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Historical Development Summary of Automatic Cannon Caliber Ammunition: 20-30 Millimeter

Dale M Davis
MUNITIONS DIVISION

JANUARY 1984

FINAL REPORT FOR PERIOD: 1952 - 1983

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This report summarizes much of the research development, test and evaluation of aircraft cannon ammunition during the past thirty years. During that time the author has accumulated samples of much of this work, which have been continuously used as training aids and briefing references for both government and industry personnel. These samples or models illustrate both the good and the bad: things that worked and things that did not; things that should have been done and things that should not have been done.

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The purpose of this report is to set forth the historical story of these models, so that they will be available, at least in photographic form, to a much wider audience. By doing so, it is hoped that future ammunition developers will have a reference work that might serve several purposes, the two most important being (1) to prevent reinvention of what has already been done and (2) to provide inspiration to continue and improve on something which may have potential, but for one reason or another was not brought to use.

PREFACE

During the past thirty (plus) years the author has collected samples of much of the research and development that has been done on aircraft gun ammunition. Many of these samples have been photographed and their what, why, when, and how described herein. Hopefully, the samples themselves will someday end up in an Armament Museum.

The Public Affairs Office has reviewed this report, and it is releasable to the National Technical Information Service (NTIS), where it is available to the general public, including foreign nationals.

The author and collector of these samples is Dale M. Davis. This manuscript was prepared by Faye Ziglar; John Henderson was the technical editor.

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

FOR THE COMMANDER

MILTON D. KINGCAID, Colonel, USAF
Chief, Munitions Division

VITA

Dale M. Davis received a BS degree in Mechanical Engineering from West Virginia University in 1951. Upon graduation, he received a commission in the USAF and was assigned to the newly formed Air Research and Development Command at Wright Air Development Center. In 1952 he was transferred to Aberdeen Proving Ground, on the ordnance officers' exchange program, where he was assigned to the Small Arms and Aircraft Weapons Branch. Upon release from active duty in 1954 he retained his position and duties as a civilian until he transferred to the Air Force Armament Center at Eglin AFB in 1956. With the de-emphasis of guns beginning in 1957 he worked on warheads, explosives, and fuzing until 1965 when he returned to school, receiving a Master of Engineering Science degree from Florida State University in 1966.

Returning to the Armament Laboratory in 1966, he was charged with reinstituting a gun and ammunition research and development program. Recalling some of the gun/ammunition compatibility problems that occurred with the M39, M61, and T182 when guns were developed at Springfield Armory and ammunition at Frankford Arsenal, he decreed that while under his direction all Air Force guns and ammunition would be developed with one individual or agency responsible for both guns and ammunition and their interface. In late 1966 he visited each potential Air Force gun contractor and informed them of this policy, stressing that they would either have to learn about ammunition or associate themselves with someone who was skilled in the art. Much of the success and rapid development of the GAU-8 (less than 5 years from initial contract to production) is attributed to this policy.

Dale M. Davis has been associated with, involved in, or in responsible charge of, all Air Force gun and ammunition research and development from October 1952 until his retirement in February 1984. During this time he has also served as a consultant to the Army, Navy, DARPA, DoD, and NATO in these and related fields.

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SECTION I

INTRODUCTION

This report summarizes much of the research development, test and evaluation of aircraft cannon ammunition during the past thirty years. During that time the author has accumulated samples of much of this work, which have been continuously used as training aids and briefing references for both government and industry personnel. These samples or models illustrate both the good and the bad: things that worked and things that did not; things that should have been done and things that should not have been done.

The purpose of this report is to set forth the historical story of these models, so that they will be available, at least in photographic form, to a much wider audience. By doing so, it is hoped that future ammunition developers will have a reference work that might serve several purposes, the two most important being (1) to prevent reinvention of what has already been done and (2) to provide inspiration to continue and improve on something which may have potential, but for one reason or another was not brought to use.

This will not be a typical technical report filled with data, numbers, graphs, and tables. It will not even quote specific dates. It will simply state what was done or tried, why it was done, who did it, when it was done, especially in relation to other events, and the general result. An attempt will be made to provide enough identification so that the serious student can seek further reference on any specific subject.

SECTION II

20 MM AMMUNITION

The 20 mm is to automatic cannon what the caliber 30 is to rifles. That is, there are or have been literally dozens of distinctly different rounds of ammunition in this bore size. As a matter of fact, the US military services during and following World War II have used six distinctly different noninterchangeable rounds. There are probably guns and ammunition of each type still in inventory somewhere.

Two types were used in World War II: the Oerlikon (Figure 1(A)) as a shipboard antiaircraft weapon and the Hispano-Suiza (Figure 1(B)) which was used as an aircraft cannon. Both were of similar performance, firing projectiles of about 2,000 grains weight at muzzle velocities of about 2700 feet per second. Although manufactured in large numbers in the US until recent years (the Oerlikon shown is dated 1964), both were Swiss developments, the Oerlikon evolving at Oerlikon Machine Tool Works in Zurich and the Hispano-Suiza being developed by a company of that name in Geneva. As for the guns which fired these ammunitions, the Oerlikon was a straight blowback-operated weapon and the Hispano-Suiza was a gas unlocking, blowback-operated device; as a consequence, the ammunition had to be lubricated (oiled) for the guns to operate.

The Hispano-Suiza gun, known in the US as the AN-M1, AN-M2, and finally M3 was widely used from early in World War II until the end of the Vietnam Conflict, where it was still being used in USAF A-1E aircraft.

From the earliest days of arming aircraft, there has been a need to synchronize or precisely time the firing of guns for various reasons: firing through propeller arcs, simultaneous firing of twin guns, interrupting fire of

