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FUZE BAFFLE DELAY CONCEPT EVALUATION

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AUGUST 1976

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The technical feasibility of a baffle delay system for an M505A3 type fuze has been studied. Baffle delay design concepts were screened by means of quasi-dynamic impact simulating experiments. Simplified designs were prepared for 20 mm gun fired tests. Both the quasi-dynamic tests and the gun-fired tests indicate the technical feasibility of the baffle delay fuze concept for 20 to 30 mm ammunition.

PREFACE

This report documents work performed during the period from June 1975 through August 1976 by Shock Hydrodynamics Division, Whittaker Corporation, 4710-16 Vineland Avenue, North Hollywood, California 91602, under contract F08635-75-C-0155 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida 32542. Mr. John J. Howanick (DLDG) managed the program for the Armament Laboratory.

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

GERALD P. D'ARCY, Colonel, USAF
Chief, Guns, Rockets and Explosives Division

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SECTION I

INTRODUCTION

It has long been known from both foreign (References 1 and 2) and American (Reference 3) studies as far back as 1944 that an improvement in the lethality of a contact fuzed detonating HEI projectile occurs when it detonates inside an aircraft target rather than in contact with the exterior surface.

The present M505A3 fuze is a contact fuze which can initiate the 20 mm or 30 mm HEI projectile. Its required sensitivity range is such that it should function reliably on targets as thin as 0.04 inch aluminum alloy. It may also encounter target thicknesses which are substantially greater, ranging through the equivalent of 0.25 inch to 0.50 inch of aluminum as well as other target materials such as steel and titanium.

The objective of the present program was to determine the feasibility of introducing a non-pyrotechnic baffle delay system into an M505 type fuze as a means for providing the additional delay necessary to permit the desired increase in projectile penetration prior to detonation.

The vehicles to be used for these studies were the basic M505A3 fuze design, as lengthened for the 25 mm GAU-7 application and the 20 mm M56 series projectile, although the baffle delay technique is widely applicable to many other calibers as well.

The baffle design studies were planned to be carried out in simulated (quasi-dynamic) impact experiments, and it was planned that the final fuze designs were to be fired from a 20 mm gun attached to live HEI projectiles in order to determine their dynamic performance.

References:

1. Unterluss 44, "Ammunition for Automatic Weapons," by Drs. Schuler and Grasse, 1944, Aberdeen Proving Ground Library.

2. Rheinmetall-Borsig, Sommerda Report, "Ballistics and Ammunition for Automatic Cannons," Published by Rheinmetall-Borsig, Sommerda 1944, Aberdeen Proving Ground Library.

3. BRL Memorandum Report No. 436, "Report on Tests of the Effects of Blast from Bare and Cased Charges on Aircraft," by James N. Sarmousakis, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., 1946.

SECTION II

PERFORMANCE OF THE M505A3 FUZE

1. GENERAL

The functioning delay time of the current M505A3 fuze depends upon a number of sequential factors, which include:

(1) The firing pin velocity imparted by the target interaction on impact.

(2) The distance that must be traveled by the firing pin before it reaches the M57A1 detonator in the armed rotor.

(3) The functioning delay time of the M57A1 detonator after the firing pin first touches its surface.

The major contribution to the delay time is expected to arise from factors (1) and (2), although factor (3) is not negligible and is a function of firing pin velocity. It should decrease with increasing firing pin velocity.

Figure 1 displays the relationship between firing pin velocity and firing pin travel distance which determines the delay time contribution from the first two factors. The M505A3 fuze has a firing pin travel distance of about 0.186 inch or 0.0155 feet (paragraph 2, Section IV 2).

The firing pin velocity and therefore the delay time of an M505A3 fuze is definitely dependent upon the thickness of the target and the striking velocity. Shock Hydrodynamics has carried out detailed computer studies of the interaction between the M505A3 fuze components and two thicknesses of aluminum alloy target at two different striking velocities (Reference 4). These studies which cover the first 4 or 5 microseconds of the interaction, clearly indicate the effect of the two parameters of interest. The results of that computer study indicate that for a given target thickness higher striking velocity increases the firing pin velocity. In addition, for a given striking velocity, the thicker target increases the firing pin velocity. The striking velocity range which was studied included 2000 and 4000 ft/sec and the target thickness varied from 0.06 inch to 0.085 inch.

Reference:

4. "Analysis of Dynamic Interactions During the Impact of an M505A3 Fuze" by L. Zernow and J. Reid, Report 3260F, March 1973. Unclassified. Submitted to Frankford Arsenal by Shock Hydrodynamics under Contract DAAA25-72-C-0669.

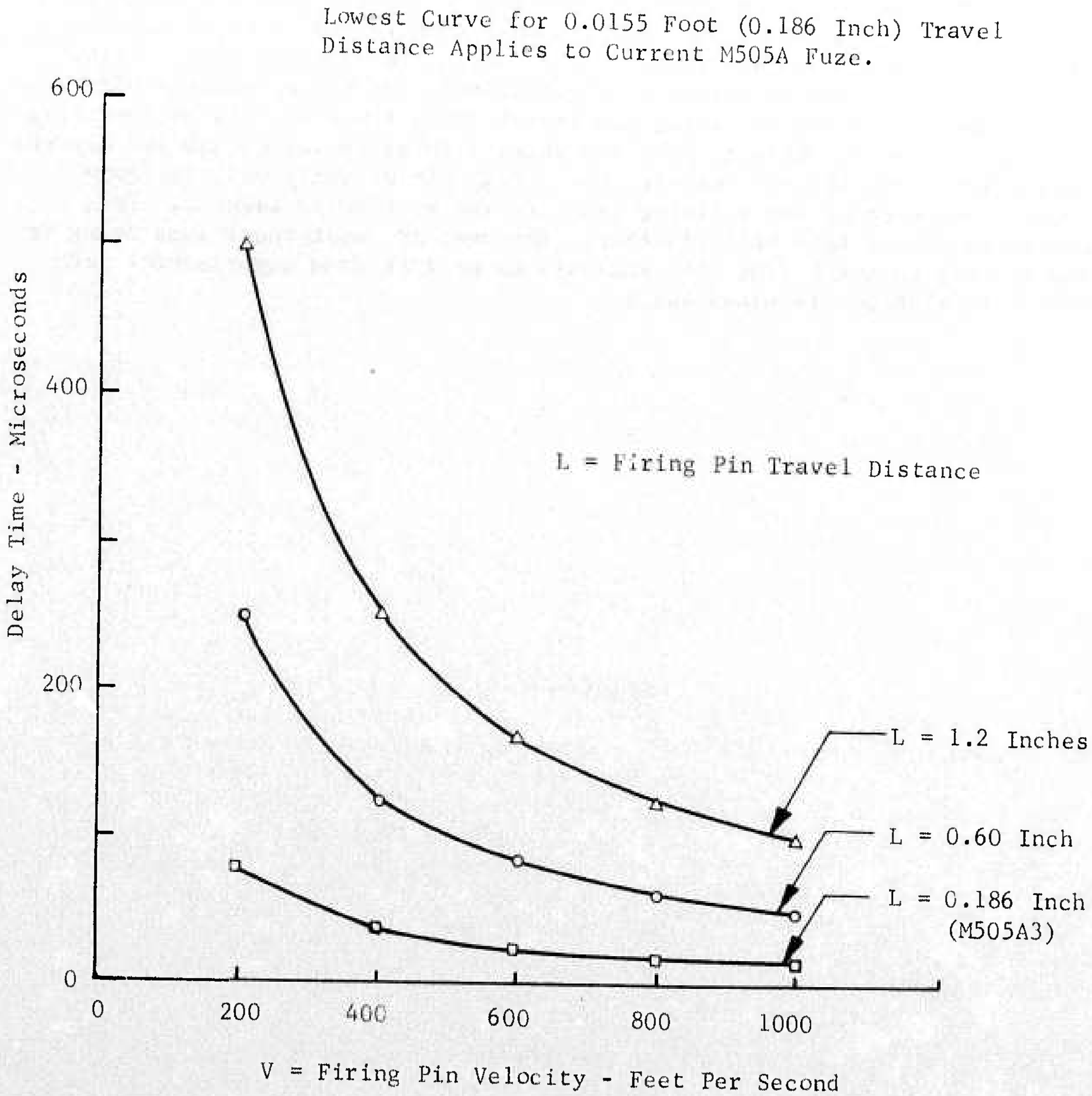


Figure 1. Relation Between Firing Pin Velocity (V), Firing Pin Travel Distance (L) and Firing Pin Travel Delay Time (t) for Various Travel Distances

The nosecap crushup curves shown in Figure 2 are taken from Reference 4 and clearly display the effect of striking velocity. They are of course related to the firing pin velocity.

While a more detailed quantitative discussion will be given later relative to the longest possible delay times attainable with the existing M505A3 fuze, it is useful for the present to note that even at the relatively low projectile striking velocity of 2000 ft/sec against a thin 0.060 inch target, the minimum firing pin velocity that is attained is expected to lie between 350 ft/sec and 650 ft/sec. This firing pin velocity when combined with a firing pin travel distance of 0.0155 feet for the standard M505A3 fuze, corresponds to a range of firing pin travel delay times of ~ 44 microseconds to 24 microseconds. This is much too short a delay to accomplish the desired penetration. For thicker targets, the firing pin velocity will increase further, approaching the striking velocity for very thick targets. This reduces the delay time still further. The need for additional fuze delay is thus clearly apparent from this analysis as well as from experimental data, which will also be discussed later.

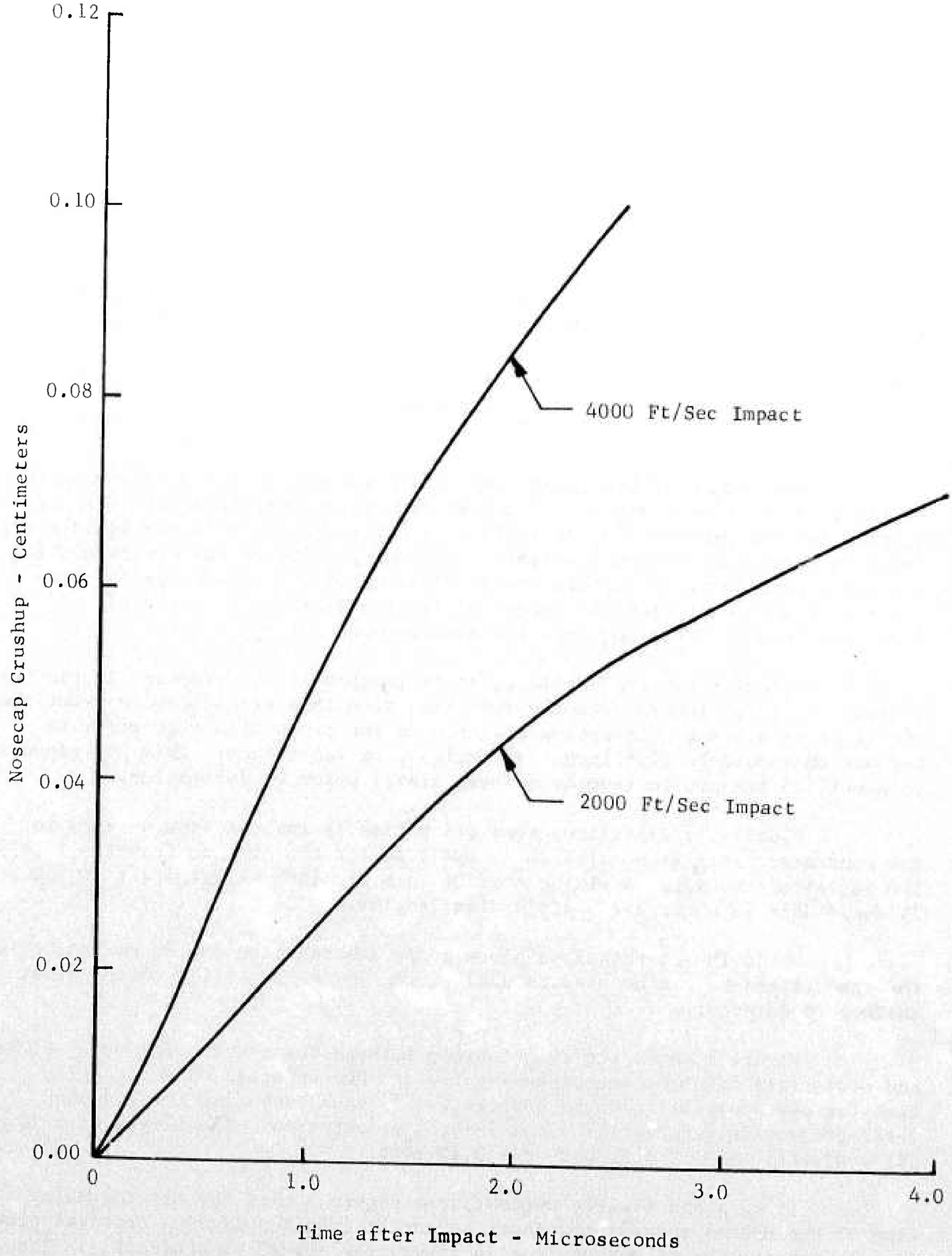


Figure 2. Computation of Nosecap Crushup for M505A3 Fuze Impacting 0.060 Inch Thick 2024-T3 Aluminum Alloy Target at the Two Specified Velocities

SECTION III

RELATIONSHIP BETWEEN DELAY TIME AND PROJECTILE PENETRATION DISTANCE

For a projectile penetrating a thin target at an average velocity V_s, a delay time t_d permits the projectile nose to travel a distance d given by

$$d = V_s t_d$$

For a projectile of length, L, the minimum critical delay time required to permit the full projectile length to penetrate the target is given by

$$(t_d)crit = \frac{L}{V_s}$$

One choice of the delay time, which recognizes the possible variability in delay times, may be defined as the one corresponding to 1-1/2 projectile lengths penetration, or 1-1/2 (t_d) critical. In fact one Eglin specification defines a minimum desirable functioning delay as the one permitting a minimum additional projectile travel distance of 3 inches after the projectile cg has penetrated the target plate at a striking velocity of 2500 ±100 ft/sec. This requires 150 microseconds delay.

Assuming the projectile cg to be roughly at the midpoint in projectile length, i.e., 1.5 inches from the fuze tip, then this specification means that the shortest average penetration distance of the projectile nose prior to detonation should be (1.5 inches +3 inches), or 4.5 inches. This corresponds to about 1.5 projectile lengths of nose travel prior to detonation.

Finally, a 235-microsecond delay time is indicated as desired in the contract. This is a value which would permit the nose to travel ~ 7 inches before detonation after striking an 0.06 inch aluminum alloy target at 2500 ft/sec. This is about 2-1/3 projectile lengths.

While the computations given above are based on the 20 mm projectile, the same procedure can be used to analyze the 30 mm projectile or any other caliber of interest.

Figure 3 shows the relationship between the functioning delay times and projectile velocity corresponding to both the critical value of delay time for one projectile length penetration (3-inch) and also for 1.5 and 2-1/3 projectile lengths (4.5- and 7-inch) penetration. The length of a 20 mm HEI projectile is ~ 3.0 inches or ~ 0.25 foot.

It is again clearly evident from Figure 3 that the natural delay time of the M505A3 fuze is too short to permit even the minimum critical projectile penetration of one projectile length for the 20 mm projectile. The discrepancy is even greater for the 30 mm projectile which is almost 5.50 inches long.

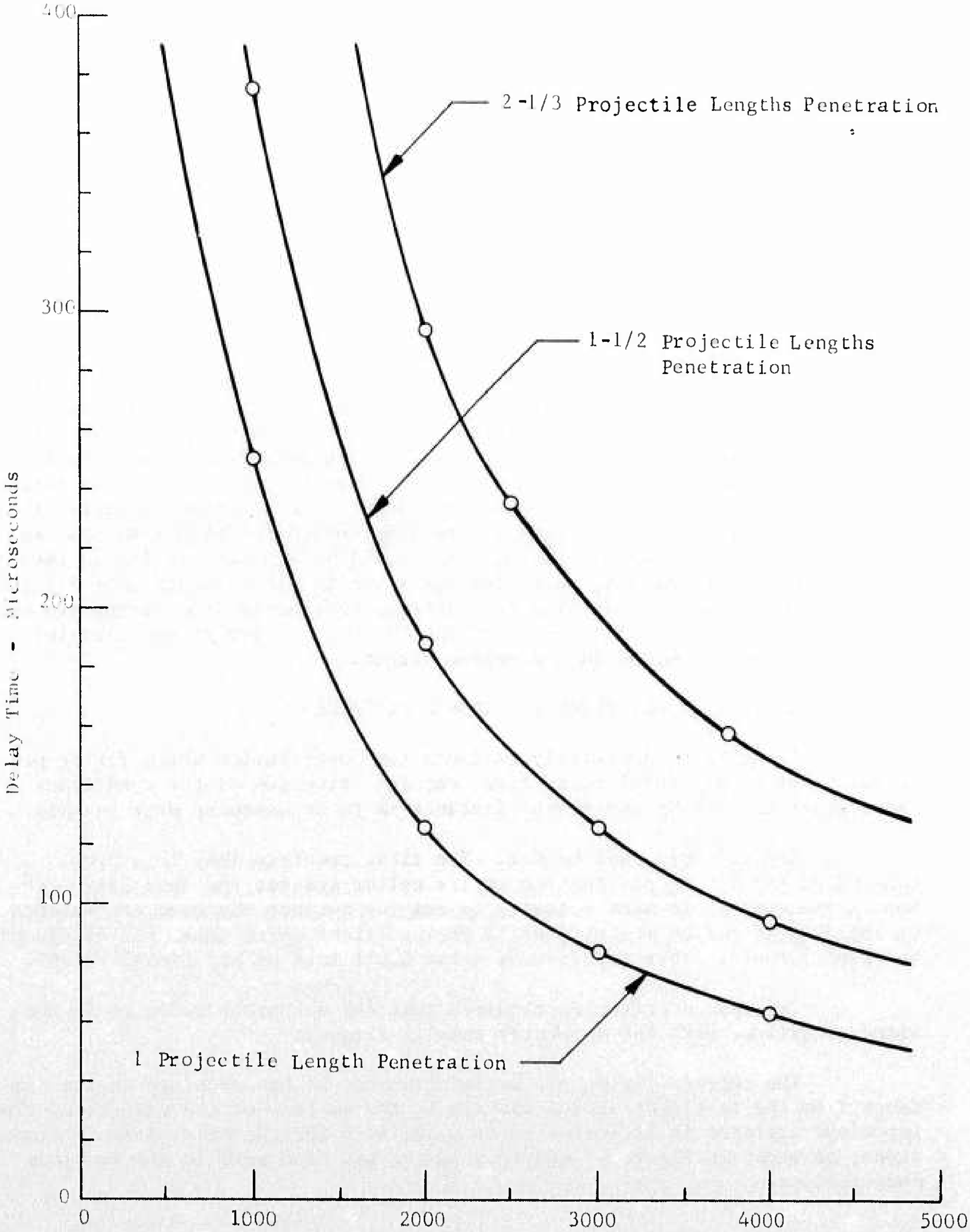


Figure 3. Relationship Between Required Fuze Delay Time and Projectile Velocity for Attaining the Penetration Limits of 1, 1-1/2 and 2-1/3 Projectile Lengths

SECTION IV

ANALYSIS OF SOLUTIONS TO THE DELAY PROBLEM

1. GENERAL

The curves in Figures 1 and 3 clearly indicate that additional delay must be added to the present configuration of the M505A3 fuze to permit delayed functioning according to the penetration requirement of 4.5 inches to 7.0 inches at 2500 ft/sec velocity. Thus, at a striking velocity of 2500 ft/sec, Figure 3 shows that it requires ~150 microseconds delay to permit 4.5 inches of penetration of the nose tip.

The numerical computations previously described, which were carried out by Shock Hydrodynamics (Reference 4), indicate that at 2000 ft/sec striking velocity against a 0.060-inch-thick 2024-T6 aluminum alloy target, the M505A3 firing pin acquires a velocity between 350 ft/sec and 650 ft/sec. Therefore, as previously noted, the expected contribution to fuze delay time caused by the firing pin travel distance in the M505A3 fuze of 0.186 inch, lies between 44 microseconds and 24 microseconds. At 2500 ft/sec striking velocity, the firing pin velocity would be expected to tend toward the higher values, so that the expected firing pin travel delay would be expected to lie in the range of ~ 30 microseconds, which implies a firing pin velocity of ~ 517 ft/sec. This is the estimated delay time contribution obtainable from firing pin travel delay in the current configuration of M505A3 fuze at 2500 ft/sec striking velocity against an 0.060 inch aluminum target.

2. ESTIMATION OF FIRING PIN TRAVEL DISTANCE

In order to accurately estimate the contribution which firing pin travel makes to the total delay time, careful selection of the conditions under which the firing pin travel distance is to be measured must be made.

