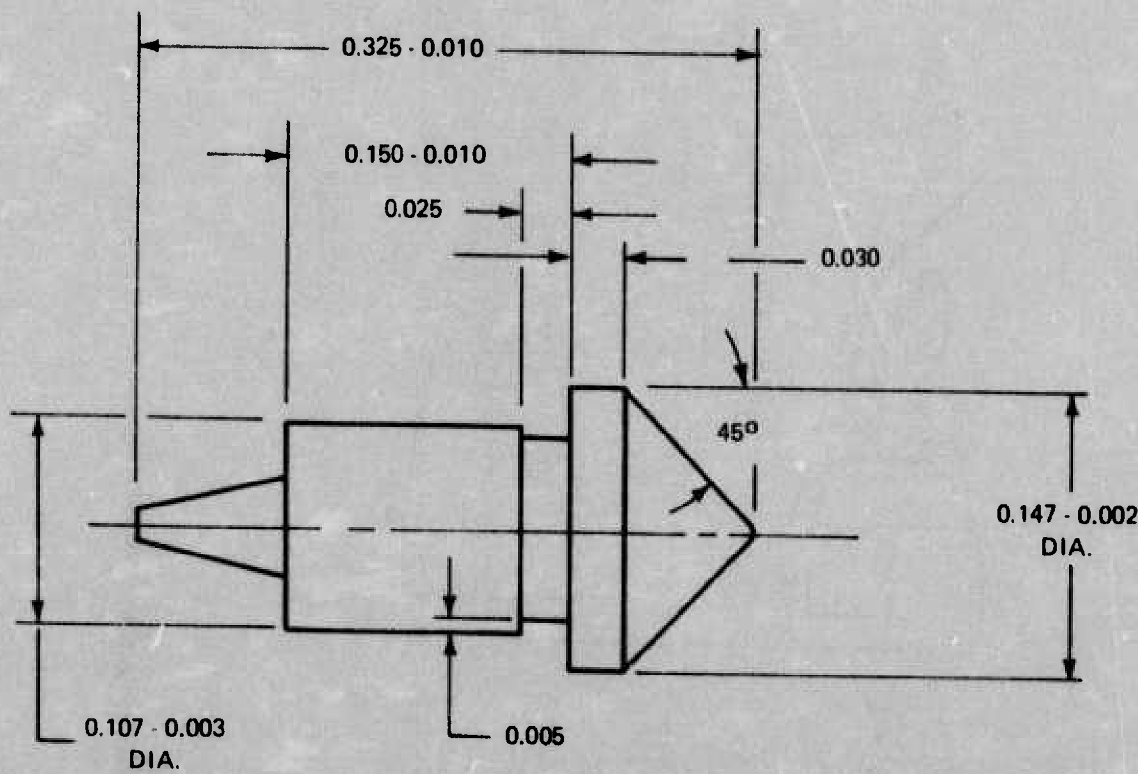


Figure 22. WITCHES HAT FIRING PIN

with a 0.017-inch-thick shoulder as originally designed and shown in Figure 23. Tests 64 through 73 were final tests conducted to determine the impact velocity limitation against the 0.040-inch target and the obliquity limitations against 0.063- and 0.090- inch aluminum targets. These tests utilized hardware originally scheduled for environmental tests and also represented rounds to be fired as quality control or deliverable fuzes. Because the fuze design was the same by analogy as the standard M505A3 fuze, environmental extremes were of no scientific value. Further, because all hardware was of the same fabrication group, elimination of repetitive tests provided the opportunity to obtain maximum information on the design with minimum expenditure of rounds.

During the final tests conducted in the latter part of August 1974, the following conclusions relative to recommended target condition restrictions were reached:

a. At muzzle velocity 2500 ft/sec and target 0.063-inch thickness obliquity angle should not exceed 55 degrees to achieve a minimum delay function.

b. At target thickness of 0.040-inch and vertical impact delay function will be achieved provided muzzle velocity does not go below 1800 ft/sec.

c. At muzzle velocity 2500 ft/sec and target thickness of 0.090-inch an obliquity angle of 0 to 20 degrees is recommended to achieve fuze delay.

d. The following functioning delay distances on vertical targets were measured using a muzzle velocity of 2500 ft/sec.

Target Thickness (inch)	Approx Delay Distance (inch)
0.040	8 to 12
0.063	6 to 8
0.090	2

In the above, muzzle velocities quoted are based on measurement during the first 35 feet of travel after muzzle exit with target impact occurring 151 feet from the muzzle.

3.2.15 Results of Special Test to Restrict Target Mass Inflow

In addition to the final tests discussed in the previous section, a secondary effort continued to design a steel cap which would allow the brass pin to perform its delay function in spite of the intrusion of target mass into the fuze cavity during low graze targets.