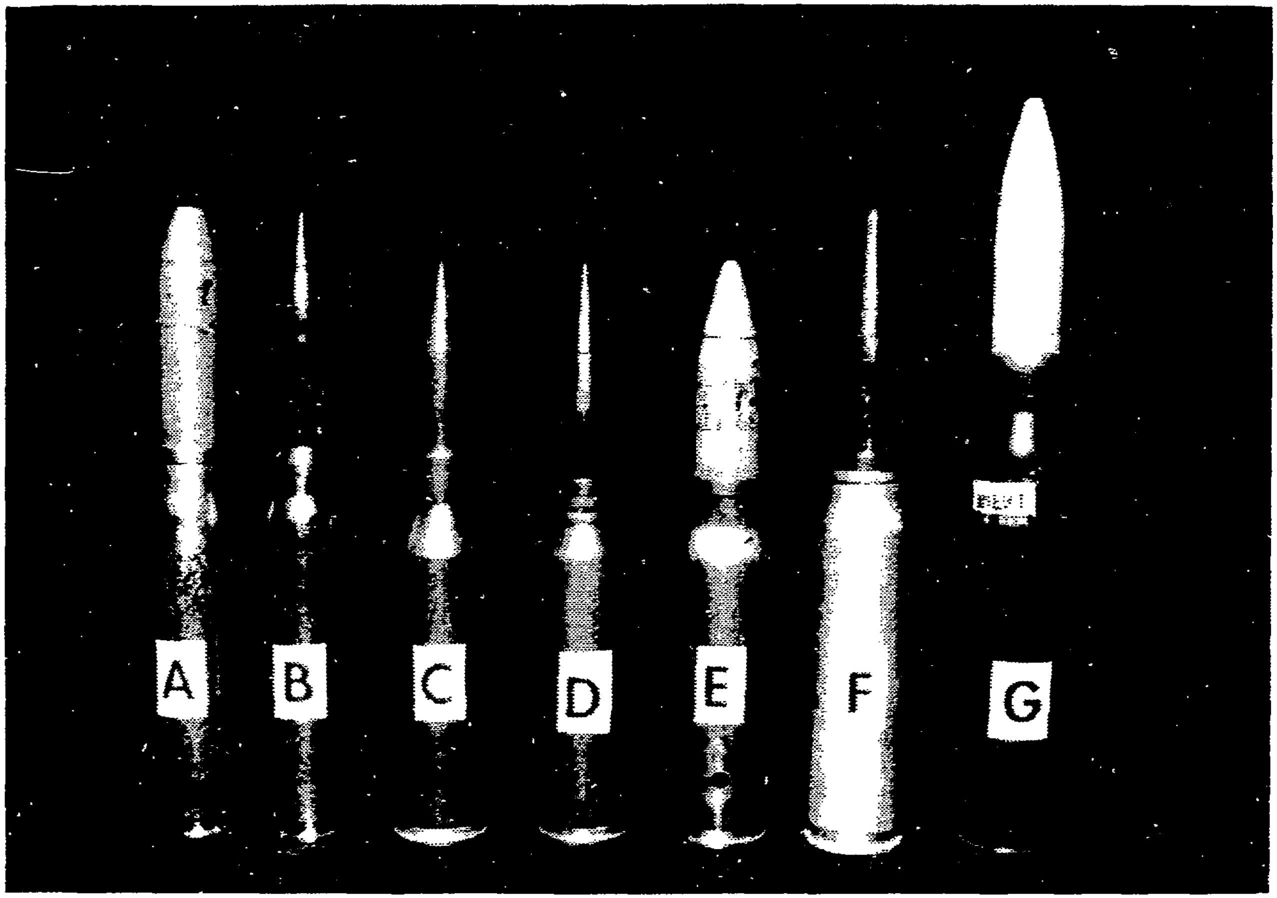


Figure 1. US 20 mm and Caliber .60 Ammunition
A. Oerlikon, B. M90-Series, C. Caliber .60,
D. 60/20, E. M50-Series, F. MK100-Series
G. HS820

turrets to prevent hitting your own ship, etc. Perhaps the best method of doing this was via the electric primer pioneered in Germany during World War II. A simple switch could precisely regulate when a gun would or could not fire. The M3 was modified from percussion to electrical ignition and called the M24. This gun was widely used and perhaps reached its zenith with the eight-turret, sixteen-gun installations on the B-36 aircraft. The nose guns carried 400 rounds each, the tail guns carried 960 rounds each, and the remaining twelve guns carried 600 rounds each: sixteen guns and 9,920 rounds of ammunition on one aircraft!

Of course, the simple act of changing the primer from percussion to electric made it an entirely new round of ammunition which was not interchangeable. To add to the confusion, it was not given a new designation and both rounds were known collectively as the "M90-series." They were:

M95	Armor Piercing
M97	High Explosive
M99	Target Practice

But when you ordered it, you had to specify electric primed for the M24 gun or percussion primed for the M3. We now had three distinct types of 20 mm ammunition in inventory.

In 1939 the Army developed a caliber .60 antitank cartridge. Early in World War II our ordnance engineers anticipated a need for a machine gun heavier than our caliber .50 Browning and began work on this caliber .60 which would fire a 1200-grain projectile at the then "hypervelocity" of 3500 fps (Figure 1(C)). This round was later necked down to caliber .50 and achieved a velocity of 3900 fps! Later yet, it was necked up to 20 mm, known as the 60/20, and fired a 1500-grain projectile at 3300 fps (Figure 1(D)). This round gradually evolved into the M50-series (Figure 1(E)) which is now the most widely used 20 mm ammunition in the world. It is built in several countries and uses perhaps a dozen different projectile types. In its nominal configuration for the USAF, it fires a 1560-grain projectile at 3380 fps. The USAF stocks API M53, TP M55, and HEI M56 configurations. We have now identified four distinct types of 20 mm ammunition in the US inventory.

While the USAF in conjunction with the US Army was developing the M39 revolver and M61 Gatling guns to fire the M50-series of ammunition, the Navy was working on its own aircraft gun designs. A twin-barrel revolver, designated MK11, was being developed, and work was continuing on the Hispano-Suiza design, a new high performance variation known as the MK12. Of course the Navy was looking for higher performance from its ammunition as well. In an effort to get the maximum case volume within the size constraints of the Hispano-Suiza receiver, they utilized the case diameter of the caliber .60 and the length of the Hispano-Suiza, or M90-series. This resulted in the USN MK100-series (Figure 1(F)), the fifth distinctly different and noninterchangeable round.

The sixth and last 20 mm round got into our inventory because the Army wanted something bigger than the caliber .50 Browning yet lighter than a 76 mm tank gun to put on some lightly armored vehicles--a quite reasonable requirement. Through an unbelievable series of events which will not be discussed in this report, the Army got the Hispano-Suiza 820 (M139) gun and the ammunition that went with it (Figure 1(G)). (Perhaps the Army didn't know exactly what they wanted, but this certainly was not it.) The Hispano-Suiza gun was never known for its reliability, regardless of the size in which it was built. Also it had to be kept clean and well lubricated, a difficult requirement in dusty or sandy environments.

So much for the origin of the six different US 20 mm cartridges. Subsequent developments and variations will be treated later; meanwhile, we will continue with the origin of inventory ammunition.

SECTION III

25 MM AMMUNITION

After the proliferation of 20 mm ammunition, it is interesting to note that only one 25 mm round has ever entered the US inventory. It came about as a result of the same Army need that brought about the 20 mm HS820, or M139, namely something better than the caliber .50 Browning.

The Army, in the early 1960's, established a requirement for a Vehicle Rapid Fire Weapon System (VRFWS) capable of, among other things, penetrating a specific thickness of armor, of a specific hardness, at a specific obliquity, at a specific range. (The actual figures were, and still are, classified.) If one tries to determine just what battlefield target that specification might represent, he would soon find out there was no such thing then, is none now, nor is there likely to ever be. This author soon reached the conclusion that the requirement was written specifically and solely so that the HS820 could not satisfy it. By making that assertion he almost started a fight at a joint service meeting at Rock Island some years ago, but the Army could not give a better explanation then nor have they yet. (If that was the only way they could get rid of the M139, I don't blame them.)

The weapon system specifications were sent out to industry; the Army provided some sporadic funding and many industrial firms provided various degrees of company funding to develop guns and ammunition. Some of the ammunition in contention is illustrated in Figure 2. Only the first has survived.