Two criteria must be met. The first requires that in flight, instead of the firing pin resting on its collar against the fuze body, the top of the firing pin must actually be resting against the nose cap because of the drag forces on the projectile during flight which cause the firing pin to creep forward. This contributes about 0.011 inch of additional travel.

The second criterion requires that the detonator rotor be in the armed condition, with the detonator axially aligned.

The correct firing pin travel distance is now obtained as the distance from the in-flight firing pin tip to the surface of the detonator. This important distance is estimated to be 0.186 inch for the mid-tolerance dimensions, as shown in Figure 4, and this number has been used in the previous computations.

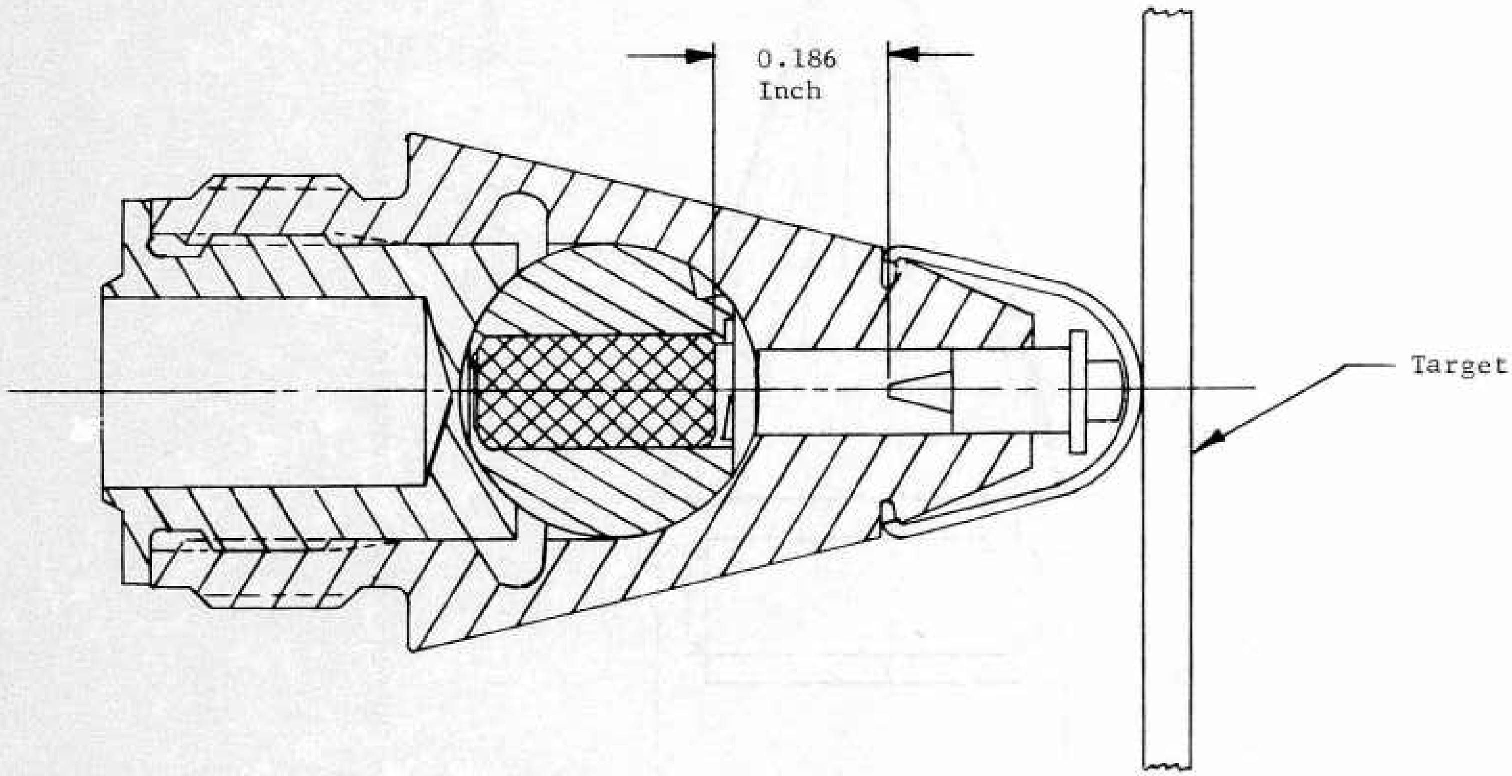


Figure 4. Definition of In-Flight Firing Pin Travel Distance

3. EFFECT OF ALLOWED INCREASE IN FUZE LENGTH

Figure 5 indicates the allowed fuze contours into which the M505A3 fuze could be expanded. The increased length permits an additional 0.550 inch of firing pin path length to be added, since the original M505A3 fuze has a length from shoulder to nose cap tip of 0.865 inch while the elongated version shown in Figure 5 has a length from shoulder to nose cap tip of 1.415 inches maximum. Even this additional firing pin travel distance does not bring the firing pin travel delay into the desired range at 2500 ft/sec impact velocity, since the estimated travel delay would only go to about 118 microseconds if all of the extra travel distance was utilized. If a delay element is introduced in the available added space, it will also have to make up the firing pin travel delay time lost by its use of part of the path length.

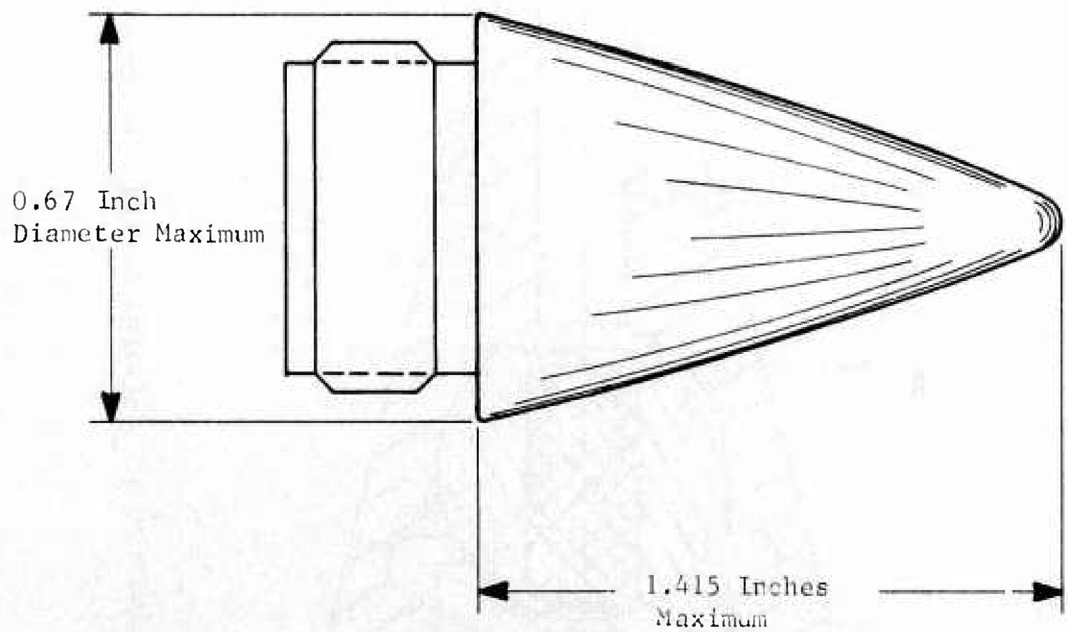


Figure 5. Fuze Dimensions, Guideline Specifications

SECTION V

CONTRIBUTION TO FUZE DELAY DUE TO DETONATOR INITIATION DELAY

The initiation delay of the M57A1 detonator is not presently known under the specified impact conditions. Experimental data obtained by Squier and Zernow (Reference 5) on other detonators and primers indicates an initiation delay which varies substantially with the firing pin velocity.

Thus, when M18 detonators were subjected to the standard ball drop test and their initiation delay measured (Reference 5), the average delay time was observed to be 0.198 millisecond. When M18 detonators were initiated instead by a detonator driven firing pin, the observed average delay time dropped to 0.025 millisecond, which is shorter by a factor of 7.7. The detonator driven firing pins are estimated to have had velocities of the order of 100 ft/sec.

The prior analysis of fuze delay as affected by firing pin travel length has been based on the initial assumption that the detonator initiation delay is negligible. This is known not to be the case. The data on detonator initiation delay given above suggests that under the impact conditions which actually exist, with firing pin velocities around 500 ft/sec, initiation delays in the range of $\sim$ 10 microseconds may be expected from the M57A1 detonator which has a primer composition similar to the M18 as well as M26 primer. While it was not proposed that these detonator delays would be separately measured during the present program, it is clearly a matter of some concern if all the contributions to the total delay are to be understood. A separate study would therefore be useful. There are some novel techniques available for making such measurements.

Reference:

5. J. Squier and L. Zernow, "Short Delay Baffle Detonators for Anti-Aircraft Contact Fuzes," Aberdeen Proving Ground, Md., BRL Report 690, Feb. 1949.

SECTION VI

NET ADDED DELAY REQUIREMENT FOR THE BAFFLE DELAY ELEMENT

The previous discussion indicates that there exists a direct procedure for providing the proper overall average fuze delay time. This involves lengthening the fuze nose to the maximum allowed, and then using the added space to insert a baffle delay element whose average delay time, when added to the firing pin travel delay and the detonator initiation delay, brings the total delay time to the level required to obtain 1, 1-1/2 or 2-1/3 projectile lengths of penetration.

The required delay time of the additional delay element is outlined in the following steps for a 235-microsecond total delay time:

(1) 235 microseconds = total delay required for 2-1/3 projectile lengths of penetration at 2500 ft/sec against 0.06 inch aluminum alloy.

(2) Estimated M57A1 detonator delay, 10 microseconds, assumed same as primer in delay system, e.g., an M26 primer.

(3) 225 microseconds required delay in the sum of firing pin travel time plus baffle delay element time

(4) The maximum allowed lengthening of the fuze nits the addition of 0.550 inch to the existing 0 6 inch path length of the firing pin.

(5) The insertion of a delay element between the firing pin and the unarmed rotor will however dec e enlarged firing pin path length by an amount (L) equa o the length of the delay element in inches. L should be about 0.40 inch in order to retain the firing pin spacing.

(6) The estimated firing pin travel delay time under the specified conditions of impact will therefore be

$$t_{FP} = 30 + \left(\frac{0.550 - L}{12}\right) \frac{10^6}{517} \text{ microseconds}$$

(7) The required additional delay time for the baffle delay element will therefore become

$$t_{DE} = 225 - [t_{FP}] \text{ microseconds}$$

(8) If, for example, L, the length of the delay element, is 0.465 inch, then

$t_{FP} = 30 + 13.7 = 43.7$ microseconds and

$t_{DE} = 225 - 43.7 = 181$ microseconds

required for the baffle delay element.

However, if L = 0.550 inches then

$t_{FP} = 30$ microseconds

$t_{DE} = 225 - 30 = 195$ microseconds

required for the baffle delay element.

Similarly, if the requirement for 1-1/2 projectile lengths of penetration was to be met, the total delay requirement would be 150 microseconds. Deducting 10 microseconds for primer delay would leave 140 microseconds to be made up of firing pin travel delay (t_{FP}) and the baffle delay (t_{DE}).

Again, consideration of the length of the delay element (L) enters the calculation in determining the firing pin travel delay.

If L = 0.465 inch

$t_{FP} = 30 + 13.7 = 43.7$ microseconds

$t_{DE} \cong 96$ microseconds

required for the baffle delay element.

If L = 0.550 inch

$t_{FP} = 30$ microseconds

$t_{DE} = 110$ microseconds

required for the baffle delay element.

This analysis combines all elements contributing to the total delay, including the firing pin velocity, the firing pin travel time and the primer initiation delay, thereby specifying the required delay element performance.

SECTION VII

DESIGN PARAMETERS OF THE DELAY ELEMENT

The previous analysis indicates that in order to fit easily within the available space, the delay element should be no longer than ~ 0.550 inch and its contribution to the delay time should be ~ 195 microseconds, which when added to the existing estimated 30-microsecond firing pin travel delay and the 10-microsecond initiation delay estimated for the primer, yields a total fuze functioning delay of 235 microseconds. This has been calculated as the total functioning delay required to obtain 2-1/3 projectile lengths of penetration at 2500 ft/sec against an 0.06 inch aluminum alloy target with a 20 mm projectile.

It will be shown that it is possible to design the baffle delay system, including the M26 primer with overall lengths of the order of 0.40 inch and less, by making use of the existing volume above the armed rotor as part of the baffle delay system. This will not disturb the rotor, rotor cavity or the arming process in any way, so that this design can be introduced into the lengthened M505 fuze system without introducing any new requirements for redesign of any part of the fuze other than the region between the rotor cavity and the firing pin.

SECTION VIII

PHYSICAL DESIGN OF THE DELAY ELEMENT

The required total delay time of 235 microseconds is too small to be obtained reliably with a conventional pyrotechnic delay element such as a black powder delay or a gasless powder pyrotechnic delay. A variety of alternate non-pyrotechnic design concepts have previously been considered and the results of some prior work will be noted in connection with this problem.

In Reference 5, Squier and Zernow designed and tested a large range of baffle delay detonators based upon the German concept used in the VC-70 delay detonator shown in Figure 6, which was used during WW II in the fuzing system of the German R4M rocket for the purpose of permitting full warhead penetration of the aircraft structure prior to detonation.

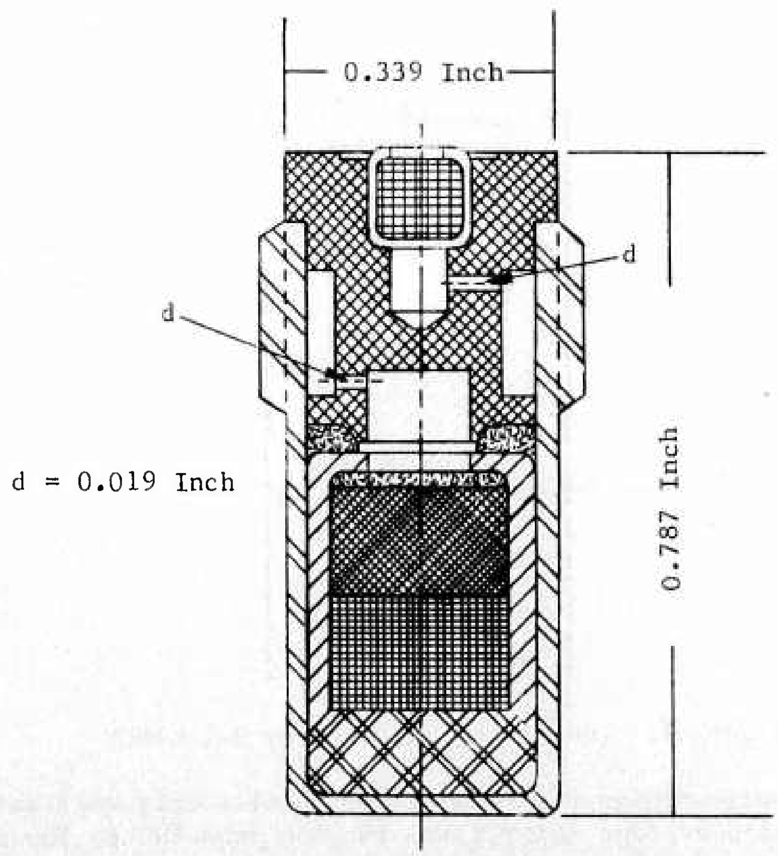


Figure 6. German VC-70 Baffle Delay Detonator

An idealized description of the baffle delay detonator is shown in Figure 7. In essence, it consists of a primer chamber and two expansion chambers connected by two small orifices through which the detonation products of a primer charge must pass before impinging on the detonator. The entire assembly has been called a baffle-delay detonator.

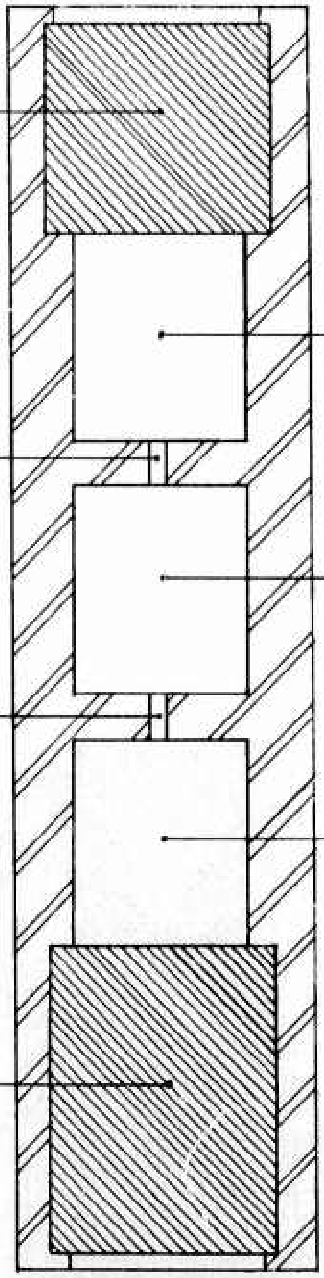


Figure 7. Idealized Baffle Delay Detonator

This configuration was found to be particularly well suited to obtaining controlled average delay times ranging from 100 to 500 microseconds. The design concept can also be used for delays ranging well past 1 millisecond.

For shorter delays, it is possible to design even simpler systems which involve only a primer chamber and one expansion chamber connected by a single orifice (Figure 8). Experience has shown that it is possible to make these baffle systems very small and, in particular, that it is possible to

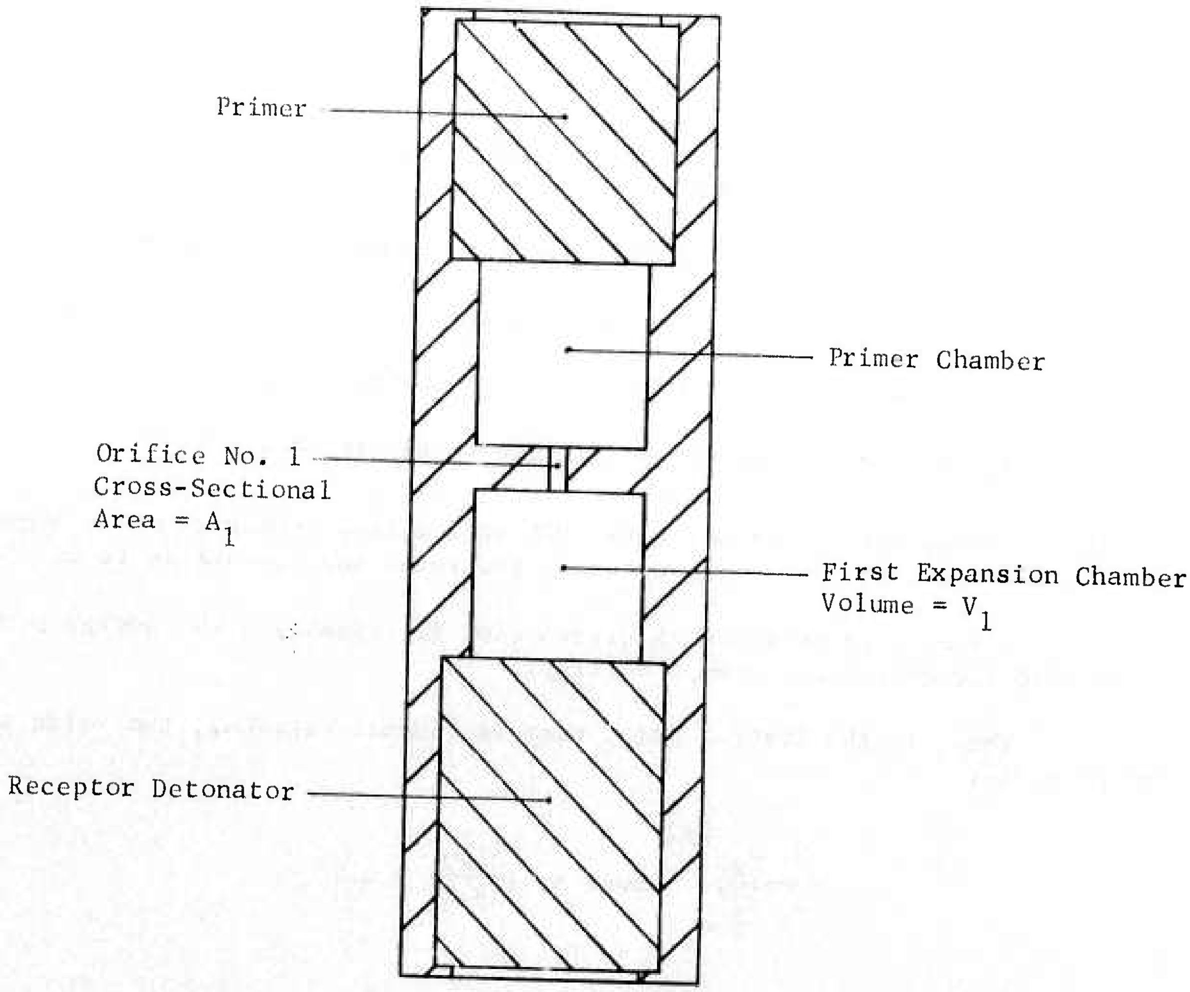


Figure 8. Idealized Single Orifice Baffle Delay Detonator

design these delay configurations in the very small sizes which are compatible with the limited available space in the M505A3 fuze. These designs can be carried out rationally because the theoretical analysis carried out in the referenced report indicates how the correlating design parameters are defined in terms of the baffle dimension which involve the chamber volumes and orifice areas. Thus, the correlating design parameters which define the average baffle delay time are obtained from the expression

$$t_{delay} = K \left(\frac{V_1 V_2}{A_1 A_2}\right)^{1/2}$$

where

t = delay time in microseconds

K = a constant for a given explosive primer and detonator combination

V_1 = volume of the first expansion chamber in cubic inches

V_2 = volume of the second expansion chamber in cubic inches

A_1 = area of the first orifice in square inches

A_2 = area of the second orifice in square inches

For baffle delay detonators using the M26 stab action primer shown in Figure 9, and the M18 detonator as the receptor, K was found experimentally to be 38.2.