This effort resulted in design and fabrication of eight steel, truncated cone-shaped protector caps for trial tests on 21 August 1974. The protector

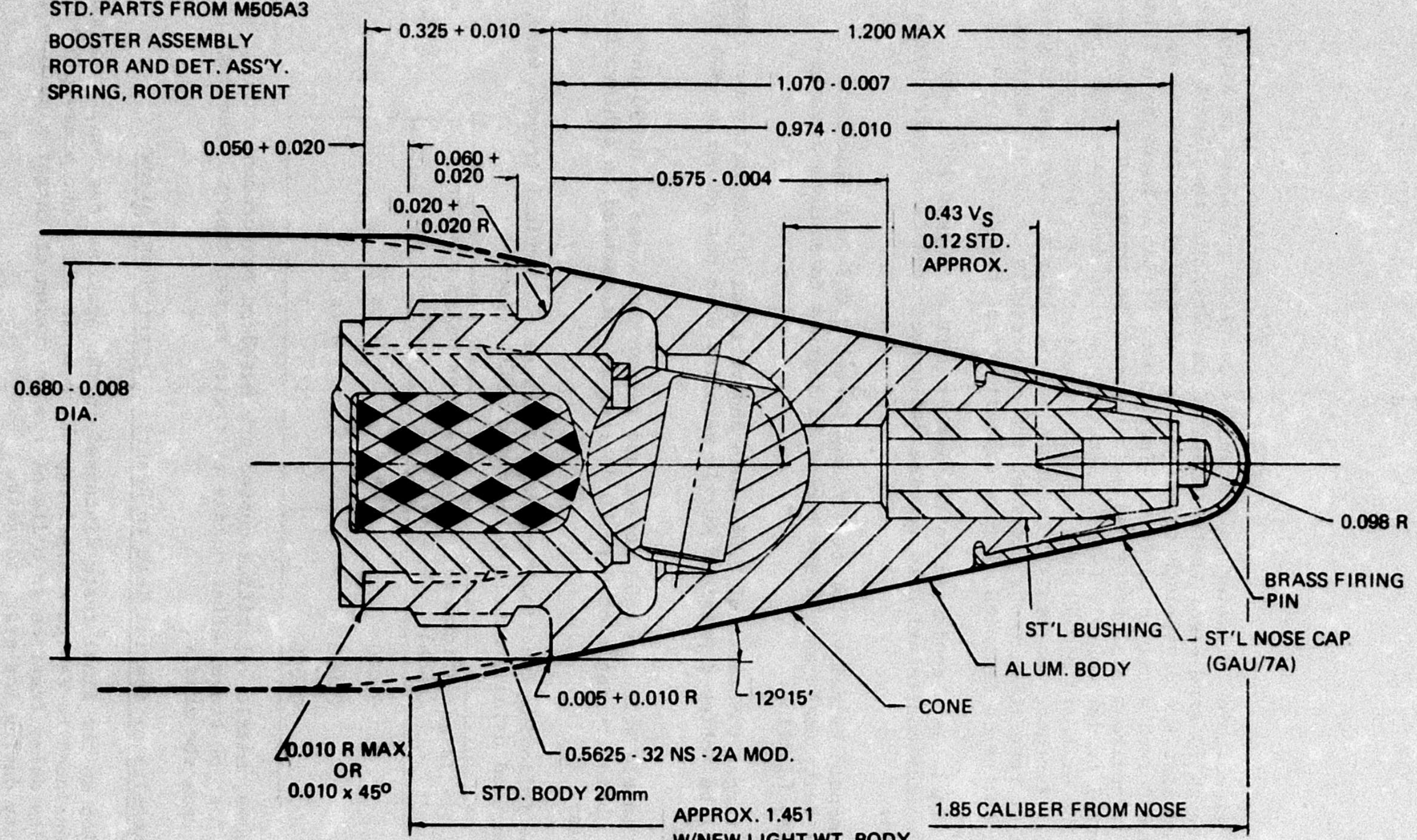


Figure 23. MODIFIED M505A3 FUZE WITH DELAY FUNCTION

cap shown installed in Figure 24 is a steel device that was designed to fit snugly over the forward end of the firing pin sleeve. The nub on the firing pin was reduced in diameter to accommodate the protector cap, and protruded slightly beyond the forward surface of the cap. The cap is shown in a photograph of a cutaway model in Figure 25.

The purpose of the cap is to hold the firing pin in position on low graze targets and to restrict target mass inflow into the firing pin sleeve by virtue of the reduced diameter central hole.

Five steel protector caps were assembled in modified M505A3 fuzes. Three were fired in Test 75 with a muzzle velocity of 2500 ft/sec against 0.063-inch-thick targets set for 75-degree obliquity. All three produced excellent delay noted by the "banana peel" effect on the target and is shown as Shot 8 in Figure 19. One protector cap design was fired in Test 76 against a 0.090-inch-thick target at 75-degree obliquity. This round resulted in a "partial delay" -- obviously better than without the cap. (Compare with Tests 7, 17 and 70.) The final round was fired on a 0.063-inch-thick vertical target resulting in a function delay of approximately 8 inches. Both the 75-degree and vertical 0.063-inch target functions are shown in the enlarged film strip in Figure 26.

In view of the previous failures to achieve satisfactory target results on 0.063-inch targets, 75-degree obliquity, the use of the protector cap in the modified fuze was a distinct improvement. Proper delay achieved on a vertical 0.063-inch target was also an encouraging result because it indicated that the change in sensitivity to achieve delay at high obliquity angles apparently did not penalize fuze delay at vertical impacts.

Generally, the tests with a steel protector cap indicated that the modified M505A3 fuze can produce satisfactory function delay on both high oblique and vertical targets of 0.063-inch thickness. Function against thin (0.040-inch) targets is also expected to be good because the delay with and without the protector cap against 0.063-inch target is comparable (Tests 77 and 65). Fuze delay against 0.040- and 0.063-inch targets is also comparable (Tests 64 and 65).