Figure 2(A) is the 25 mm Oerlikon, now known in the US as the "Bushmaster." Figure 2(B) is the 25 mm round developed by AAI which is semi-telescoped with a composite plastic/aluminum case. Note the snap fit between case and

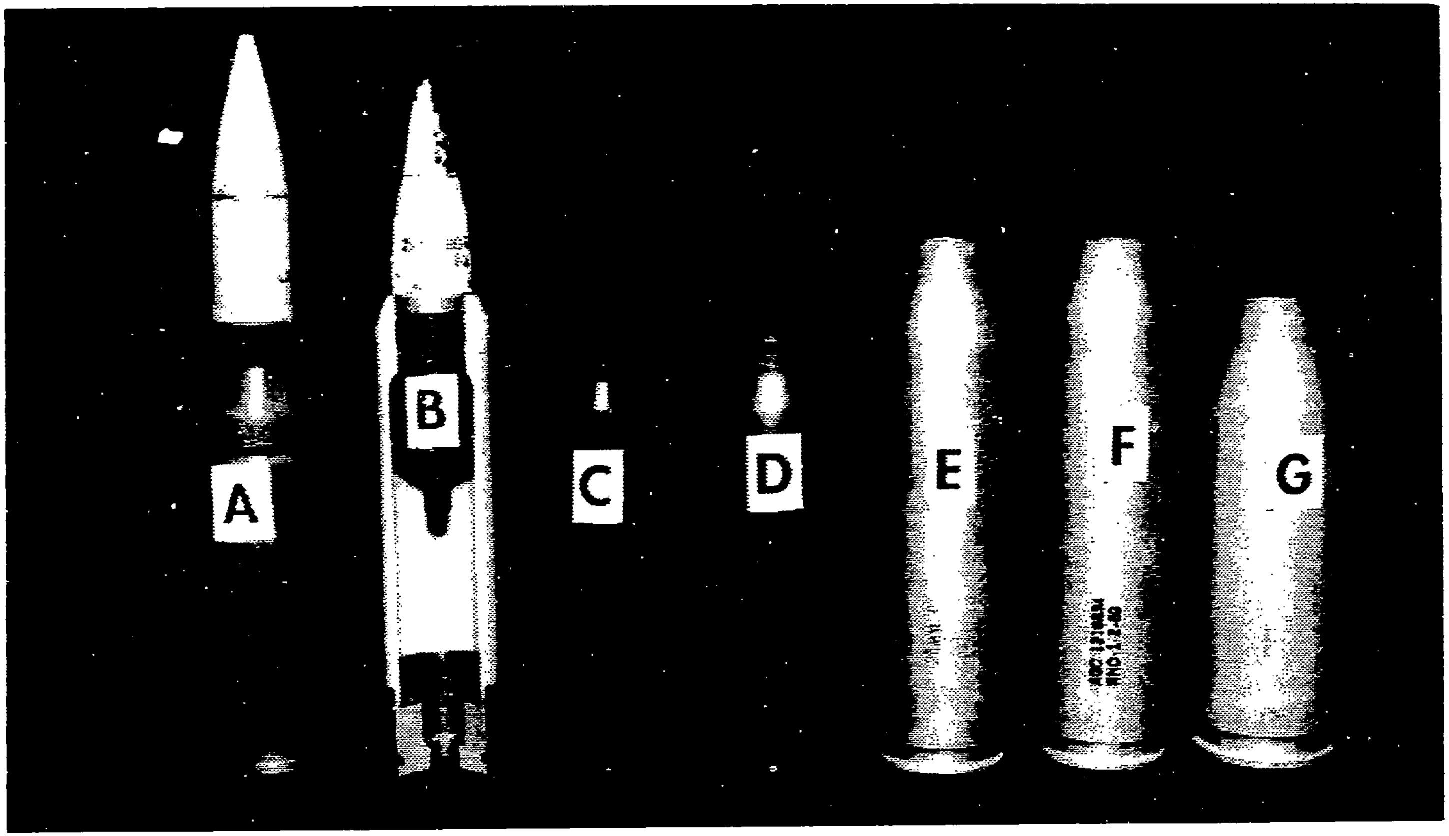


Figure 2. Some Army Bushmaster Candidates
A. Oerlikon/TRW 25 mm, B. AAI 25 mm, C. Colt 26 mm Steel Case,
D. Colt 26 mm Aluminum Case, E. GE/Amron 25 mm Steel Case,
F. GE/Aerojet/Amron 27.5 mm Steel Case, G. GE/Amron 27.5 mm Steel Case

projectile and between case body and base. Also note the rubber internal seal at the plastic/aluminum junction. This round is dated 1973. Colt chose to submit a 26 mm design. They used cases in both steel (Figure 2(C)) and aluminum (Figure 2(D)). Although the steel case does not have a maker's mark, it appears to be Oerlikon. It is dated 1969. The aluminum case was made by General Impact Extrusions of Canada and bears no date. Three other cases, all believed to have been made by Amron for General Electric, are also shown. Figure 2(E) is marked "25 mm GE." It has no date, but is probably from the early 1970's. Figure 2(F) bears an Aerojet drawing number, an Amron lot number, and date of 1969. It is 27.5 mm. Figure 2(G) is also 27.5 mm. It was made for General Electric by Amron in 1968.

As is now well known, the Army chose the 25 mm Oerlikon round, but not the original gun for which it was designed. The original gun, designed by Gene Stoner, has been known as the TRW 6425, Ford Bushmaster, and is being produced by Oerlikon for worldwide sales as the KBA B002.

The gun which the Army chose is a 25 mm version of the Hughes Chain Gun originally designed by Lenny Price (a motorcycle rider who recognized the versatility of the roller chain).

General Electric, always ready to invest venture capital where there is an obvious need, recognized that if the 25 mm round was going into the US inventory, it would be available for other applications, so they designed and built a five-barrel Gatling gun to fire it. This gun, designated GAU-12, is going on the Marine AV-8B Harrier aircraft and possibly on a Marine version of the Light Armored Vehicle (LAV).

This 25 mm round, in a variety of guns, is destined to find wide application in this country and abroad. The Army did the right thing in causing the development of something to replace the HS820.

The 25 mm Oerlikon/Bushmaster is a well designed round in most respects. In 1975 when it became obvious that this would become the US standard 25 mm cartridge, this author took a critical look at the design to see if there was anything about it that would limit its universal use. Only one point was apparent: the extractor groove is uncommonly shallow. Although this is of no great concern in a steel case for a belt-fed reciprocating weapon, it is a consideration in linkless feed systems and positive displacement guns which achieve their extreme reliability through complete and continuous round control. The rounds are controlled by holding and guiding the base of the case and the shallow groove limits engagement. The shallow groove becomes even more of a concern in the event we should elect to utilize aluminum cases for aircraft guns: anodized aluminum, as is now used for cases, tends to have higher friction and to wear and gall on sliding control surfaces. A deeper groove with greater extractor surface would help. The Air Force sent a letter to all concerned parties in 1975 along with a proposed design change. Figure 3 illustrates the results of this letter. The standard case is shown in Figure 3(A); a modified steel case, Figure 3(B); a modified aluminum case, Figure 3(C); a modified aluminum case after firing in a KBA B002 chamber (presumably a Mann barrel), Figure 3(D). Nothing further came of it; the change was not made, and all future gun/feed/handling systems will have to work with an uncommonly shallow extractor groove.