A sample calculation is given below to illustrate the design procedure and the dimensional compatibility.

Thus, if the desired delay time is 160 microseconds, the value of the parameter

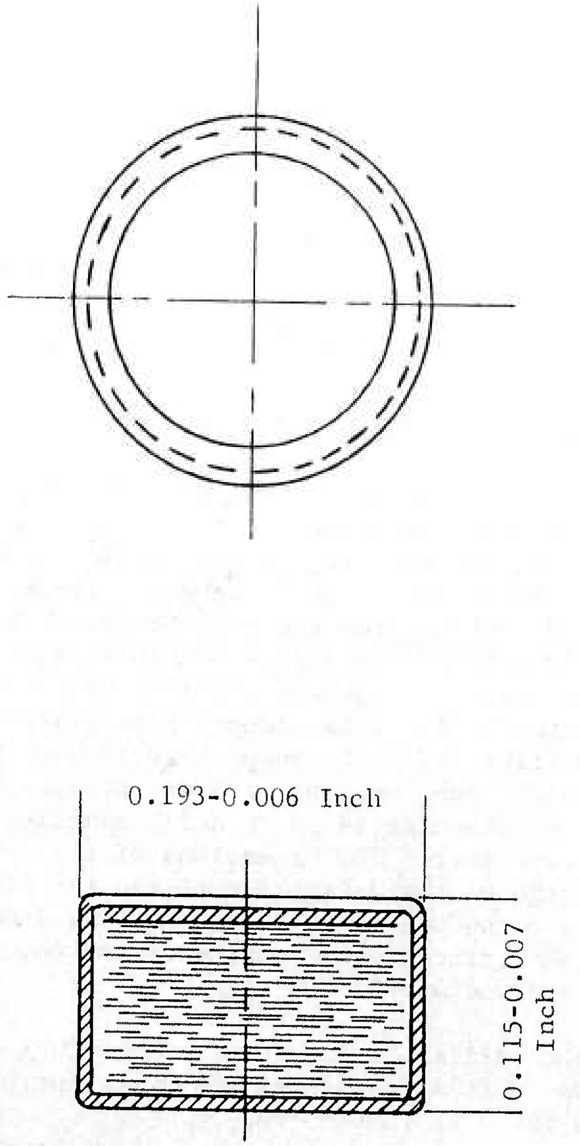
$$\left(\frac{V_1 V_2}{A_1 A_2}\right)^{1/2} \text{ must be } \left(\frac{160}{38.2}\right) = 4.2$$

Therefore $\frac{V_1 V_2}{A_1 A_2}$ must be equal to $\sim$ 17.6.

This hypothetical design could be accomplished as follows. If $A_1 = A_2 = 2.01 \times 10^{-4}$ square inches then the diameter of the orifices would each be 0.016 inch. $A_1 A_2$ would be 4.04×10^{-8}. Therefore, in order to make the design parameters fit the required delay time

$$V_1 V_2 = 17.6 \times 4.04 \times 10^{-8} = 71.1 \times 10^{-8}$$

For illustrative purposes let $V_1 = V_2$. If $V_1 = V_2$, then each expansion chamber should have a volume of 8.43×10^{-4} cubic inches. This is the volume of a cylinder which is 0.15 inch high and 0.085 inch in diameter. This sample calculation shows that the dimensions of a possible baffle delay element can indeed be fitted into the available space in the fuze.



Primer: Composition:—

Potassium Chlorate	Grade "A" Class 2 —	53% ±2%
Antimony Sulphite	Grade "A" or "B" —	17% ±1%
Lead Sulphocyanate	—	25% ±1%
Lead Azide	—	5% ±1%

Above percentages are by weight.

Figure 9. M26 Primer

SECTION IX

INITIAL FUZE PROTOTYPE CONFIGURATION FOR QUASI-DYNAMIC TEST

1. GENERAL

In order to minimize the costs of the baffle delay development it was planned that the initial prototype metal parts assemblies prepared would be as simple as possible and would use as much of the standard M505A3 fuze as possible. This was an intermediate cost saving step and it was understood that final fuze metal parts used in the gun tests would not be made this way.

2. DETAILED DESCRIPTION OF INITIAL PROTOTYPE HARDWARE

Figure 10 shows an assembly drawing of a prototype test fuze design. Part A was obtained from the existing fuze nose, containing the cap and firing pin, by cutting off the appropriate portion from existing M505A3 metal parts as shown in Figure 11. Part D, shown in Figure 12, the main body portion, containing everything from the rotor on down to and including the booster, was similarly obtained by simple machining from the present fuze body. The adapter (Part B), which joined the fuze nose (Part A) to the main body (Part D) and which extended the total length H to 1.415 inches, and was a new part and is shown in Figure 13. The adapter could have been made to fit the full new extended conical fuze contour with an increase in unit cost, but the simplified design was considered to be quite adequate functionally and considerably cheaper to fabricate. The dimensions of the spacer (Part C) depended upon the detailed design of the delay element and the dimensions of the explosive component used in the baffle delay element, as discussed below. It should be noted that the entire rotor, detonator and booster portion of the explosive train remained unchanged.

The initial baffle delay element was selected to be a double chamber baffle, whose initial design is shown in Figure 14a. The associated spacer (Part C) is shown in Figure 14b.

3. OPERATIONAL FUZE DESIGN

While the prototype test fuze design shown here was a low cost expedient for the initial part of the present development program, it was later determined that an operational gun-fired fuze design, which used a simplified, smaller diameter baffle delay element, could be assembled by using elongated fuze bodies, previously prepared for the 25 mm gun program. The experimental results that led to the simplified baffle design and the gun-fired fuze designs will be discussed later in the report.

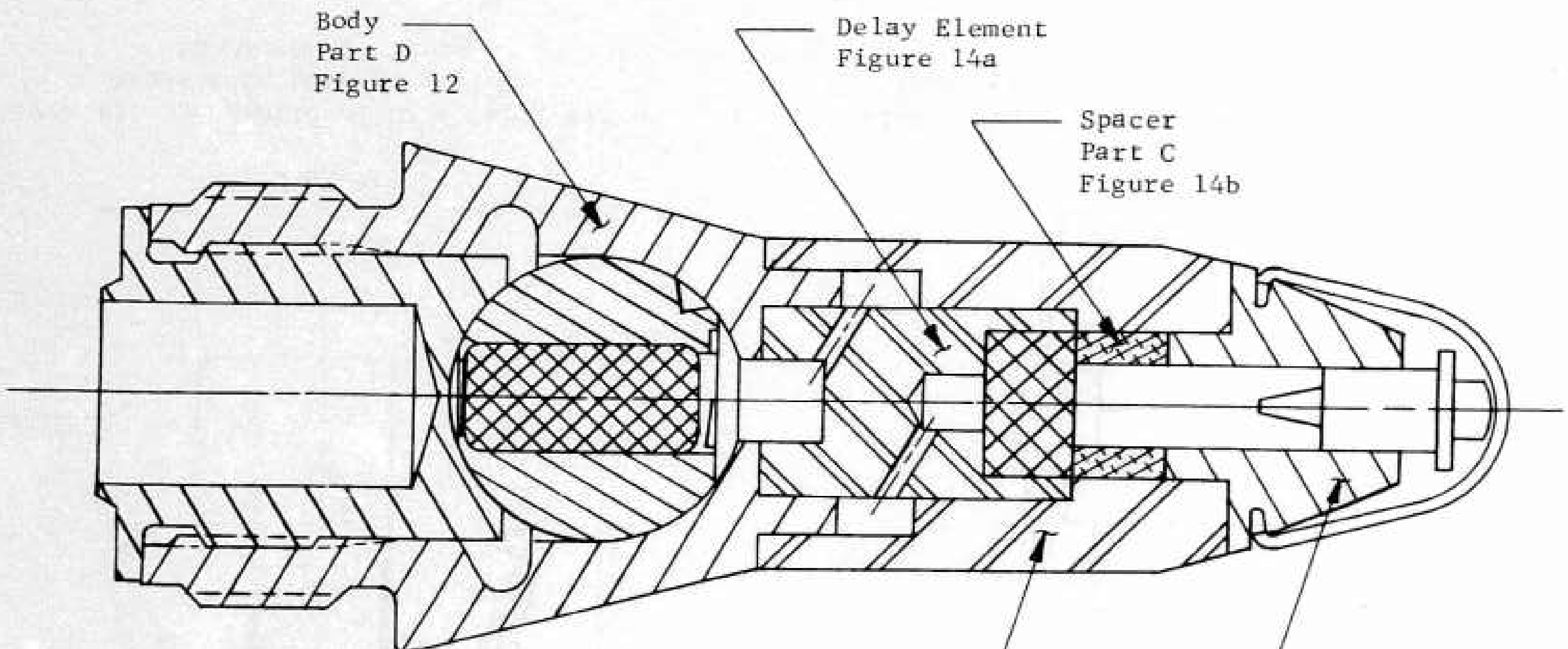


Figure 10. Schematic Drawing of Typical Prototype Test Fuze Design Used for Testing Various Baffle Delay Configurations

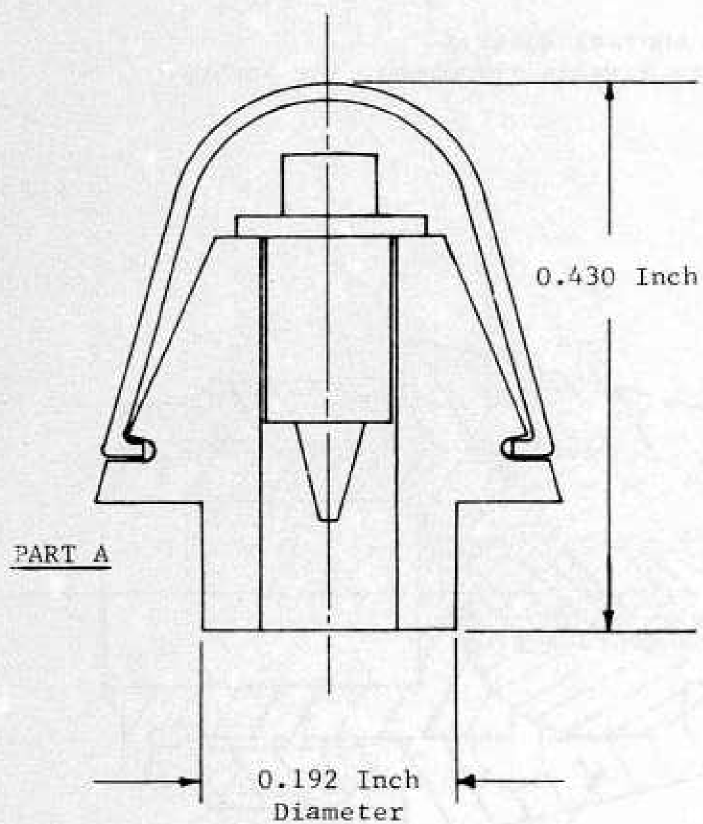


Figure 11. Schematic of Nose Cap Portion Removed by Machining From M505A3 Metal Parts

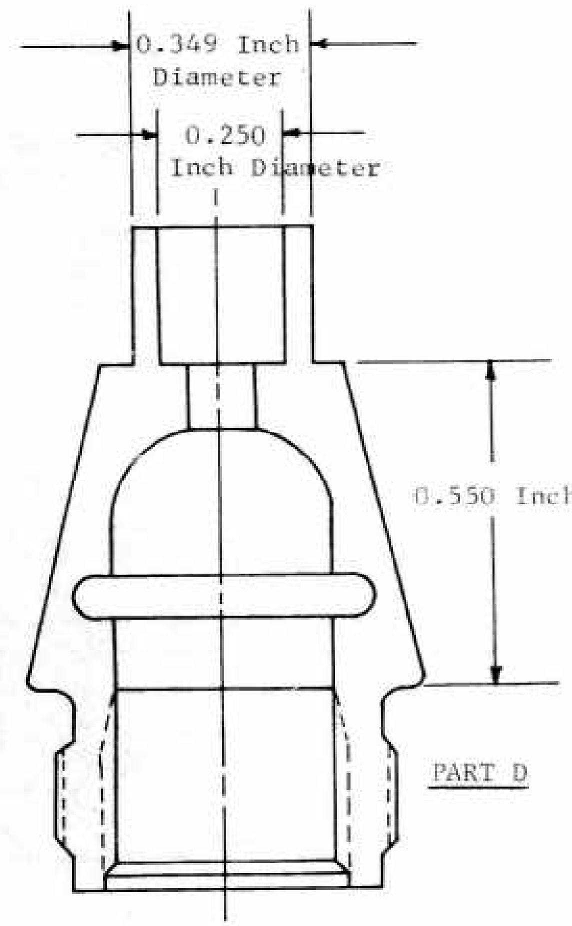


Figure 12. Schematic of Lower Portion of Body Machined From M505A3 Metal Parts

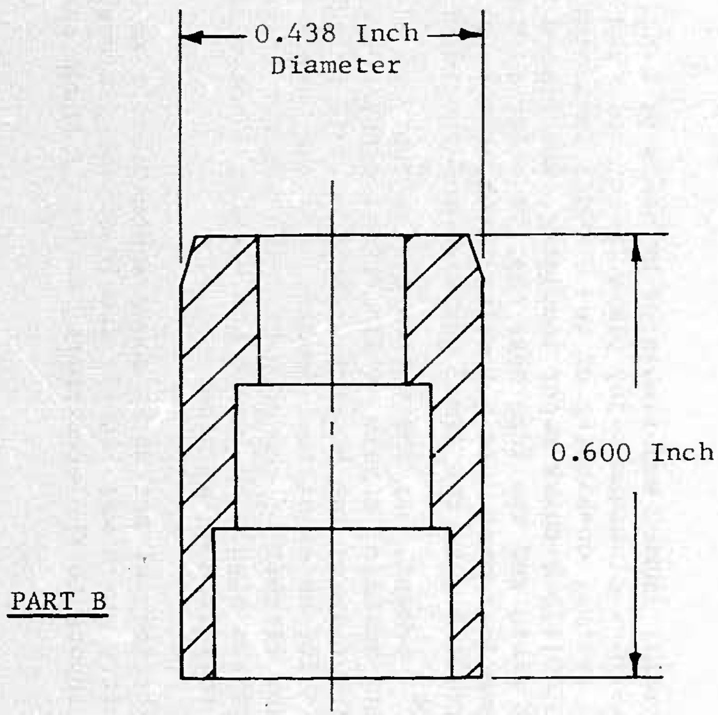


Figure 13. Schematic View of Adapter - Part B

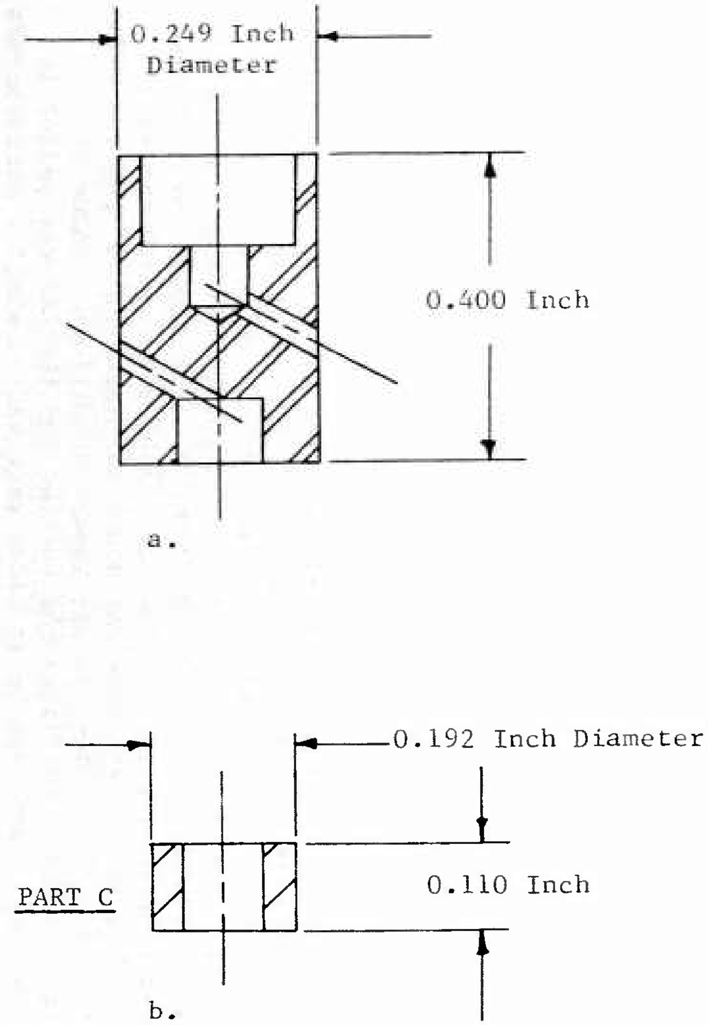


Figure 14. Schematics of Baffle Delay Element and Spacer

SECTION X

QUASI-DYNAMIC EXPERIMENTAL EVALUATION PROCEDURE

The quasi-dynamic evaluation procedure was designed specifically to evaluate baffle design concepts in an economical fashion, without having to shoot the specific baffle design variants in gun-fired fuzes. Aside from reducing the test expense, this also permitted the use of simplified prototype hardware.

The technical problem in quasi-dynamic measurements of fuze functioning delays, involves simulation of the impact and electrically sensing the time interval between the simulated impact and the functioning of the fuze. In previous discussions of the earlier computational and experimental studies, it was estimated that the standard M505A3 fuze should have a total delay time consisting of several components. About 30 microseconds should come from the firing pin travel time and about 10 microseconds from the M57A1 detonator initiation delay under dynamic impact conditions. Since the detonator in turn directly initiates the booster and the booster pellet is about 0.375 inch long, there may be an added interval of about 2 microseconds if the functioning time of the booster is sensed as the end of the elapsed fuze functioning time. Thus, a properly simulated dynamic impact delay measurement on the standard M505A3 fuze should show delay times of the order of $(30 + 10 + 2) = \sim 42$ microseconds. This estimate turned out to be remarkably accurate, as will be seen in the later discussion of the experimental data. Standard M505A3 fuzes were always fired at the start of any baffle delay measurement series, as calibrators and measurement system checks. The close agreement found supports the validity of the quasi-dynamic measurement procedure.

The dynamic impact was simulated by means of a No. 8 detonator driving a 0.125-inch-thick aluminum alloy plate in contact with the fuze nose cap. A very thin foil switch, consisting of two 0.00075 inch aluminum foils separated by a 0.001-inch-thick paper insulator, was placed between the detonator driven plate and the fuze nose cap, in order to sense the start of the simulated dynamic impact. In all delay tests, the rotor and M57A1 detonator were rotated into the armed position and the rotor was cemented in place with DUCO® cement. At the bottom of the fuze, in close proximity to the booster output surface, a pair of electrical probes were deployed in order to sense the detonation of the booster. The nose foil switch was connected to the start circuit for an electrical counter, and the output probe was connected to the stop circuit of the counter. The counter therefore measured the time interval between simulated impact and booster functioning on the fuze, which is the overall fuze delay time.

The experimental set-up is shown schematically in Figure 15. The electrical circuitry which was finally developed for processing the start and stop signals as inputs to the electrical counter is shown in Figure 16.

