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AFATL-TR-75-76

DEVELOPMENT OF A THIN-WALL 20mm EXPLOSIVE PROJECTILE

AAI CORPORATION
INDUSTRY LANE
COCKEYSVILLE, MARYLAND 21030

MAY 1975

FINAL REPORT: APRIL 1974 - APRIL 1975

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AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 19 AFATL-TR-75-76

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): 6 DEVELOPMENT OF A THIN-WALL 20MM EXPLOSIVE PROJECTILE.

5. TYPE OF REPORT & PERIOD COVERED: 9 Final Rep[redacted]t. Apr[redacted] 1974 – [redacted] Apr[redacted] 1975

6. PERFORMING ORG. REPORT NUMBER: 14 AAI-ER-8296

7. AUTHOR(s): 10 Walter L. Black

8. CONTRACT OR GRANT NUMBER(s): 15 F08635-74-C-0116 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
AAI Corporation
Industry Lane
Cockeysville, Maryland 21030

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
Project No. 670F 16 AF-670F
Task No. 01
Work Unit No. 009 17 1

11. CONTROLLING OFFICE NAME AND ADDRESS:
Air Force Armament Laboratory
Air Force Systems Command
Eglin Air Force Base, Florida 32542

12. REPORT DATE: 11 May 1975

13. NUMBER OF PAGES: 76 12 76p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):
Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied May 1975. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:
Available in DDC.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
20mm Projectiles
Plastic Rotating Bands
Thin Wall Projectiles
High Explosive Incendiary Projectiles

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
Development of an improved 20mm high explosive incendiary (HEI) projectile is discussed. Improved performance is accomplished by configuration changes which reduce projectile weight, improve the aerodynamic shape, and increase the high explosive material. The improvements are achieved by thinning the projectile walls, by the choice of material, heat treat, and incorporation of a plastic rotating band. The analytical design and test experience acquired in developing this improved projectile are reviewed.

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SUMMARY

A development program was conducted to explore means of improving the performance characteristics of 20mm high explosive incendiary (HEI) projectiles. The goal was to improve its hit probabilities by reducing its time of flight and further enhance its effectiveness by increasing its kill capability after a hit has been scored. The findings of this program show this goal can be accomplished with a thin-wall projectile design having a significantly reduced weight and improved aerodynamic properties, yet concurrently providing added space for high explosive and incendiary materials which enhance its lethality. Furthermore, it is fully compatible with existing cartridge case and M-61 gun systems.

This improved design was accomplished by reducing the thickness of the projectile wall to the least practical value, thereby replacing space occupied by high density steel with low density high explosive. This provided a significant increase in the charge-to-metal ratio, an important parameter in terminal effectiveness. This configuration change in the projectile was achieved through the choice of material, heat treating the material, and the use of finite element analytical techniques to provide a minimum weight design. The use of a bonded plastic rotating band having a small intrusion into the projectile wall was also very instrumental in reducing the wall thickness.

The experience acquired in developing the projectile is reviewed in this report. Approximately 400 units were expended in tests designed to acquire information on various aspects of the projectile design. This test experience is reviewed along with the analytical work and other considerations pertinent to the projectile design. An appreciable effort was devoted to the investigation of materials and the method of bonding the plastic rotating band to the projectile. A review of this work is included.

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PREFACE

This program was conducted by the AAI Corporation, Industry Lane, Cockeysville, Maryland 21030, under Contract F08635-74-C-0116 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida. Captain Earl Connor (DLDG) managed the program for the Armament Laboratory. The program was conducted during the period from April 1974 to April 1975.

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

FOR THE COMMANDER

ALFRED D. BROWN, JR., Colonel, USAF
Chief, Guns, Rockets and Explosives Division

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SECTION I

INTRODUCTION

The Air Force is sponsoring a program to update the design of the 20mm projectile to increase its effectiveness in the air-to-air and air-to-ground combat situations. The program embraces development work on both the fuze and the projectile body. This program was performed to investigate means of improving the projectile. Development work on the fuze was performed under a separate program.

Air-to-air combat effectiveness can be improved by two factors: (1) short time-of-flight for combat ranges and (2) greater warhead lethality. Short time-of-flight improves the probability of hitting the target, particularly in combat between modern high performance aircraft. Two ways of reducing time-of-flight are (1) increase the muzzle velocity and (2) reduce the aerodynamic drag of the projectile.

Working with the current M103 cartridge case and the M-61 gun systems are logical constraints which leaves two means open to increase muzzle velocity: One is to alter the propellant, and the other is to reduce the weight of the projectile. Both of these approaches were employed,but the major effort was devoted to reducing the weight of the projectile. This was accomplished by thinning the walls of the projectile, thus switching space occupied by high density steel to space occupied by low density explosive. Thinning the walls of the projectile was accomplished through the choice of material, heat treating the material, and configuration changes. Configuration changes were accomplished by sizing the walls of the projectiles to work at stress levels commensurate with the stress allowables that heat treating provided. A finite element analysis technique was instrumental in achieving a design that provides uniform stress levels throughout the projectile. The use of a plastic rotating band that limited intrusion of the band into the wall of the projectile was also quite instrumental in achieving a practical thin-wall projectile design.

The weight reduction achieved by thinning the walls and the use of a plastic rotating band to reduce the start force resulted in a marked reduction in the peak chamber pressure. The chamber pressure was raised back to the level permitted by the gun by blending propellants to provide more rapid burning. This resulted in a substantial increase in the muzzle velocity. Since the muzzle velocity and cross-sectional density of the projectile are fixed, the only way to further decrease time-of-flight is by decreasing the drag. Some of the projectile configurations employ an improved low drag aerodynamic shape.

Greater warhead lethality improves projectile effectiveness and can be accomplished by improvements in a number of areas. Parameters to be considered are:

(1) Increased charge-to-metal ratio.

(2) Increased HE capacity.

(3) Improved incendiary effects.

(4) Choice of explosive.

(5) Controlled fragmentation.

(6) Use of a delay fuze to inhibit functioning past the point of initial contact with the skin of the aircraft.

The delayed action fuze was the subject of a separate program and no effort was expended here except to interface properly with the modified fuze configuration. Also, no effort was expended in developing or locating an alternate explosive. The explosive employed in the M-56 current design was used. No attempt was made to control fragment size by any of the devices available for this purpose. However, other factors such as the charge-to-metal ratio and the configuration changes have some effect on this parameter. The charge-to-metal ratio was increased appreciably by thinning the projectile walls, and the amount of HE compacted into the projectile was increased significantly. Also, special provisions were made to improve the incendiary property of the projectile by inclusion of zirconium metal in the HE cavity.

The foregoing discussion provides an overview of the objectives of the program and the nature of the designs that were generated to achieve these objectives. The following discussions review the development experience and summarize the results of this development effort.

SECTION II

INVESTIGATIONS

1. CONFIGURATION STUDIES

The program was planned to investigate four basic projectile configurations. They encompassed minimum weight and maximum HE capacity projectile designs for each of two fuze configurations. The two fuze configurations were the standard M505A3 fuze and a version of this fuze that was modified to improve the aerodynamic shape and provide delayed action that will explode the projectile inside aircraft structure. In the minimum weight design the emphasis is on time-of-flight; the maximum HE capacity approach emphasizes its lethality.

Actually, all four projectile designs are minimum weight designs insofar as the projectile body itself is concerned. The objective was to minimize the metal and maximize the HE cavity in each projectile. The constraints were compatibility with their respective fuze, the M103 cartridge case, and the M-61 gun systems.

Compatibility with the M505A3 fuze was accomplished by making the threaded connection that receives the fuze identical to the current M-56 design. The external shape forward of the rotating band also matched the M-56 design. The modified fuze has a longer body and an altered shape, but the threaded connection is identical to the M505A3 requirement. The projectile bodies designed to receive this fuze were configured to be compatible with their modified shape. This new shape has favorable drag properties and is instrumental in reducing the time-of-flight to the target. The external configuration of these two projectiles forward of the rotating band is identical.

Compatibility with the M-61 gun systems was established through consultation with General Electric, the contractor for the gun systems. The distance from the crimp groove to the tip of the fuze matches that of the M-56 projectile. The configuration of the rotating band, however, was altered to obtain as much length as possible. It was determined that the band could extend forward .300 inch from the mouth of the M-103 cartridge case and remain compatible with the M-61 gun and the F-4E, F-15, and F-16 ammunition feed and storage systems. This constraint influenced considerably the configuration of the rotating band adopted for these thin-walled projectiles.

Compatibility with the M103 cartridge case was accomplished by making the external diameter of the projectiles aft of the rotating band identical to the M-56 design. The M-56 configuration for the crimp groove was also employed on all designs.

Initial minimum weight designs for each projectile body were achieved by structural analysis using a finite element analytical technique. The object was to configure the walls of the projectile to achieve a uniform level of stress throughout the body under the various loads applied to the projectile. The choice of material and heat treat contributed significantly to this design process. The configuration of the rotating band also influenced the design, but intrusion of the band into the wall was established at a value less than that of the crimp groove so the effect of the rotating band on the wall thickness was fairly minor. The two maximum HE capacity designs extended the length of the body aft of the crimp groove as much as possible consistent with a computed stability factor ≥ 1.20. Initial basic designs established by this process proved to be practical in extensive testing and remained essentially unchanged throughout the program.

The configuration of the minimum weight design for the modified fuze is illustrated in Figure 1. This projectile is shown in Figure 2. The zirconium sleeve shown in the illustration was added to improve the incendiary properties of the projectile. It had no effect on the basic configuration. Similar illustrations are included for the other three basic designs. The maximum HE capacity projectile with a modified fuze is shown in Figures 3 and 4, the minimum weight design with a M505A3 fuze is shown in Figures 5 and 6, and the maximum HE capacity projectile with a M505A3 fuze is shown in Figures 7 and 8.

The illustrations show two configurations for the aft end of the projectile. If the projectile body is manufactured by machining, the design utilizing a closure disc is employed. If a cup-and-draw method