Many types of this 25 mm ammunition have been developed or produced in at least R&D quantities. Figure 4 illustrates the three US Army standard rounds,

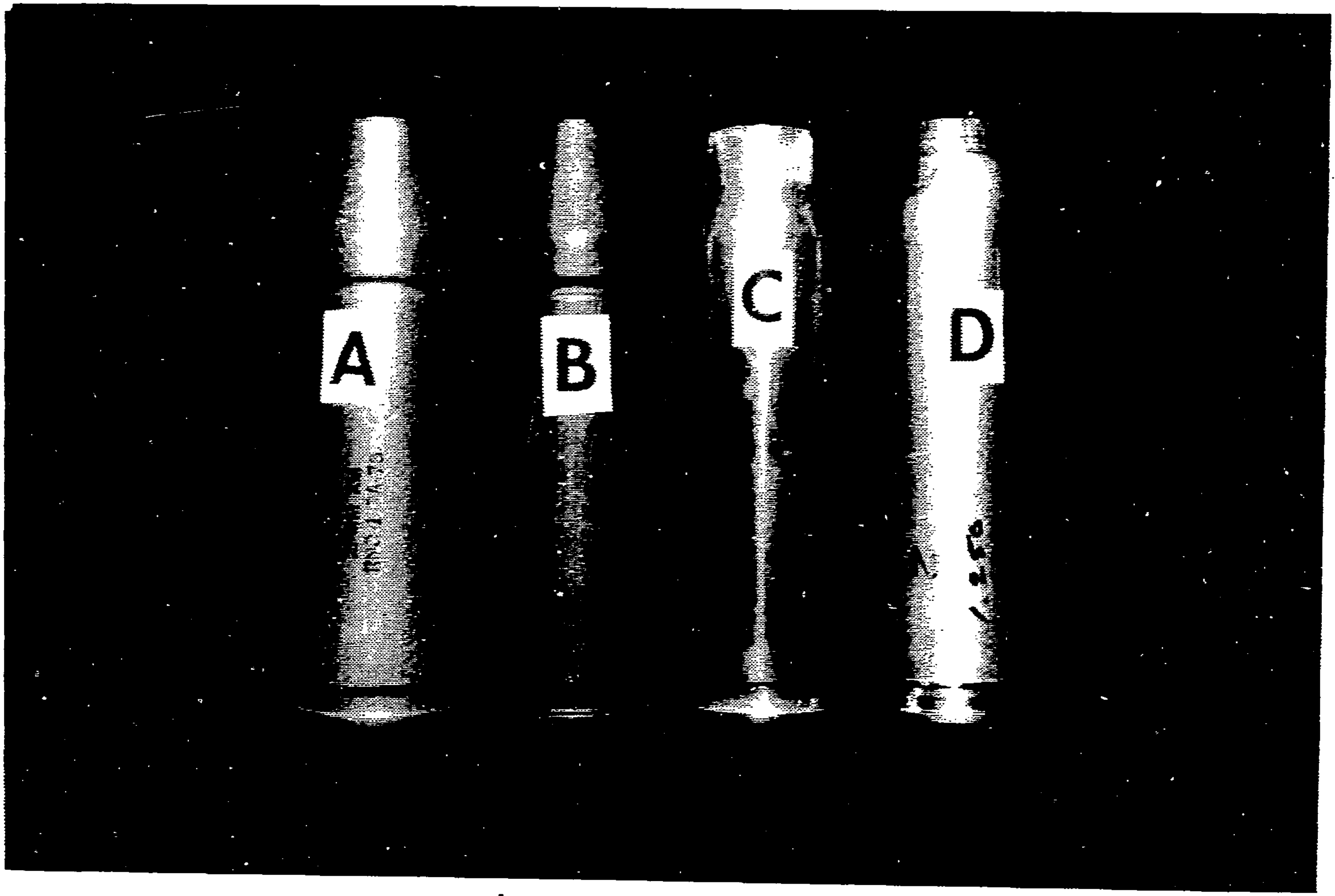


Figure 3. 25 mm Bushmaster Rim Variations
A. Standard Amron Case, B. Amron Case with Deep Extractor Groove, C. Aluminum Case, Deep Groove, D. Aluminum Case, Deep Groove after Firing

from left to right: spin stabilized armor piercing discarding sabot (SSAPDS), high explosive incendiary (HEI), and target practice (TP). Fin stabilized APDS and API made similar to the GAU-8 API (see Section V) have also been made in the US. In addition, two base fuzed types have been made in Europe, a high capacity anti-material round and a semi-armor piercing high explosive (SAPHE). Virtually all of these types have been made in both traced and non-traced versions. The TP and HE type shells weigh about 2850 grains and have a muzzle velocity of about 3600 fps. The SSAPDS round has a core weight of 1600 grains and a muzzle velocity of around 4400 fps. The full caliber projectiles use iron bands; the sabot has a plastic band. Nominal charge weight for all rounds is on the order of 1950 grains, and chamber pressure is about 56 kpsi.