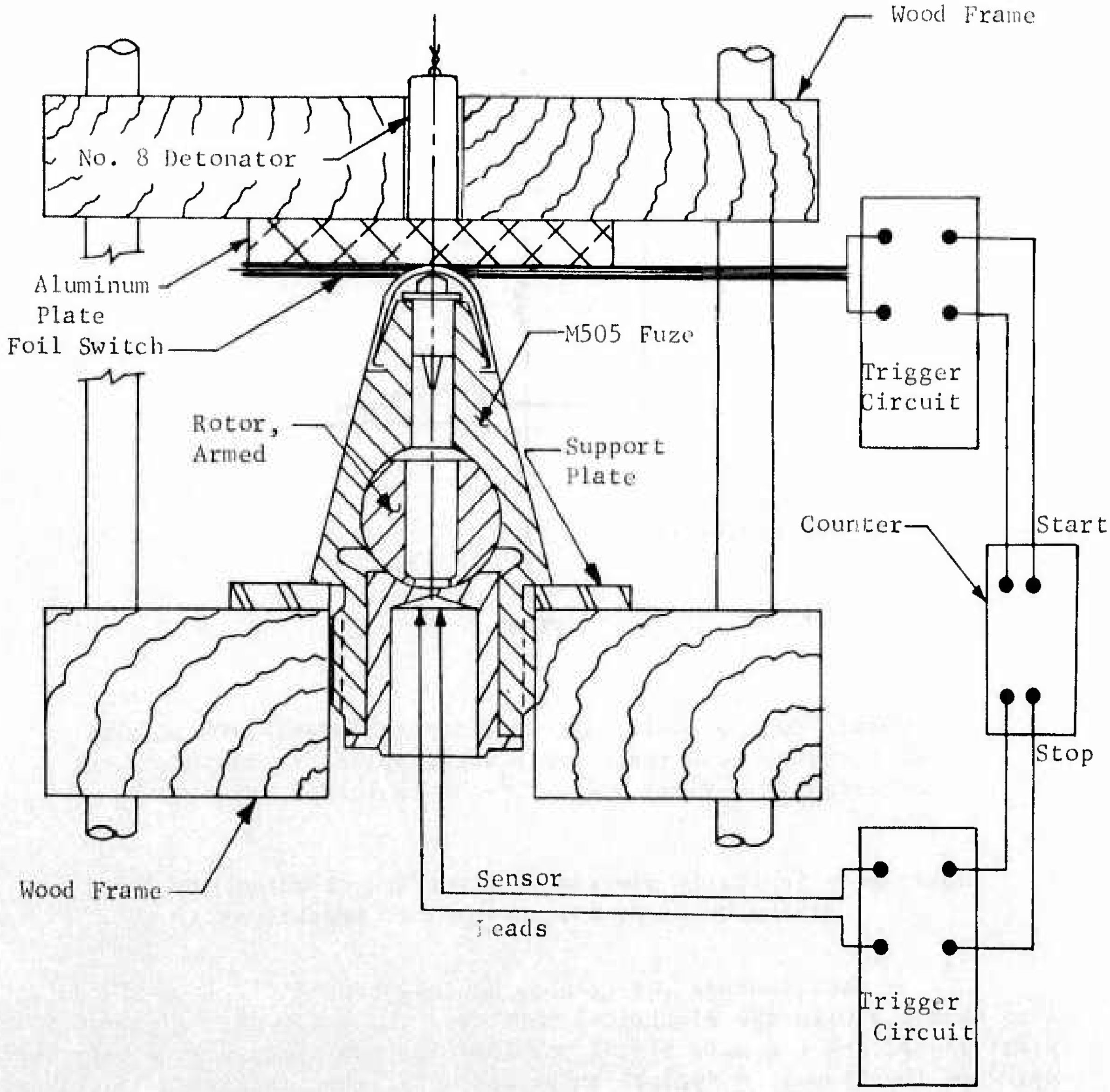
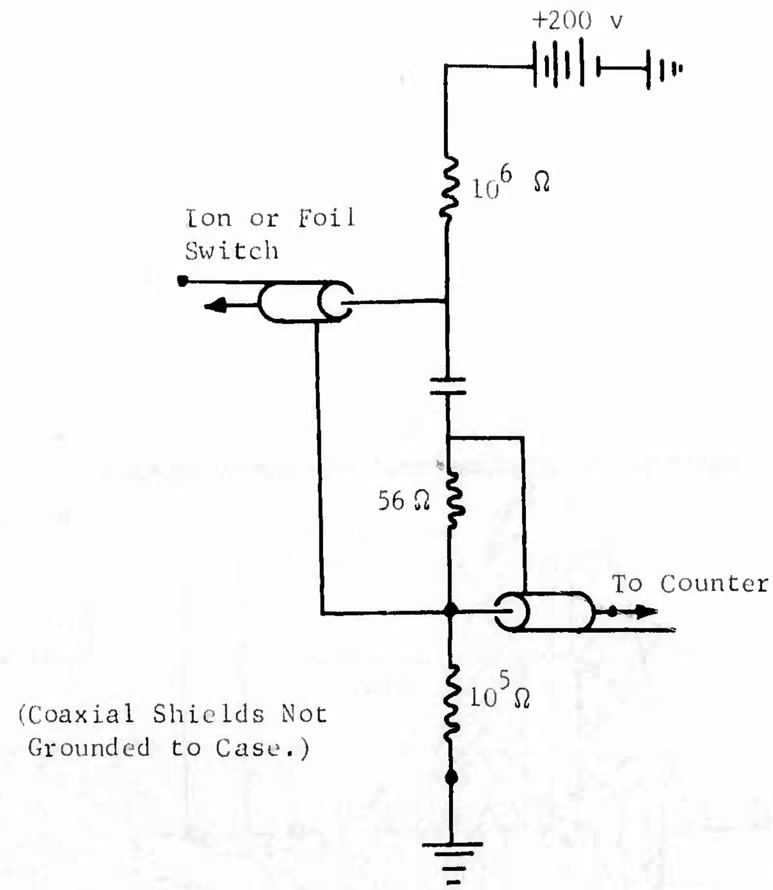


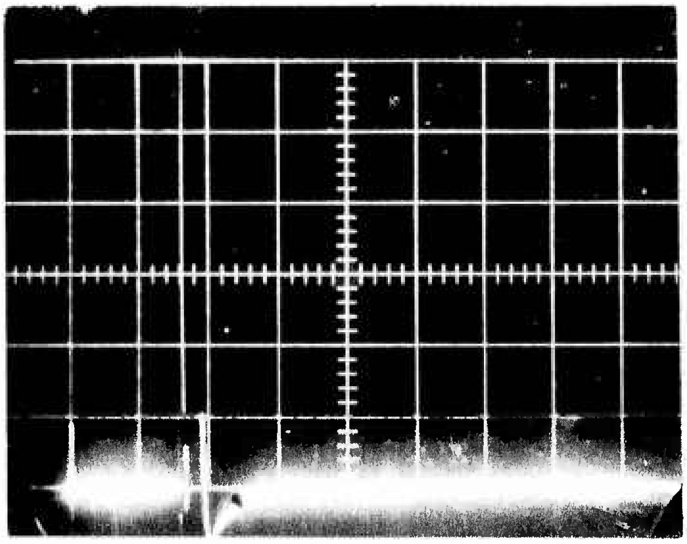
Figure 15. Schematic of Test Assembly for Quasi-Dynamic Fuze Delay Time Measurements



Separate twin circuits are provided for START/STOP pulses. The circuits have their own power supplies (three 67.5-volt batteries in series) and a 10^5-ohm isolation resistor to ground.

Figure 16. Schematic Diagram of Electrical Circuit Developed for Making Quasi-Dynamic Delay Time Measurements

An oscilloscope was used as an independent check on the delay time measured with the electrical counter. The sweep was triggered by the start signal and the stop signal provided its own signature, a very sharp spike on the trace. A typical scope trace is shown in Figure 17. There were no instances in which the scope delay times differed from the counter delay times by more than the reading uncertainty on the trace.



Oscilloscope Record

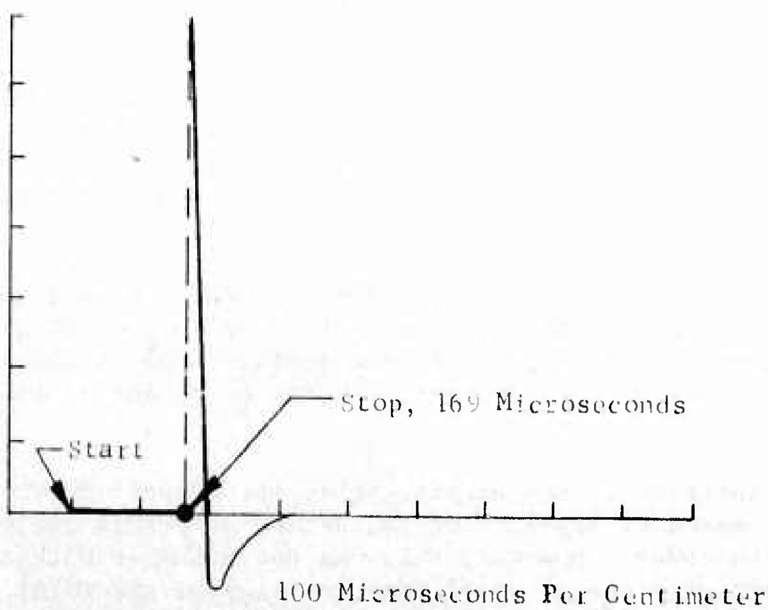


Figure 17. Typical Trace of an Oscilloscope Measurement of Quasi-Dynamic Fuze Time Delay

SECTION XI

RESULTS OF THE QUASI-DYNAMIC MEASUREMENTS

1. INITIAL RESULTS

The initial baffle delay experiments were carried out with baffle designs 1343A and 1343B, shown in Figure 14 and Figure 18. In addition, the M57A1 detonators were initially used in their normal closed form as fabricated, despite the fact that earlier work (Reference 4) had been done with open face detonators whose primer surface was directly exposed. While the initial delay time measurements were confused by the early difficulties in the final circuit development, it was clear from the experimental observations of the non-functioning of the M57A1 detonator that the two initial versions of the baffle design were not permitting enough hot gas from the M26 primer to initiate the M57A1 primer mix in the detonators through the aluminum detonator cover.

Two design changes were made. The first involved the pre-perforation of the M57A1 detonator at the primer end with a puncture tool which generated a conical hole about 0.02 inch in maximum diameter and 0.02 inch deep, thereby exposing the primer mix directly. The second design change involved a baffle redesign (Figure 19) requiring a change in the angle of the second aperture, so that the hot M26 primer gases could impinge more directly on the exposed primer mix in the M57A1 detonator.

Perforating the primer end of the detonator to expose the primer mix did result in detonator functioning most of the time but occasional non-functions were observed. In order to try to increase the functioning reliability the second design change shown in Figure 19 was made.

It turned out that, for freshly perforated M57A1 detonators, the fuze delay measurements were right in the desired range and therefore quite encouraging, as shown in Tables 1 and 2, which compare the standard M505A3 calibration delay time with the baffled delay time. However, when the perforated detonators were stored overnight, their delay increased substantially by almost a factor of ten as can be seen from Table 3.

The general conclusion that could be drawn is that the perforated detonator method of sensitizing the M57 detonator to the hot gas from the M26 primer, while serving the purpose of demonstrating the technical feasibility of the miniature baffle delay designs, did not represent an ideal explosive train design.

In principle, if the erratic delay performance of the pre-perforated detonators was caused by exposure of the primer mix, this could be solved by the use of a thin cover. However, this was not possible within the scope of the present contract since it would mean redesign of the M57A1 detonator and prototype production of the new detonators. Instead, it was considered to be a better cost-performance tradeoff to consider baffle designs which were

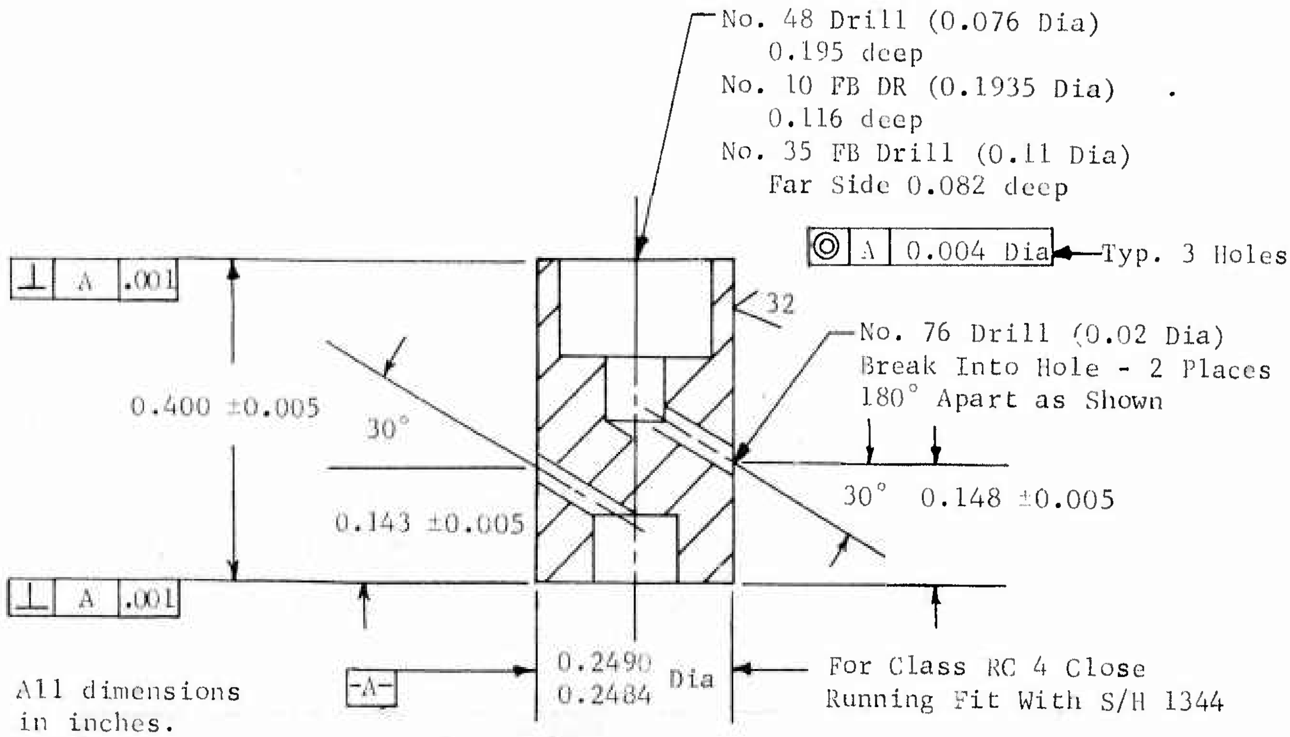


Figure 18. Delay Baffle Designs 1343B

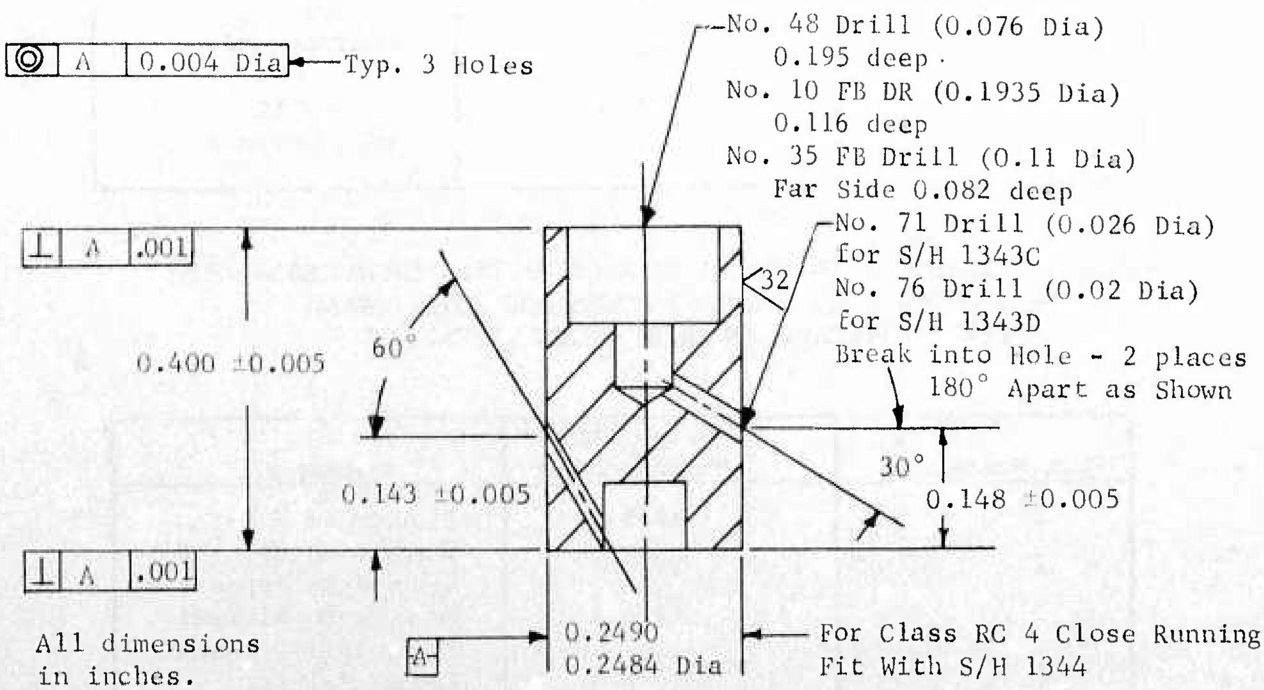


Figure 19. Delay Baffle Modified to Improve Impingement Angle of Primer Gases on Detonator

TABLE 1. SUMMARY OF INSTRUMENTATION CHECK SHOTS INVOLVING QUASI-DYNAMIC DELAY TIME MEASUREMENTS WITH STANDARD M505A3 FUZES

Shot Number	Delay Time - Microseconds	Shot Number	Delay Time Microseconds
1	38	6	43
2	38	7	37
3	45	8	40
4	39	9	36
5	40	10	37
Average Delay 39.3 microseconds σ 2.9 microseconds			

TABLE 2. QUASI-DYNAMIC DELAY TIMES MEASURED WITH BAFFLE DESIGN 1343C, HAVING AN 0.026 INCH DIAMETER EXIT APERTURE AT AN ANGLE OF 60° TO THE HORIZONTAL. THE M57A1 DETONATOR WAS PRE-PERFORATED AT THE PRIMER END TO EXPOSE THE PRIMER MIXTURE JUST PRIOR TO THE EXPERIMENTS

Shot Number	Delay Time - Microseconds	Comments
1	250	Average Delay 251 microseconds
2	214	
3	198	
4	240	σ = 60 microseconds
5	352	

TABLE 3. EFFECT OF OVERNIGHT STORAGE OF PRE-PERFORATED M57A1 DETONATORS. ALL BAFFLE DESIGNS AND EXPERIMENTAL CONDITIONS SAME AS THOSE SHOWN IN TABLE 2

Shot Number	Delay Time - Microseconds	Comments
1	1446	Storage of Pre-Perforated M57A1 D Detonators Appears to Have De-sensitized Them, Causing Much Longer Delays.
2	2270	
3	1274	
4	1130	

capable of being used with the existing, standard unperforated M57A1 detonator. This was not only more cost-effective for the present program, but it had an even greater significance with respect to the production aspects of any fuze design which would come out of this work.

2. MODIFIED BAFFLE APERTURE DESIGNS FOR INITIATING UNPERFORATED M57A1 DETONATORS

The first exploratory experiments in this direction involved opening up the baffle apertures on the 1343C design to 0.073 inch and determining whether the increased gas flow could directly initiate the unperforated M57 detonator. It was found that despite the fact that the M26 primer gas flow was now strong enough to tilt the rotor to a partially out of line position because of the tangential flow component, the thickness of the aluminum wall on the primer face of the M57A1 detonator was such as to prevent initiation of the detonator in two successive shots. This approach therefore did not appear to be very promising.

The next set of experiments involved a major redesign of the baffle, namely the drilling of a direct central hole 0.0625 inch in diameter in three remaining baffles with the enlarged hole. The question to be answered was whether the direct gas path would be more effective than the baffled gas path in initiating the M57A1 detonator. The results on these three shots (Table 4) were positive and very informative. It was clear from these results that the direct central impingement method does permit the unperforated M57A1 detonator to be initiated by the M26 primer. It was also clear that even with the relatively large (0.0625 inch diameter) central hole permitting direct impingement on the unperforated M57A1 detonator, there was an increase from ~ 40 microseconds to ~ 70 microseconds in the delay time. This suggested progressive reduction of the central hole to determine how this parameter affects the

TABLE 4. INITIAL EXPERIMENTS WITH BAFFLE DESIGNS FOR INITIATING M57A1 ROTOR DETONATORS

Baffle Design	Delay Time - Microseconds	Comments
1343C with apertures enlarged to 0.073 inch diameter	2 NO GO's[a]	Rotor rotated to partially armed position by gas flow without M57A1 initiation
Central hole 0.0625 inch diameter drilled into 1343C with enlarged apertures	64, 67, 85	All three M57 detonators fired initiating the boosters. One booster showed lower yield (85 microseconds)

[a] NO GO means M26 primer was initiated but failed to initiate the M57A1 unperforated detonator.

overall delay. The reduced hole diameter would be expected to slow down the gas flow, but excessive diameter reduction could ultimately result in failure to initiate the M57A1. To check out these factors, three sets of modified baffles were designed, which used the existing 1343C baffle as a starting point. The modification involved simply drilling an axial central hole of the desired diameter (Figure 20).