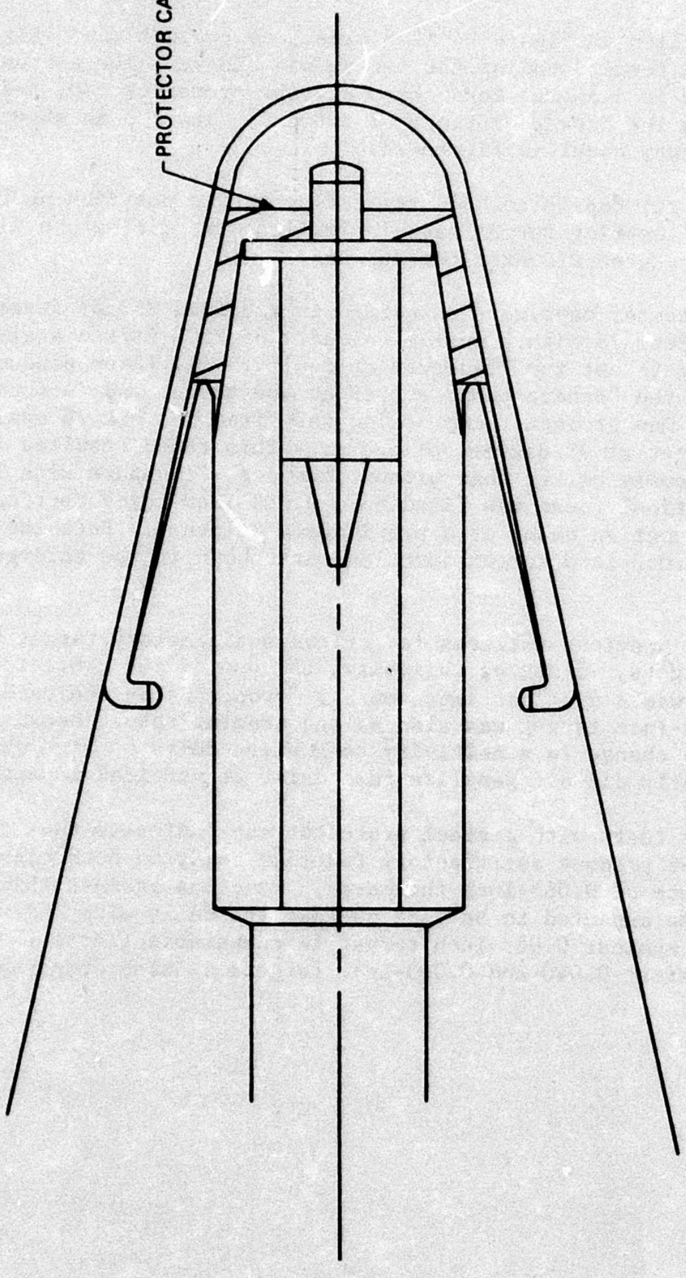
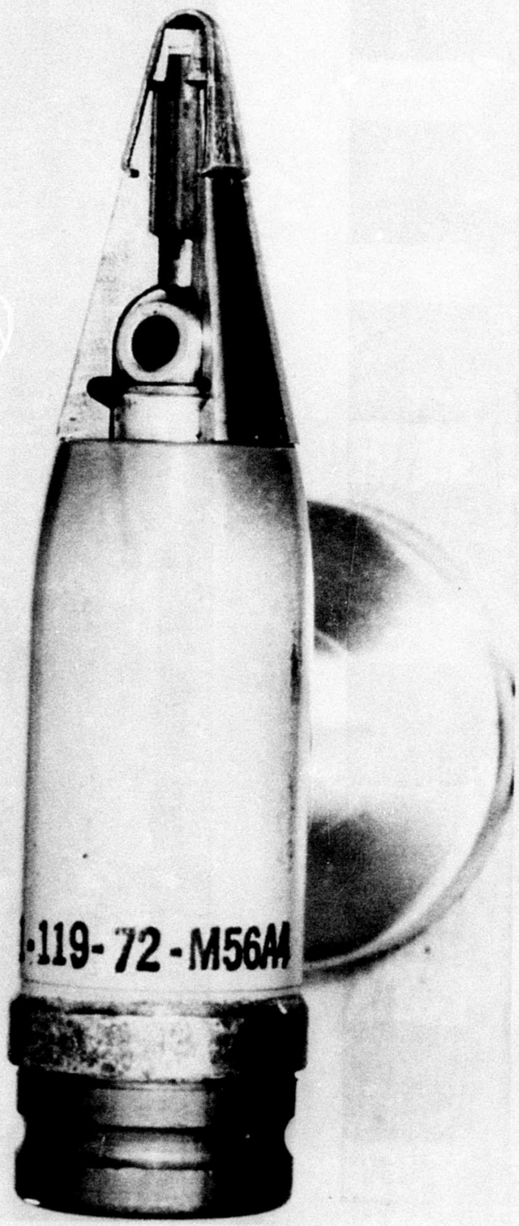