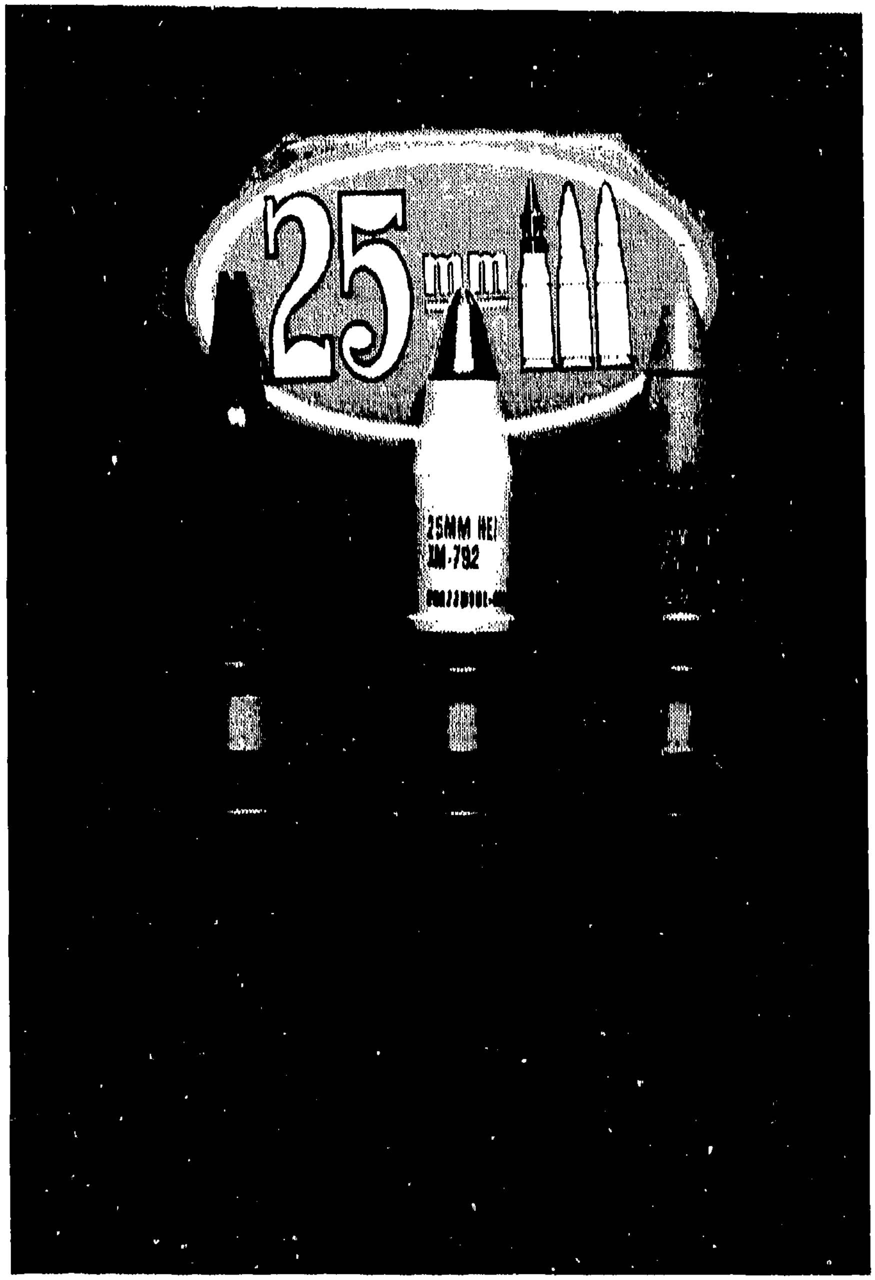


Figure 4. 25 mm M790-Series Ammunition as Manufactured by Ford (1977-79)

SECTION IV

30 MM ADEN/DEFA

Possibly the most interesting series of aircraft ammunition is that which is commonly referred to as the 30 mm ADEN/DEFA. It is also a round which, although of wartime German origin, was one of the first to be subject to a NATO Standardization Agreement (STANAG). It is also a good example of how STANAGs do not work. Actually in this case, as in many others, national interests and priorities outweigh desire for standardization, and true interoperability is not achieved. In this case, STANAG 3231 covers "ADEN and DEFA 30 MM Gun Barrel Chambers" and STANAG 3232 covers "30 MM Link for ADEN and DEFA Guns." There is no STANAG for the cartridge! As a result, the British, French, and the US, who produce this ammunition and guns to fire it, produce different guns, and different ammunition which will dimensionally fit each other's chambers, but may or may not function in each other's guns (depending on specific installation and maybe even ammunition lot number). The important differences are variation in voltage/power required to ignite the primer and variation in interior ballistics, specifically variation in pressure at the gun gas port. Minor variations are differences in: projectile weight, muzzle velocity, spin rate, case base dimensions, case materials, rotating band design and dimension, etc., none of which specifically affect interoperability. Also, even though links are a specific subject of a STANAG, British and French links are not interchangeable. They look alike but vary in strength and belt flexibility. Some interchanges can be made in an emergency, some simply will not work at all.

Figure 5 illustrates a series of ammunition, all of which is related. All except the one on the extreme right were derived as a result of the MG213C and

MG213/30 guns developed by Mauser in Germany during World War II. A brief discussion of this gun and its descendants will aid in understanding this ammunition. It started as a 20 mm gun firing a round outwardly identical to Figure 5(A) which fired a 2100-grain projectile at 3400 fps. This development was a consequence of a 1942 German requirement for a 20 mm gun with a rate of 1000 shots per minute and a muzzle velocity of 1000 meters per second. The MG213C was the third approach to the problem and history's first automatic revolver weapon. By the time the gun was proving successful, Germany had jet- and rocket-powered aircraft which reduced the requirement for muzzle velocity, but their guns were not sufficiently lethal against allied bombers. They then developed a round with the same length and diameter as the 20 mm but with a large "mine-type" 30 mm projectile at the relatively low velocity of about 1800 fps. Thus, the MG213C became the MG213/30. The war ended before the weapon got into production; the allies captured the weapons, and various engineers working on the guns went to Oerlikon in Switzerland, DEFA in France, and Enfield in Great Britain, where they continued the gun's development. This resulted in the Oerlikon 20 mm 206RK and 30 mm 304RK (a much larger gun), the 30 mm DEFA, and the 30 mm ADEN. These guns were all produced in the early 1950's. The DEFA at least is still in production. We in the US, in our typically arrogant fashion, "improved" on the original design by completely redesigning the system so that it didn't work so well. It took us another five years to get the new designs working satisfactorily, resulting in the 30 mm T182, of which perhaps 100 were built but never put in service, and the 20 mm M39 which went into the last F-86's, was used in the F-100, F-101, B-57, and is still being installed in the F-5. The M39 uses M50-series 20 mm ammunition.