Since the original three-shot data series shown in Table 4 was obtained with the 0.0625-inch-diameter central hole, the new design modifications had axial holes having the following diameters:

0.052 inch	(#55 drill)
0.040 inch	(#60 drill)
0.031 inch	(#68 drill)
0.020 inch	(#76 drill).

It was planned that these baffles would be fired in fuze assemblies with unperforated M57A1 detonators for comparison with the results shown in Table 4 for central holes of 0.0625 inch diameter.

As an additional control on the delay time, it was felt that thin aluminum foil, placed between the M26 primer and the baffle input hole, would be capable of an additional contribution to the delay if this became necessary.

The effect of central aperture diameter alone was quickly determined in a preliminary set of experiments. These results are given in Table 5.

There are two conclusions that could be drawn from these preliminary results.

(1) The decreasing central hole diameter resulted in an increasing delay time, as expected.

(2) The delay time obtained even with the 0.020 inch drilled central hole was still not long enough to meet the desired objective of ~ 235 microseconds minimum average delay. Thus, the desirability of exploring the additional delay obtainable with interposed aluminum foil became apparent.

3. EXPERIMENTAL RESULTS OBTAINED WITH ALUMINUM FOIL INSERTS

The aluminum foil inserts were discs cut from standard commercial aluminum foil rolls. The thickness of the foil was measured to be 0.00075 inch. The foil was placed, as shown in Figure 21, at the top of the baffle, below the M26 primer. The variable which was controlled and studied was the number of aluminum foil discs which permitted a controlled variation of the total thickness of aluminum foil interposed.

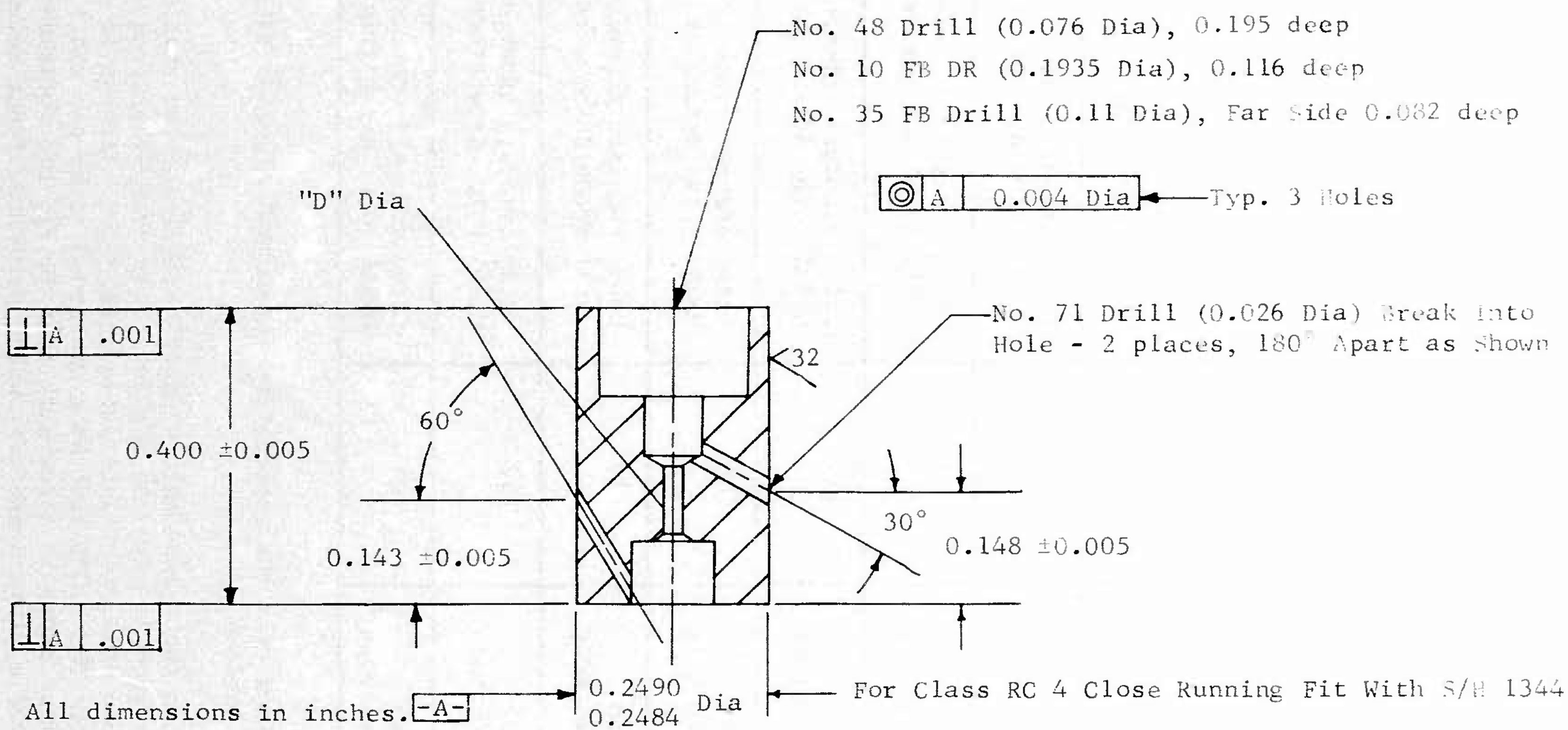


Figure 20. Modified Delay Baffle Design 1343C Mod 1 Containing Central Hole in Baffle to Permit Initiation of Unperforated M57A1 Detonators

TABLE 5. INITIAL DELAY TIME RESULTS OBTAINED WITH AXIALLY PERFORATED DESIGN 1343C MOD-1 BAFFLES AND UNPERFORATED STANDARD M57 ROTOR DETONATORS

Baffle Design	Delay Time-Microseconds	Comments
Axial hole, 0.0625 inch diameter drilled into 1343C with 0.073 inch baffle apertures	64 67 85	All three M57 detonators fired, initiating the boosters. One booster showed a slightly reduced output. This has been seen before on standard M505A3 fuzes
Baseline M505A3 Standard	44	Standard startup check test
1343C Mod 1 0.051 inch diameter axial drilled hole	82	Using standard unperforated M57A1 rotor detonators
1343C Mod 1 0.041 inch diameter axial drilled hole	87	Using standard unperforated M57A1 rotor detonators
1343C Mod 1 0.031 inch diameter axial drilled hole	139	Using standard unperforated M57A1 rotor detonators
1343C Mod 1 0.031 inch diameter axial drilled hole	105	Using standard unperforated M57A1 rotor detonators
1343C Mod 1 0.020 inch diameter axial drilled hole	111	Using standard unperforated M57A1 rotor detonators
1343C Mod 1 0.020 inch diameter axial drilled hole	152	Using standard unperforated M57A1 rotor detonators
1343C Mod 1 0.020 inch diameter axial drilled hole	146	Using standard unperforated M57A1 rotor detonators

The data obtained from the exploratory interposed aluminum foil experiments is shown in Table 6.

The results from these exploratory experiments indicated that the 0.040 inch hole was too large to give the desired delay even if sixteen foils were used. The 0.031 inch hole with eight foils interposed appeared to give a delay in the right range. The 0.020 inch hole was found to be too small for this method, because three shots in a row with four foils, two foils and one foil, respectively, showed a plugged aperture which prevented functioning of the M57A1 detonator.

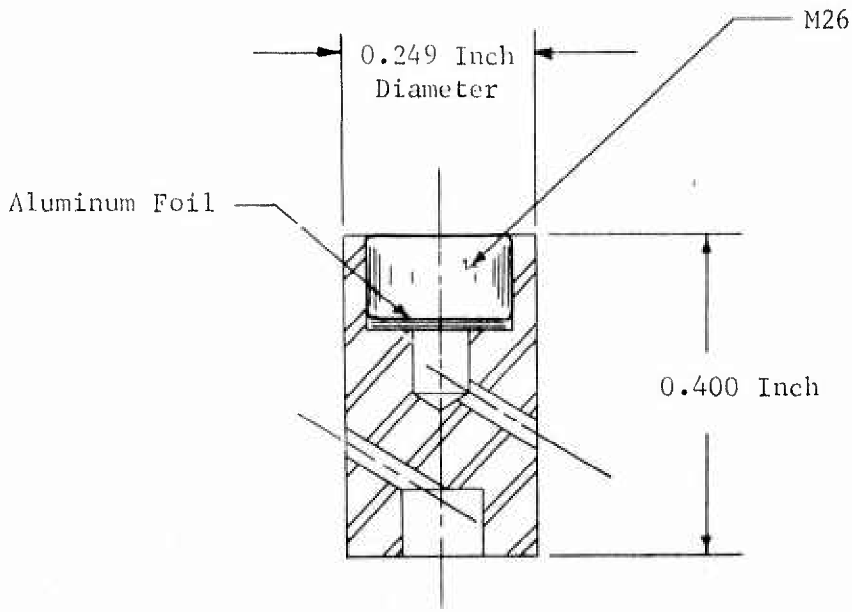


Figure 21. Aluminum Foil Disc Deployment in the Baffle Assembly

TABLE 6. DELAY TIME INCREASES OBTAINED BY INTERPOSING CONTROLLED THICKNESSES OF LAMINATED ALUMINUM FOIL (BASIC FOIL t = 0.00075 inch) BELOW THE M26 PRIMER. STANDARD UNPERFORATED M57 DETONATOR USED IN ALL SHOTS

Baffle Design 1343C Mod 1			
Axial Hole Diameter - Inch	Number of Basic Foil Thicknesses	Delay Time - Microseconds	Comments
0.031	1	91	
0.031	4	135	
0.031	8	243	
0.040	8	109	
0.040	8	79	
0.040	8	90	
0.040	16	101	
Baseline	M505A3	38	Standard fuze check
0.020	4	Failed to initiate M57A1 detonator	Plugging of hole by foil
0.020	2		
0.020	1		

The next efforts in the study were therefore concentrated on the 0.031 inch hole design in the 1343C baffle design.

Two foil arrays were used in the comparison, in order to get some feeling for the sensitivity of the results. These data are displayed in Table 7 and summarized in Table 8.

TABLE 7. DELAY TIMES OBTAINED WITH BAFFLE DESIGN 1343C MOD 1 USING A CONSTANT 0.031 INCH DIAMETER AXIAL HOLE AND A LAMINATE OF EITHER SIX OR EIGHT ALUMINUM FOILS BELOW THE M26 PRIMER

Baffle Design 1343C Mod 1		Delay Time-Microseconds	Comments
Axial Hole Diameter-Inch	Number of Basic Foil Thicknesses		
0.031	8	552	All with standard unperforated M57A1 detonators in the rotor
0.031	8	311	
0.031	8	107	
0.031	8	243	
Baseline	M505A3	39	Standard fuze check
0.031	6	342	All with standard unperforated M57A1 detonators in the rotor
0.031	6	446	
0.031	6	133	
0.031	6	340	
0.031	6	122	
0.031	6	156	

TABLE 8. AVERAGE DELAY TIMES FOR A BAFFLE DESIGN 1343C MOD 1 WITH TWO DIFFERENT ALUMINUM FOIL LAMINATE ARRAYS BELOW THE M26 PRIMER

Baffle Design 1343C Mod 1		Average Delay Time Microseconds	σ Microseconds	Comments
Axial Hole Diameter-Inch	Number of Basic Foil Thicknesses			
0.031	6	256	137	All with standard unperforated M57A1 detonators
0.031	8	303	186	All with standard unperforated M57A1 detonators

The summary results given in Table 8 indicate the average values of delay time obtained with the 1343C Mod 1 baffle design using the 0.031 inch axial hole of eight or six foils of 0.00075 aluminum foil below the M26 primer.

4. EFFECT OF ELIMINATING OBLIQUE BAFFLE APERTURES IN DESIGN 1343C

Examination of the 1343C Mod 1 design suggests that further simplification might be possible if the two oblique apertures were eliminated and only the central axial hole was left. However, a question would arise regarding the possible contribution, if any, of the peripheral venting provided by the oblique apertures, to the overall delay.

In order to determine whether the delay times obtained with the 1343C Mod 1 design were dependent upon the additional venting provided by the original oblique baffle apertures as well as the central axial hole, a set of these baffles was prepared without the original baffle apertures but with the central axial hole. This design is designated 1343C Mod 2 and is show in Figure 22.

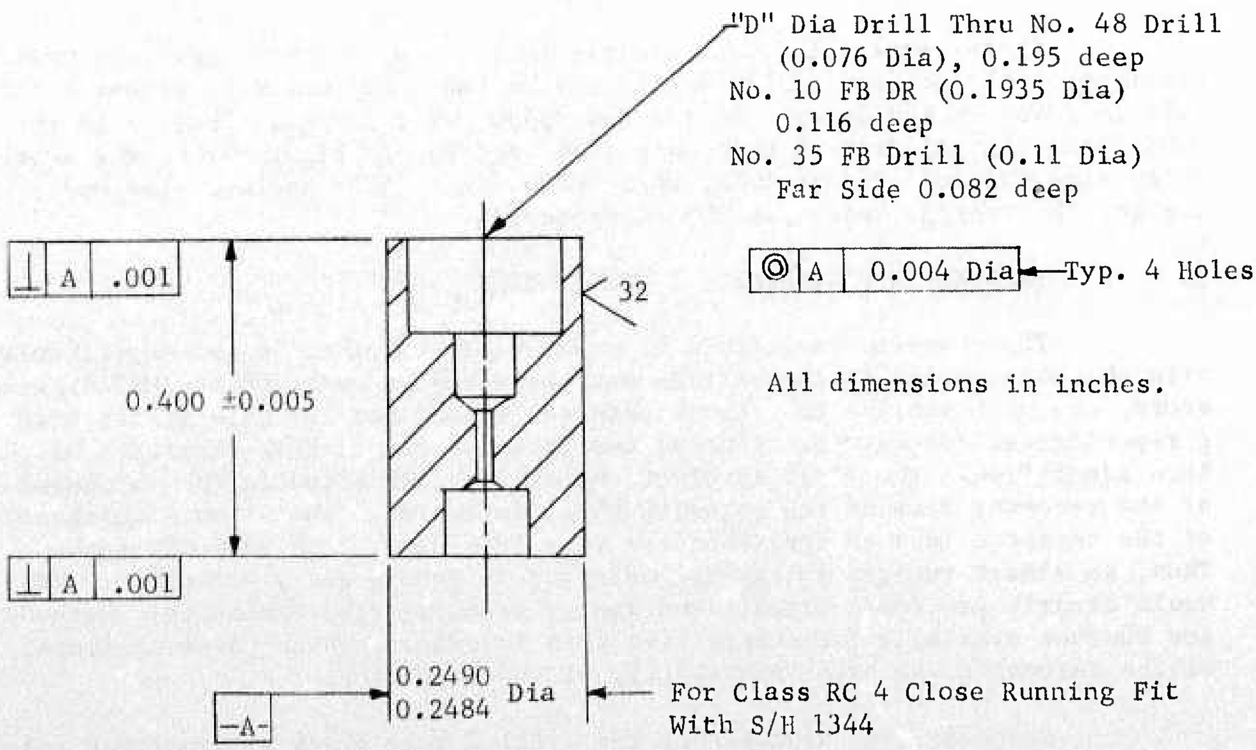


Figure 22. Simplified Delay Baffle Design Containing Only an Axial Hole Design 1343C Mod 2

These baffles were tested in the standard delay fuze array and the results are shown in Table 9.

TABLE 9. DELAY TIMES OBTAINED WITH 1343C MOD 2 BAFFLE DESIGNS USING 0.031 INCH DIAMETER AXIAL HOLES, AND EIGHT LAMINAE OF 0.00075 INCH ALUMINUM FOIL, WITH STANDARD M57A1 DETONATORS

Baffle Design 1343C Mod 2		Delay Time-Microseconds	Comments
Axial Hole Diameter-Inch	Number of Basic Foils		
0.031	8	91	Standard unperforated M57A1 detonator in rotor
0.031	8	114	
0.031	8	127	
0.031	8	93	
0.031	8	111	
Baseline	M505A3	40	Standard fuze check
Average Delay Time Design 1343C Mod 2		107	

These results indicate clearly that the additional auxiliary venting provided by the original 1343C baffle system had contributed to almost a three-fold increase in the delay time for the 1343C Mod 1 design. Thus, with the 0.031 inch central drilled hole only (1343 Mod 2) and eight foils, the average delay time was 107 microseconds, while with eight foils and with the Mod 1 design, the average delay was 303 microseconds.

5. SOURCES OF VARIABILITY IN DELAY TIME

The observed variations in delay time, obtained in the experiments with the axial holes in the baffles and the standard unperforated M57A1 detonators, are much smaller than those observed in the earlier experiments with pre-perforated detonators. Several possible sources of this variation have been identified. The first involves the allowed variation in the thickness of the receptor face of the standard M57A1 detonator. The allowed thickness of the receptor face as specified can vary from 0.007 inch to 0.004 inch. Thus, an almost twofold thickness variation is considered permissible. This would clearly provide a significant source of delay time variation. Methods are however available for controlling this thickness, which involve coining of the detonator cup prior to assembly of the detonator.

Secondly, the diameter of the drilled hole plays an important role. A drilled hole is normally held within ±0.003 inch of the nominal diameter. However, in a diameter of 0.031 inch, this represents a ±10 percent diameter variation or ~ ±20 percent hole area variation. Methods and procedures are also available for controlling the hole diameter more tightly.

While both of these sources of variation are considered to be controllable, engineering a reduction in delay time spread appears to be more suitable for a follow-on effort, since the major purpose of the present effort was to prove the feasibility of the baffle delay concept in this application. This has been done in principle.

SECTION XII

FUZE AND BAFFLE DESIGNS PREPARED FOR GUN FIRED TESTS

1. DESIGN PROBLEMS ENCOUNTERED

In examining the question of the fuze and baffle designs for use in the gun fired tests, it quickly became apparent that use of the best of the original baffle designs, namely design 1343C Mod 1, would require a major amount of additional machining work equivalent to the fabrication of a new fuze body, in order to permit the baffle to be fitted into the body with the annular venting space. In addition, if the baffle was to be inserted from the direction of the rotor cavity, new threaded parts would have to be made to support the baffle against setback. On the other hand, if the 1343C Mod 1 baffle was to be inserted from the firing pin end of the fuze body, the body would have to be made in two pieces, with the smaller upper part of the body either threaded or force fitted on top of the lower body containing the baffle and annular cavity. This was also undesirable since, aside from the costs, a two-piece fuze body could cause problems either in the gun or at the target.

2. DESIGN SOLUTIONS

The decision was therefore made to start with the elongated fuze bodies used in the 25 mm gun program. These bodies which met the length limitation requirements were made available by Eglin Air Force Base, which also supplied the firing pins, nose caps and nose cap crimping tools.

Fitting the baffles into these bodies through the nose required further size reduction and simplification of the baffle. The final fuze assembly design is shown schematically in Figure 23 and a simplified and miniaturized baffle design is shown in Figure 24.

It should be noted that the fuze design selected involves no change at all in the rotor or booster end of the body. Thus, the arming process should be unaffected. The change required at the firing pin end of the body was a simple counterbore, large enough to permit the M26 primer to be inserted. The baffle diameter was matched to the M26 primer. The shoulder below the baffle supported the primer and baffle against set-back during gun acceleration. The only new metal part required was the nose plug insert, which was a simple and inexpensive item (Figure 25).

Since it was not possible to easily provide the annular venting space used in conjunction with the successful 1343C Mod 1 baffle design, it was decided that the simplified baffle design parameters would be explored to determine how the fuze delay might be further increased to make up for the loss of delay arising from the elimination of the annular venting.