Figure 24. PROTECTOR CAP



Mod. M505A3

Figure 25. CUTAWAY MODEL WITH STEEL PROTECTOR CAP

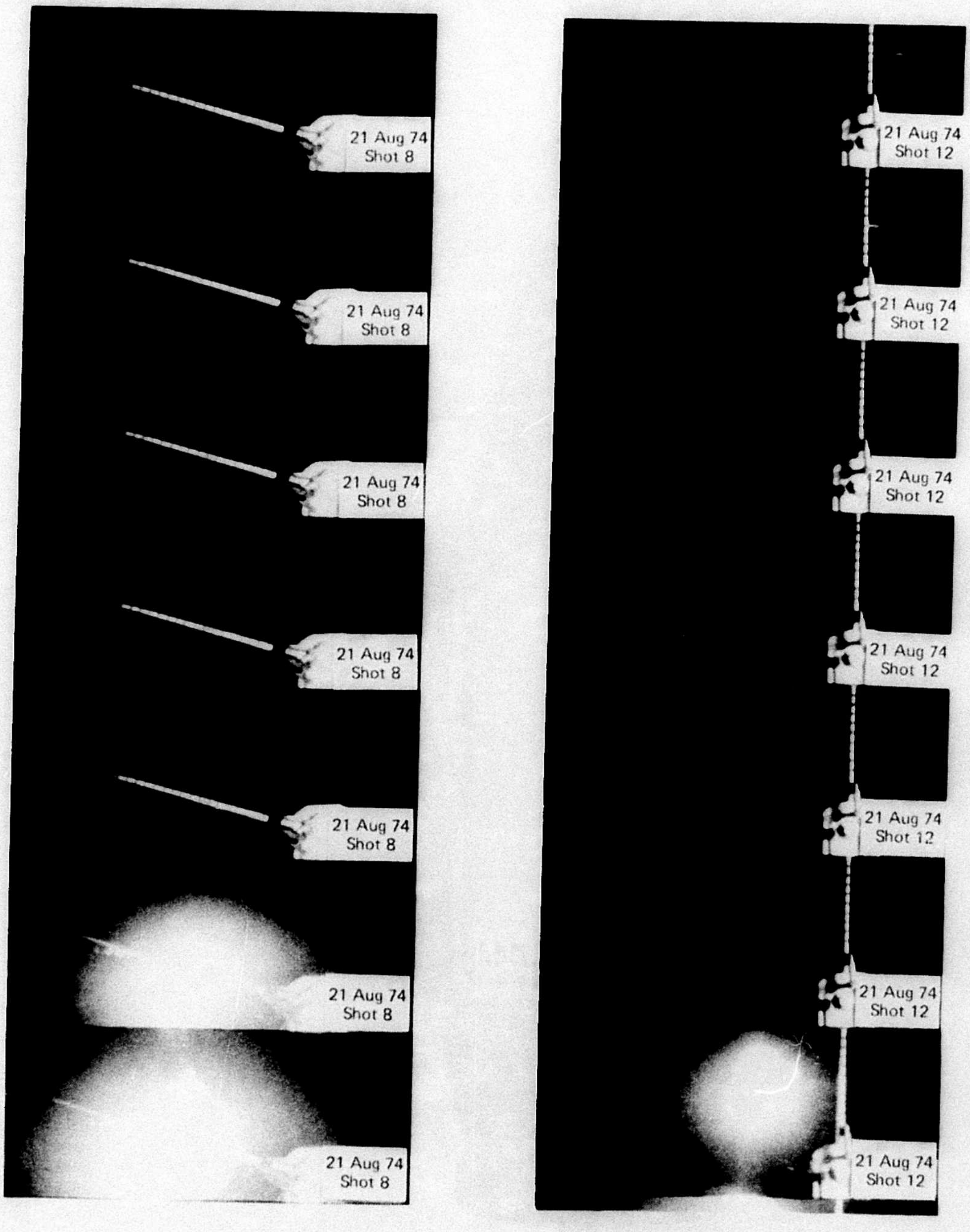


Figure 26, FILM SEQUENCE -- MODIFIED M505A3 WITH PROTECTOR CAP

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The following conclusions were reached as a result of the tests conducted under the contract.

1. M505A3 fuze can be modified to provide penetration and detonation behind target.

   a. Penetration can be achieved on 0.063-inch targets from 0 to 55 degree obliquity at 2500 ft/sec.

   b. Sensitivity can be achieved on 0.040-inch targets at 0-degree obliquity at velocity above 1800 ft/sec.

   c. Penetration can be achieved on 0.090-inch targets from 0 to 20-degree obliquity.

2. Penetration performance predictions agree reasonably well with test data.

   a. Fuze with a brass firing pin impacting vertically against an 0.040-inch aluminum target demonstrated a delay of 3-1/2 to 4 inches compared to a prediction of 6.7 inches.

   b. Fuze with a brass firing pin impacting at 80-degree obliquity against an 0.040-inch aluminum target demonstrated a delay of 3 to 4 inches compared with prediction of 3.6 inches.

   c. Fuze with an aluminum firing pin impacting vertically against an 0.040-inch aluminum target demonstrated a delay of 6 to 13 inches compared to a prediction of 5.4 inches.

3. At high angles of obliquity, target material travels down sleeve with firing pin and effects delay and subsequent penetration. Improvements in penetration performance can be achieved by eliminating or reducing the effects of this phenomena.