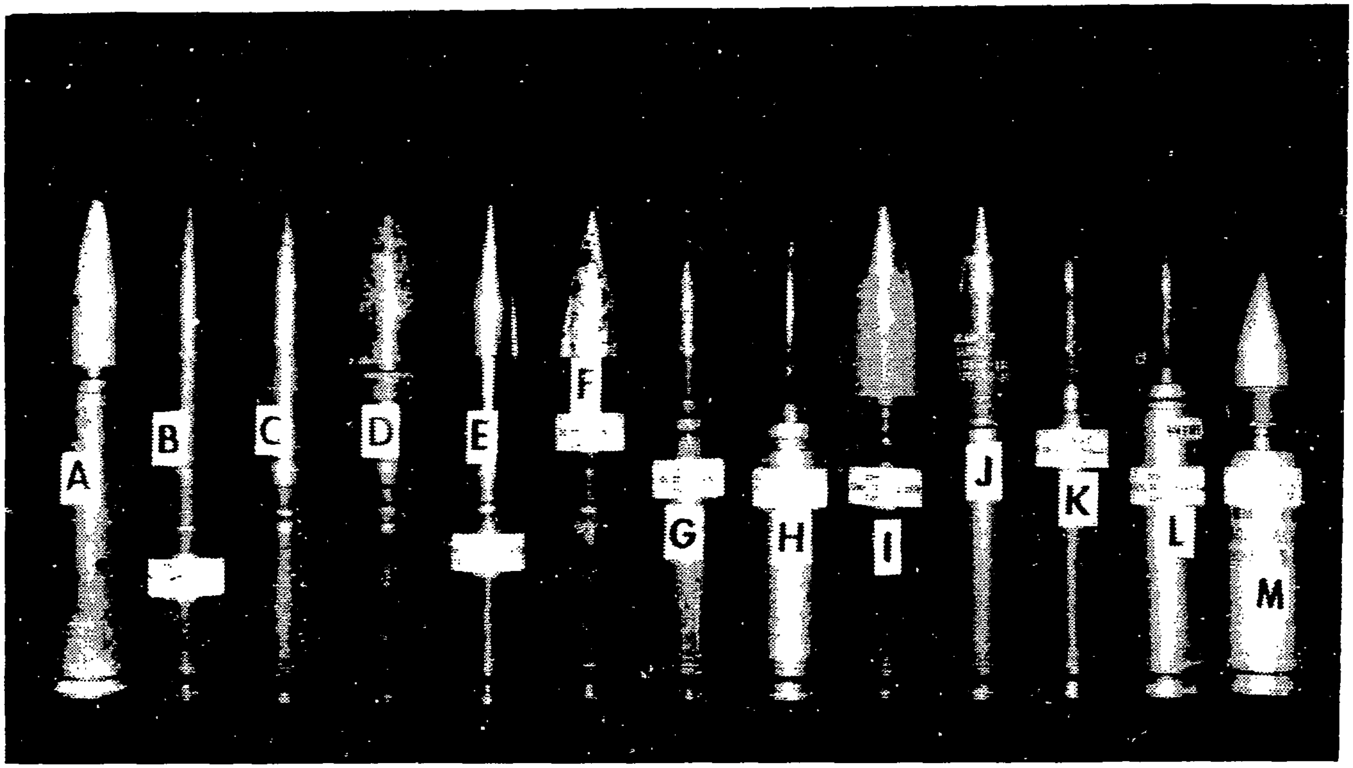


Figure 5. MG213/30, ADEN, DEFA, etc.
A. 20 mm Oerlikon (1951), B. MG213/30 Dummy (1944), C. MG213/30 (1945),
D. MG213/30 (1945), E. British ADEN (1952), F. US T158 (1953),
G. US T204 (1953), H. British ADEN (1973), I. Non-NATO DEFA (1968),
J. US ADEN/AAH (1977), K. US T239 (1955), L. US T239 (1957)
M. US WECOM 30 (1970)

Referring to Figure 5 and going from left to right, Figure 5(A) is a 20 mm Oerlikon round for the 206RK which is believed to be a direct descendant of the original MG213C. The German round was reported to fire a 2100-grain projectile at 3400 fps. The Oerlikon round fired a 1925-grain projectile at 3600 fps. This sample was made in 1951. Figure 5(B) is an original German dummy used in the development of the MG213/30. It is made of steel and was originally blued. It is bored out from the base to simulate weight and balance and the base is closed with a 0.93-inch (24 mm)-diameter plate which is countersunk about 0.5 mm below the base and staked in place with four punch marks.

Figures 5(C) and 5(D) are two different German rounds. The cases are identical, made of steel, and dated 1945. The projectiles are presumably of mild steel as they appear to have integral rotating bands machined into the shell body. Both have thin steel ogives, one of which extends to within about 1/4 inch (6 mm) of the rotating band and appears to be spot welded to the shell body. The other windscreen stops about one inch (25 mm) short of the rotating band and is attached by a very sharp roll crimp. These projectiles are both square based and measure about 5-1/2 inches (140 mm) in length. Both projectiles are dated 1944. They probably weigh around 5000 grains and, in keeping with German design practice at the time, were probably intended to carry about 1500 grains of HE or 2000 grains of incendiary in the combat versions. On both of these cartridges, as well as the dummy, the extractor rim has the same dimensions as the 20 mm, and the same diameter as the case body forward of the belt. All later versions have the rim diameter increased to nearly or actually belt diameter.

Figure 5(E) is an early British round made for their ADEN derivation of the MG213/30. Obvious differences from the German are brass case, copper rotating band, aluminum ogive, sharper profile, and increased rim diameter as noted above. The projectile was originally painted brown. This example is not dated but is known to be 1952 or earlier.

Figure 5(F) is an early US version of the round for the T121 gun. This round was designated T158 (T241 projectile) and in outward appearance is virtually identical to the British round except for a smaller diameter primer and a slight chamfer on the base of the rim. The British primer was designed to fire with 28V DC power. The US primer required 100+ volts DC across a 4-microfarad condenser. Both the US and British shells have hemispherical bases, a feature probably copied from the German 30 mm MK108, since the MG213/30 shells had flat bases. The projectile weight was about 4200 grains, and the muzzle velocity was about 2100 fps. The sample shown is dated 1953.

Figure 5(G) is an early sample of the T204 configuration designed to increase projectile velocity. The projectile weight was reduced to 3200 grains, and the case was lengthened from a nominal 3-3/8 inches to 4-1/2 inches. The gun was redesignated T182. Muzzle velocity was quoted as 2700 fps. The projectile still had a round base. This dummy round was made before this configuration was assigned a nomenclature and is marked "- - - EXP-1953 - - -".

This may be an appropriate place to discuss hemispherical bases, their reasons, and faults. The Germans utilized them extensively in their high capacity "mine"-type HE and incendiary for two reasons: (1) they were an easy configuration to make with drawn steel shell bodies, and (2) they provided maximum strength to resist chamber pressure in thin wall configuration. More recently we have used hemispherical bases to enhance fragmentation control and coverage from the shell base. So we have at least three good reasons for round bases. However, there is an overwhelming negative factor. Round base shells are far less stable than square base shells. A round base does not provide a clearly defined flow separation point. Given any degree of yaw, as the base of the projectile swings outward, the flow tends to adhere to the surface around the spherical base generating additional outward lift on the base which tends to increase yaw. Any shell designed today with a spherical base should have a skirt or trip ring to assure flow separation at the same point around the circumference of the base regardless of yaw.

Now we come to the first of the modern rounds. Figure 5(H) is a British ADEN MK/1Z AP shot(see also Section XIX(F) and Figure 46). The case is brass and measures 4-3/8 inches long. The projectile body is aluminum with a tungsten carbide core. Projectile weight is nearly 4200 grains. The rotating band is copper. This particular round was fabricated in 1973.

The tungsten carbide core AP is probably the heaviest of the current ADEN/DEFA series of ammunition. The lightest is probably closer to 3200 grains. Ammunition for use in these guns has been built in several countries with many variations of design and material. The guns also vary in such important features as barrel length and rifling exit angle. As a consequence, any specific quotation of projectile weight and/or muzzle velocity must, as a minimum, specify ammunition type, manufacturer, gun type, and barrel length. Suffice it to say that projectile weight ranges from about 3200 to 4200 grains and muzzle velocity ranges from about 2400 to 2700 fps, with the higher velocity associated with the lighter projectiles.

Figure 5(I) illustrates a round for the DEFA gun manufactured in a non-NATO country. The case is steel, 4-7/16 inches in length, with a lacquer finish. The rotating band is copper. Date of manufacture is 1968.

Figure 5(J) is a dummy of a US round for the chain gun or ADEN in the Marine AV-8A. It has a 4-7/16-inch aluminum case and an iron rotating band. It was fabricated in 1977.

Figure 5(K) illustrates an attempt in the US to upgrade the T204 (Figure 5(G)) performance. The new round, T239, was to fire a 3900-grain projectile at 3000 fps muzzle velocity from the T182 gun. The HEI round was to have a 750-grain HEI charge. The 3000 fps was not achieved within the 40,000 psi designated pressure; 2750 to 2800 fps was the norm. A new problem developed with the T239. The longer (4-15/16 inch) brass case was necessarily thinner at the neck. It was also rather severely neck annealed. This thin soft neck, together with the heavy projectile, created a condition such that when the rammer impacted the base of the case, it created an accordion pleat on both sides of the crimp to such an extent that the round would no longer fit in the chamber. (This example has a fired case so the crimp is not visible.) The problem was eventually solved by converting to steel cases, Figure 5(L). The brass-cased sample was made in 1955; the steel case sample was made in 1957. All projectiles in the T239 series were square based.