Two parameters were available for increasing the delay. The first was the central hole diameter and the second was the number of aluminum foils interposed between the M26 primer and the miniaturized baffle. However, it

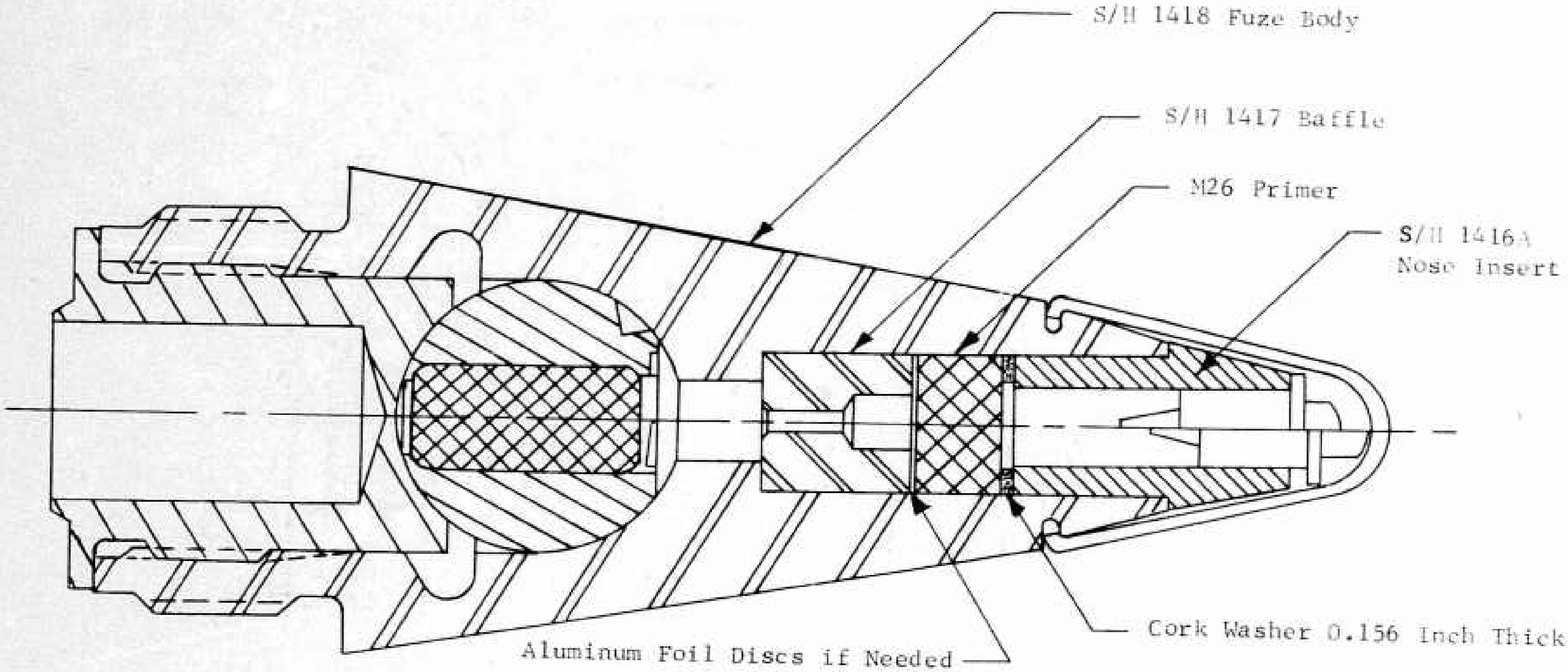
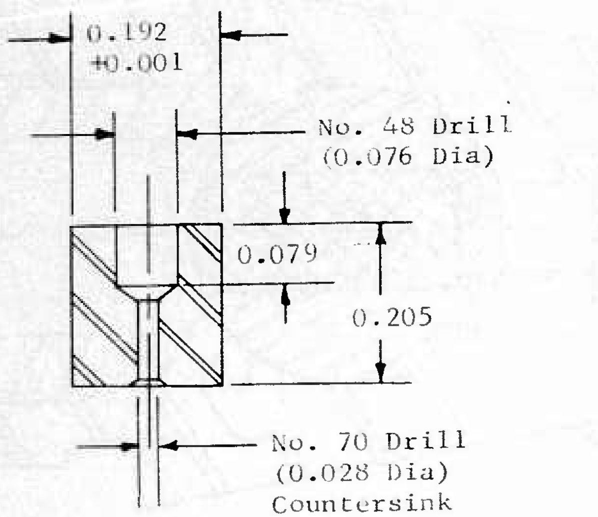
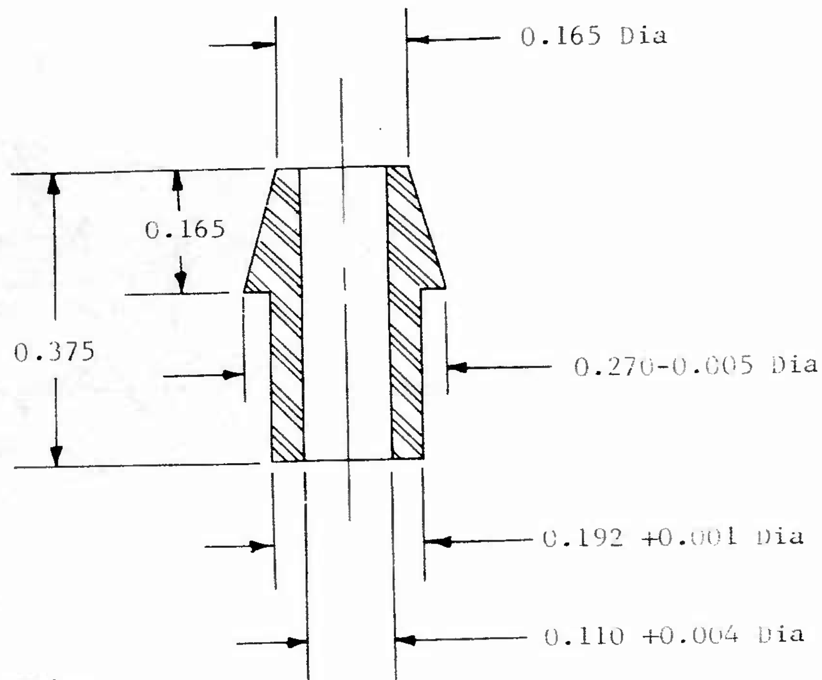


Figure 23. New Simplified and Miniaturized Baffle Delay Fuze Assembly Design 1419A





All dimensions in inches.

Figure 24. New Simplified and Miniaturized Baffle Design 1417A

Figure 25. Nose Plug Insert Design for Gun-Fired Fuzes

had already been observed that an 0.020 inch central hole in the baffle could not tolerate the use of aluminum foils, because it would become plugged and cause detonator initiation failure.

The first check experiments on the new fuze and baffle design were carried out quasi-dynamically with an 0.028 inch diameter axial hole in the simplified miniaturized baffle. The baffle design was designated 1417A (Figure 24) and the total fuze assembly was designated 1419A (Figure 23). No aluminum foil was used in this set of experiments.

The results of these experiments are given in Table 10.

TABLE 10. DELAY TIME MEASUREMENTS OBTAINED WITH MINIATURIZED AND SIMPLIFIED BAFFLE DESIGN 1417A, IN FUZE ASSEMBLY 1419A

Baffle Design	Delay Time-Microseconds	Comments
Baseline M505A3 Standard Fuzes	44	Standard Instrumentation Check
	39	
Fuze Assembly Design 1419A with baffle 1417A containing an 0.028 inch axial drilled hole without aluminum foil below M26 primer.	212	All boosters functioned normally.
	157	
	435	
	112	
	100	
	161	
	144	
	383	
Average Design 1417A	213	Without aluminum foil below M26 primer.
σ	126	

SECTION XIII

GUN-FIRED FUZE TESTS

1. THE AMMUNITION COMPONENTS

The ammunition components used in the gun fired tests included the M103 cartridge case with electric primer, the M56E3 HEI projectile and WC870 propellant. The experimental fuze baffle designs attached to the projectile will be discussed in more detail later. The standard M505A3 fuze was used to obtain baseline data.

2. THE GUN PARAMETERS

The gun used in these firings was a 20 mm Mann Barrel mounted at two locations to a heavy support. The barrel was designed to fire standard M50 series 20 mm ammunition. The standard rifling has a right-hand twist, with a constant pitch of one turn in 20 calibers.

3. FUZE ARMING DISTANCE REQUIREMENTS

Information about past experience or design data on the fuze arming distance was difficult to obtain. Initial information which was obtained indicated that all fuzes should be armed 30 feet from the gun muzzle. This ultimately proved incorrect. Later information indicated that 50 meters was the arming distance. This also proved to be inaccurate. It was not possible to obtain any prior experimental data describing the percentage of fuzes armed at various distances from the muzzle.

The initial incorrect information about the arming distance of 30 feet was used as a basis for spacing the target 46 feet from the muzzle to carry out the first gun fired experiments. This resulted in problems with fuze function failures because even with the gun located 46 feet from the target, numerous duds occurred, and it was clear from the quasi-dynamic experiments that the duds were not attributable to the armed fuze explosive train.

In view of these initial results, the gun was brought back to a distance of 165 feet from the target. However, at this range, impact accuracy problems occurred, which would have required doubling all target dimensions. The gun was therefore brought back to a 100-foot distance from the target, and all subsequent gun firings were carried out successfully at that range.

4. THE TARGET STRUCTURE

The fuze functioning test target was made of 0.063 inch 2024-T3 aluminum alloy and was one foot square. This plate was held in a target frame which contained two replaceable steel side witness plates oriented parallel to the projectile trajectory and displaced about 6 inches from the hypothetical central trajectory passing through the longitudinal axis of the target frame. The witness plates were 24 inches long and 12 inches wide. Their purpose was to record the location of the fragment spray from the detonating projectiles, thereby providing a basis for making an estimate of the fuze functioning delay time. A sand box was located behind the target frame to catch any forward projected fragments or any non-functioning projectiles.

5. FRONT TARGET PLATE SIGNATURES

Additional information about the fuze functioning delay could be obtained from the front target plate itself. A normal M505A3 fuzed projectile which has a measured delay time (quasi-dynamic) from impact to booster function of about 40 microseconds, generates a large hole with forward peripheral petalling on the target plate varying from 2.5 inches to 3.5 inches in diameter. This indicates that the projectile had only partially penetrated the target plate at the time of the detonation and that some of the projected fragments moving with a slight net forward component of velocity had impacted and perforated the target plate. A 40-microsecond delay time at 3000 ft/sec velocity corresponds to ~ 1.44 inches of travel from first contact of the nose cap to booster detonation. The projectile is 3.563 inches long with the delay fuze attached, and 3 inches long with the standard M505A3 fuze. Therefore, the projectiles with the standard fuze would have penetrated to a depth such that almost all the high explosive in the projectile was still on the gun side of the target, as shown in Figure 26. In the case of the longer baffled fuze, 40 microseconds delay corresponds to penetration only as far as the base shoulder of the fuze, so that none of the main HEI charge has penetrated the target.

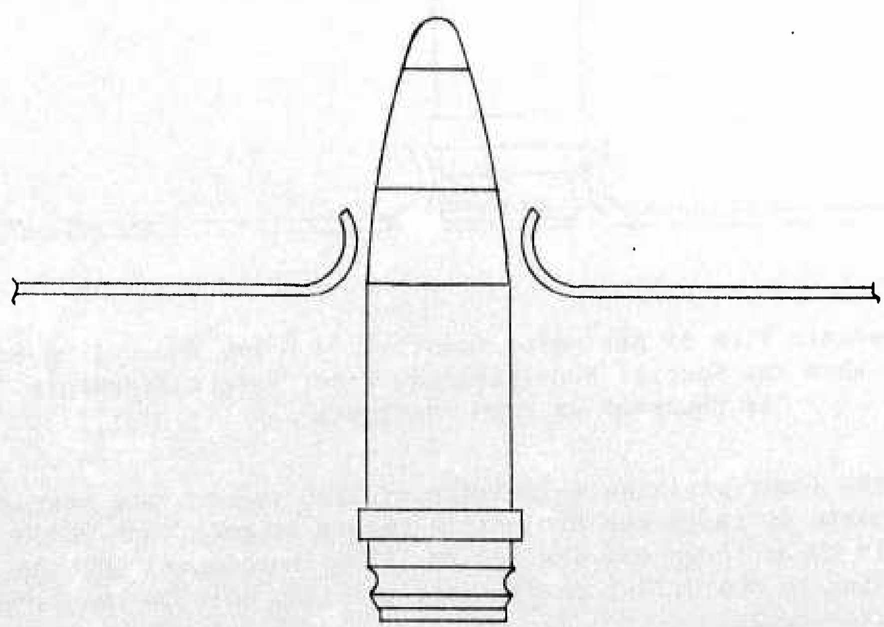


Figure 26. Schematic View of Estimated Location of M505A3 Fuzed Projectile at Time of Detonation After 40 Microseconds Delay at 2500 Feet/Second

After about 100 microseconds delay the projectile with the delay fuze would have traveled 3.6 inches. This would place the base of the projectile just about in the plane of the original target plate with the petalled portion of the target around the rear of the projectile, as shown in Figure 27. The fragments from the projectile rear would then be expected to cut off the target petals in the delay range between 100 and 110 microseconds yielding a relatively flat hole with a diameter of possibly 1 to 1.5 inches. For delay times greater than 110 to 120 microseconds (at 3000 ft/sec) the target hole should appear to be the small petalled hole about 0.75 inch in diameter similar to that generated by an inert target practice projectile.

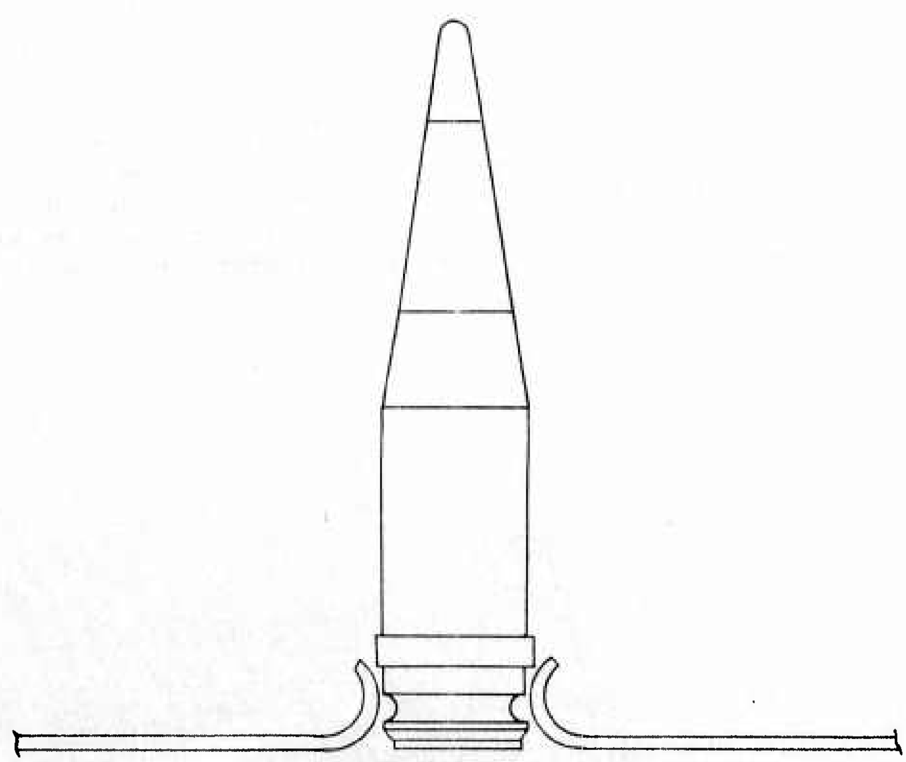


Figure 27. Schematic View of Estimated Location of Delay Fuzed Projectile at Detonation When the Special Non-Petalled, Front Target Signature is Observed as Seen in Figure 33

For the lower striking velocities of 2500 ft/sec, the corresponding delay times required to reach the projectile-target orientations which cause the target petals to be flown off are 120 to 132 microseconds, and the delay times corresponding to the 0.75-inch-diameter petalled hole in the target are > 132 to 144 microseconds.

It will be shown in the analysis that the front witness plate information obtained from the actual gun firings provided a very useful independent basis for estimating fuze delays, since there were as many as eight occurrences of the special type signature corresponding to Figure 27 in which the charge detonated when the base of the projectile was in or near the plane of the target. Fortunately, these occurred over a range of velocities, as well, which made it possible to evaluate the corresponding delay times at various velocities.

6. SIDE WITNESS PLATE SIGNATURES

In principle, the side witness plates provide a basis for estimating the spatial location of the detonating projectile and therefore a basis for estimating the fuze delay time. One method involves comparison with the signatures from M505A3 fuzed rounds having a short (~ 40 microsecond) delay. The procedure for making these estimates must however be carried out very carefully, since the reference data obtained from the standard rounds with M505A3 fuze is more complex than it first appears. The reason for the complexity is that the fragments from the standard round are launched with the projectile so located (see Figure 26) that practically all of the HEI and projectile body have not yet penetrated the target plate. Therefore, those fragments that are emitted in a direction toward the side witness plates must first pierce the target plate at relatively high obliquity angles including grazing angles. Thus, the apparent witness plate signature from the M505A3 fuzed projectiles has been shielded by the target and needs to be corrected for this shielding. The targets themselves show numerous fragment craters which fail to pierce the target.

7. CORRECTION FOR TARGET PLATE SHIELDING WITH M505A3 FUZE

Detailed examinations of the target plates on which standard fuzed (M505A3) HEI projectiles have detonated confirm that numerous projectile fragment hits show a near grazing incidence or high obliquity incidence angle on the front target plate and fail to get through the target plate under these conditions. Thus, on one typical target plate, out of 35 high angle fragments, only one penetrated and, on another plate, out of 70 high obliquity impacting fragments four penetrated. There is thus no doubt about the shielding effect of the target plate when the standard M505A3 fuzed projectile has not penetrated more than ~1.25 to 1.44 inches because of the M505A3 fuze delay which is characteristically ~ 44 microseconds.

The target plate has therefore shielded the side witness plates from some of the fragments that would have hit them in these short delay (~ 40 microseconds) M505A3 firings. This shielding does not occur once the projectile penetrates the target plate prior to detonation leaving either the characteristic 0.75-inch-diameter petalled hole (delay time > 132 to 144 microseconds at 2500 ft/sec) or even the 1.5-inch-diameter unpetalled hole (delay time between 120 and 132 microseconds at 2500 ft/sec).

A first order correction for this shielding effect can be estimated by using the observations noted above and also using JMEM data. Thus, under flight detonation conditions, in a ground fixed coordinate system centered at the detonation point quite a few fragments from the body (probably from the lower half of the projectile) are dynamically projected laterally at angles of 80 to 90 degrees to the projectile trajectory axis. In addition, examination of the JMEM statically detonated fragment velocity distribution data shows that, even when the gun-fired velocity is superimposed, there are still actually some fragments that move backward in the ground fixed coordinate system. In order to be conservative in not overestimating the baffle fuze delay times, no consideration will be given in the shielding correction to fragments having a rearward component of velocity in the dynamic (gun-fired) situation, since these fragments have relatively low net velocities which result from the counterbalancing of the rearward components of the static projection velocities and the forward gun fired velocities. A gross correction for shielding which is averaged over the middle of the velocity range results in a one-inch correction to the witness plate signatures of the standard rounds.

This type of shielding correction applies only to the baseline standard M505A3 fuzed projectile firings and will be used in the data reduction of the dynamic witness plate signatures. The correction procedure will be discussed later.

8. VELOCITY CONTROL OF FIRED PROJECTILES

Since it was desired that the baffle delay fuzes be fired at velocities near 2500 and 3000 ft/sec and since the normal full load of the propellant gave muzzle velocities of > 3300 ft/sec, the propellant load was reduced to 410 grains for obtaining velocities near 2500 ft/sec and 510 grains for velocities near 3000 ft/sec. The standard WC-870 propellant was used.

9. VELOCITY MEASUREMENT TECHNIQUE

The velocity measurement technique was designed to use double aluminum foil sensors placed 2 feet apart. The arrival at the first sensor started a counter and the arrival at the second sensor stopped the counter. The elapsed time recorded on the counter indicated the time for the projectile to travel 2 feet. The velocity screens were placed on a fixed metal frame centered about 2.5 feet in front of the target plate.

10. GUN AIMING TECHNIQUE

The gun aiming technique which was finally evolved used a 6X rifle telescope centered accurately within a 20 mm cartridge case, which was inserted into the gun chamber. The magnification was helpful in setting the telescope cross hairs on the target plate center.

11. IMPACT DISPERSION

Although all rounds hit within a 6-inch-diameter circle, there was less impact accuracy than would be expected from a 20 mm gun at a range of 100 feet from the muzzle. The impact locations were however noted and the resultant asymmetry in the witness plate signatures was corrected by averaging.

SECTION XIV

DATA OBTAINED DURING GUN-FIRED FUZE TESTS

1. BAFFLE DESIGN VARIATIONS

Since it was desired that the final baffle delay fuze design be as simple as possible, the gun fired tests provided an opportunity to check design variations and simplifications within the framework of the basic design arrived at from the quasi-dynamic firings (Figure 23). While the use of thin aluminum foils between the M26 primer and the baffle appeared to provide a convenient method for increasing the delay time, their omission would represent a design and assembly simplification. Therefore, three variations of the basic design were tested during the gun firings. The standard baffle design with an 0.028-inch-diameter axial hole was tested with zero and six aluminum foils. In studying the possibility of eliminating the aluminum foils below the M26 primer, two compensatory design changes were made. The first involved a further reduction of the axial hole diameter to 0.024 inch. The second involved an increase in the expansion volume below the baffle itself. Thus, rounds 1 to 7 were all fired with the standard baffles having 0.028-inch-diameter central holes and with aluminum foil, ranging from zero to six foils. This assembly is shown in Figure 28. Rounds 9 to 13 were also fired with baffles having 0.028-inch-diameter central holes but with an increased expansion volume below the baffle (Figure 29). These all contained eight aluminum foils. Rounds 14 through 32 were fired with an 0.024-inch-diameter central hole, increased expansion volume below and the baffle and no aluminum foils. Rounds 33 through 36 were M505A3 fuzed rounds.