4. Detonator safety of the modified M505A3 fuze with zirconium booster is comparable to the standard M505A3 fuze.

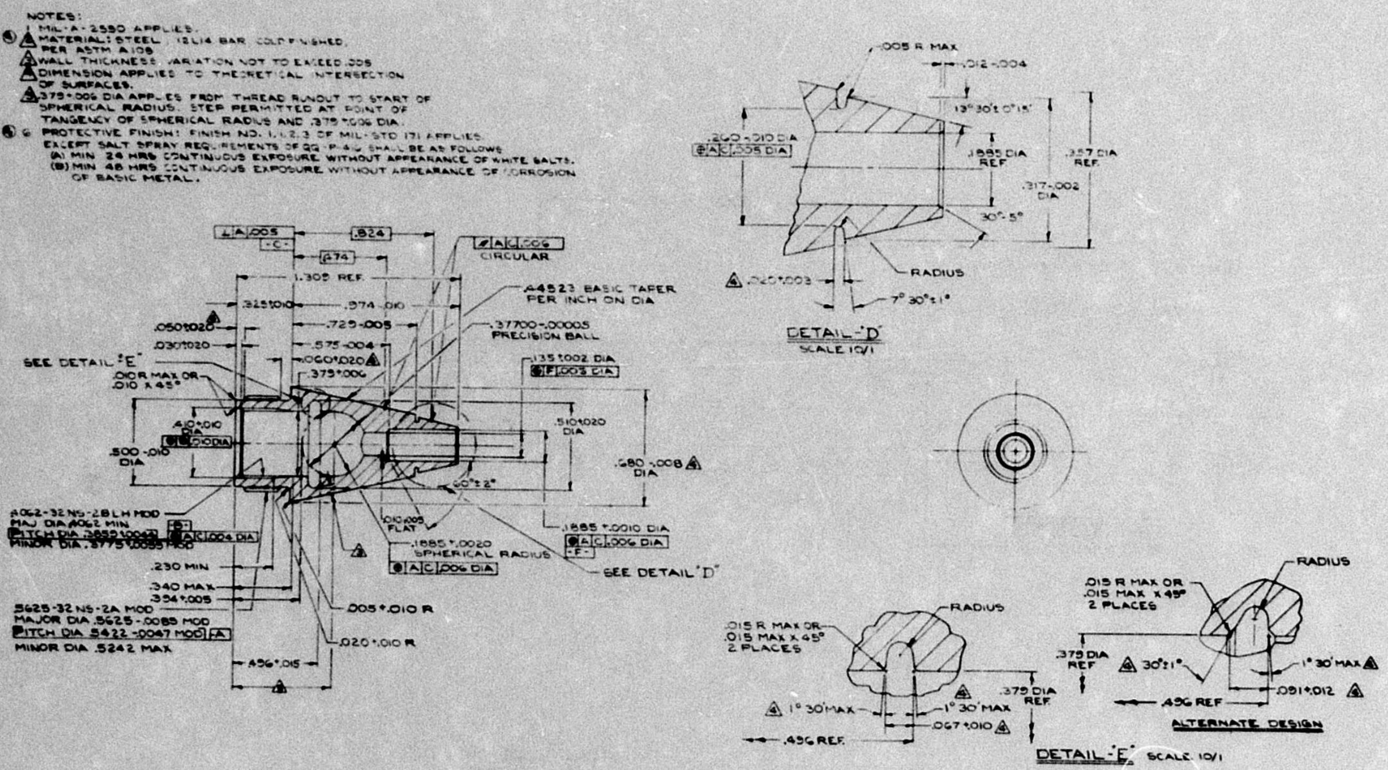
4.2 RECOMMENDATIONS

It is recommended that further work on a modified M505A3 fuze with delay function should proceed because the feasibility of penetrating aluminum targets was established. Such a program would be low risk because many standard M505A3 fuze parts are used in the modified version of the fuze.

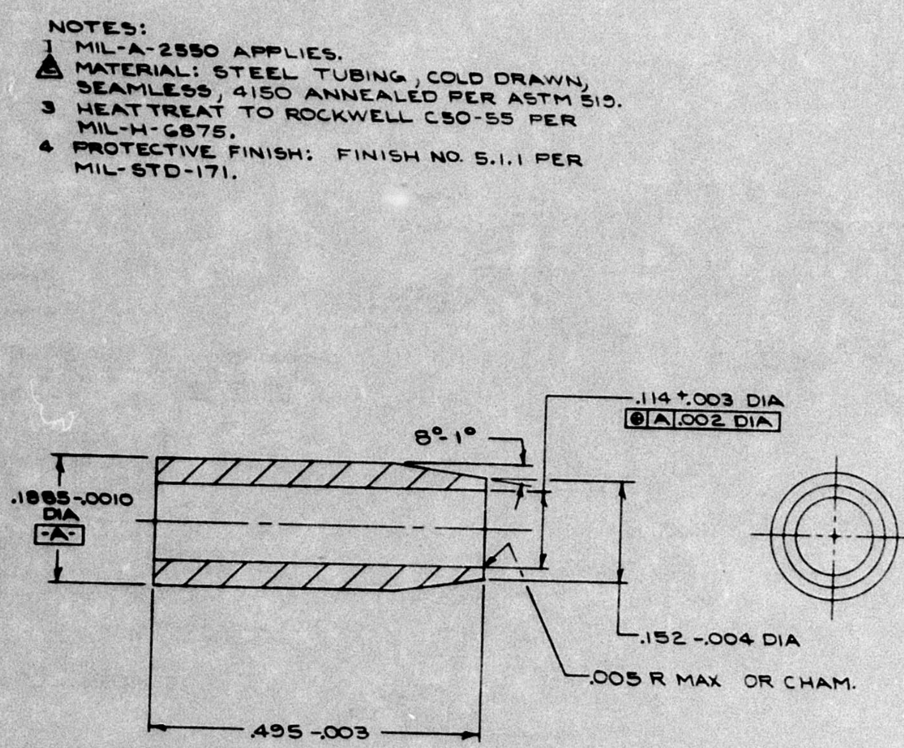
It is further suggested that an investigation of techniques to prevent target mass inflow into the fuze should be conducted. Target failure mechanisms and damage assessment as related to fuze penetration should also be evaluated.