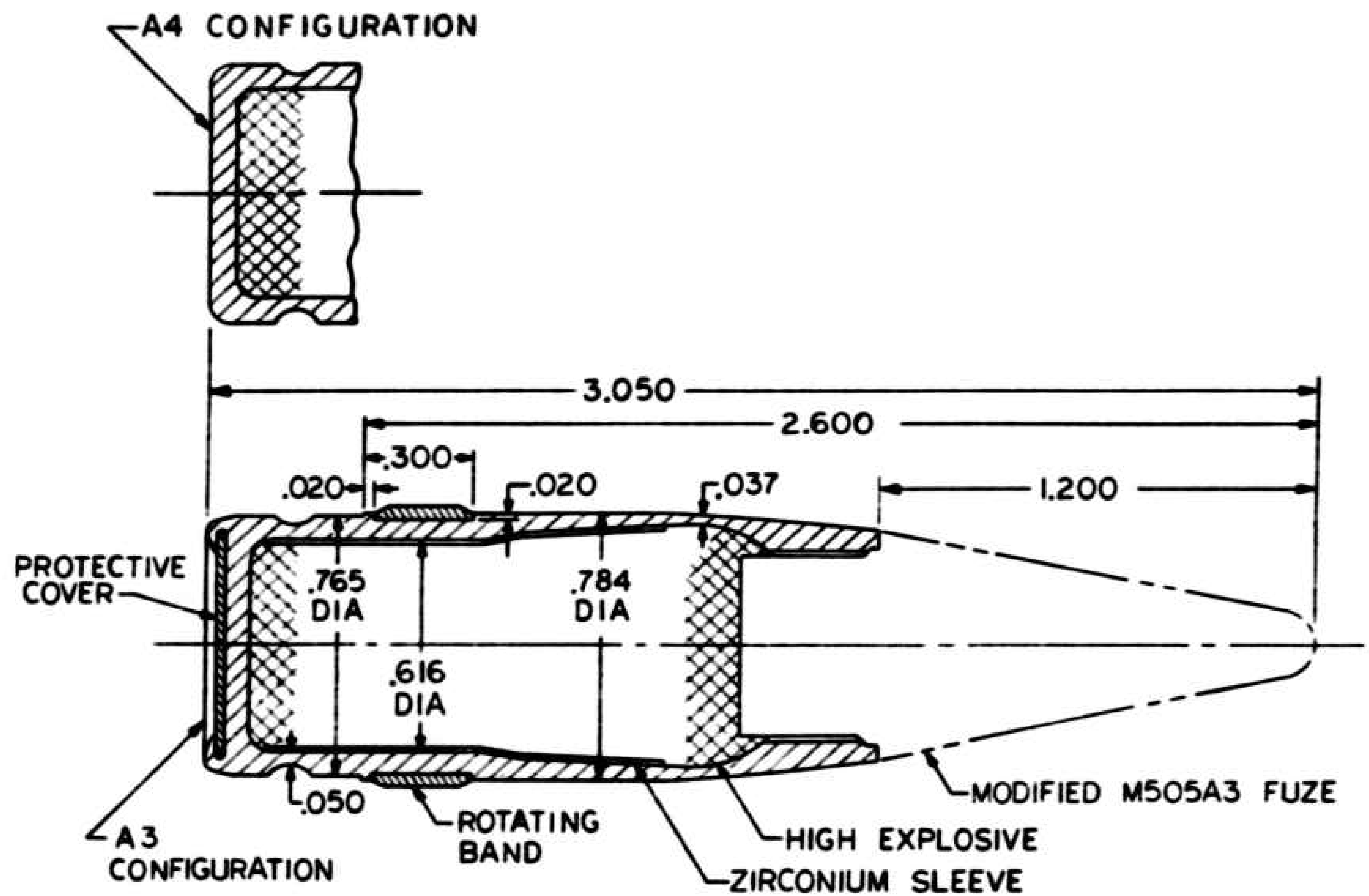

Figure 1. Projectile Body - Minimum Weight Modified Fuze Configuration

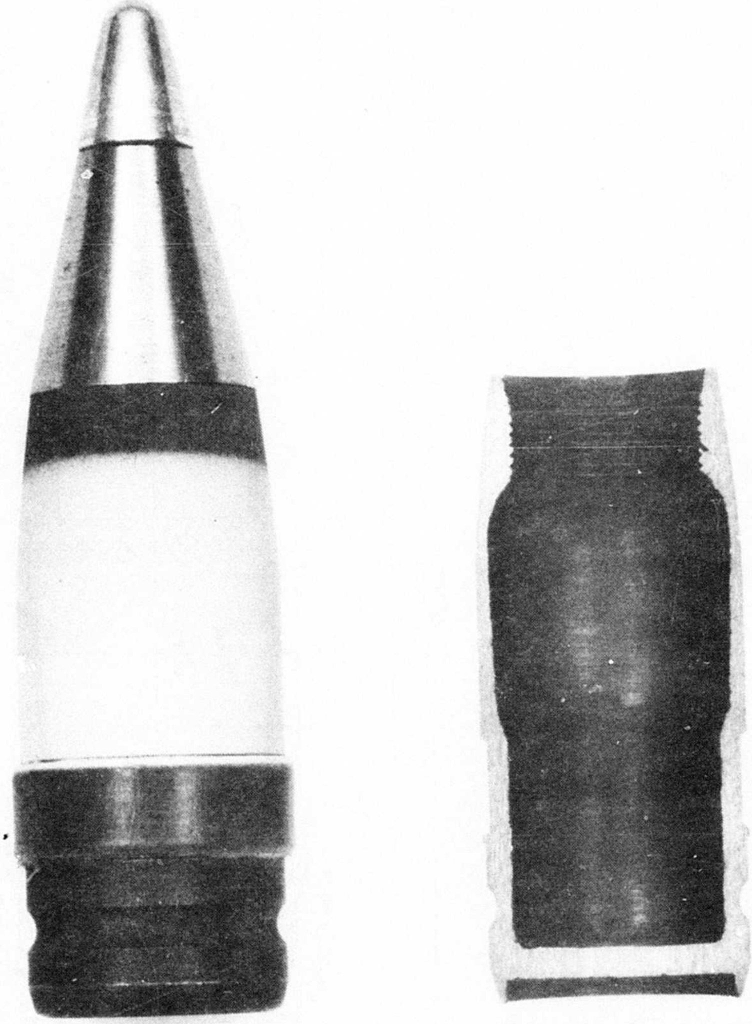

Figure 2. Minimum Weight, Modified Fuze Projectile

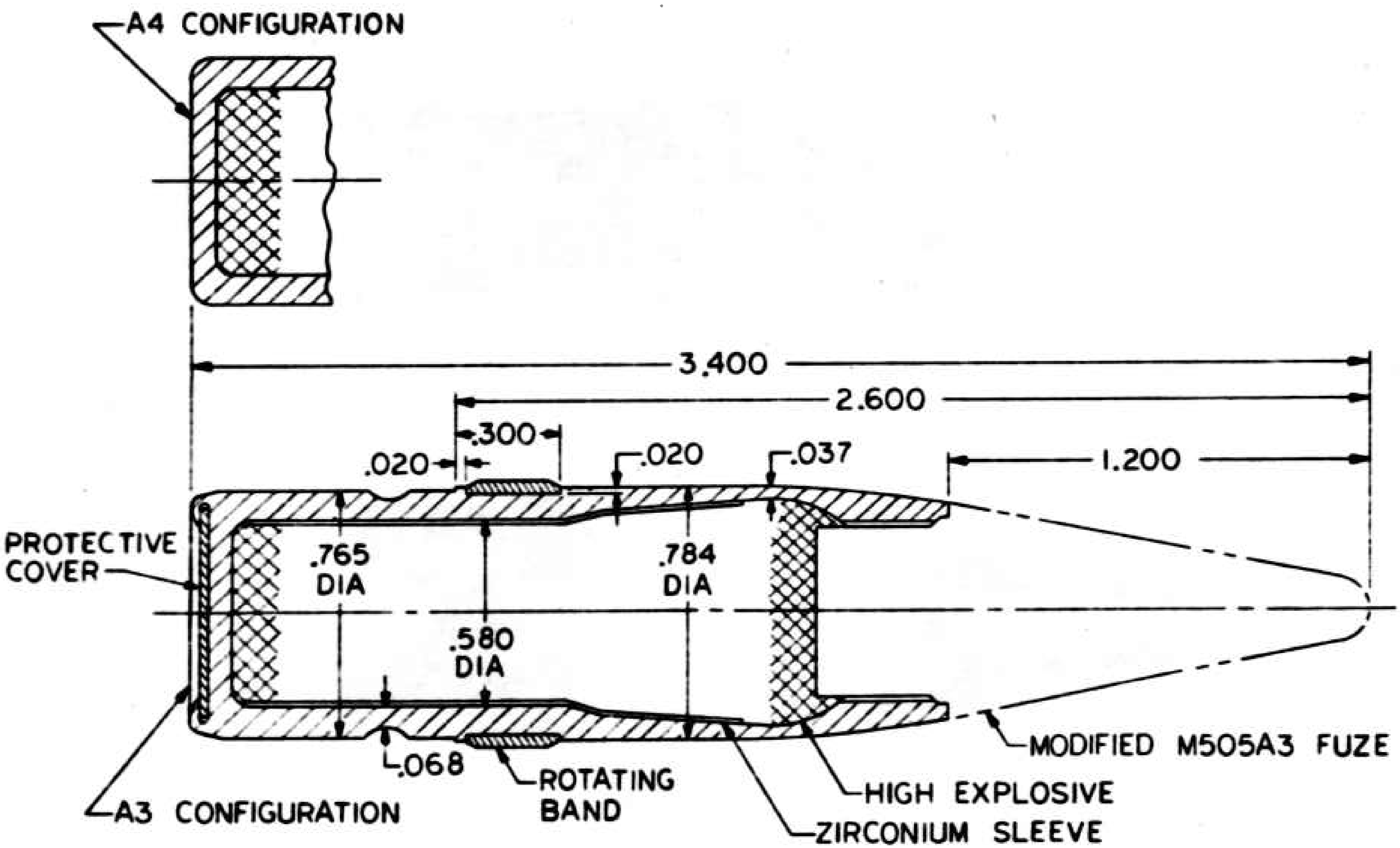

Figure 3. Projectile Body - Maximum HE Capacity, Modified Fuze Configuration

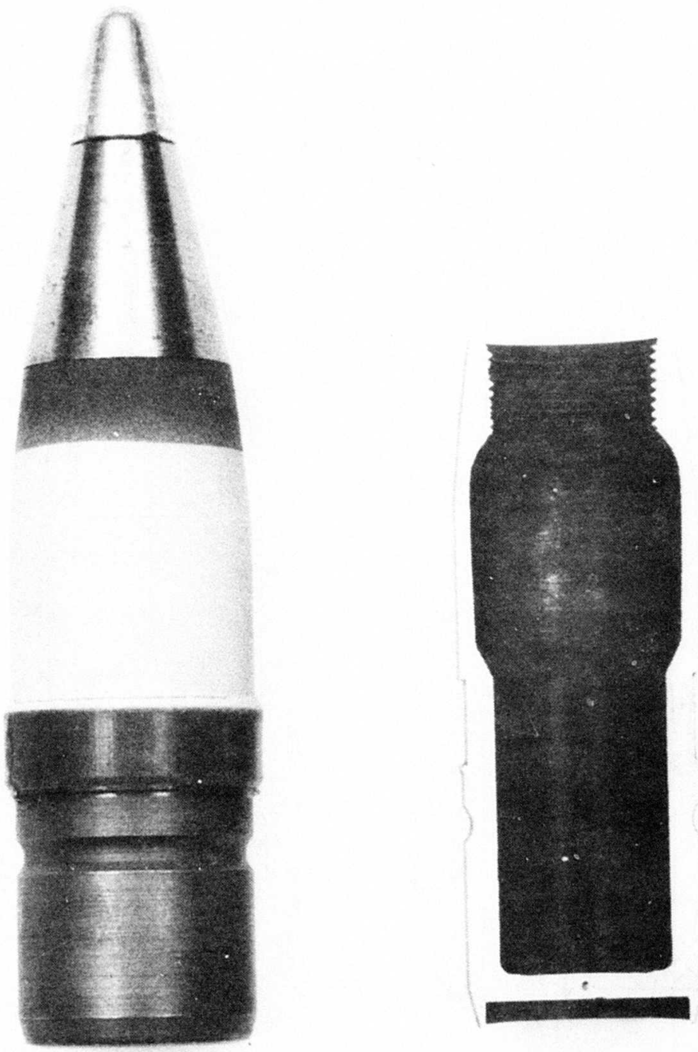

Figure 4. Maximum HE Capacity, Modified Fuze Projectile

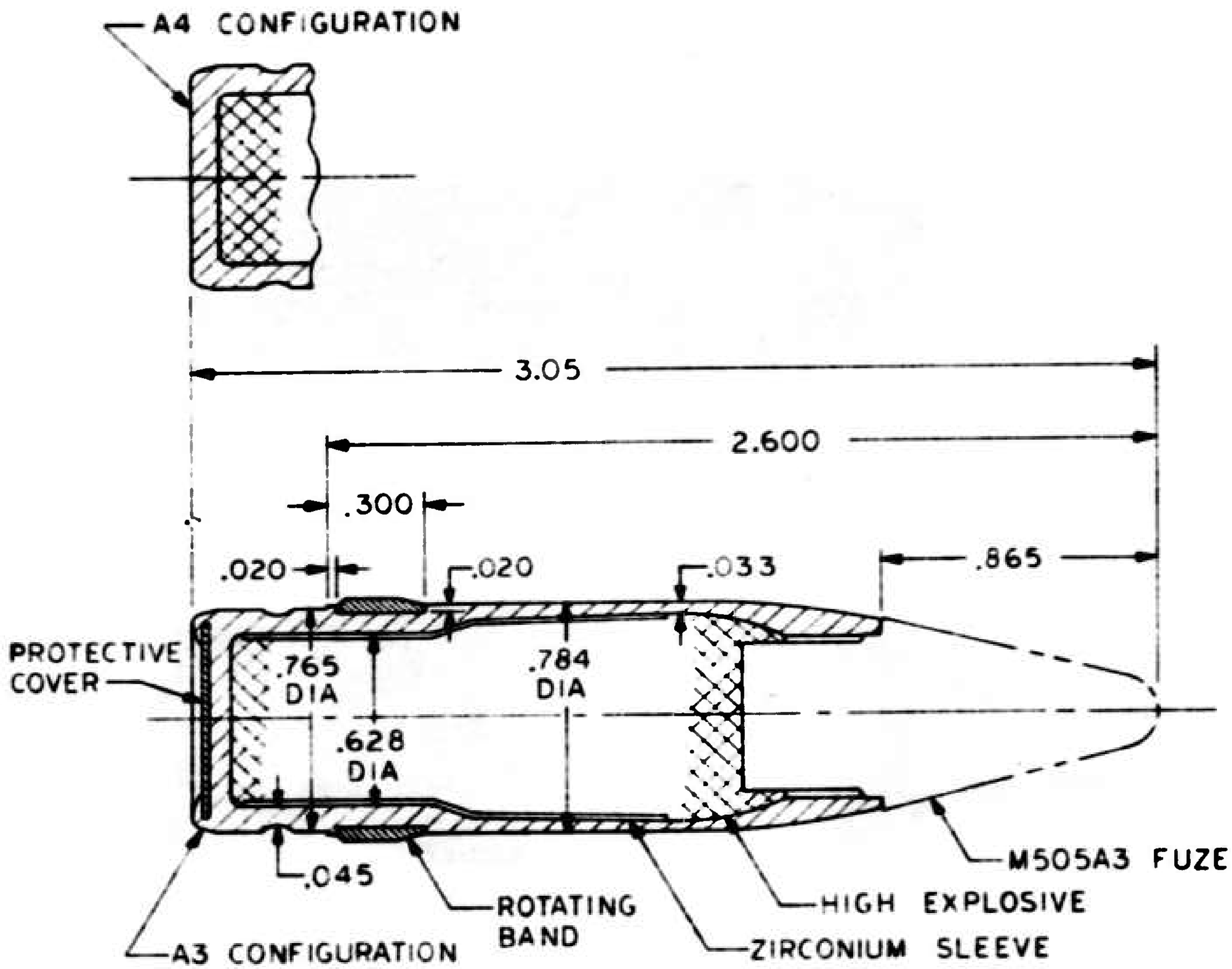

Figure 5. Projectile Body - Minimum Weight, M505A3 Fuze Configuration

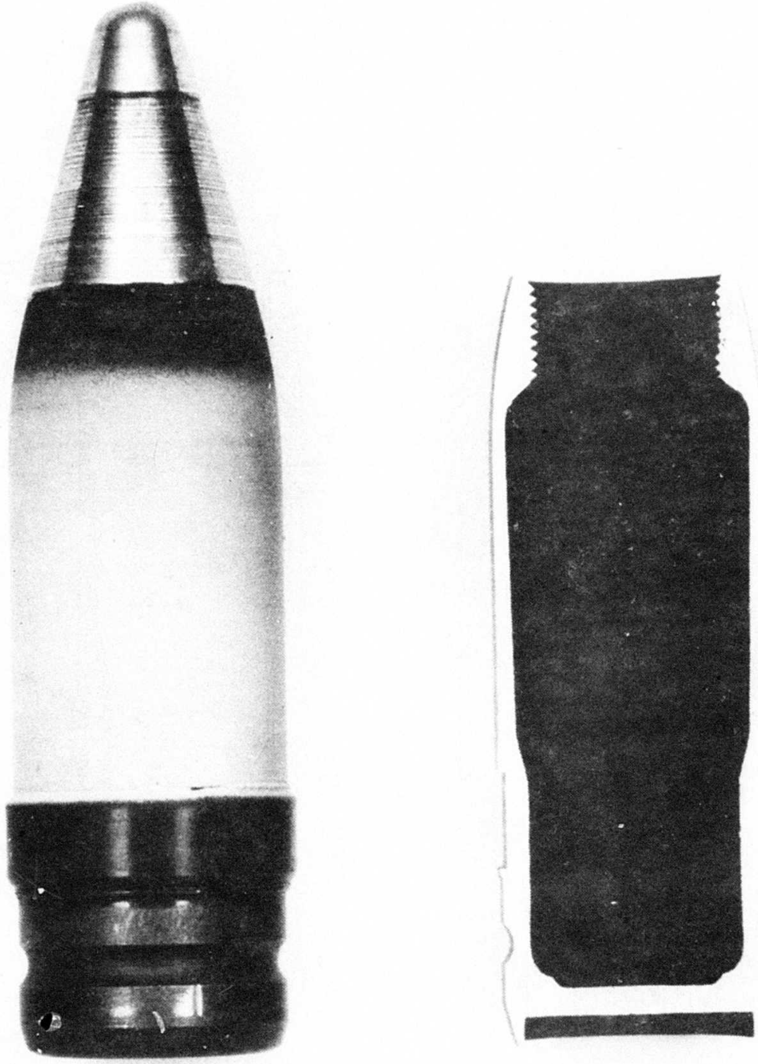

Figure 6. Minimum Weight, M505A3 Fuze Projectile

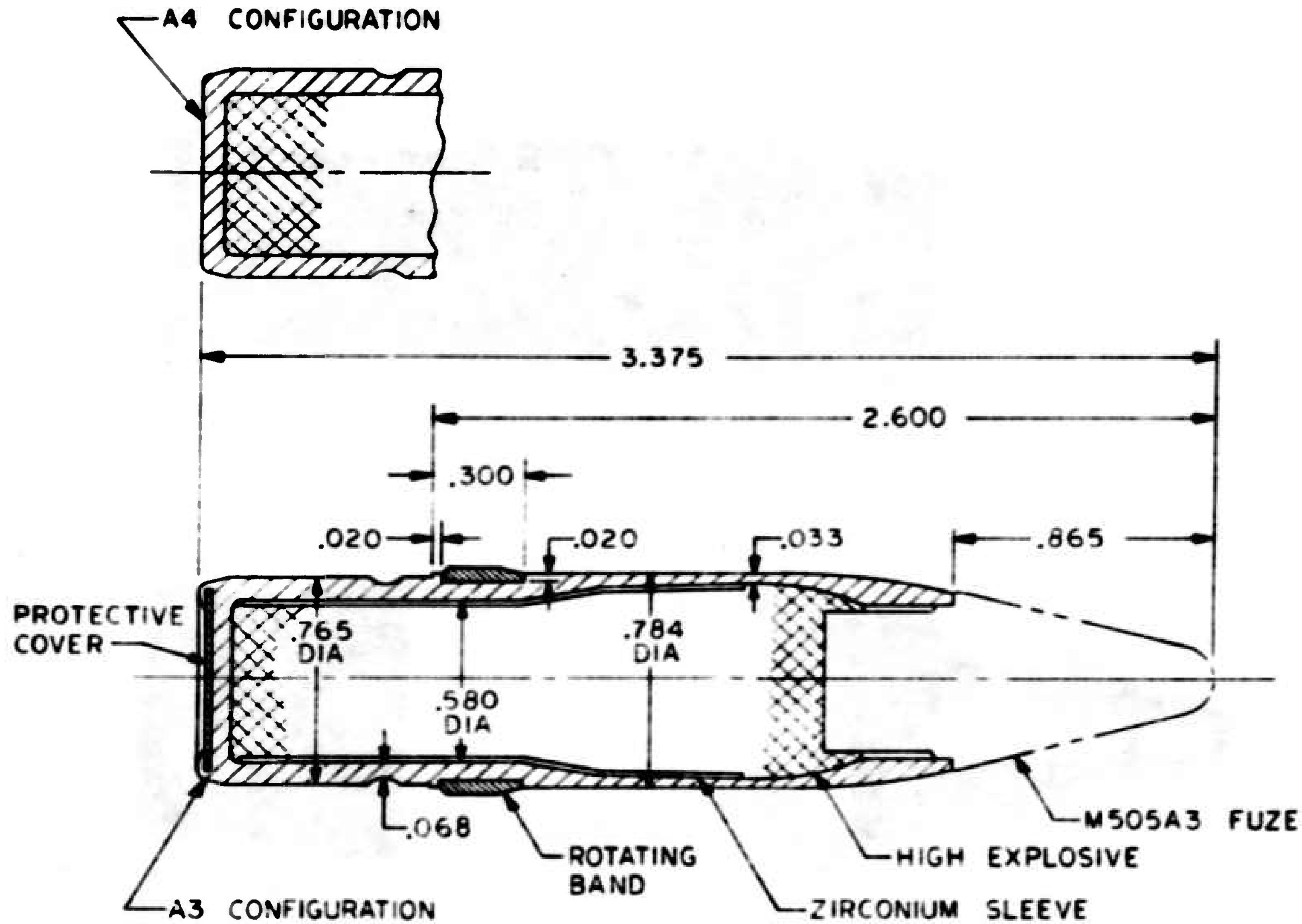

Figure 7. Projectile Body - Maximum HE Capacity, M505A3 Fuze Configuration

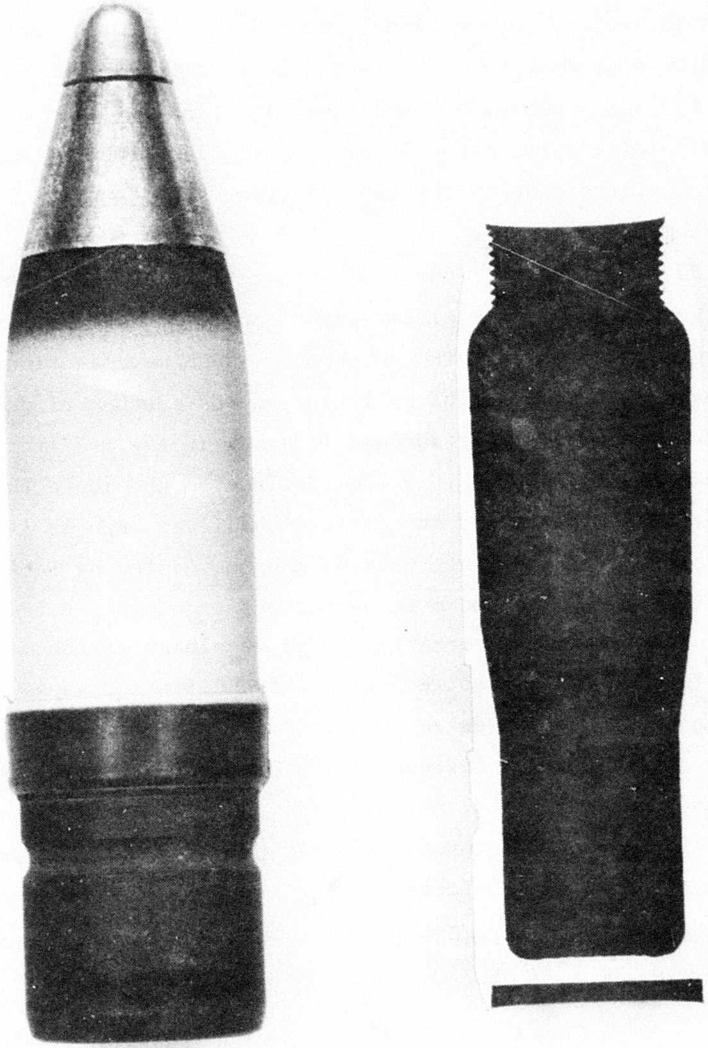

Figure 8. Maximum HE Capacity, M505A3 Fuze Projectile

of fabrication is employed, the alternate design can be used. These two designs correspond to the A3 and A4 versions of the M-56 projectile. The disc used in the machined version is a safety provision. Bar stock is subject to occasional seams in the material and if a part is made from such material, a path is provided for the propellant gases to reach the HE compartment and cause ignition while in the gun tube. The use of a disc makes the probability of this happening almost negligible. Parts made by the cup-and-draw method are not subject to this problem.

In addition to these four basic projectile configurations, three modified versions of the minimum weight, modified fuze configuration were designed and tested. The purpose of these modifications was to reduce dispersion by limiting balloting in the gun barrel during launch. The length of the bourrelet surface is small in the modified fuze configurations. This results in a short effective wheelbase that allows the projectile to pitch off the centerline of the bore as it progresses down the barrel. These perturbations can be reduced by increasing the effective wheelbase and a corresponding reduction in the dispersion of the projectile will be realized. The wheelbase of the minimum weight, modified fuze design was increased in three different ways. One method was to change the curved ogive to a conical section. Another was to create an aft support by increasing the diameter of the projectile at the aft end over a short distance. Still a third design was to incorporate both of the above features. Details of these modified configurations are illustrated in Figures 9, 10, 11, 12, 13, and 14.

A distribution of weight for the seven designs described above is listed in Table 1.