2. SUMMARY OF DATA COLLECTED DURING GUN FIRINGS

The data collected during the gun firings is summarized in Table 11 and 12. Table 11 contains the target plate and witness plate data. Table 12 contains the velocity, baffle delay details, average side witness plate signature, and the average estimated fuze delay time determined by two independent methods. The first method is based upon the target plate shielding correction for the side witness plate data. The second method is based upon the information contained in those characteristic front witness plate signatures that correspond to the geometrical conditions shown in Figure 27, in which the base of the projectile must be very close to the plane of the target plate at the time of detonation. Figure 33 shows such a target plate. These two methods will be discussed in the section on analysis of data.

Typical target and witness plate signatures are shown in Figures 30, 31, 32 and 33. The arrow shows the direction of projectile motion. Thus, Figure 30 illustrates how the standard M505A3 fuzed projectile (~ 40 microseconds delay) generates the characteristic large target hole and the side witness plate pattern (close to the right hand edge of the plates) which also provides additional evidence of target shielding.

Figure 31 provides an illustration of a target plate showing the characteristic small hole (designated at 1-P) associated with delayed fuze action. This hole is about one inch in diameter and petalled about 0.375 inch

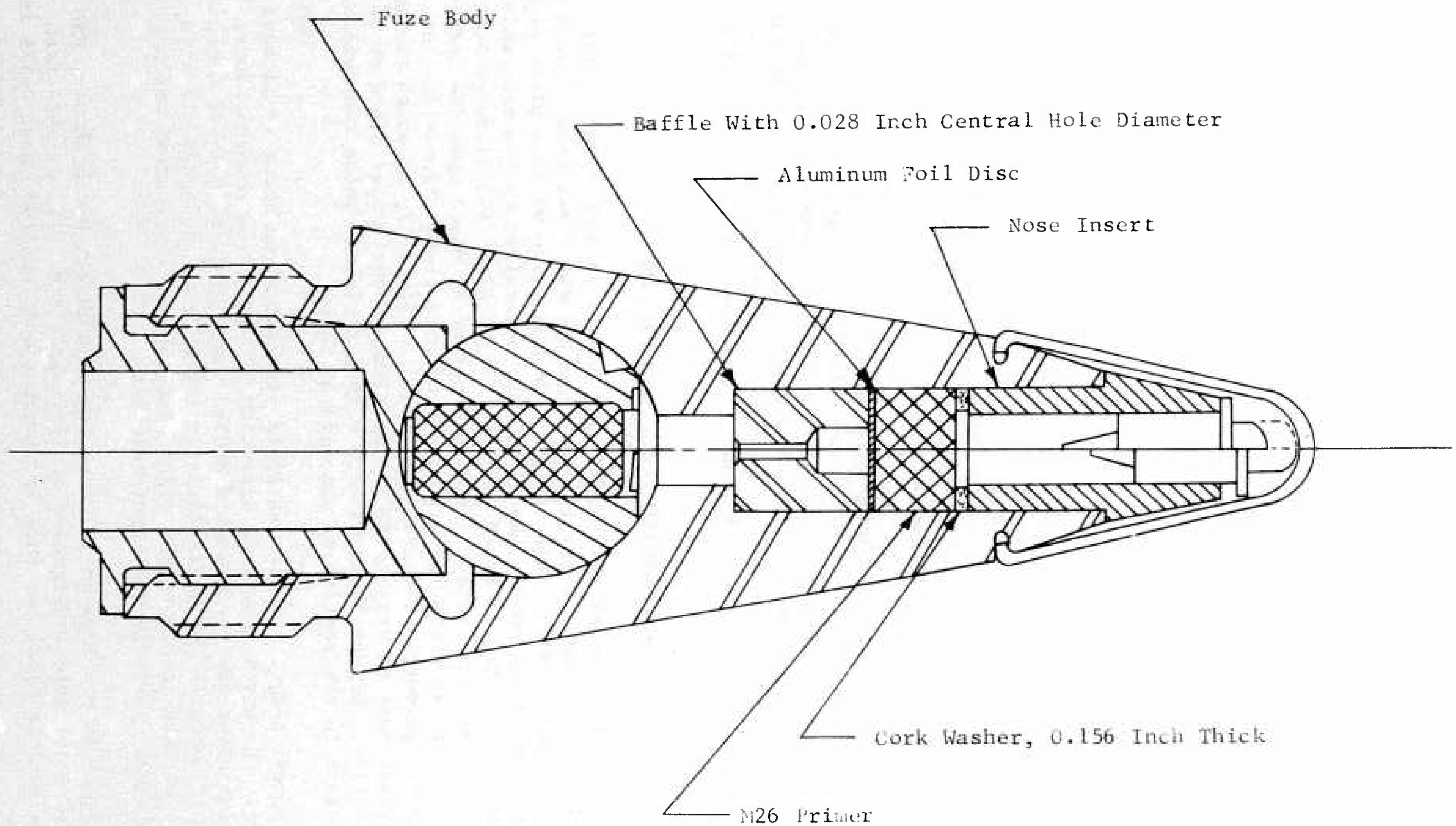


Figure 28. Delay Fuze Assembly Used for Rounds 1 - 7 Inclusive

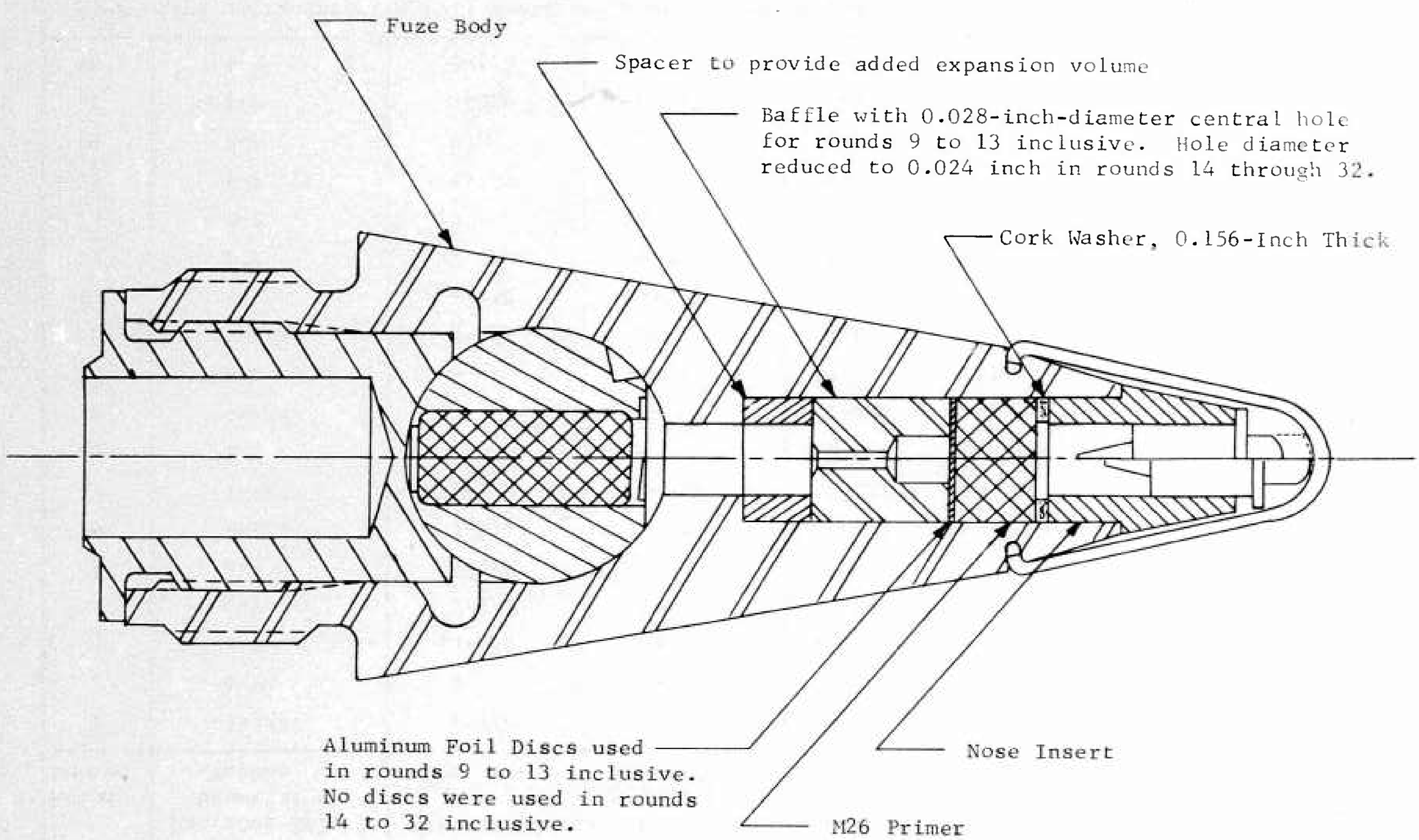


Figure 29. Delay Fuze Assembly Variations Used in Rounds 9 to 13 and Rounds 14 to 32 Inclusive

TABLE 11. SUMMARY OF TARGET AND SIDE WITNESS PLATE MEASUREMENTS

Round Number	Target Plate Entrance Hole Diameter - Inches	Location of First Signature on Side Witness Plates - Distance Behind Target in Inches			Remarks
		Left Plate	Right Plate	Average	
1	1-1/2	4-7/8	4	4-3/8	Special target signature (Fig 27)
2	1-P*	7	4-3/4	5-7/8	
3	1-P	13-1/2	15-1/4	14-3/8	
4	1-P	5-1/2	3	4-1/4	
5	1-P	4-1/2	7	5-3/4	
6	2-1/8	2-3/4	2-3/4	2-3/4	Special target signature (Fig 27)
7	1-1/8	2-1/2	2-1/2	2-1/2	Special target signature (Fig 27)
8	3	7	4	5-1/2	Standard M505A3 fuze-anomalous
9	1-3/8	3-1/2	4	3-3/4	Special target signature (Fig 27)
10	1-P	----	19	19	Deflagration
11	1 1/2	3-1/2	3	3-1/4	Special target signature (Fig 27)
12	1-P	4-1/2	4-1/2	4-1/2	
13	1-P	2-3/4	4-3/4	3-3/4	
14	1-P	19	20	19-1/2	Deflagration
15	1-P	5-1/2	7	6-1/4	
16	1-P	8	5	6-1/2	
17	1-P	4-3/4	4-1/2	4-5/8	
18	1-P	6-1/2	5	5-3/4	

*1-P means characteristic hole about one inch in diameter with petalling seen for delays longer than ~ 120 microseconds or penetrations by inert target practice projectiles.

TABLE 11. SUMMARY OF TARGET AND SIDE WITNESS PLATE MEASUREMENTS (Concluded)

Round Number	Target Plate Entrance Hole Diameter-Inches	Location of First Signature on Side Witness Plates - Distance Behind Target in Inches			Remarks
		Left Plate	Right Plate	Average	
19	1-P	----	7	7	Deflagration
20	1-P	4-1/2	4-1/4	4-3/8	
21	1-P	6	4-3/4	5-3/8	
22	1-P	4-3/4	5	4-7/8	
23	1-5/8	5-1/2	2-1/2	4	Special target signature (Fig 27)
24	1-P	12-1/4	9	10-5/8	
25	1-P	20	----	20	Deflagration
26	1-P	6	4	5	
27	1-1/2	4	1-1/2	2-3/4	Special target signature (Fig 27)
28	1-P	13-1/2	20-1/4	17	Deflagration
29	1-P	3-1/2	3-1/2	3-1/2	
30	1-P	5	3-1/2	4-1/4	
31	1-P	4-1/2	2-1/4	3-3/8	
32	1-3/4	3-1/2	1-1/2	2-1/2	Special target signature (Fig 27)
33	4-1/2	2-1/2	2-1/4	2-3/8	Standard M505A3 fuze
34	4-1/2	3	1	2	Standard M505A3 fuze
35	3-1/2	3	1	2	Standard M505A3 fuze
36	1-P	Failed to	function	----	Standard M505A3 fuze

TABLE 12. SUMMARY OF GUN FIRED DATA - WITH BAFFLE DELAY FUZES FIRED IN 20 mm PROJECTILES AT NORMAL OBLIQUITY AGAINST 0.063 INCH THICK 2024-T3 ALUMINUM ALLOY PLATE

Round Number	Measured Velocity- Feet Per Second	Type*	Central Hole Diameter- Inches	Number of Aluminum Foils	Average Side Witness Plate Signature Locations Inches Behind Target	Average of Two Methods Estimated Fuze Delay Time in Microseconds	Remarks
1	3295	A	0.028	0	4-3/8	108	Full propellant charge
2	3288	A	0.028	6	5-7/8	156	Full propellant charge
3	3292	A	0.028	6	14-1/2	365	Full propellant charge
4	2895	A	0.028	6	4-1/4	127	Reduced propellant charge
5	2887	A	0:028	6	5-3/4	171	
6	2486	A	0.028	6	2-3/4	110	Reduced propellant charge
7	2413	A	0.028	6	2-1/2	108	
8	3273	Standard M505A3 Complete Round		Fuzed	5-1/2	(40)	Anomalous - not corrected for shielding
9	2890	B	0.028	8	3-3/4	112	
10	2920	B	0.028	8	19	543	Deflagration
11	2778	B	0.028	8	3-1/4	108	
12	2941	B	0.028	8	4-1/2	133	
13	2874	B	0.028	8	3-3/4	114	
14	2882	B	0.024	0	19-1/2	568	De agration

* Type A Baffle - Figure 28. Normal Expansion Volume
Type B Baffle - Figure 29. Additional Expansion Volume

TABLE 12. SUMMARY OF GUN FIRED DATA - WITH BAFFLE DELAY FUZES FIRED IN 20 mm PROJECTILES AT NORMAL OBLIQUITY AGAINST 0.063 INCH THICK 2024-T3 ALUMINUM ALLOY PLATE (Continued)

Round Number	Measured Velocity- Feet Per Second	Type*	Central Hole Diameter- Inches	Number of Aluminum Foils	Average Side Witness Plate Signature Locations Inches Behind Target	Average of Two Methods Estimated Fuze Delay Time in Microseconds	Remarks
15	2945	B	0.024	0	6-1/4	181	
16	2937	B	0.024	0	6-1/2	190	
17	2915	B	0.024	0	4-5/8	138	
18	2928	B	0.024	0	5-3/4	168	
19	2915	B	0.024	0	7	205	Deflagration
20	2907	B	0.024	0	4-3/8	130	
21	2972	B	0.024	0	5-3/8	156	
22	2946	B	0.024	0	4-7/8	143	
23	2928	B	0.024	0	4	118	
24	2484	B	0.024	0	10-5/8	376	
25	2488	B	0.024	0	20	690	Deflagration
26	2445	B	0.024	0	5	173	
27	2513	B	0.024	0	2-3/4	109	
28	2442	B	0.024	0	17	600	Deflagration

*Type B Baffle - Figure 29. Additional Expansion Volume

TABLE 12. SUMMARY OF GUN FIRED DATA - WITH BAFFLE DELAY FUZES FIRED IN 20 mm PROJECTILES AT NORMAL OBLIQUITY AGAINST 0.063 INCH THICK 2024-T3 ALUMINUM ALLOY PLATE (Concluded)

Round Number	Measured Velocity-Feet Per Second	Type*	Central Hole Diameter-Inches	Number of Aluminum Foils	Average Side Witness Plate Signature Locations Inches Behind Target	Average of Two Methods Estimated Fuze Delay Time in Microseconds	Remarks
29	2361	B	0.024	0	3-1/2	144	
30	2460	B	0.024	0	4-1/4	164	
31	2451	B	0.024	0	3-3/8	135	
32	2427	B	0.024	0	2-1/2	97	
33	2541	Standard M505A3 Fuzed Projectiles with Reduced Propellant Charges for Velocity Control			2-3/8	(40)	Uncorrected for shielding
34	2532				2	(40)	Uncorrected for shielding
35	3026				2	(40)	Uncorrected for shielding
36	3021				----		Failed to function

*Type B Baffle - Figure 29. Additional Expansion Volume

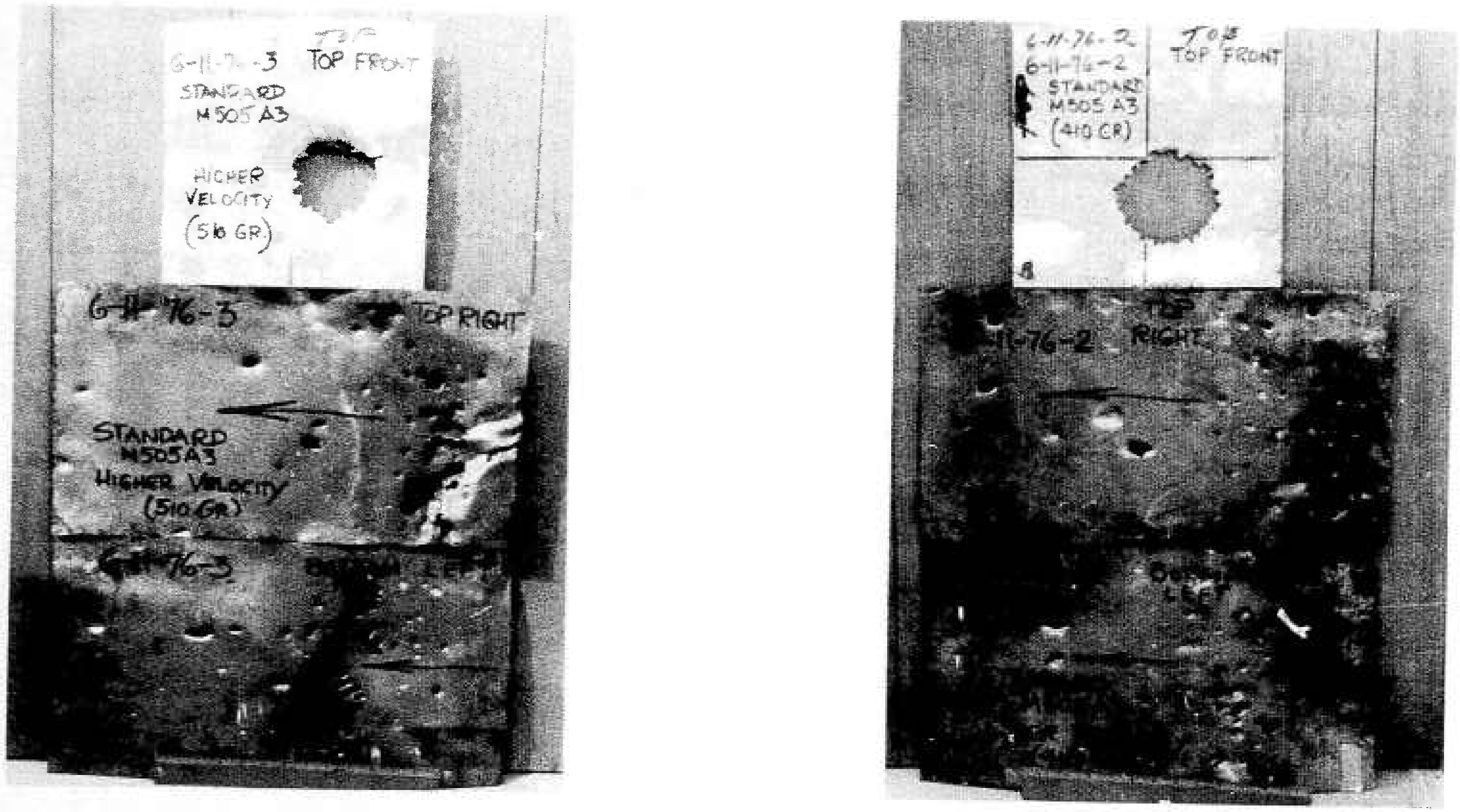
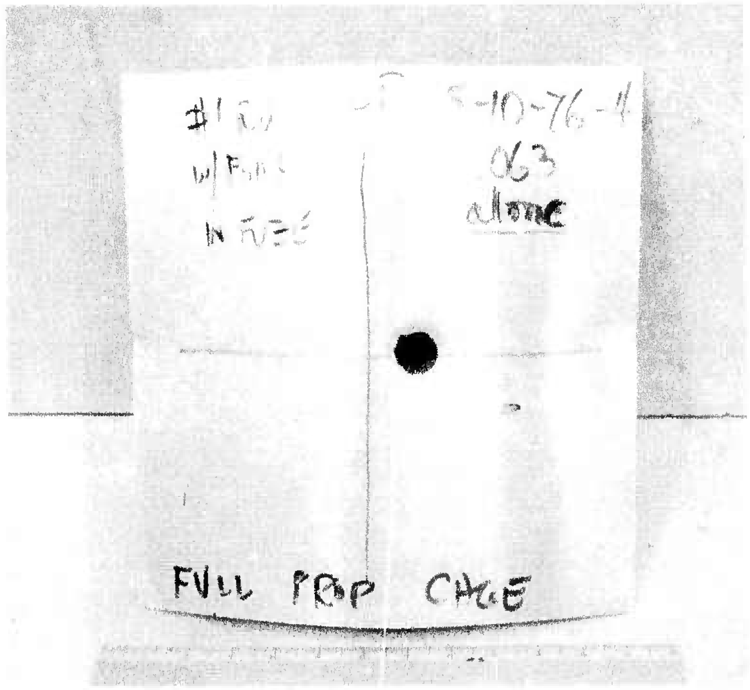