APPENDIX A

DRAWINGS SHOWING
DETAILS OF THE NEW PARTS OF THE MODIFIED
M505A3 FUZE

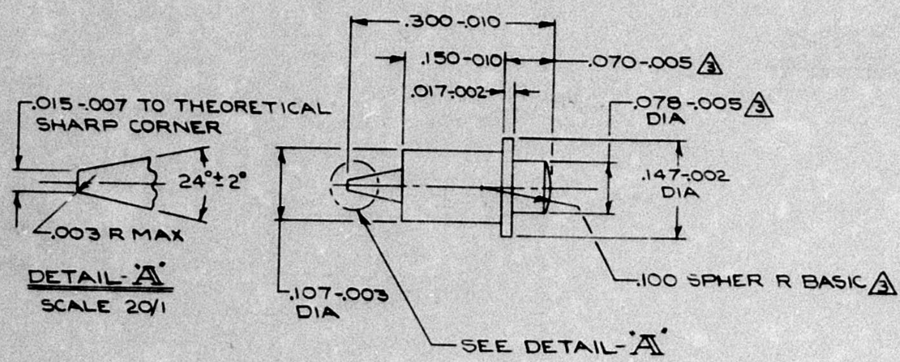

NOTES:
1 MIL-A-2550 APPLIES.
2 MATERIAL: STEEL, 12L14 BAR, COLD FINISHED, PER ASTM A108
3 WALL THICKNESS VARIATION NOT TO EXCEED .005
4 DIMENSION APPLIES TO THEORETICAL INTERSECTION OF SURFACES.
5 .379 ±.006 DIA APPLIES FROM THREAD RUNOUT TO START OF SPHERICAL RADIUS. STEP PERMITTED AT POINT OF TANGENCY OF SPHERICAL RADIUS AND .379 ±.006 DIA.
6 PROTECTIVE FINISH: FINISH NO. 1.1.2.3 OF MIL-STD 171 APPLIES. EXCEPT SALT SPRAY REQUIREMENTS OF QQ-P-416 SHALL BE AS FOLLOWS
(A) MIN 24 HRS CONTINUOUS EXPOSURE WITHOUT APPEARANCE OF WHITE SALTS.
(B) MIN 48 HRS CONTINUOUS EXPOSURE WITHOUT APPEARANCE OF CORROSION OF BASIC METAL.
SEE DETAIL "E"
SEE DETAIL "D"
.44523 BASIC TAPER PER INCH ON DIA
.37700-.00005 PRECISION BALL
SPHERICAL RADIUS
DETAIL "D"
SCALE 10/1
RADIUS
DETAIL "E" SCALE 10/1
ALTERNATE DESIGN

Body Fuze

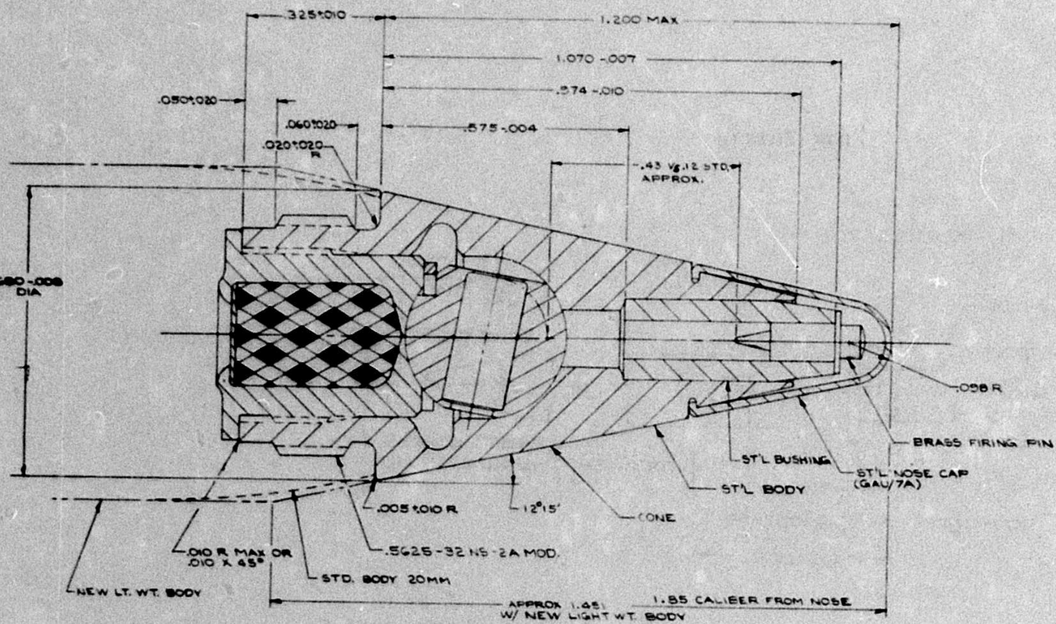


Fuze Bushing

NOTES:
1 MIL-A-2550 APPLIES.
2 MATERIAL: BRASS, FREE CUTTING QUALITY, ROD, CA ALLOY 360, PER QQ-B-626.
3 PROFILE, INCLUDING CUT-OFF NIB IF PRESENT, MUST FALL WITHIN ZONE GENERATED BY DIMENSIONS SHOWN.
4 BREAK ALL SHARP CORNERS AND EDGES .010 MAX UNLESS OTHERWISE NOTED. ALL DIAMETERS ON COMMON AXIS MUST BE WITHIN TOTAL RUNOUT OF .002 T.I.R.
5 DO NOT SUBJECT TO CAUSTIC OR OTHER CHEMICAL TREATMENT.