As mentioned earlier, the ADEN/DEFA ammunition has been made in many variations in many countries. In addition to the original German ammunition, one might expect to find today ammunition manufactured at: Grantham in the UK; Manhurin in France; Hispano-Suiza and Oerlikon in Switzerland; Frankford Arsenal, Kingsbury Ordnance Plant, and Honeywell in the US; IMI in Israel; and probably other places as well. The DEFA guns are probably used on more different aircraft and in more nations than any other gun in history, with the one possible exception being caliber .50 Browning. When this is added to the widely used ADEN gun, it is found that most nations with ammunition-manufacturing capability have some incentive to build ADEN or DEFA ammunition.

The variations in projectile type, although not limitless, have been extensive. Almost any type that can be imagined has been built, in not one but several variations. The base fuzed HE shell, for example, (not even made in the USA) has been made in thick wall APHE, thin wall high capacity for use against aircraft, general purpose (intermediate thickness), self-destruct, non-self-destruct,traced and non-traced, with different manufacturers' proprietary fuze designs, etc. Add to this the many types and variations, and the student should expect to find over 100 variations on the basic ADEN/DEFA round.

Figure 5(M) is included in this section because it looks like it might belong here, but it does not. It is also included here because it does not belong anywhere else. It is a round known as the WECOM 30, developed by the US Army Weapons Command for use on helicopters. Developed in the mid- and late-1960s, it was designed to have a low recoil impulse and yet be capable of defeating significant armor; hence, it had a shaped charge liner. Since it also was designed for preferred fragmentation with a skirted spherical base, it was called a dual-purpose round, hence HEDP. Since it did employ a shaped charge, which is degraded by spinning, the shell body was designed for maximum stability at an absolute minimum rifling angle. As a result, its spin rate was only about one-half of the ADEN/DEFA rounds. After the Marines got AV-8A Harrier aircraft with ADEN guns, someone in the Department of Defense, cognizant of the past proliferation in 20 mm caliber, questioned the wisdom of having two such similar but non-interchangeable rounds in US inventory. The Army, in order to get a disinterested opinion, asked the Air Force in 1976 to study the question and make a recommendation. The recommendation was to discontinue the WECOM 30 and transfer the HEDP technology to the ADEN/DEFA configuration. This was done.

It is interesting to note that the T158, T204, and T239 were developed for the Navy and Air Force by the Army's Frankford Arsenal. The WECOM 30 was developed by the Weapons Command at Picatinny Arsenal. Frankford was a small arms facility; Picatinny was an artillery facility. The people working on the WECOM 30 obviously did not use any of the residuals, tooling, or even dimensions from the Frankford program. It is also interesting to note that every diameter of the WECOM 30 is larger than any of the ADEN/DEFA series. Even the rim thickness is different, being 5/32 inch rather than 3/32 inch. The WECOM round follows artillery practice of having a bourrelet of greater diameter than the shell body. Of the other samples, only the one shown in Figure 4(I) has an enlarged bourrelet. Table 1 lists critical diameters measured from some of the samples of Figure 5. The WECOM sample shown was made in 1970.

TABLE 1. MEASURED DIAMETER OF SAMPLE 30 MM ROUNDS

	WECOM	MG213/30	T239	ADEN*	DEFA
Bourrelet	1.186	1.175	1.175	1.176	1.178
Band	1.232	1.227	1.227	1.226	1.224
Base	1.178	--	1.173	1.172	--
Rim	1.355	1.257	1.311	1.309	1.309
Belt	1.396	1.327	1.325	1.323	1.325
Case	1.287	1.264	1.259	1.264	1.260

Measurements in Inches

* Fired Case

-- Not Applicable

SECTION V

GAU-8 AND SIMILAR ROUNDS

The GAU-8 gun system had its beginning in the Air Force Armament Laboratory in late 1966 with the realization that the Soviet Union possessed some 250,000 armored vehicles of all types and that the USAF had no economically feasible means to defeat them. By the spring of 1967, a 30 mm round of ammunition and a Gatling type gun which could defeat this armor had been described. Also, the simple "optimization" expedient of selecting the smallest round that would defeat the hardest target had been used. During a 1968 directed "AX Gun Definition Study," this concept was refined. Figure 6(A) illustrates a first estimate of what the ammunition configuration should be. (Note: Machining errors left the extractor groove and crimp groove too shallow and narrow.) This configuration was selected, among other reasons to provide for high density storage in a 30-inch-diameter linkless feed system drum.

At this time, Armament Laboratory personnel were trying to get authority to begin the development of a large 30 mm gun system and had a pretty good description of both the required gun and ammunition; however, as yet, no contractors had been hired to tell us what we should do. HQ USAF solved that problem by directing that we award several "System Definition Contracts," keep hands off, and not try to influence the contractor's results. Contracts were awarded to Ford, General Electric, Harvey Aluminum, and TRW. The results of these studies were that Harvey Aluminum recommended a large automatic recoilless cannon, and General Electric, Ford, and TRW each recommended high rate 30 mm guns, the performance of which bracketed our estimates. For example, Figure 6(B) illustrates the Ford-proposed round. It looks strangely like the