Figure 30. Characteristic Large Petalled Target Hole Signatures Obtained With M505A3 Fuzes



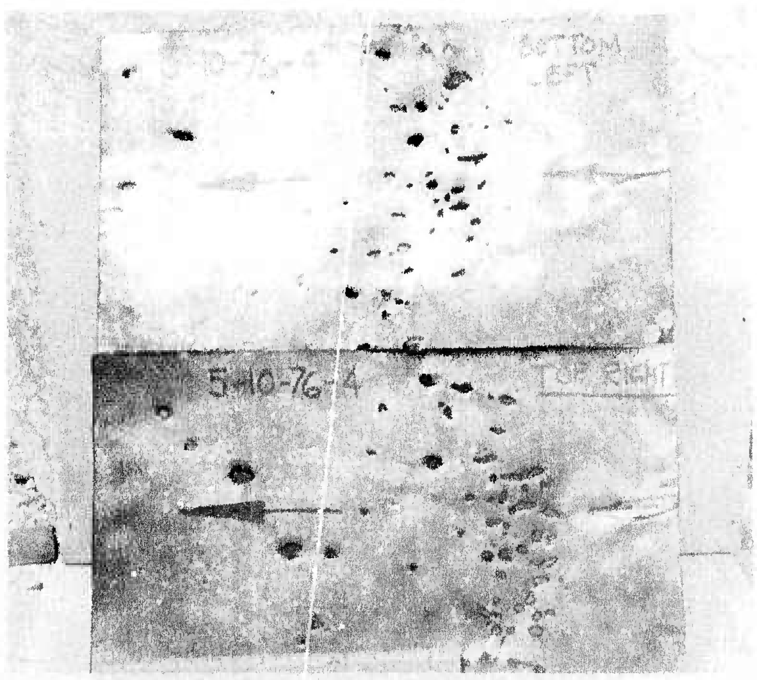
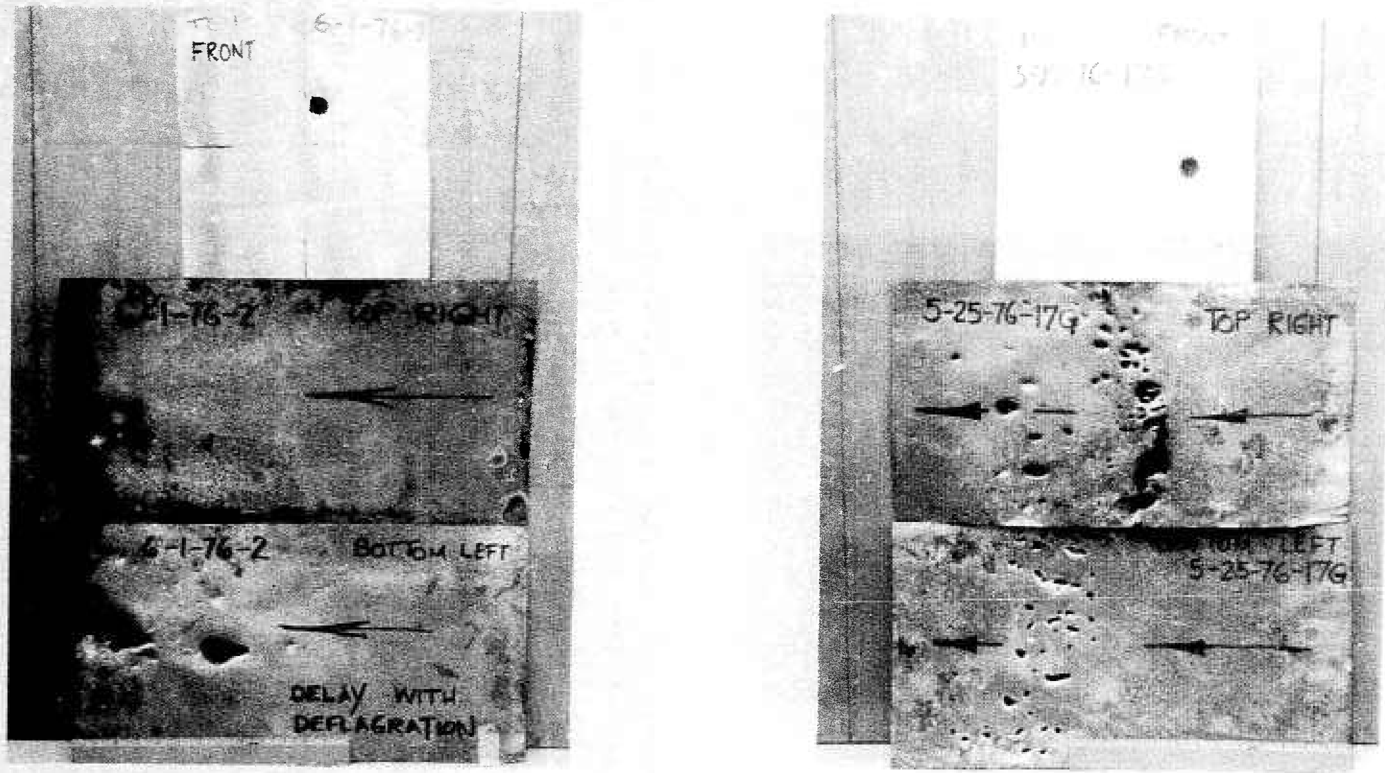


Figure 31. Characteristic Small 1-Inch-Diameter Petalled (1-P) Target Hole and Side Witness Plate Signature Obtained With Delay Fuze Functioning



(a) (b)

Figure 32. Example of Deflagration Signature (a) and Example of Long Delay (376 microseconds) Signature (b)

Figure 33. Example of Fuze Functioning Which Yielded Special Signature on Target Plate, Associated With the Projectile Location Shown in Figure 27

in the direction of the projectile motion. It is identical to the hole made by an inert target practice projectile. The associated side witness plates show the fragment pattern displaced in the direction of the projectile motion from the right-hand edge of the plates because of the fuze delay.

Figure 32 illustrates two other interesting results. The upper photograph illustrates a relatively long fuze delay with the characteristic front target hole (1-P) and with the asymmetry in the side witness plate signatures due to the displacement of the impact point from the target center. Thus, it is evident from the location of the target plate hole that the detonation of the projectile occurred when the projectile axis was about 3 inches from the right-hand side witness plate and about 9 inches from the left-hand side witness plate. This asymmetry is corrected by averaging the two witness plate measurements. The bottom photograph in Figure 32 illustrates a delayed fuze functioning accompanied by what was interpreted as a deflagration rather than a detonation of the HEI in the projectile because the witness plate signature showed large projectile pieces rather than the usual small ones resulting from a normal detonation. This phenomenon is believed to be associated with the ammunition itself rather than the delay fuze.

Finally, Figure 33 illustrates an example of an important special signature condition noted in some of the delayed fuze functioning observations which correspond to the geometrical condition shown in Figure 27. The hole left in the target plate is only moderately larger than the characteristic (TP) hole but much smaller than the characteristic M505A3 fuzed signature. The special signature hole does not show the petalling found on either of the other two types of target plate signatures. These observations mean that the projectile base must have been just within or slightly past the plane of the target when it detonated. Since the projectile velocity was measured to be 2890 ft/sec for this round, and since the projectile length from fuze tip to base is 3.6 inches, the functioning delay time would have to be at least 104 microseconds. This delay corresponds to a particular side witness plate signature measurement of 3.75 inches, and represents the limiting condition for which no target shielding is possible.

There were a total of eight such special signature data shots, including one near 3300 ft/sec, three near 2900 ft/sec, and four near 2500 ft/sec, in which similar signatures occurred. The data they present will be used in Method II in the analysis.

SECTION XV

ANALYSIS OF GUN-FIRED FUZE DATA

1. GENERAL

Two independent methods were used for analyzing the target and witness plate data in order to estimate the fuze functioning delay. The first method made use of the reference witness plate data from Rounds 33, 34 and 35, which were obtained with M505A3 fuzes fired in the same velocity range as the delay fuze firings. A target shielding correction was applied to obtain an estimate of what the witness plate signature locations would have been in the absence of target shielding. The corrected signature for the reference rounds was then compared with the test fuze signatures.

The second method made use of the eight rounds in which the special target plate signature was observed by obtaining from these target signatures the side witness plate signatures corresponding to one projectile length penetration. This reference yardstick was then used to measure the displacement of the other side witness plate signatures. The two methods will be discussed and examples will be given of a typical computation.

2. METHOD I - M505A3 REFERENCE METHOD

In order to simplify the computations by this method, a single correction was applied to the signatures of the reference rounds. Thus, if the distance of the uncorrected first fragment hole behind the target in the side witness plate was observed to be D, then the corrected location became $D_C = (D-1)$. The corrected signature indicates the estimated location of the first fragment holes if target shielding had not prevented the closer fragments from reaching the side witness plate.

Since this method is relatively simple a single corrected signature was assigned without considering all of the possible refinements based upon striking velocity and firing pin velocity. Considering the simplicity of this approach, it is surprising how well these estimates agreed with those obtained independently by using Method II.

The procedure for applying Method I is as follows:

(1) The single corrected value of D_C for the three rounds was taken as 1 inch for the M505A3 fuzed rounds.

(2) This corrected signature, D_C, was associated with the approximate 40-microsecond fuze delay time observed repeatedly during the quasi-dynamic fuze tests, with the M505A3 calibration fuzes.

(3) For a delay-fuzed round which gave a side witness plate signature location D_d, the difference (D_d-D_C) was attributed to additional projectile travel before detonation.

(4) At a given velocity the time, t_Δ, in microseconds required for the projectile to travel the additional distance $(D_d - D_C)$, where both D_d and D_C are measured in inches, is given by

$$t_\Delta = \left(\frac{D_d - D_C}{12V}\right) \times 10^6$$

(5) Hence the total fuze delay time is given by adding 40 microseconds to t_Δ, i.e., $t_d = t_\Delta + 40$ microseconds.

A simple calculation is given below for round number 26

$$D_d = 5 \text{ inches}$$

$$D_C = 1 \text{ inch}$$

$$D_d - D_C = 4 \text{ inches} \qquad V = 2488 \text{ ft/sec}$$

$$t_\Delta = \frac{4 \times 10^6}{12 \times 2488} = 136 \text{ microseconds}$$

$$\therefore t_d = 136 + 40 = 176 \text{ microseconds total fuze delay.}$$

Method I was applied to all of the delay fuzed witness plate measurements and compared with independent Method II which will be discussed below. The results obtained with the two independent methods were then averaged. It is these average estimates that appear in Table 12.

3. METHOD II - SPECIAL TARGET PLATE SIGNATURE TECHNIQUE

The information contained in those shots in which the special signature was obtained on the target plate is that the particular value of D_d is associated with one projectile length penetration (Figure 27).

If all the special signature rounds are tabulated, it is found that there are four such signatures at around 2460 ft/sec, three signatures at around 2865 ft/sec, and one signature at 3295 ft/sec.

Table 13 shows a very important result since it becomes possible to correlate the average value of D_d with the projectile striking velocity, under the identical condition that in all cases the projectile which generated that witness plate signature had penetrated one projectile length at the time of detonation. This reference mark for the signature can now be used to determine how many projectile lengths of penetration can be associated with any given signature location.

TABLE 13. PERTINENT DATA FOR ALL EIGHT ROUNDS SHOWING THE SPECIAL TARGET HOLE SIGNATURE CORRESPONDING TO ONE PROJECTILE LENGTH OF PENETRATION.

Round Number	Measured Velocity-Feet Per Second	Side Witness Plate Signature in Inches D_{IL}
6	2486	2.75
7	2413	2.50
27	2513	2.75
32	2427	2.50
AVERAGE	2460	2.63
9	2890	3.75
11	2778	3.25
23	2928	4.0
AVERAGE	2865	3.66
1	3295	4.38

At any given striking velocity, the delay time required to penetrate one projectile length is easily determined. For projectile lengths measured in inches, the delay time in microseconds and the velocity in ft/sec, the relationship is given by

$$t_{IL} = \frac{L \times 10^6}{12 \times V} \text{ microseconds}$$

When the witness plate signature in a given velocity range is D_d, then the difference between D_d and the average value of D_{IL} in Table 13 is given for that velocity range, then $(D_d - D_{IL})$ represents the extra distance traveled by the projectile beyond one projectile length of penetration. Hence, the additional time, t_Δ, associated with the additional travel is

$$t_\Delta = \left(\frac{D_d - D_{IL}}{12 \times V}\right) \times 10^6 \text{ microseconds}$$

The total delay time t_{total} is now given by the sum

$$t_{total} = t_\Delta + t_{IL} \text{ microseconds}$$

A sample calculation using Method II is given below for the same round number 26 which was used in the example for Method I.

$$L = 3.6 \text{ inches (projectile length with delay fuze)}$$

$$D_d = 5 \text{ inches (first signature behind target)}$$

$$V = 2445 \text{ ft/sec}$$

$$\therefore D_{IL} = 2.63 \text{ inches (for IL penetration)}$$

$$(D_d - D_{IL}) = 1.37 \text{ inches further travel}$$

$$t_\Delta = \frac{1.37 \times 10^6}{12 \times 2445} \cong 47 \text{ microseconds}$$

$$t_{IL} = \frac{3.6 \times 10}{12 \times 2445} \cong 123 \text{ microseconds}$$

$$t_{total} = 123 + 47 = 170 \text{ microseconds}$$

4. COMPARISON AND AVERAGE OF THE TWO METHODS

In the particular case of round 26, the agreement between Method I (176 microseconds) and Method II (170 microseconds) is considerably better than the average agreement observed over all rounds. However, the agreement overall is reasonable considering the simplistic approach used for Method I.

Table 14 shows the individual round delay time estimates obtained with the two methods, as well as the delay time value obtained by averaging the two estimates.

An analysis of the differences between the two methods shows that Method I tends to be systematically on the high side for the high velocities (~ 3300 ft/sec) on the low side for the low velocities (~ 2500 ft/sec) and systematically only slightly high (~ 14 microseconds) in the intermediate velocity range (~ 2900 ft/sec). Differences of that order ,ould easily arise from firing pin velocity differences at the different striking velocities which have been ignored in simplifying the method.

TABLE 14. COMPARISON OF THE DELAY TIME ESTIMATES BY THE TWO INDEPENDENT METHODS AND THE AVERAGE ESTIMATED DELAY TIME.

Round Number	Delay Time Estimates		Difference In Microseconds	Average of Both Methods
	METHOD I	METHOD II		
1	125	91*	34	108
2	164	149	15	156
3	382	347	35	365
4	134	121	13	127
5	177	164	13	171
6	99	121*	22	110
7	92	124*	32	108
8	M505A3 Fuze			(40)
9	119	104*	15	112
10	544	542	2	543
11	107	108*	1	108
12	139	126	13	133
13	120	107	13	114
14	575	561	14	568
15	189	174	15	181
16	196	183	13	190
17	144	131	13	138
18	175	162	13	169
19	211	198	13	205
20	137	124	13	130
21	163	149	14	156
22	150	137	13	143
23	125	112*	13	118
24	363	389	26	376
25	676	704	28	690
26	176	171	5	173

*Represents special signature data point for Method II.

TABLE 14. COMPARISON OF THE DELAY TIME ESTIMATES BY THE TWO INDEPENDENT METHODS AND THE AVERAGE ESTIMATED DELAY TIME (Concluded)

Round Number	Delay Time Estimates		Difference In Microseconds	Average of Both Methods
	METHOD I	METHOD II		
27	98	119*	21	109
28	586	613	27	600
29	128	158	30	143
30	150	177	27	164
31	121	148	27	135
32	92	103*	11	97
33	M505A3 Fuzes			(40)
34	M505A3 Fuzes			(40)
35	M505A3 Fuzes			(40)
36	M505A3 Fuze - Failed to Detonate			----

*Represents special signature data point for Method II

5. EVALUATION OF THE PERFORMANCE OF A HOMOGENEOUS SAMPLE

If the five questionable long delay time estimates associated with the deflagrations are eliminated, the remaining individual average fuze delays can be further analyzed to provide an overall average. There are 26 total valid observations with the baffle delay fuze. However, of these only 15 valid data points were obtained in rounds 14 to 32, in which all rounds involved the same delay baffle design fired at two different velocities. The delay baffle design in these 15 rounds involved the 0.024 inch central hole with the spacer below the baffle to provide added expansion volume. No aluminum foils were used.

The average delay time for these 15 identical delay baffles is 162 microseconds, with the extremes in the 15 rounds ranging from 376 microseconds to 97 microseconds. All of these rounds penetrated the target at least one projectile length. Since the average delay time was 162 microseconds, the average penetration was in excess of 1-1/2 projectile lengths.

This is the simplest version of the delay baffle, containing no aluminum foil delay extenders. It was not possible to evaluate the effect of such aluminum foils on the gun fired experiments, since it was felt that the statistical base needed for evaluation did not permit the changing of any more variables. However, on the basis of the quasi-dynamic data obtained earlier and shown in Tables 6, 7 and 8, it is believed that the average delay time could be substantially extended from the present average of 162 microseconds by means of the addition of aluminum foils below the primer. The potential disadvantage of the added requirement for the foils as well as the desire to avoid the potential plugging problem in these firings is what prompted the gun fired evaluations to be made without foil delay extenders.

SECTION XVI

SUMMARY AND CONCLUSIONS

The primary objective of the program was to determine the technical feasibility of using a baffle delay system to obtain additional fuze functioning delay in an M505A3 type fuze.

There were two major phases of the program. The first involved the use of quasi-dynamic impact simulation techniques to obtain fuze functioning delay times in the study of the baffle delay designs. The second phase involved the firing of live projectiles assembled with baffle delay fuzes from a 20 mm gun.

The original basic baffle delay design concept consisted of several elements. The first element was an M26 primer which was initiated upon target impact by the standard fuze firing pin. The combustion products from the M26 primer were passed through a first aperture, an expansion chamber and a second aperture before expanding into an expansion chamber above the M57A1 detonator. Simpler versions were devised later which consisted of only one central aperture and one expansion chamber.

The results of the quasi-dynamic studies indicated that there were several baffle delay designs which could fit into an M505A3 fuze with a lengthened body, and which could produce delays averaging in excess of 250 microseconds. These baffle delay configurations were specifically simplified to permit the initiation of the M57A1 detonator in the rotor, without requiring perforation to expose the primer mix.

This was an important improvement over earlier design concepts, both foreign and American, which had required the exposure of a free primer mix surface in the detonator. Avoiding this requirement avoided many problems including storage problems, some of which were noted during the experiments.

In order to adapt the basic delay baffle designs to gun-fired fuzes, further design simplifications were devised, which permitted the baffle delay system to be inserted into a slightly modified fuze body from the firing pin end. These designs were ultimately tested in the 20 mm gun firings.

The 20 mm gun firings indicated that the baffle delay concept was indeed a technically viable one. The simplifications that were necessary for program cost effectiveness reasons in the selected gun-fired baffle delay designs were such as to reduce the delay obtained without the use of aluminum foil delay extenders to an average of 162 microseconds, which is still sufficient to make the average projectile penetrate more than 1-1/2 projectile lengths. All projectiles, including those with the shortest dynamic delay, penetrated at least one projectile length before detonation. However, additional methods, previously tested during the quasi-dynamic firings, involving the use of aluminum foil between the M26 primer and the baffle delay element, would be expected to bring the delay level back to the range of 250 microseconds.

The present study indicated that the inherent design of some of the standard components, e.g., the M57A1 detonator in the rotor, were likely contributors to the observed variability of the delay times. Thus, the allowed thickness specification at the primer end of the detonator cup is 0.007 to 0.003 inch. This large allowed thickness variation can in fact be reduced to the order of 0.001 inch by a coining operation on the detonator cup and would be expected to reduce the spread in the delay times.

The ultimate cost-effective solution to the fuze delay problem for the 20 to 30 mm range of projectile calibers is believed to be the further miniaturization of the baffle delay to permit it to be placed within the detonator itself.

It is concluded that the results obtained both in the quasi-dynamic studies and the gun firings indicate that the baffle delay concept is a technically viable one for obtaining the desired range of fuze functioning delays, and it is recommended that work be undertaken to develop the intrinsic baffle delay detonator.

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