Firing Pin

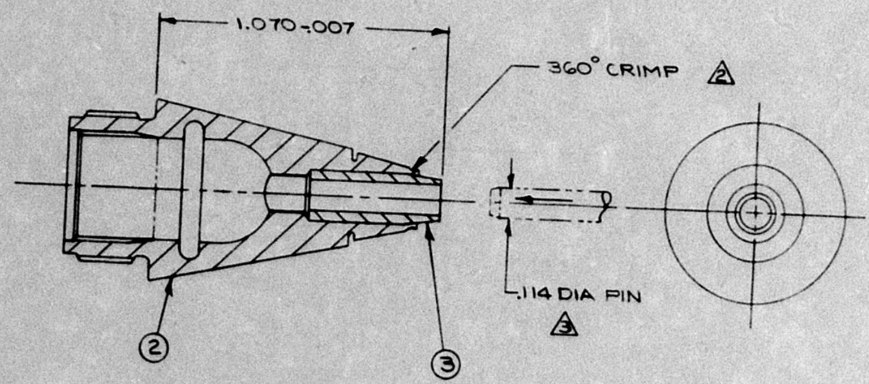


STD. PARTS FROM M 505A3
BOOSTER ASSEMBLY
ROTOR & DET. ASS'Y
SPRING, ROTOR DETENT

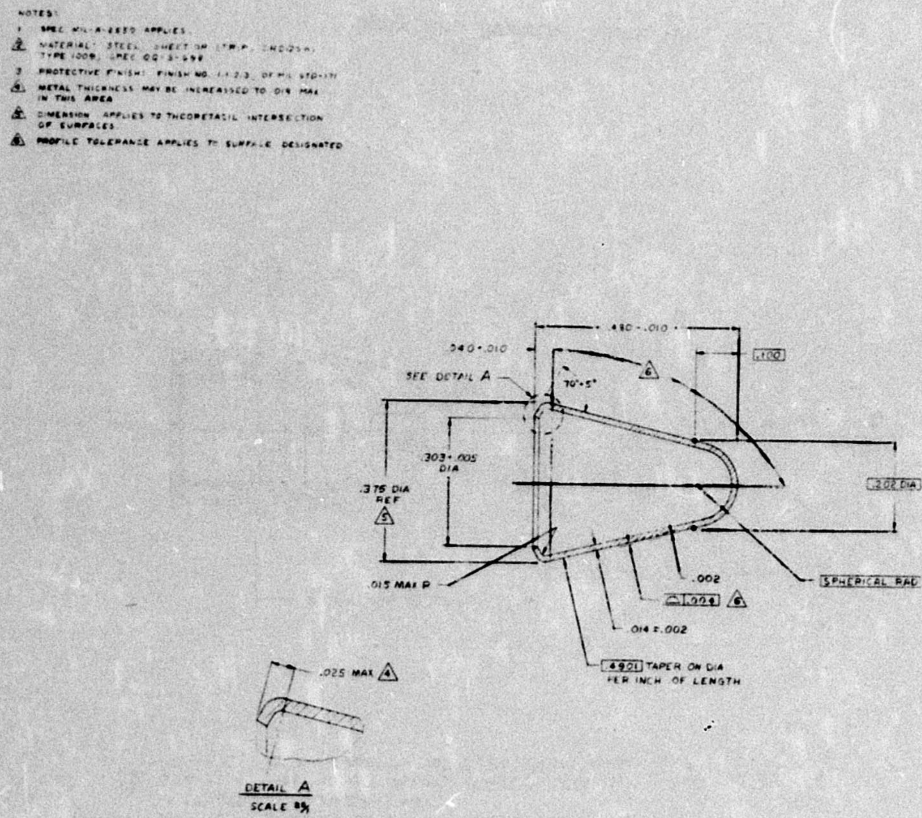
Mod M 505A3

NOTES:

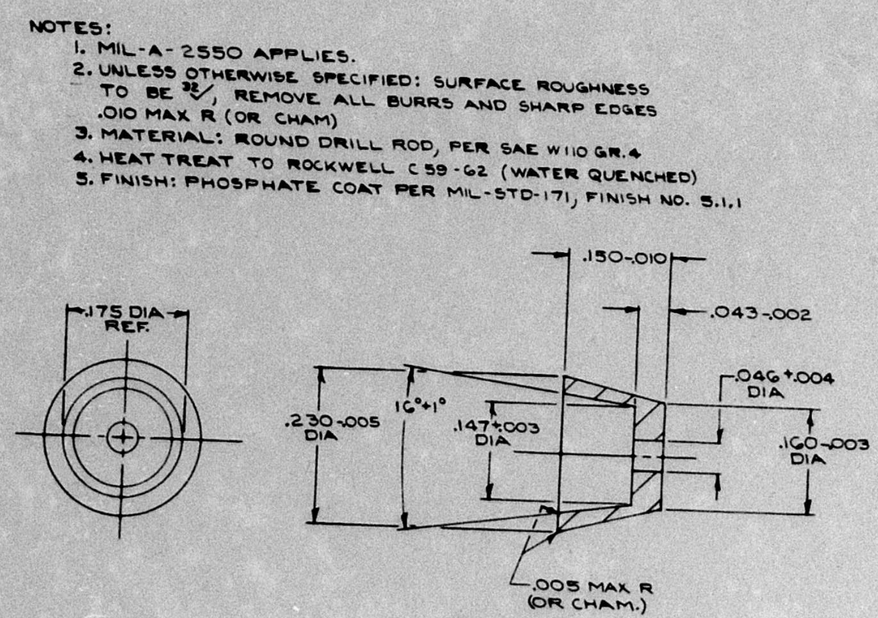
1. MIL-A-2550 APPLIES.
2. AFTER CRIMPING BUSHING MUST WITHSTAND A 10-15 LBS STATIC LOAD PULL OUT TEST WITHOUT MOVEMENT.
3. .114 DIA PIN MUST PASS THROUGH BUSHING INTO FUZE BODY CAVITY AFTER CRIMPING.