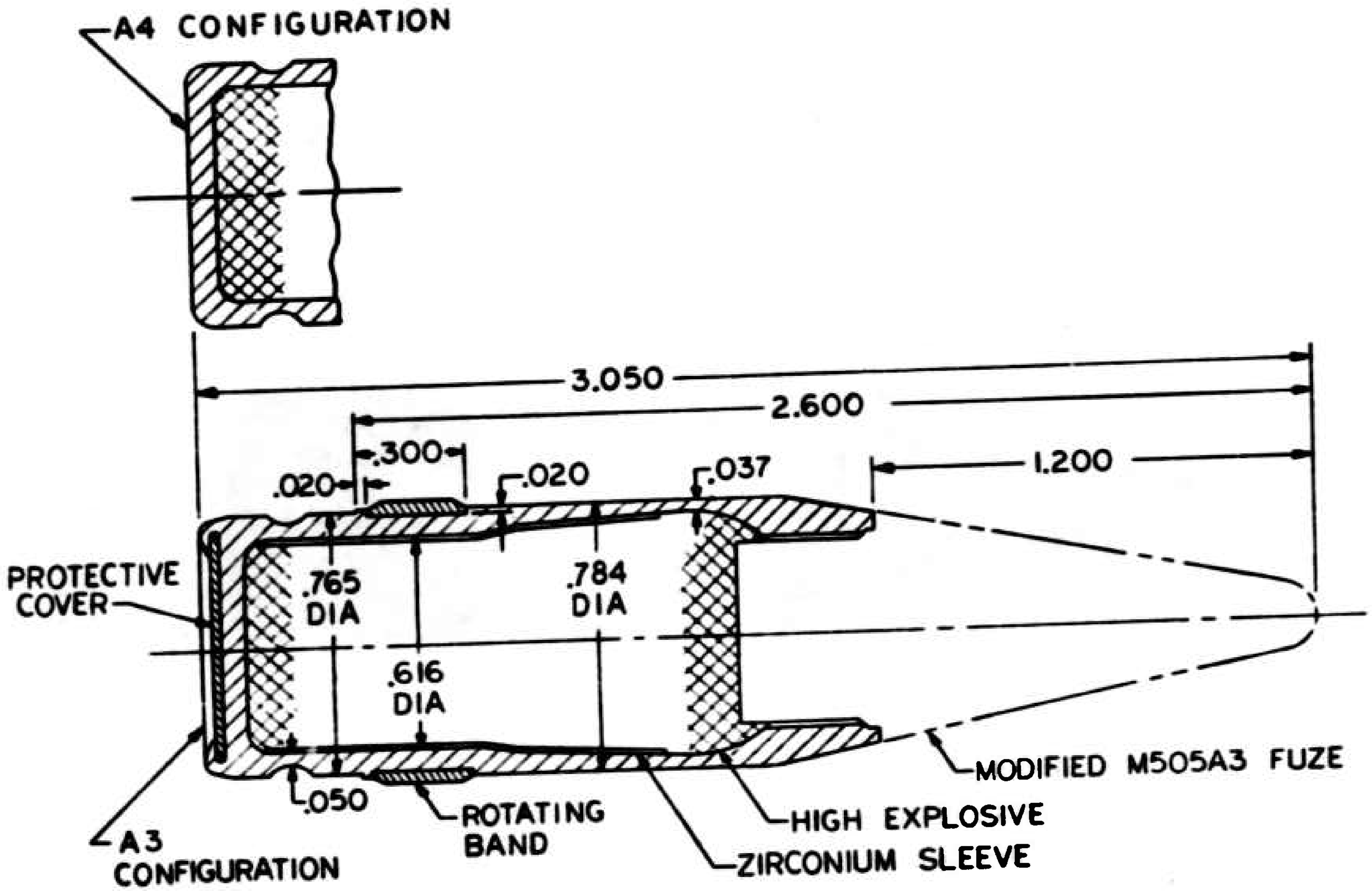

Figure 9. Projectile Body - Minimum Weight, Modified Fuze Conical Section

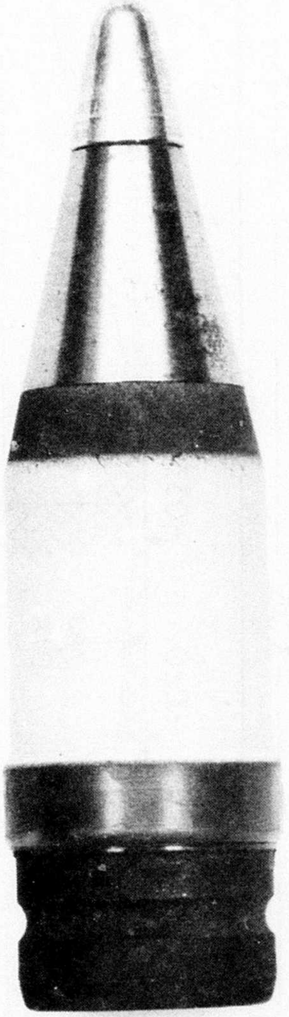

Figure 10. Minimum Weight, Modified Fuze, Conical Section Configuration

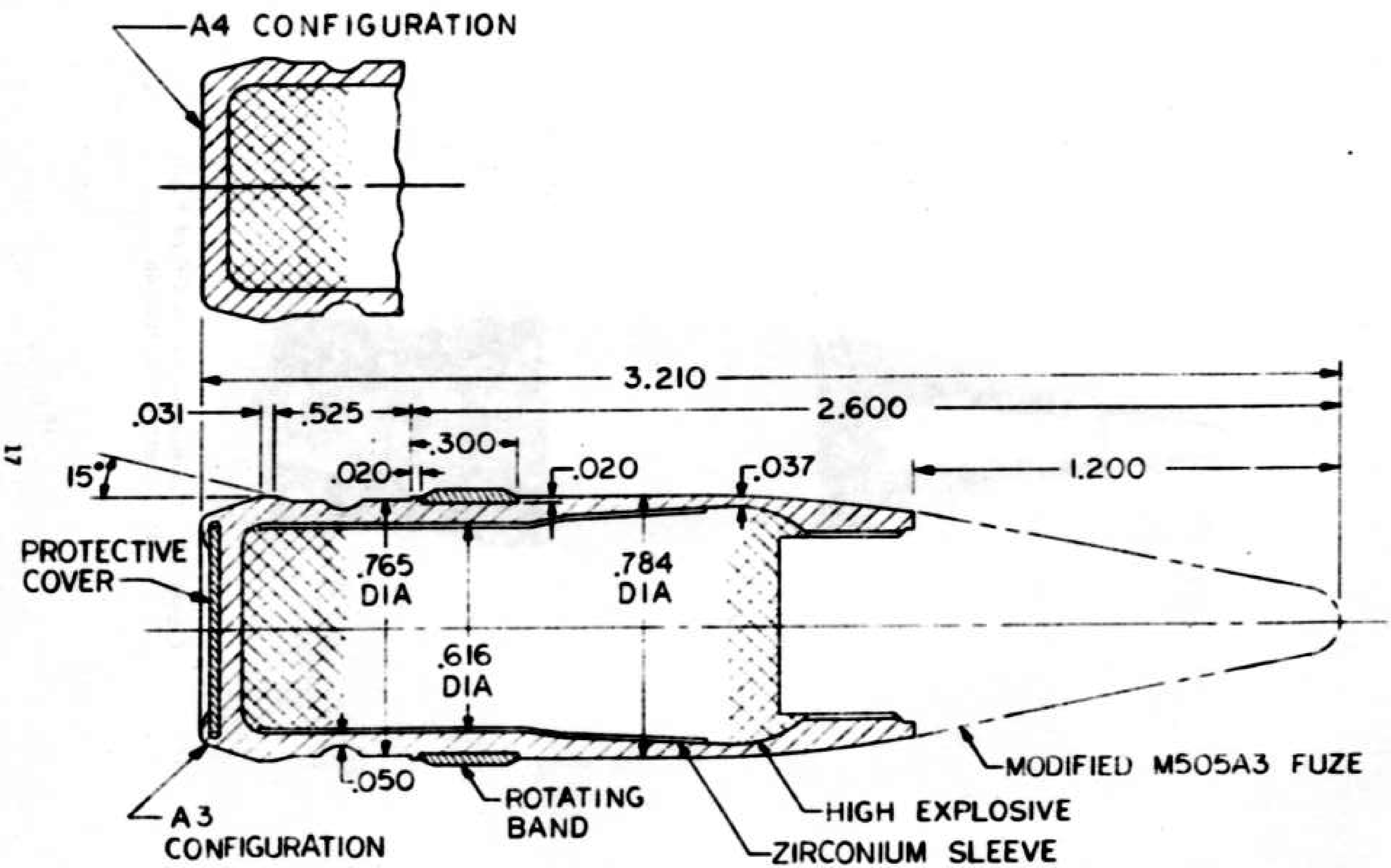

Figure 11. Projectile Body - Minimum Weight, Modified Fuze, Aft Support

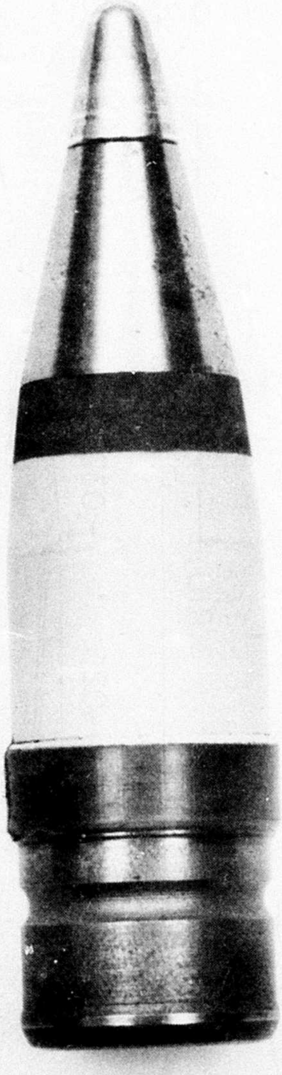

Figure 12. Minimum Weight, Modified Fuze, Aft Support Configuration

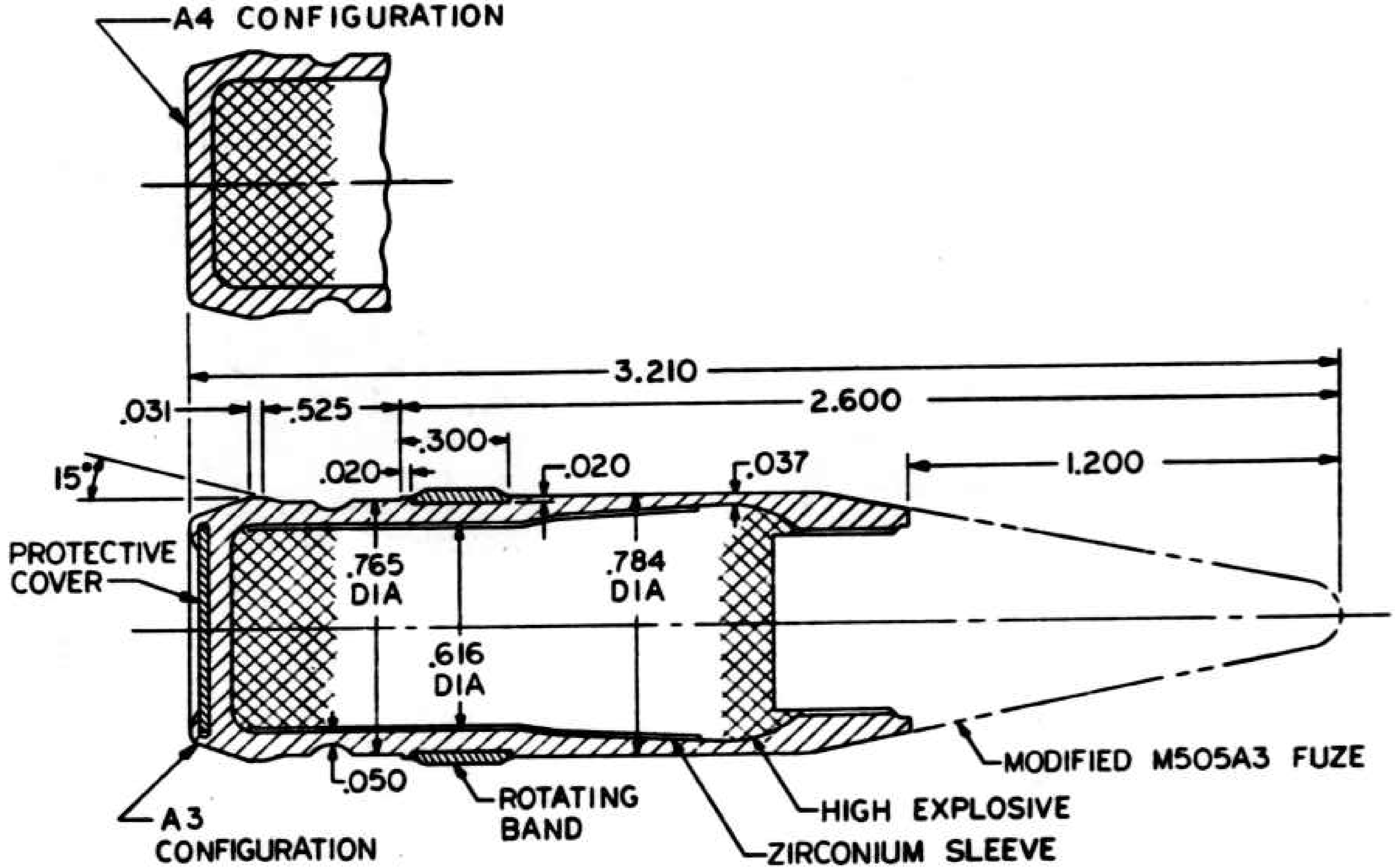

Figure 13. Projectile Body - Minimum Weight, Modified Fuze, Aft Support/Conical Section

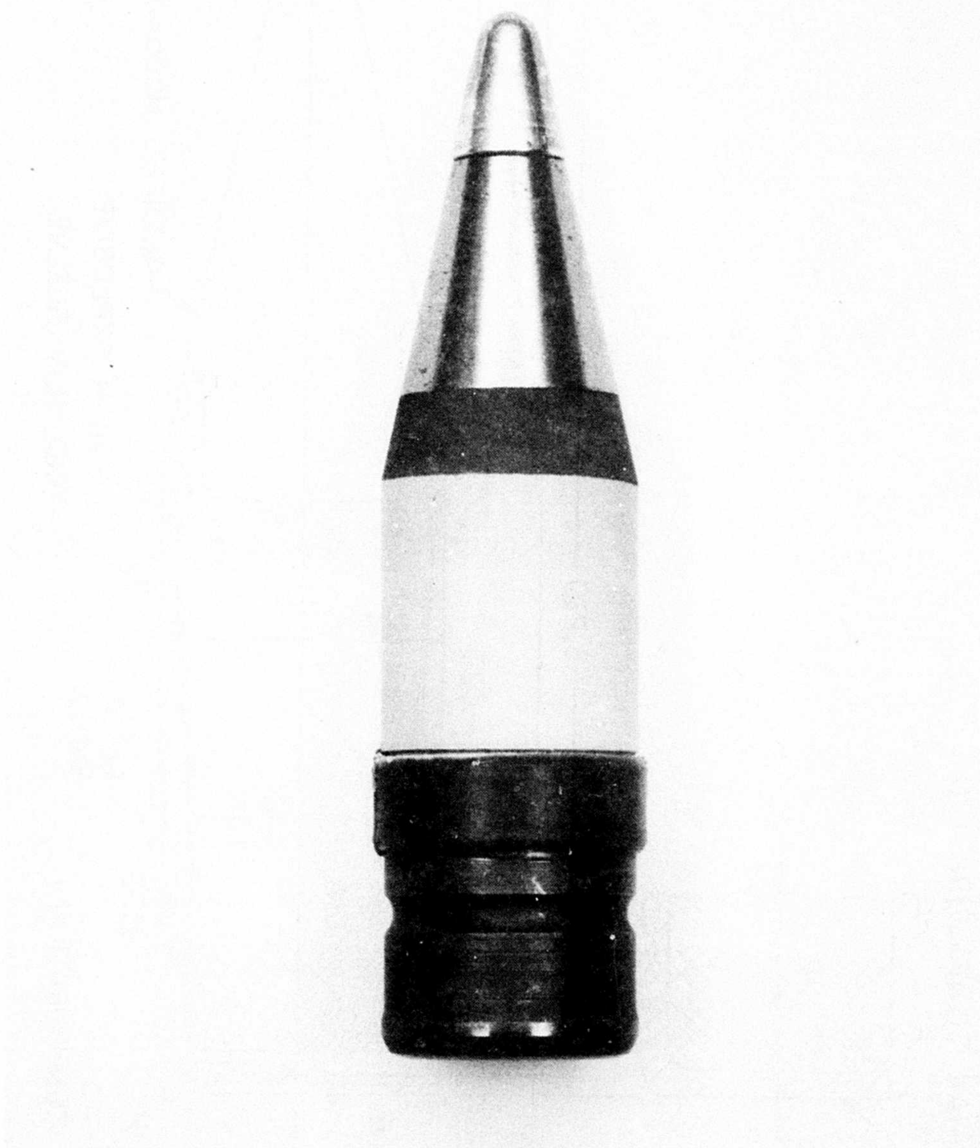

Figure 14. Minimum Weight, Modified Fuze, Aft Support/Conical Section Configuration

TABLE 1. WEIGHT DISTRIBUTIONS OF SEVEN THIN-WALL PROJECTILE DESIGNS - GRAINS

Configuration	Disc	Rot. Band	Zirc. Liner	HE	Case	Total	CG (1) Location
Min. Weight Modified Fuze	16	7	50	202	526	801	1.772
Max. H.E. Capacity Modified Fuze			64	237	712	1036	2.005
Min. Weight Standard Fuze			62	270	583	938	1.709
Max. H.E. Capacity Standard Fuze			75	293	750	1141	1.938
Min. Wt. Mod. Fuze Conical Section			50	202	571	846	1.772
Min. Wt. Mod. Fuze Aft Support			57	217	599	896	1.853
Min. Wt. Mod. Fuze Aft Support/Conical Section			57	217	629	926	1.853

(1) Length from tip of fuze - inches.

2. STRUCTURAL ANALYSIS

The four candidate 20mm thin-wall projectiles were analyzed using a finite element technique. The concept of finite element theory involves the dividing of a complex geometric structure into a finite number of substructures, each of which can readily be defined by geometry, material, and equilibrium equations. These substructures or elements are connected to each other at points called nodes or grid points. The collection of the equations of equilibrium for all the elements are solved simultaneously to give grid point displacements. The displacements are used to calculate element forces and stresses.

The finite element approach simplifies the mathematical definition of a complex structure. Without such an approach the analyst is forced to make many simplifying assumptions in order to make his particular problem conform to classical deflection equations which are to be found in structures textbooks. Many times such solutions are inaccurate because of the nature of the approximations and assumptions required in order to obtain a solution with a reasonable amount of effort. The finite element approach allows a complex structure to be divided into simple elements such as bars, plates, and cubes which can readily be defined mathematically. This provides a large number of simple equations which are solved simultaneously to obtain a distribution of stresses. A computer is employed to obtain a solution to the equations.

In recent years a number of finite element structural analysis computer programs have been developed. Of these, NASTRAN is probably the best known and most widely used structural program. NASTRAN is the acronym for NASA Structural Analysis and was developed by NASA as a general purpose digital computer program for the analysis of complex structures. The NASTRAN program is currently capable of handling the following: static response to concentrated and distributed loads, thermal expansion, and enforced deformation; dynamic response to transient loads, steady-state sinusoidal loads, and random excitation; real and complex eigen values; dynamic and elastic stability analyses; and heat transfer analyses.

The structural analysis results discussed below were developed by the use of NASTRAN.

The first step in performing the NASTRAN analysis was to draw an enlarged half longitudinal cross-section of each projectile. By modeling the sector with single elements across the wall thickness, the computer run time was minimized. This resulted in a solution which gave the average stress across the thickness of the wall. It was theorized that some local yielding could be allowed as long as this did not result in yielding across the entire wall in any element. The average stress could therefore be used to design the projectile assuming the material was ductile enough to prevent cracking at points of stress concentration.

Applied loads were based on a peak chamber pressure of 60,000 psi. Three loads were considered as follows: a pressure load surrounding the base of the projectile, a torque load at the rifling band, and centrifugal loading due to projectile spin. The magnitude of each of these loads was determined from an interior ballistics analysis. The inertia relief format of NASTRAN was used which gave a pseudo-dynamic analysis by using dynamic loads to perform stepwise static analyses as the projectile traversed the barrel. The results of such an analysis very nearly approximate a dynamic analysis if the natural period is short compared to the period of the applied force, or restated, the stiffer the projectile, the better the approximation. A complete analysis at a series of positions along the barrel was performed for one of the projectiles. It was determined that peak stresses occur at peak pressure. The tabulated stresses which follow are maximum stresses.

A summary of the results for each configuration which was analyzed is included in Figures 15 through 17 and Tables 2 through 4. The tabulated stresses reference the element numbers on the drawing. The design stress criteria chosen was the maximum shear theory of failure. The stresses shown are octahedral shear stresses. The material tensile yield strength is 155,000 psi which results in an allowable shear strength of 89,400 psi. All dimensions used in the analysis represent minimum wall thicknesses on the working drawings, the single exception being Figure 15, which was an early computer run where the nominal crimp groove dimension was used. The relatively high stress in element 20 of