Body and Bushing Assembly


NOTES:
1 SPEC MIL-A-2550 APPLIES.
2 MATERIAL: STEEL, SHEET OR STRIP,
TYPE 1009, SPEC QQ-S-698
3 PROTECTIVE FINISH: FINISH NO. 1.1.2.3 OF MIL STD-171
4 METAL THICKNESS MAY BE INCREASSED TO .019 MAX
IN THIS AREA
5 DIMENSION APPLIES TO THEORETICAL INTERSECTION
OF SURFACES
6 PROFILE TOLERANCE APPLIES TO SURFACE DESIGNATED
.040 ±.010
.430 ±.010
.100
SEE DETAIL A
70°±5°
.303 ±.005 DIA
.375 DIA REF
.202 DIA
.015 MAX R
.002
.004
.014 ±.002
SPHERICAL RAD
.4901 TAPER ON DIA PER INCH OF LENGTH
.025 MAX
DETAIL A
SCALE 8/1

Nose Cap



Firing Pin Cap

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APPENDIX B

DERIVATION OF EQUATION FOR PENETRATION DISTANCE

The basic momentum equation is:

$$m_1 V_1 = m_2 V_2 \quad \text{Also}$$

$$V_1 = \frac{m_2 V_2}{m_1} \quad \text{and}$$

$$V_2 = \frac{m_1 V_1}{m_2} \quad \text{solving for } \Delta V$$

$$\Delta V = V_1 - V_2 = \frac{m_2 V_2}{m_1} - \frac{m_1 V_1}{m_2}$$

where

m_1 = mass before impact

m_2 = mass after impact, and

V_1 = velocity before impact

V_2 = velocity after impact

Where $m_2 = m_1 + \Delta m$,

m = target mass intercepted by the firing pin. Then

$$V = \frac{m_1 V_2 + \Delta m V_2}{m_1} - \frac{m_1 V_1}{m_1 + \Delta m} \quad \text{substituting}$$

$$\frac{m_1 V_1}{m_2} = V_2 \quad \text{we have}$$

$$\Delta V = \frac{m_2 m_1 V_1}{m_1 m_2} - \frac{m_1 V_1}{m_2} = V_1 - \frac{m_1 V_1}{m_2} \quad \text{or}$$

$$\Delta V = V_1 \left(1 - \frac{m_1}{m_2}\right) \quad \text{or}$$

$$V_1 = \Delta V \left(\frac{1}{1 - \frac{m_1}{m_2}}\right)$$

The basic velocity equations state:

$$V_1 = \frac{dS}{dt} \quad \text{and} \quad \Delta V = \frac{d\,\Delta S}{dt} \quad \text{where}$$

dt is a constant for both the shell travel and pin travel. The resulting equation is:

$$S = \Delta S \left(\frac{1}{1 - \frac{m_1}{m_2}}\right) = \frac{\Delta S}{1 - \frac{m_1}{m_2}}$$

where

S = Shell travel and

ΔS = Pin travel

INITIAL DISTRIBUTION

Hq USAF/RDQRM	2
Hq USAF/SAMI	1
Hq USAF/XOXFCM	1
Ha USAF/XOOWA	2
AFSC/IGFG	1
AFSC/SDWM	1
ASD/ENYS	1
TAC/DRA	1
WRAMA/MMEBL	1
AFWL/LR	1
AUL/AUL-LSE-70-239	1
Comd Ofcr, Frankford Ars/Lib	1
Comd Ofcr, Picatinny Ars SARPA-TS	1
USN Wpns Lab	1
USN Wpns Ctr/Code 533	2
Nav Air Sys Comd/Code AIR-5323	1
Battelle Memorial Inst/Rpts Lib	1
Rand Corp/Lib-D	1
Harry Diamond Labs/AMXDP-TC	1
DDC/TC	2
USAFTFWC/TA	1
Ogden ALC/MMNOP	2
Comdr, Picatinny Ars/SARPA-FR-S-A	1
TAWC/TRADOCLO	1
AFATL/DL	1
AFATL/DLB	1
AFATL/DLY	1
AFATL/DLOU	1
SARA-FA MDAD	1
AFATL/DLOSL	2
AFATL/DLYV	1
AFATL/DLDL	1
AFATL/DLDA	1
AFATL/DLDT	1
ADTC/WE	1
AFATL/DLDG	20
SMUPA-MDC-A	1
Avco Systems Div	2
AFIS/INTA	1
ASD/ENYEHM	1

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