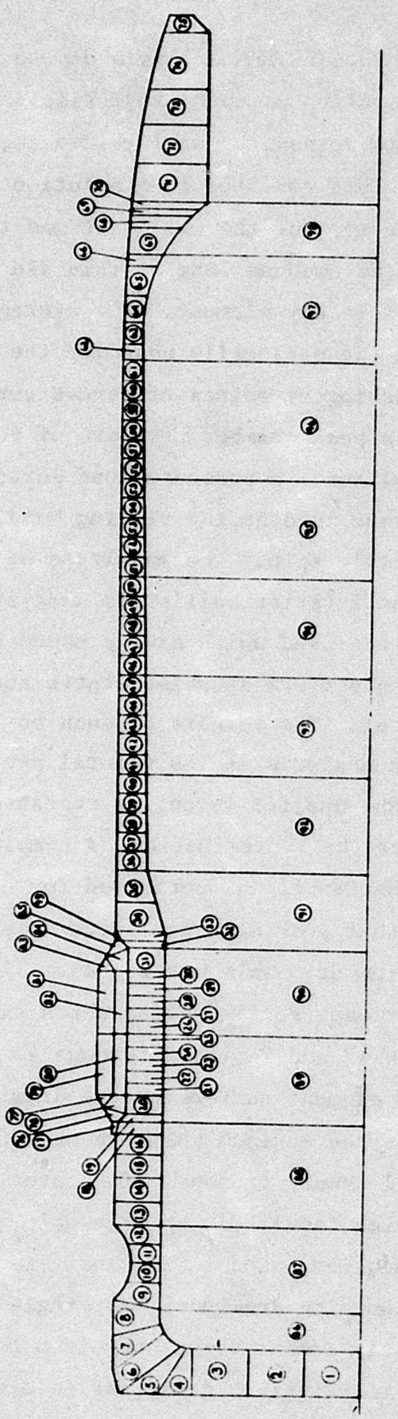

Figure 15. Element Pattern - Minimum Weight Design M505A3 Fuze

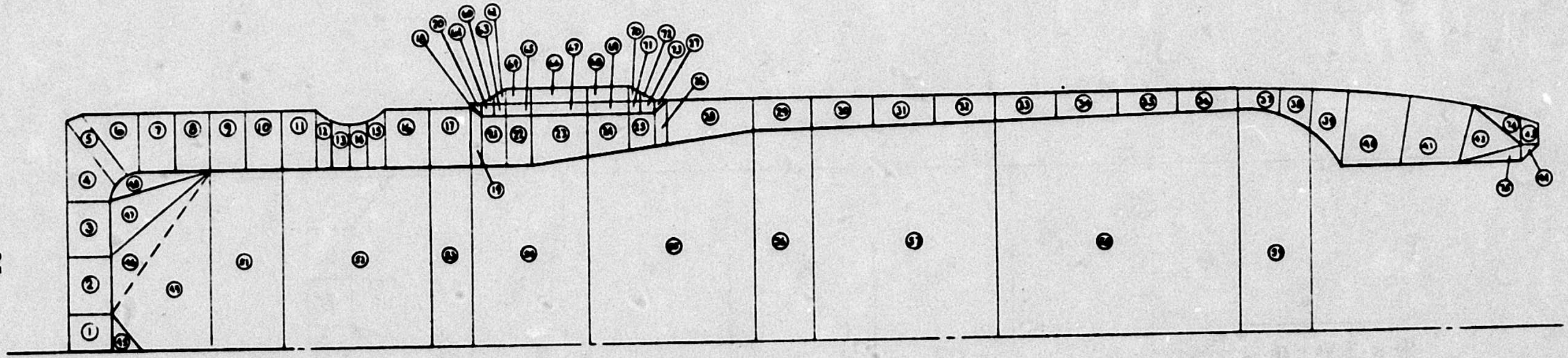

Figure 16. Element Pattern - Maximum HE Capacity Design, M505A3 Fuze

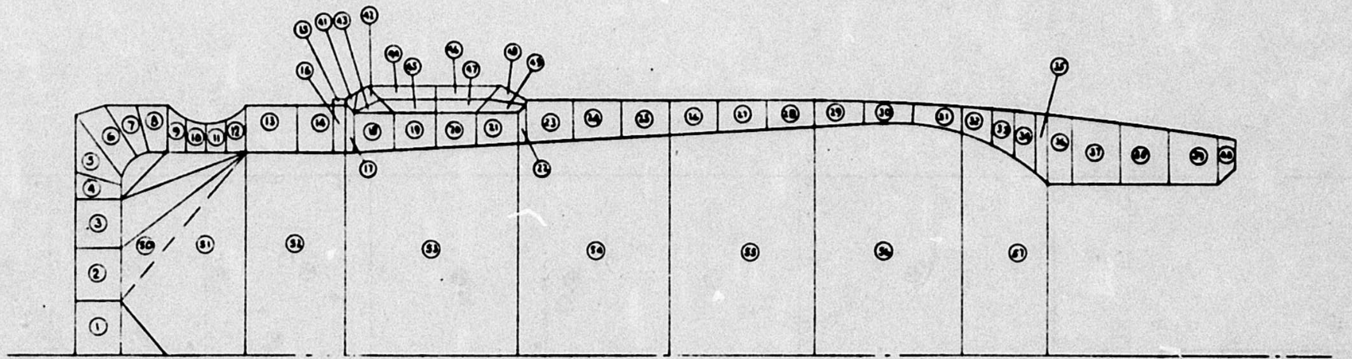

Figure 17. Element Pattern - Minimum Weight Design Modified M505 Fuze

TABLE 2. OCTAHEDRAL SHEAR STRESS RESULTS FOR MINIMUM WEIGHT CONFIGURATION WITH A STANDARD M505A3 FUZE (FIGURE 15)

Element No.	Shear Stress (psi)	Element No.	Shear Stress (psi)
1	53735	24	72318
2	52375	25	70496
3	68401	26	70033
4	30485	27	70179
5	25671	28	70585
6	29402	29	71088
7	27272	30	71516
8	38000	31	71642
9	82982	32	65461
10	85928	33	63236
11	84697	34	69566
12	74555	35	77840
13	69391	36	83849
14	68179	37	85664
15	66803	38	86704
16	65719	39	87207
17	49517	40	87288
18	67391	41	85658
19	77898	42	85357
20	75153	43	85036
21	80687	44	84637
22	77614	45	84279
23	74722	46	82028

TABLE 2 (CONCLUDED)

Element No.	Shear Stress (psi)	Element No.	Shear Stress (psi)
47	81727	70	34542
48	81595	71	29118
49	81620	72	27090
50	81576	73	25587
51	79534	74	24369
52	79704	75	28965
53	80073		
54	80554		
55	81018		
56	79108		
57	79772		
58	80669		
59	81675		
60	82683		
61	83520		
62	81201		
63	80613		
64	79869		
65	78686		
66	76586		
67	69547		
68	53946		
69	41319		

TABLE 3. OCTAHEDRAL SHEAR STRESS RESULTS FOR MAXIMUM H.E. CAPACITY DESIGN WITH STANDARD M505A3 FUZE (FIGURE 16)

Element No.	Shear Stress (psi)	Element No.	Shear Stress (psi)
1	57081	24	66485
2	49657	25	72691
3	68554	26	63629
4	26982	27	26956
5	20742	28	64538
6	31136	29	68742
7	47236	30	67742
8	48388	31	68772
9	57266	32	70388
10	64785	33	67741
11	71656	34	68414
12	82155	35	69276
13	89166	36	68984
14	88224	37	57815
15	79764	38	39506
16	66855	39	29420
17	58802	40	23620
18	76785	41	22483
19	63713	42	20882
20	65979	43	32386
21	62938	44	26231
22	60016	74	30272
23	60062	75	17256

TABLE 4. OCTAHEDRAL SHEAR STRESS RESULTS FOR THE MINIMUM WEIGHT CONFIGURATION WITH A MODIFIED M505 FUZE (FIGURE 17)

Element No.	Shear Stress (psi)	Element No.	Shear Stress (psi)
1	75440	21	64618
2	51770	22	56439
3	61580	23	72439
4	33370	24	81443
5	26802	25	85116
6	29955	26	84611
7	28222	27	85633
8	36932	28	86741
9	81640	29	85660
10	88282	30	87957
11	84699	31	86552
12	69480	32	74045
13	58368	33	57868
14	59444	34	45860
15	43994	35	38520
16	59444	36	35082
17	69129	37	33647
18	90490	38	32094
19	65005	39	30339
20	60446	40	33934

Figure 16 is a local stress concentration and as such was neglected in determining the minimum wall thickness.

The maximum HE capacity design using the modified M505 fuze (Figure 3) was not modeled for finite element analysis for it was found that stability considerations were as important as stress requirements in determining wall thicknesses of these long projectiles and wall thicknesses less than those used for the standard fuze design could not be tolerated for stability reasons. Because of their similarity in the region aft of the rotating band, it was reasoned that the analysis performed for the standard fuze design (Figure 16) indicates acceptability for this design also. In the region forward of the rotating band the design is identical to the minimum weight design (Figure 17) and stresses should be lower because of reduced accelerations so adequacy from a stress standpoint is assured here too.

The finite element technique for determining structural properties has given results that agree rather closely with results obtained by conventional analytical methods. It provides an excellent record of stress distributions which were valuable in resolving design and manufacturing problems. For example, it indicated that the material in the region around the tab at the rear of the projectile could be annealed to permit upsetting to secure the closure disc.

3. MATERIAL SELECTION AND HEAT TREAT

One of the principal considerations during the program was the selection of the material for the projectile body and the development of a satisfactory heat treat process. The requirements dictated that the material have adequate mechanical properties, the best possible fabrication properties, and low cost. The fabrication properties include good heat treat characteristics. The material must have a through hardening capability, low distortion, and good ductility in the final drawn condition.

The walls of the projectile were proportioned by a finite element analytical technique. This technique utilizes the yield strength of the material to develop the analysis and one of the tasks was to find a suitable match of material properties with a design configuration that achieved the desired weight goal and charge-to-metal ratio. After a few trials it was found that a satisfactory configuration could be obtained with a material having a yield strength of 155,000 psi. The ultimate tensil strength of this steel will be about 185,000 psi. This corresponds to a hardness value on the Rockwell C scale in the 38 to 42 range. Steels in the low-to-medium carbon range can be heat treated to this value without serious sacrifice of ductility and were considered for the projectile body.

In determining the mechanical properties of the steel, the hardenability, or depth of hardness is an important factor. In general, surface hardness attainable after quenching is largely a function of the carbon content of the steel, while the depth to which the hardness will penetrate depends, in addition to the carbon content, upon the total content of the alloying elements and the grain size. Therefore, in low carbon steels, through hardness can only be achieved in thin cross sections, while high carbon and alloy steels can be through hardened in cross sections up to several inches in thickness.

If the cross section is thin enough, any steel that will surface harden to R_C40 would be suitable. The lowest carbon content steel capable of attaining an as-quenced surface hardness of R_C40 is AISI 1020, so any carbon steel with 0.20 percent carbon or more was a candidate.

Through hardness, ductility, and workability are also necessary properties. The low carbon steels give better ductility and are more workable while the higher carbon steels provide through hardness, so a trade-off situation results. Carbon steels in the 0.15 to 0.40 percent range, except for the free machining varieties, have the best machining qualities. A steel with less than 0.15 percent carbon gives soft, gummy chips that are likely to adhere to the cutting tool. The 0.40 percent carbon steel through hardens well, has suitable ductility, and machines well, so a decision was reached to use AISI 1040 steel. This proved to be a satisfactory choice for no problems traceable to the material were encountered during the program.

Carbon steels can be made easier to machine by adding either 0.10 to 0.30 percent sulfur, 0.20 to 0.30 percent lead, or a combination of both sulfur and lead. These steels cost about 10% more than the plain carbon steels. A 1141 steel was given careful consideration for it machines very well and has excellent hardening qualities. It was rejected, however, when it was learned that it had been considered at one time for M-56 production but abandoned when a failure rate of approximately one in six thousand was encountered in projectiles made of this steel. These additives tend to segregate in the steel, thereby increasing the possibility of a structural failure which was the probable cause of the failures.

Heat treatment of the 1040 steel was satisfactorily resolved by some research and development effort with the heat treat process. Excellent results were obtained by using a fast oil quench and supporting each projectile properly so it would be flooded with the quenching fluid. The hardened material is brittle in the as-quenched condition and is drawn to the final hardness range. Several samples were dimensionally checked before and after heat treatment for evidence of distortion. Distortion of a minor nature was observed, but its extent in no way threatened the dimensional or functional integrity of the projectile. This was very important for it permits finishing the projectile to final dimensions before heat treatment which is a major consideration in limiting the fabrication cost.

The machined version of the projectile requires a safety disc at the aft of the projectile which is secured by upsetting a tab. This tab requires annealing to avoid cracking when it is upset. This was accomplished by locally drawing the tab to the R_C 28 to 32 range. Induction annealing was used during this program, but other methods such as flame annealing could be employed.

4. ROTATING BAND DEVELOPMENT

The development of a practical rotating band having minimum intrusion into the wall of the projectile is vital to the thin-wall projectile concept. Recognizing this, the Air Force sponsored an exploratory program for investigation of a plastic rotating band for 20mm projectiles. This program produced a method of accomplishing a chemical bond between the plastic and metal which makes it possible to apply the band with very little intrusion into the projectile wall. The work on this program continued the investigation of this process and expanded experience and knowledge of the application technique to a stage that indicates the plastic rotating band is a practical concept for 20mm thin-wall projectiles.

The configuration for the band shown in Figure 18 was established early in the development program and was not changed during the course of the investigations. The 0.300-inch extension forward of the mouth of the cartridge case was determined by compatibility requirements with the M-61 gun systems. The 0.020-inch intrusion into the wall was chosen when analysis indicated, due to the nearness of the crimp groove, that this amount of intrusion would have very little effect on the design of the wall. The 0.020-inch-wide shoulder at the base of the band serves as a stop when installing the projectile in the cartridge case.

Investigations during the program concentrated on the choice of materials and the application process. Most of the materials investigated were various grades of types 11 and 12 unfilled nylons. The scope of this materials study was far from exhaustive, but it failed to show any significant difference between several of the grades. This being the case, a decision was made to use an 1801 grade, type 12 nylon for most of the delivered items.

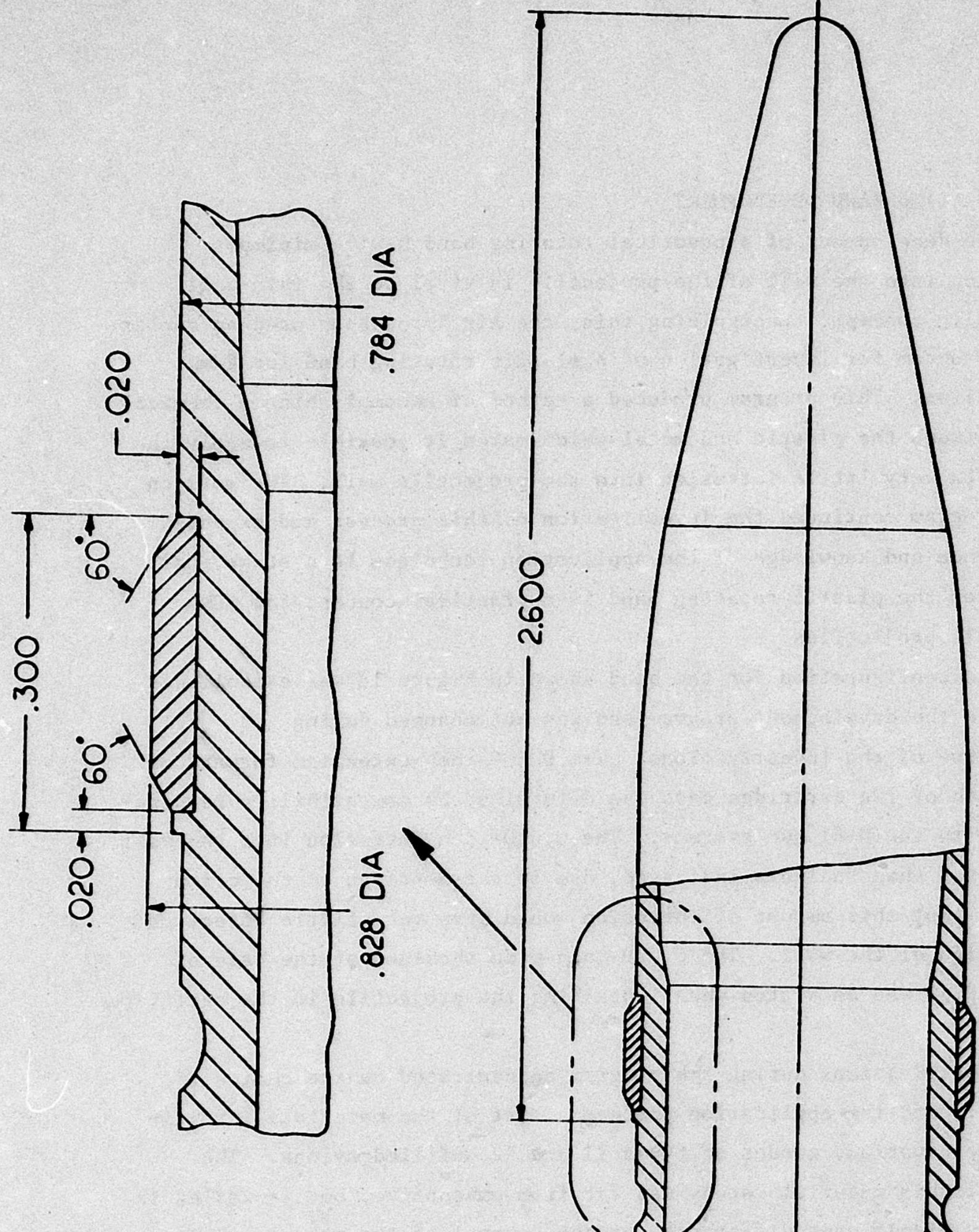

Figure 18. Rotating Band Configuration

Eight different types of materials were investigated during the program. They are summarized in the listings of Table 5. Of the eight materials investigated, only the N1901 type 12 nylon and the glass-filled G-12 material were completely unsatisfactory. Some success was obtained with all the remaining materials. Personnel from HULS recommend their grade L-2101F material for the rotating band, and it was used on some of the early projectile deliveries. However, testing was not extensive enough to discern any significant difference between this grade and HULS L1901 and L1801 grades.

One series of tests was run at cold and elevated temperatures. The band material was type 12, grade L2101F non-filled nylon furnished by HULS. Five each of the minimum weight and maximum HE standard fuze designs were tested at -65°F and +160°F. All rotating bands at the -65°F temperature functioned exceptionally well. At the +160°F temperature two bands on the maximum HE design were partially lost. Feathering of the bands at this elevated temperature was quite pronounced.

Feathering of the rotating band both at the leading and trailing edge is evident in nearly all tests. The effect this had on the performance of the projectile is not known. It is likely, however, that it has some negative effect on dispersion and time of flight and future development effort should be devoted to its control. This probably can be accomplished by a small configuration change and/or use of an alternate or modified material.

All of the test experience indicated that the plastic rotating band obturates very well and permits very little gas leakage. Also it appears to be quite capable of transmitting spin-up torque to the projectile. No evidence of slippage was noted even in tests performed in a constant twist barrel.

Achieving a satisfactory plastic-to-metal bond is critical to the success of this thin-wall projectile concept and is the area where considerable development effort was concentrated. Some mechanical aids

TABLE 5. SUMMARY OF ROTATING BAND MATERIALS

Type	Grade	Supplier	Remarks
Type 12 - Unfilled	N1901	HULS	Flexible and difficult to mold. Band unsatisfactory.
Type 12 - Unfilled	L1901	HULS	Bands satisfactory.
Type 12 - Unfilled	L-2101F	HULS	High density material. Bands O.K.
Type 12 - Unfilled	L-1801	HULS	Bands satisfactory.
Type 12 - Unfilled	--	Rilsan	Bands O.K.
Type 11 - Unfilled	BESNO	Rilsan	Some bonding trouble. Bands that stayed on were satisfactory.
Type 11 - Unfilled	BECV-Black-T	Rilsan	Bands satisfactory.
G12 - 43% Glass	Zytel 77G-43 NC-10	Dupont	Poor bond. Bands came off.

such as used in the Navy 20mm work and on GAU-8 ammunition were tried, but due to the shallow intrusion into the wall they appeard to contribute little or nothing to the solution and were abandoned. It is necessary, therefore, to rely on a chemical bond to secure the band to the projectile, and this is the area where the development effort was concentrated.

The application process recommended by DeBell and Richardson was employed as the basic approach in the band application studies. It consists of the following basic steps:

Step 1 - Clean the band application area thoroughly.

Step 2 - Apply a chemical primer to the band application surface.

Step 3 - Injection mold the plastic rotating band in place on the projectile.

Step 4 - Induction heat the interface between the projectile and the band to improve the bond.

Molding was planned in the contractor process to avoid any secondary operations so the steps listed above completed the process. The DeBell and Richardson process required a secondary machining operation to remove gate material and chamfer the trailing edge of the band. The efforts to develop a practical application process that would produce a reliable band achieved a gradual improvement in quality and good success in the latter part of the program. The bands applied to the final lot of delivered projectiles exhibited excellent quality and performed with no indication of bonding failure in tests of the 25 acceptance rounds.

Upon receipt and inspection of this final lot of projectiles by the Air Force at Eglin AFB, almost all of the projectiles had visible corrosion under about 30% of the plastic rotating band area. As a result of Air Force and contractor investigation of this problem, it is theorized that the corrosion was accelerated by the zinc phosphate coating process that was applied to the projectile surface for a paint base after the plastic rotating band had been molded in place. It was discovered at about the same time on another Air Force program that a zinc phosphate coating on the entire projectile surface, including the band seat area, before applying the plastic rotating band would prevent corrosion. Uncoated projectiles were observed to corrode during temperature/humidity cycling.

Details of the four-step basic application process outlined above as implemented in the final stage of the program are the following:

Step 1 - Cleaning

a. Bead blast band area.
b. Immerse in MEK and vibrate on an ultrasonic cleaner for 10 to 15 minutes.
c. Air dry for 30 minutes.

Step 2 - Primer Application

a. Apply a thin coat of P-253 primer to the band area.
b. Air dry for 30 minutes.
c. Final dry at 450°F for 25 minutes.

Step 3 - Molding

a. Preheat projectiles to 350°F before molding. Limit preheat time to 15 minutes maximum.

b. Transfer projectiles to the molding machine and mold band immediately. Mold temperature - 200°F.

Step 4 - Induction Heating

a. Induction heat for 10 seconds.
b. Water quench the projectile in water.

Some of the subleties of the process were: (1) the mold finish should be ground and polished, (2) avoid overcure of the primer, and (3) select current densities during induction heating that melts the plastic at the interface surface after 8 to 9 seconds of exposure.

The process outlined above is the basic process developed by DeBell and Richardson except for one feature: The recommendation of a mold temperature of 280°F. They do not preheat the projectile except for the temperature rise it experiences when it is inserted in the mold. This temperature rise is rapid, and the projectile temperature approaches that of the mold by the time the band material is injected. Trouble was encountered in implementing this approach in the style mold that was employed. The material requires a long freeze time at this mold temperature for it is only a few degrees below the melt temperature of the material (315°F). When the mold opened, the band material would not be completely frozen and the band would be destroyed. This would not be as prevalent a problem in the style mold employed by DeBell and Richardson. It was learned, however, that the temperature of the projectile is important in molding a quality band. This led to preheating the projectile to 350°F before inserting it in the mold so that the process outlined above becomes approximately equivalent to that of DeBell and Richardson. The practice of preheating the projectile reduces the molding cycle time. A cycle time of 45 seconds produces good parts by this process compared to 2 minutes in the DeBell and Richardson method. This could become an important consideration in future production planning.

The molding process that finally evolved from experiments and was used to apply the bands in the latter part of the program is the following: The material was Type 12 nylon, grade L1801 supplied by HULS of Germany. The material was dried for 4 hours at 180°F before molding. Molding was performed on a 1.0-ounce, 20-ton Arburg screw injection machine. The projectiles were warmed to 350°F and held at this temperature for a period not greater than 15 minutes prior to insertion in the mold. Operating conditions were as follows:

Screw Temperatures

- Throat - warm
- Rear - 460°F
- Front - 490°F
- Nozzle heater set at full voltage

Mold Temperature - 210°F

Mold Pressures:

- Injection - 20,000 psi/PAD
- Hold - 20,000 psi

Timers:

- Injection - 15 seconds
- Hold - 30 seconds

5. INCENDIARY PROVISIONS

The lethality of the projectile will be improved significantly if it is capable of igniting fuel and oil fires. To enhance this capability, a decision was made to use a Lake City explosive developed for use in the current M-56 projectile. This explosive contains aluminum powder, 35 percent by weight, to improve its incendiary properties.

To further improve the incendiary properties of the projectile, zirconium metal was added in the form of a thin tube that was pressed against the wall of the projectile as shown in Figures 1, 3, 5 and 7. The density of the zirconium is about 3.5 times that of the explosive it displaces (.237/.067) so the net effect is to increase the weight of the projectile. The effect on the weights of the various projectiles of adding a zirconium sleeve is summarized in Table 6.

Installation of the zirconium sleeve created a troublesome fabrication problem that required some development effort to resolve. The sleeve must be inserted through the mouth of the projectile and expanded after it is in place. In the early rounds this expansion was accomplished when the HE was compacted, but this proved to be unreliable. Some of the sleeves would expand properly but others expand unevenly, causing voids along the side of the projectile. Installation was finally resolved by fully expanding the sleeve by the use of a series of rubber dies. This required an appreciable development effort to achieve the proper combination of die design and material. The rubber finally employed was a synthetic made of polyurethane, Durometer 90A. Expansion was further assured by compacting the first increment of HE material at 30,000 to 35,000 psi.

Incendiary performance was not evaluated by the contractor. The Air Force designed and conducted a series of experiments to evaluate this terminal effect. The results will be separately reported.

TABLE 6. WEIGHT ADJUSTMENTS DUE TO ZIRCONIUM SLEEVE

Configuration	Weight of Zirconium Sleeve (grains)	Reduced HE Weight (grains)	Added Projectile Weight (grains)
Min. Weight - Mod. Fuze Figure 1	50	14	36
Max. HE - Mod. Fuze Figure 3	64	18	46
Min. Wt. - Std. Fuze Figure 5	62	18	44
Max. HE - Std. Fuze Figure 7	75	21	56
Min. Wt. - Mod. Fuze - Conical Section Figure 9	50	14	36
Min. Wt. - Mod. Fuze - Aft Support Figure 11	57	16	41
Min. Wt. - Mod. Fuze - Aft Support/ Conical Section Figure 13	57	16	41
M-56	53	15	38

6. MANUFACTURING TECHNIQUES

The fabrication of the projectile body involved no unusual manufacturing processes. The body was machined from bar stock by a series of turning operations. The body was machined to its finished dimensions before heat treatment.

Heat treating has already been discussed. The projectiles are placed in a rack that holds them in a suitable attitude for quenching. A fast oil quench is employed. The material is drawn to the proper hardness, and the tab at the aft of the projectile is then induction annealed.

The closure disc is then added, and the zirconium sleeve is installed and the rotating band is added by the processes previously discussed. After finishing and painting, the projectile is ready for HE loading.

The high explosive is added in three increments. The first increment is compacted at 30,000 to 35,000 psi. This compaction pressure is employed for two reasons. First, it further assures that the zirconium sleeve is expanded completely against the wall of the projectile and, second, it compacts this increment of HE more densely and increases the amount of HE material that can be installed by about ten grains. The next two increments of HE are compacted at 20,000 to 25,000 psi. If the compacted height exceeds specified limits, material can be removed by machining the HE with a non-sparking tool.

The projectile bodies were machined during the program because this was the most economical method of manufacture for small quantity development lots. Also, it is an acceptable method of manufacture for production quantities and is one of the approved methods for manufacture of the M-56 projectile. A cup-and-draw method of fabrication is also satisfactory and is currently used in fabricating M-56 projectiles for it has proven to be a more economical means of fabricating this projectile in large quantities. This process requires extensive tooling, the cost of which cannot be justified for small-lot development quantities where the design may be modified from lot to lot. The thin-wall design, once its configuration is stabilized, could be manufactured by the cup-and-draw process. The A-4 base configurations shown for the projectiles are suited for this method of fabrication.

7. PROPELLANT PROVISIONS

The reduced weight of the thin-wall projectiles plus the reduced start force required to push the plastic rotating band into the rifling grooves of the barrel resulted in an appreciable drop in the chamber pressure produced by the standard charge of 40 grams of WC870 propellant. This provided an opportunity to increase muzzle velocities by developing a propellant charge that would restore the chamber pressure to the design value for the gun, namely, 60,000 psi. A faster burning propellant that would produce gas at a higher volumetric rate and maintain pressure at the base of the faster moving projectile was needed.

The chamber pressure was restored to the design value by blending a fast burning IMR4350 propellant with standard WC870 propellant. After a few trials it was found that a blend of 26 grams of WC870 and 14 grams of IMR4350 propellants produced a chamber pressure in the 50,000 to 60,000 psi range for the minimum weight configurations at ambient temperatures. A blend of 26 grams of WC870 with 10 grams of IMR4350 performed properly with the maximum HE capacity designs. The propellants were mixed thoroughly before loading into the M103 cartridge case. The total weight of propellant was reduced by two grams in the maximum HE capacity designs because the body of these projectiles protruded into the case and displaced some of the propellant.

At an elevated temperature of $+160^{\circ}F$, this blend of propellants, produced in a sample of 10 projectiles, an average chamber pressure of 68,000 psi. At $-65^{\circ}F$ the average chamber pressure for a ten-unit sample was 49,540 psi. The average pressure of a similar group of these projectiles at ambient temperature was 57,862 psi.

8. CHARGE-TO-METAL RATIO

One of the design objectives was to achieve a significant increase in the charge-to-metal ratio over the current M-56 design. This objective was achieved in a very substantial manner. Using the projectile weights shown in Table 1 and including the zirconium liners as part of the metal component, the charge-to-metal ratios for the seven projectile configurations are as listed in Table 7. The charge-to-metal ratio for the M-56 projectile is included for comparison. These ratios do not include the fuze.

TABLE 7. COMPUTED CHARGE-TO-METAL RATIOS

Configuration	Weight - Grains Metal	Weight - Grains HE	Ratio
Min. Wt. - Mod. Fuze	592	202	.34
Max. H.E. Cap. - Mod. Fuze	792	237	.30
Min. Wt. - Std. Fuze	661	270	.41
Max. H.E. Cap. - Std. Fuze	841	294	.35
Min. Wt. - Mod. Fuze - Conical Section	637	202	.32
Min. Wt. - Mod. Fuze - Aft Support	672	217	.32
Min. Wt. - Mod. Fuze - Con. Section/ Aft Support	702	217	.31
M-56	1003	180	.18

9. TEST PROGRAMS

A test program was planned and conducted to obtain information for use in developing the projectiles and evaluating their performance. The tests can be separated into two categories: development tests and acceptance tests.

The acceptance tests were formal tests conducted on each of five major delivery lots. These delivery lots included projectiles designed to each of the four basic designs, Figures 1, 3, 5 and 7, and one special design, a minimum weight, modified fuze with a conical section (Figure 9). Twenty-five units were randomly selected from each lot and tested according to an approved acceptance test plan.

The development tests varied considerably, and each test was designed to obtain information on parameters of particular interest. Each test was used to obtain information on as many parameters as possible. All tests, except the soft recovery tests, were conducted on contractor test ranges. Except for special tests, such as the penetration tests, the test set-up used was as illustrated in Figure 19. A total of 265 development tests was performed. The following is a discussion of the various parameters that were studied and how the tests were performed.

a. Rotating Band Tests

On nearly every firing test that was performed this was one of the parameters that was monitored. Evidence of a band coming off could usually be detected on the muzzle X-ray, but the presence and condition of the band could be clearly monitored on a microflash photograph taken about 15 feet from the muzzle of the gun. An example of such a photograph is shown in Figure 20. The first projectiles were not scheduled to be available for several weeks into the program; so to implement an early beginning of the rotating band investigations, two simulated projectiles were designed and fabricated. They weighed

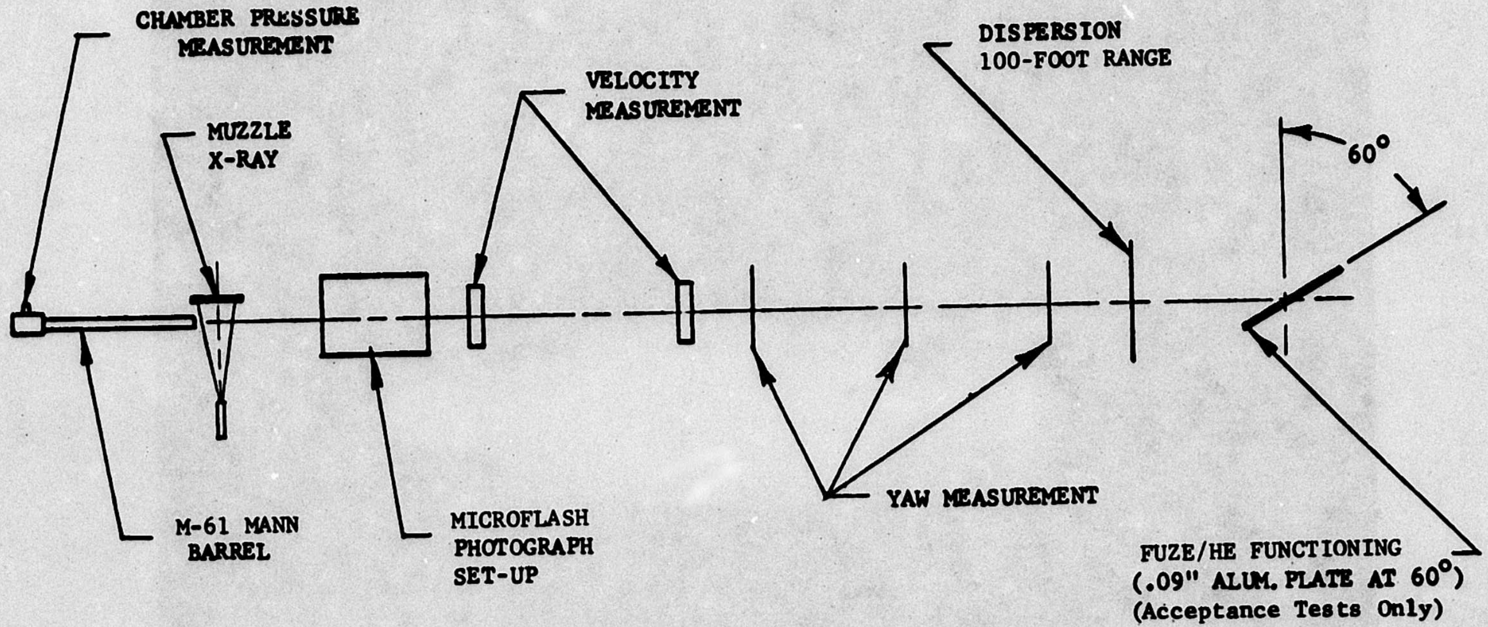

Figure 19. Thin-Wall 20mm Explosive Projectile Test Arrangements

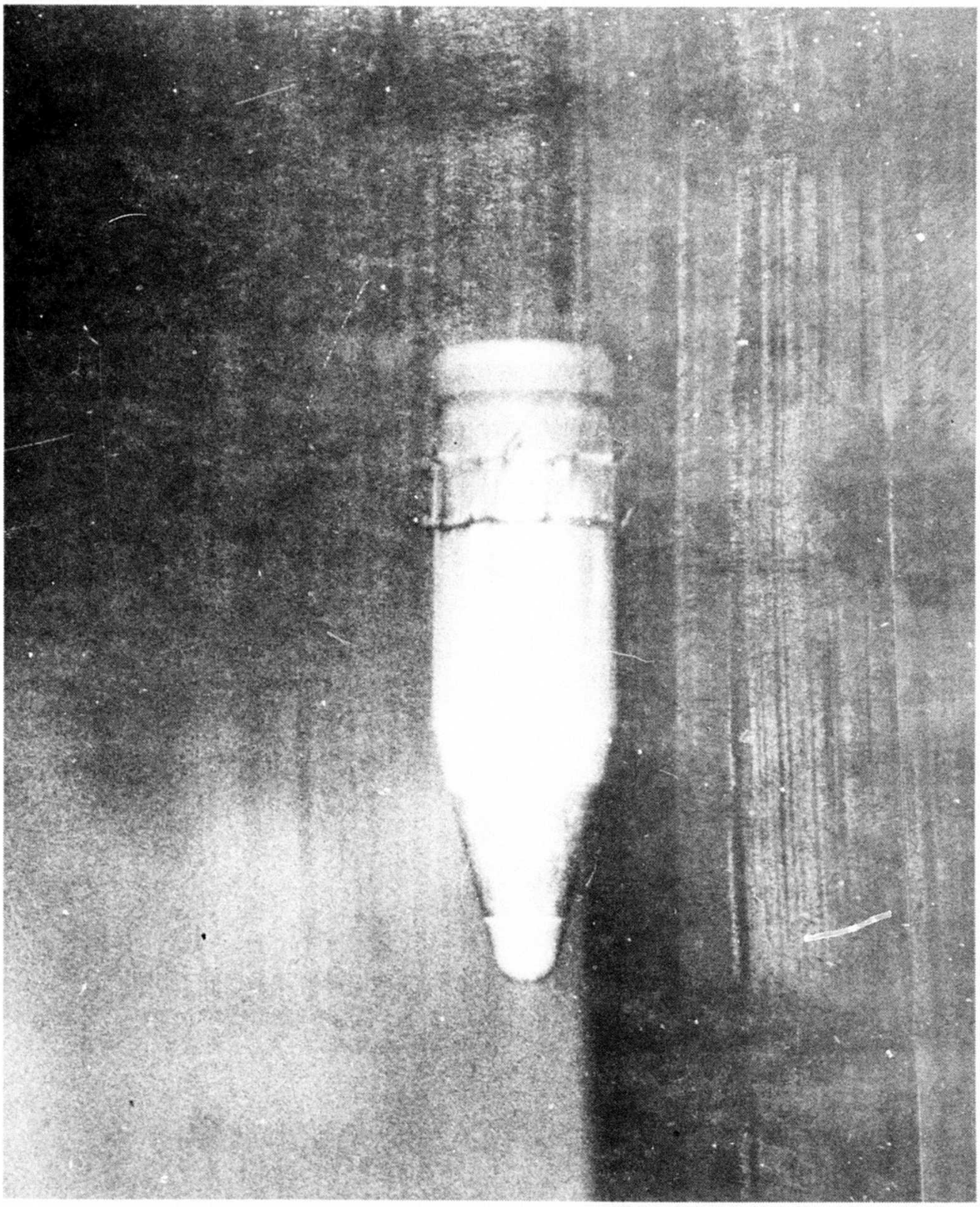

Figure 20. Microflash Photograph of Projectile in Flight

1200 and 1500 grains to correspond approximately with the minimum weight and maximum HE capacity designs. The simulated units were also proportioned to match the corresponding moments of inertia of these two projectiles. About 100 tests were conducted using these simulated units.

Functioning of the rotating band is subject to many parameters, and these were varied from test to test to acquire information on the best combination of materials and application processes. As previously indicated, eight different materials for the band were investigated. Also many parameters relating to the band application process were investigated. Each variation required firing tests to evaluate its effect on band performance.

b. Chamber pressure

Chamber pressure is measured by tapping the chamber of the Mann barrel to install a pressure transducer. There are several transducers available for this purpose, the principal requirement being that it have a frequency response capable of following the time variation of pressure which is displayed on an oscilloscope and recorded with a Polaroid camera. An occasional check of the instrumentation is made by measuring peak pressure with a copper crusher gage.

Chamber pressure was taken on most of the tests performed on the program. It provides information which might explain any noticeable performance anomaly that might occur during the tests. It was the primary measurement, of course, in the development of a propellant blend that would produce a chamber pressure in the 50,000 to 60,000 psi range for these lightweight thin-wall projectiles.

c. Muzzle Velocity

Muzzle velocity was taken on all firing tests. It was obtained by measuring the time required to traverse a known distance between two points in the trajectory. These measurements were taken about 20 feet from the muzzle of the gun using two timing screens positioned ten feet apart.

d. Stability

This was monitored by observing the extent and decay of yaw as the projectile progressed along its trajectory. The range and sophistication of the instrumentation was insufficient to obtain a quantitative evaluation of stability. However, it did provide a qualitative indication of the yaw present in the launch and to a lesser extent an indication of the damping properties of each projectile. Facilities such as the Aeroballistic Research Facility at Eglin AFB are necessary to obtain a meaningful evaluation of projectile stability.

e. Dispersion

Dispersion or the random variation of projectiles from the average flight path was obtained by measuring the deviation of individual impacts from the center of impact of a group of projectiles as recorded on a witness screen placed at a known distance from the muzzle of the gun. The witness screen was located at 100 feet downrange. All projectiles in a group were required to have identical design characteristics and to be fabricated in the same lot. The group size was usually five projectiles. Dispersion information was taken and recorded on the majority of the development tests. Also, a group of 30 projectiles, consisting of ten each of the three special designs shown in Figures 9, 11, and 13 were fabricated and furnished to the sponsor for tests at their facility.

f. Penetration Tests

This was a set of special tests designed to determine the ability of the thin-wall projectiles to strike and traverse the barrier represented by an aircraft skin without sustaining damage at a level that would impair its normal functioning. Targets made of 2024-T3 aluminum having thicknesses of 0.063, 0.090, and 0.183 inch were set at varying angles of obliquity ranging up to 85 degrees (zero obliquity angle defined as a normal or flush impact). The condition of the projectile after penetration was monitored by X-ray photograph. The threshold of failure was located in the 60- to 75-degree obliquity region on 0.188 thick skin. The 0.063 and 0.090 skins were penetrated successfully at all angles of obliquity up to 75°.

g. Fragmentation

A total of fourteen projectiles of various configurations were exploded in arena tests, and the fragments were recovered for examination. Several of these test samples were furnished to the sponsor for evaluation.

h. Structure Testing

Since the walls of the projectiles had been thinned to the point where the beginning of permanent deformation could be expected at maximum loading conditions, it was important to be able to detect any indication of structure failure or deformation. This was monitored by photographing the projectile at the muzzle of the gun by X-ray and at a point downrange by micro-flash photography. This measurement was made on nearly 100 percent of the test firings. As a further check of the structural integrity of the designs, a series of twelve soft recovery tests were performed at the H.P. White laboratories. These recovered projectiles were checked dimensionally for any indication of permanent deformation. No indication of structural deficiency was observed in any of the tests.

A series of special tests were designed in an effort to locate the failure threshold of wall thickness for each of the four basic designs. The wall thickness at the base end of these test projectiles were thinned beyond their design values by removing additional material from their walls. The additional material removed from the wall of each projectile was nominally 0.010 and 0.020 inch. The actual average values were the following:

Configuration	Wall Thinned By	
	0.010 Nom.	0.020 Nom.
Min. Wt. - Mod. Fuze	0.007	0.019
Max. HE - Mod. Fuze	0.010	0.020
Min. Wt. - Std. Fuze	0.007	0.017
Max. HE - Std. Fuze	0.009	0.018

A total of 16 projectiles were expended in these tests. They were tested at normal propellant loading giving a chamber pressure in the 55,000 psi range. No deformation could be detected in the photographs. The tests failed to locate the threshold values for wall thickness. However, they served as an indication that the nominal wall thicknesses provided a good margin of safety.

i. Test at Temperature Extremes

One series of tests were conducted at the temperature extremes of $-65^{\circ}F$ and $+160^{\circ}F$ to observe the performance of the rotating bands at these conditions. Five each of the two designs equipped with standard fuzes were tested at each temperature extreme. The performance of the bands at these temperatures has been previously discussed.

j. Fuze Provisions

A supply of M505A3 live and inert fuzes was furnished for conduct of the test programs. Except for five units supplied for a special dispersion test, no modified fuzes were available during the program. When live fuzes were required, M505A3 fuzes were used. They were a proper match for the units designed to use this standard fuze, but a mismatch existed when they were used on units designed for the modified configuration. This mismatch posed no problem insofar as functioning of the projectile was concerned. However, the flight characteristics were not a true representation of the projectiles equipped with their proper modified fuzes. Dispersion is less when equipped with the M505A3 fuze. This was first detected in the terminal effects tests conducted by the Air Force at Socorro, New Mexico, and led to the design of the three special minimum weight modified fuze configurations.

When inert tests were conducted, the booster and rotor ball assemblies of the M505A3 fuze were removed and a weight was added to bring the total weight of the fuze up to the weight of the live units. These weights, one for the standard and another for the modified fuze version, were designed to be fastened by the threads that normally secured the booster.

k. Soft Recovery

A series of soft recovery tests were conducted at H.P. White Laboratories as an additional check of the structural properties of the projectiles. At least two projectiles of each of the four basic designs were tested in their soft recovery tubes. Each projectile was given a post-test dimensional check for any indication of permanent deformation. No deformation was observed.

These tests also provided a check on the condition of the plastic-to-metal bond of the rotating band. The bond was good on all these projectiles.

l. List of Tests

A condensed summary of the tests performed during the program is provided in the listing shown in Table 8.

TABLE 8. LIST OF DEVELOPMENT AND ACCEPTANCE TESTS

Date	Proj. Config.(1)	Test Objective	Quan. Tested	Remarks
6/5/74	8	Band - 612 Nylon	2	Band came off
	9	Band - 612 Nylon	1	Band came off
6/21/74	8	Band - L1901 Nylon	3	Band came off
6/24/74	8	Band - L1901 Nylon	2	Band came off
7/5/74	8	Band - L1901 Nylon	1	Band OK
	9	Band - L1901 Nylon	2	Band OK
7/11/74	8	Band - L1901 Nylon	5	2 good, 3 bad
	9	Band - L1901 Nylon	4	1 good, 3 bad
7/15/74	8	Band - Rilsan BESNO	3	2 good, 1 bad
	9	Band - Rilsan BESNO	3	- 3 bad
7/16/74	8	Band - Rilsan BESNO	1	1 good -
	8	Band - Rilsan Black-T	1	1 good -
	8	Band - L1901	3	- 3 bad
	9	Band - L1901	5	5 good -
	9	Band - Rilsan Black-T	1	1 good -
7/17/74	8	Band - L1901	2	1 good, 1 bad
	9	Band - L1901	3	2 good, 1 bad
	9	Band - Rilsan Black-T	2	2 good -
7/24/74	8	Band - L1901	5	3 good, 2 bad
	9	Band - L1901	2	2 good -
7/25/74	8	Band - L1901	3	2 good, 1 bad
	9	Band - L1901	4	4 good -
8/1/74	8	Charge Development	9	--
8/5/74	M-55	Charge Development	5	Checked instrumentation
8/6/74	M-55	Charge Development	6	Checked instrumentation
8/12/74	8	Band - L1901	4	1 good, 3 bad
	8	D&R - L1801	1	1 good -
	9	Band - L1901	7	7 good -
	9	Band - L2101	3	2 good, 1 bad
8/14/74	1	Check projectile structure and L2101 Bands	9	Structure OK All bands OK
8/15/74	4	Check projectile structure and L2101 Bands	8	Structure OK All bands OK
8/16/74	2	Check projectile structure and L2101 Bands	11	Structure OK All bands OK

TABLE 8 (CONTINUED)

Date	Proj.(1) Config.	Test Objective	Quan. Tested	Remarks
8/16/74	3	Check proj. structure & L2101 Bands	9	Structure OK Lost one band
9/4/74	2	Penetration Test	3	
	3	Penetration Test		
9/6/74	4	Penetration Test	1	
	2	Penetration Test	3	Projectile penetrated
	1	Penetration Test	1	0.063 and 0.090 alum. plate
9/9/74	3	Penetration Test	2	at all obliquity angles.
	4	Penetration Test	1	Also 0.199 plate up to 60-
	1	Penetration Test	2	degree obliquity angle.
	2	Penetration Test	1	
9/10/74	3	Penetration Test	4	
	1	Penetration Test	1	
	4	Penetration Test	1	
9/12/74	1	Check extra thin	2	
	2	wall projectiles	2	No deformation
	3	Thinned 0.020 and 0.040	2	observed in all
	4	beyond basic design	2	four designs
9/23/74	1	Check live functioning	2	Functioned OK
	2	Check live functioning	1	
9/26/74	3	Check @ +160°F	5	
	3	Check @ -65°F	5	All L2101 bands OK
	3	Check @ +70°F	5	
	4	Check @ +160°F	5	Partial failure - 2 bands
	4	Check @ -65°F	5	All bands OK
9/27/74	4	Check @ +70°F	5	Bands OK
10/3/74	3	Evaluate L1801 Band	6	Bands OK
	1	Evaluate L1801 Band	1	Bands OK
	2	Evaluate L1801 Band	1	Bands OK
	4	Evaluate L1801 Band	2	Bands OK
10/4/74	3	Wall thinned	5	No deformation observed
	4	extra 0.010 inch	5	
10/9/74	4	Check L1901 Band	2	Bands OK
	1	in const. twist B	2	
10/17/74	1	Disp./actual Mod. Fuze	5	Increased dispersion
	1	Disp./zinc Liner	5	No effect noted
	2	Disp. no Liner	5	No noticeable difference
	2	Disp./Liner	5	
11/26/74	5	Check Functioning	2	All rounds
	6	Check Functioning	1	Functioned OK
	7	Check Functioning	1	

TABLE 8 (CONCLUDED)

SPECIAL TESTS

Date	Proj. Config.(1)	Test Objective	Quan. Tested	Remarks
9/5/74	1	Soft Recovery	3	No deformations observed
	2	Structural Tests	3	
	3	at H.P. White Labs	3	
	4		3	
8/29/74	1	Arena test to	2	Samples to Eglin for evaluation
	2	study fragmentation	2	
	3	properties	2	
	4		2	
4/10/74	5	Arena Tests	6	Samples to Eglin for evaluation
10/28/74	1	Acceptance Tests	25	Report submitted
11/1/74	2	Acceptance Tests	25	Report submitted
1/29/75	3	Acceptance Tests	25	Report submitted
1/31/75	4	Acceptance Tests	25	Report submitted
3/2/75	5	Acceptance Tests	25	Report submitted

NOTES: (1) The following key identifies the different projectile configurations:

1. Minimum weight - modified fuze
2. Maximum HE capacity - modified fuze
3. Minimum weight - standard fuze
4. Maximum HE capacity - standard fuze
5. Minimum weight - modified fuze - conical section
6. Minimum weight - modified fuze - aft support
7. Minimum weight - modified fuze - conical section-aft support
8. Minimum weight simulated projectile - 1200 grains
9. Maximum HE capacity simulated projectile - 1500 grains

SECTION III

PRELIMINARY FUNCTIONAL CONFIGURATION IDENTIFICATION

The following information has been prepared to identify the functional characteristics of the 20mm thin-wall projectiles developed on this program. Four basic configurations were fully investigated during the program. In addition, three variations of the minimum weight modified fuze configuration were studied for their ability to limit dispersion. Information on all seven designs is provided.

1. PHYSICAL CHARACTERISTICS

The principal physical characteristics of each design are summarized in the listings of Table 9 . In addition, the projectile is through hardened to R_C 38-42 except for the tabs that retain the protective disc at the aft end of the projectile. These tabs are drawn to R_C 28 to 32. The walls of the projectile have been thinned to the least practical value consistent with structural demands. A plastic rotating band is bonded to the surface of the projectile.

2. PERFORMANCE CHARACTERISTICS

Performance characteristics are separable into three categories: interior ballistics, exterior ballistics, and terminal effects. Interior ballistic parameters were measured on all seven designs and are fully reported. The measured parameters were the time-pressure variation of chamber pressure and the muzzle velocity. These parameters are summarized in Table 10 . Exterior ballistic parameters were partially monitored by the contractor. Dispersion was measured on all designs and stability as evidenced by the absence of yaw was monitored. The Air Force conducted some testing in their Aeroballistic Research Facility at Eglin AFB, and the results are partially reported here. Those parameters that were not measured were computed, and the results are included in Table 11 with the notation that they are computed values.

TABLE 9. PHYSICAL PROPERTIES OF SEVEN THINWALL PROJECTILE DESIGNS
(WEIGHT IN GRAINS)

	Drawing	Disc	Band	Shell Body	Zirc. Liner	HE	Fuze	Total	CG[(1)] Location
Min. Weight Modified Fuze	Figure 1	16	7	526	50	202	418	1219	1.772
Max. HE Capacity Modified Fuze	Figure 3			712	64	237	418	1454	2.005
Min. Weight Standard Fuze	Figure 5			583	62	270	335	1273	1.709
Max. HE Capacity Standard Fuze	Figure 7			750	75	293	335	1476	1.938
Min. Wt. Mod. Fuze Conical Section	Figure 9			571	50	202	418	1264	1.772
Min. Wt. Mod. Fuze Aft Support	Figure 11			599	57	217	418	1314	1.853
Min. Wt. Mod. Fuze Aft Support/Conical Section	Figure 13	16	7	629	57	217	418	1344	1.853

(1) Length from tip of fuze - inches.

TABLE 10. INTERIOR BALLISTIC PERFORMANCE PARAMETERS

Configuration	Proj. Wt. (4) Grains		Propellant - Grams		Pressure - psi (2)		Velocity - fps	
			WC-870	IMR 4350	$\overline{P}$	σ	$\overline{V}$	σ
Min. Wt. - Modified Fuze Figure 1	1117	(1)	26	14	50,884	1255	3913	19.7
Max. HE - Modified Fuze Figure 3	1356	(1)	28	10	49,913	910	3559	12.1
Min. Wt. - Std. Fuze Figure 5	1273	(1)	26	14	54,123	1411	3771	15.9
Max. HE - Std. Fuze Figure 7	1475	(1)	28	10	48,478	2662	3437	27.6
Min. Wt. - Modified Fuze Conical Section - Figure 9	1181	(1)	26	14	53,811	1753	3821	10.7
Min. Wt. - Modified Fuze Aft Support - Figure 11	1305	(3)	31	9	--	--	3700	19.0
Min. Wt. - Modified Fuze Aft Support - Conical Section - Figure 13	1335	(3)	31	9	--	--	3640	22

(1) Tested by contractor using M505A3 fuzes - Wt. $\approx$ 335 grains.
(2) Ambient temperature - 70°F.
(3) Tested at Eglin AFB using modified fuzes - Wt. $\approx$ 418 grains.
(4) Average weight of projectiles in test lot. Weights do not necessarily correspond to those listed in Table 9 due to changes in the zirconium liner and the HE compaction pressure.

TABLE 11. EXTERIOR BALLISTIC PERFORMANCE PARAMETERS

Configuration	Drag. Coef.(1) at Mach 3	TOF (Sec) (1) Range (Ft) 1000	2000	3000	Dispersion - D_{80} Mils (3) Std. Fuze	Mod. Fuze
Min. Wt. - Mod. Fuze Figure 1	.256	.23	.48	.76	6.00	7.08
Max. HE - Mod. Fuze Figure 3	.260	.24	.52	.82	9.74	-
Min. Wt. - Std. Fuze Figure 5	.325(4)	.23	.50	.83	3.76	-
Max. HE - Std. Fuze Figure 7	.328	.23	.54	.87	6.00	-
Min. Wt. - Mod. Fuze Con. Section - Figure 9	.301	.23	.54	.80	3.52	5.30
Min. Wt. - Mod. Fuze Aft Supt. - Figure 11	.256	.23	.48	.76		6.52
Min. Wt. - Mod. Fuze Aft Supt. - Conical Section - Figure 13	.301	.23	.54	.80		2.74

(1) Computed values.
(2) Computed at sea level, -40°F, Velocity = 4600 fps.
(3) Tests using M505 Fuze performed by contractor. Tests using modified fuze performed by Air Force. Values are diameters of circles containing 80% of impacts divided by range to target.
(4) Drag M-56 configuration - "Joint Munitions Effectiveness Manual, Weapons Characteristics".

Except for penetration tests, no contractor testing was performed to evaluate terminal effects. Several projectiles were exploded in arena tests and the fragments were furnished to the Air Force for analysis. The Air Force conducted a program to evaluate terminal effects. Data from these tests will be separately reported. In the penetration tests it was determined that the projectiles penetrate .063 and .090 aluminum plates at all angles of obliquity without disabling damage. Also, they penetrate .188 thick aluminum plate at 60 degrees obliquity. Failures begin to occur between 60 and 75 degrees obliquity on the .188 thick plate. The target material used in the tests was 2024-T3 plate.

3. RELIABILITY

A functional reliability of 90 percent at a 90-percent confidence level was the goal for the program. A test was designed wherein explosion of the projectile upon striking an .090 thick aluminum plate set 60 degrees obliquity was judged a success. If all projectiles in a sample of twenty-two function properly, it is considered that the reliability requirement has been satisfied.

4. MATERIALS

Materials and the heat treat process are critical to the success of this projectile. The properties required of the materials in the projectile body are: low cost, ease of fabrication, and a through hardening capability. These requirements can be satisfied by a number of medium carbon steels. Also the heat treat process must be carefully controlled to obtain uniform through hardness with negligible distortion. A fast oil quench combined with a method of supporting the projectiles properly during the heat treat process will produce satisfactory results.

5. INTERFACE CHARACTERISTICS

Three interface requirements must be satisfied by the projectile design. One consideration is interfacing properly with the M-61 gun systems. External projectile diameters and the configuration of the rotating band was influenced largely by this requirement. A second requirement is interfacing with the fuze. In this area the current design for the M-56 projectile was adopted without modification to assure interface with the M505A3 and the modified fuzes. A third consideration is the interface with the M103 cartridge case. Here the external diameter aft of the rotating band was made identical to the M-56 projectile. Also the configuration and location of the crimp groove was made to conform to the current M-56 design. This assures proper interface in this area.

6. TEST REQUIREMENTS

Testing is required to determine conformance with the performance goals established for the projectile. Testing is performed to check various structural and performance parameters. This testing is summarized in Table 12.

TABLE 12. SUMMARY OF TESTING REQUIREMENTS

Characteristic	Nature of Test	Test Responsibility
Projectile Hardness	a. Uniform hardness - Rockwell penetrator b. Through hardness - Macro-Etching	Contractor
Structural Integrity	Photograph projectile at muzzle exit by X-ray and microflash and inspect for structural deformation	Contractor
Plastic-to-Metal Bond Rotating Band	Microflash photographs of projectile in flight	Contractor
Chamber Pressure	Time-pressure variation of chamber pressure measured by transducer and recorded on Polaroid film	Contractor
Muzzle Velocity	Time to traverse a known distance obtained by chronograph measuring	Contractor
Dispersion	Impact pattern recorded on witness sheet placed at known target distance	Contractor
Stability	Damping of flight perturbations recorded photographically at known intervals	Government
Drag	Velocity decay rate - multiple chronograph measurements or radar tracking	Government

TABLE 12 (CONCLUDED)

Characteristic	Nature of Test	Test Responsibility
Penetration Capability	Impact target and photograph projectile with X-ray or microflash	Contractor
Fragment Velocity	Explode projectile in arena and photograph particles at known times	Contractor
Fragment Distribution	Recover fragments in arena, sort by size, and count to obtain distribution	Contractor
Spatial Distribution	Recover in gel or photograph by X-ray	Contractor
Incendiary Properties	Fire into prepared targets and determine fire ignition capability.	Government

SECTION IV

CONCLUSIONS

The following conclusions are drawn from the experience and findings of this program:

- This work demonstrated that thinning the walls of the projectile body to achieve a 20mm projectile having improved flight characteristics and greater lethality is a practical concept. For example, the minimum weight, modified fuze projectile is 20 percent lighter than the current M-56 projectile yet contains 20 percent more HE plus zirconium incendiary additives. It also has improved aerodynamic characteristics and will be equipped with an improved delayed action fuze. The other thin-wall designs have similar improved performance characteristics.

- The concept for a plastic rotating band and its application by creating a satisfactory plastic-to-metal bond is vital to this thin-wall projectile concept. It has been demonstrated that the plastic rotating band concept is sound, and prospects are excellent for achieving a completely satisfactory plastic-to-metal bond.

- The use of AISI 1040 material and the development of a satisfactory heat treat process provided a satisfactory structural design for these thin-wall projectiles. The combination employed in these designs may be only one of several practical solutions, but it provides direction and a precedent in the search for suitable materials and processes for thin-wall heat-treated projectiles.

SECTION V

RECOMMENDATIONS

Sufficient experience was acquired on this program to establish full confidence that the thin-wall projectile design concept is sound and that the goals established for this 20mm thin-wall projectile can be satisfied in every respect. It is recommended, therefore, that the basic designs generated for this projectile be refined by instituting an engineering development program planned to complete development and prepare drawings and specifications suited for fabrication of production quantities. Refinements of the designs and manufacturing processes should be considered in the following areas:

1. Final proportioning of the projectile walls should be accomplished by analysis and test. Indications are that the dynamic nature of the loading is such that the walls can be thinned beyond the values represented by the current designs. The possibility should be investigated of utilizing a form of finite element analysis that compensates for the dynamic quality of the loading. Other factors requiring consideration in establishing final wall thicknesses are: projectile stability, fragmentation properties, and producibility.

2. Investigations should continue on the choice of material. The material must heat treat properly, satisfy performance requirements, and be the most economical from the standpoints of its raw material cost and its workability.

3. Investigation of fabrication methods should be instituted to determine the most economical method of fabricating production quantities. Designs should be modified, if necessary, to achieve a satisfactory trade-off of performance and producibility.

4. Investigation of the rotating band design should be continued. Materials, the configuration of the band, and its application process are areas where further refinements can be helpful in achieving a totally reliable plastic rotating band.

5. Continued investigation of terminal effects is suggested. Added information on the size and spatial distribution of the fragments is needed. This may influence the final configuration of the projectile wall. Also further study of the best way to enhance incendiary properties is desirable.

6. Experimental data on exterior ballistic parameters such as stability and drag should be acquired to substantiate satisfactory performances predicted by theory and computation.

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