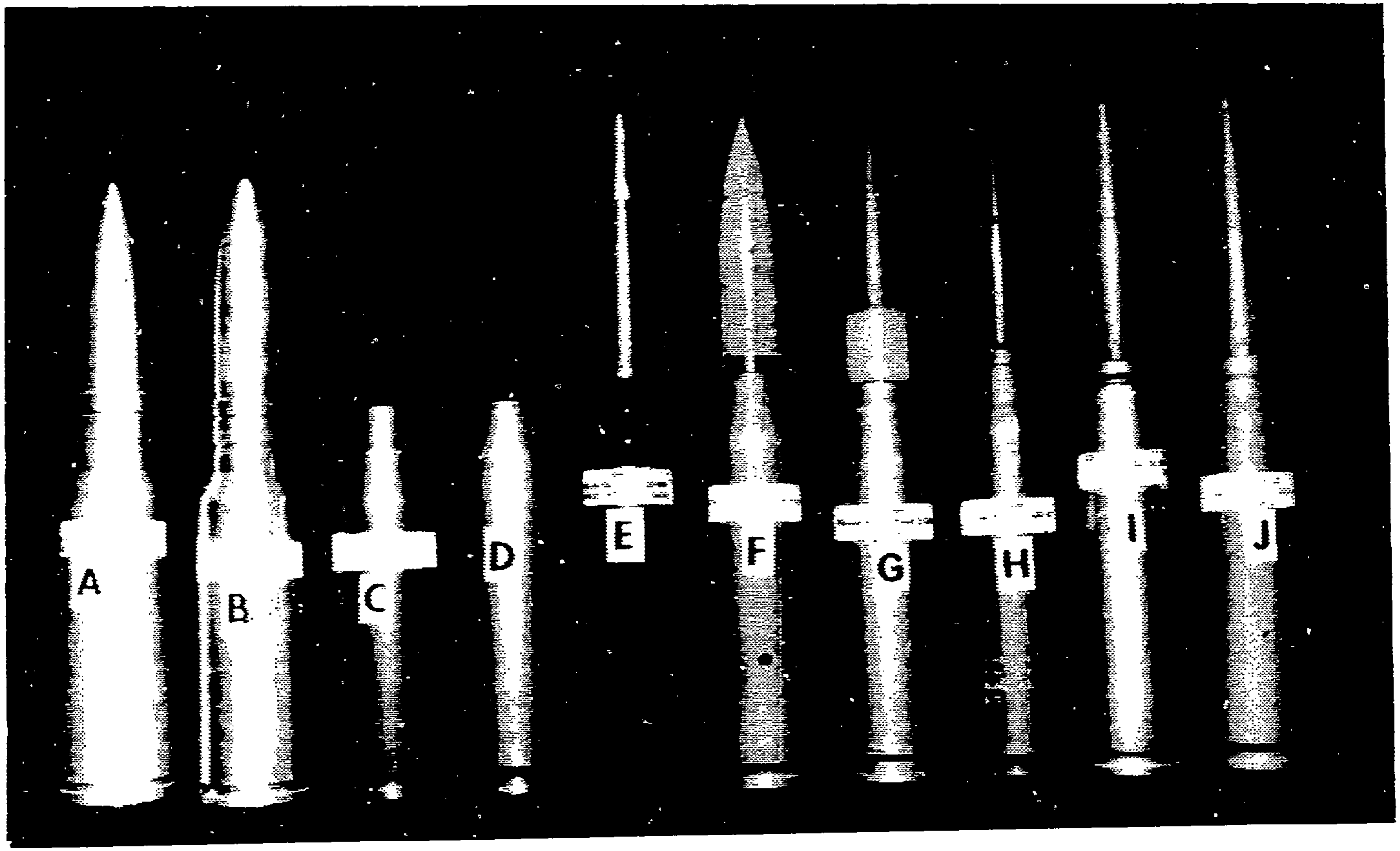


Figure 6. Predecessors of the GAU-8
A. AF Proposed AX (1968), B. Ford Study Result (1969), C. Harvey/AF Aluminum Case (1969), D. Ford/Harvey Rebated Case (1970?), E. Oerlikon 304RK (1971), F. GE/Aerojet Prototype (1971), G. Ford/Honeywell Phase I GAU-8 (1972), H. GE/Aerojet Phase I GAU-8 (1972), I. GE/USN CPIC Proposal (1972) J. Hughes/Amron GAU-9 (1972)

AF proposal in Figure 6(A); however, it did not derive from it, but rather from the Harvey Aluminum case, Figure 6(C), which Harvey Aluminum was developing for the Air Force under an aluminum case technology contract.

In 1971 the Air Force awarded two competitive development contracts to develop GAU-8 guns and ammunitions. Ford had one with Honeywell as ammunition subcontractor; General Electric had the other with Aerojet developing their ammunition. In Ford's early work, they modified the Harvey Aluminum case to a rebated rim as in Figure 6(D). General Electric, on the other hand, had bought a number of Swiss Oerlikon 304RK rounds, Figure 6(E), and had modified the design in several respects to that shown in Figure 6(F).

Since we had two different gun makers and two different ammunition makers involved in the development program, it was conceivable that the best gun would result from one prime contract and the best ammunition would result from the other subcontract. In order to assure the maximum return on our investment, it seemed prudent to standardize the ammunition configuration so that it was functionally interchangeable. This author obtained dimensional data from both contractors and designed a compromise round midway between the two. Drawings were sent to both prime contractors with a letter explaining the rationale for a common round and requesting they both consider adopting the compromise as a standard. (We were not allowed to direct them.) Ford was quite willing; in fact, they said, the new compromise round actually improved their gun design. Ford adopted it, and Honeywell developed their ammunition in the new configuration (Figure 6(G)). General Electric, on the other hand, would not consider the change. They said they had too much time and money invested in the Oerlikon configuration to make a change. They kept the Oerlikon configuration and, being extremely conservative, adopted a copper rotating band. The Air Force had, of course, specified aluminum cases. The General Electric/Aerojet round submitted for the competition is shown in Figure 6(H).

There are two other closely related rounds from this time frame, both based on the Oerlikon design. One, Figure 6(I), is identical to the General Electric Phase I GAU-8 (Figure 6(H)) except that it employs a steel case rather than an aluminum one. This round, also a General Electric directed development, was built to satisfy a Navy requirement for a gun for a Coastal Patrol and Interdiction Craft (CPIC) and the Navy specified steel cases. The other round resulted from a Department of Defense request that we test the Oerlikon 304RK at the same time and in competition with the GAU-8 contenders. A contract was let with Hughes Tool Company (now Hughes Helicopters) to take the Oerlikon gun, which we designated GAU-9, modify it as required, and assemble it into an A-X compatible system. They also Americanized the ammunition through an Amron subcontract and produced the round in Figure 6(J).

The competitive "shoot off" between Ford, General Electric, and Hughes took place in 1973. The rounds involved were the ones depicted in Figures 6(G), (H), and (J). Note that all had aluminum cases, all had similar dimensions, and all had essentially the same ballistic performance, having projectiles weighing from 5,000 grains to about 6,000 grains, muzzle velocities from 3,250 to 3,500 fps, and peak chamber pressures of 55,000 to 60,000 psi. The Ford and General Electric rounds were percussion primed, and the Hughes/Oerlikon was electric. One significant technical difference exists between the three rounds: the Ford round has a plastic rotating band, the General Electric round has a copper band, and the Hughes round has an iron band. Although our technology programs had clearly demonstrated the advantage of plastic bands, no one but Ford was willing to take the risk of submitting them as a primary design in the competition. Late in the program when it became clear that General Electric was going to win the competition, General Electric staged a demonstration that illustrated once and for all that plastic bands were far superior to metal. They produced a few thousand rounds with plastic bands and fired several complements of ammunition through a new set of barrels using plastic banded ammunition in two barrels and copper banded projectiles in the remainder. The final result was that when the barrels firing copper banded ammunition were worn out, the ones firing plastic bands appeared to be new. It has since been determined that the life of a barrel firing plastic banded ammunition is at least three times as great as one firing copper banded ammunition.

After General Electric won the competition, they were contracted to complete the development of the system, including the ammunition. They were given three specific directives that affected the ammunition: (1) develop two sources, (2) use plastic rotating bands, and (3) develop an armor piercing round using a depleted uranium (DU) penetrator (see Section VII). The second source developed was Honeywell, both manufacturers used plastic bands, and the penetrators were successfully developed.

Figure 7 shows the Aerojet and Honeywell rounds at the completion of full scale development. An interesting point to note here is that although each manufacturer developed target practice, high explosive incendiary and armor piercing incendiary, and they are functionally interchangeable, they are not the same. Each contractor was allowed complete freedom to design a minimum cost round suited to their production facilities, so long as they met

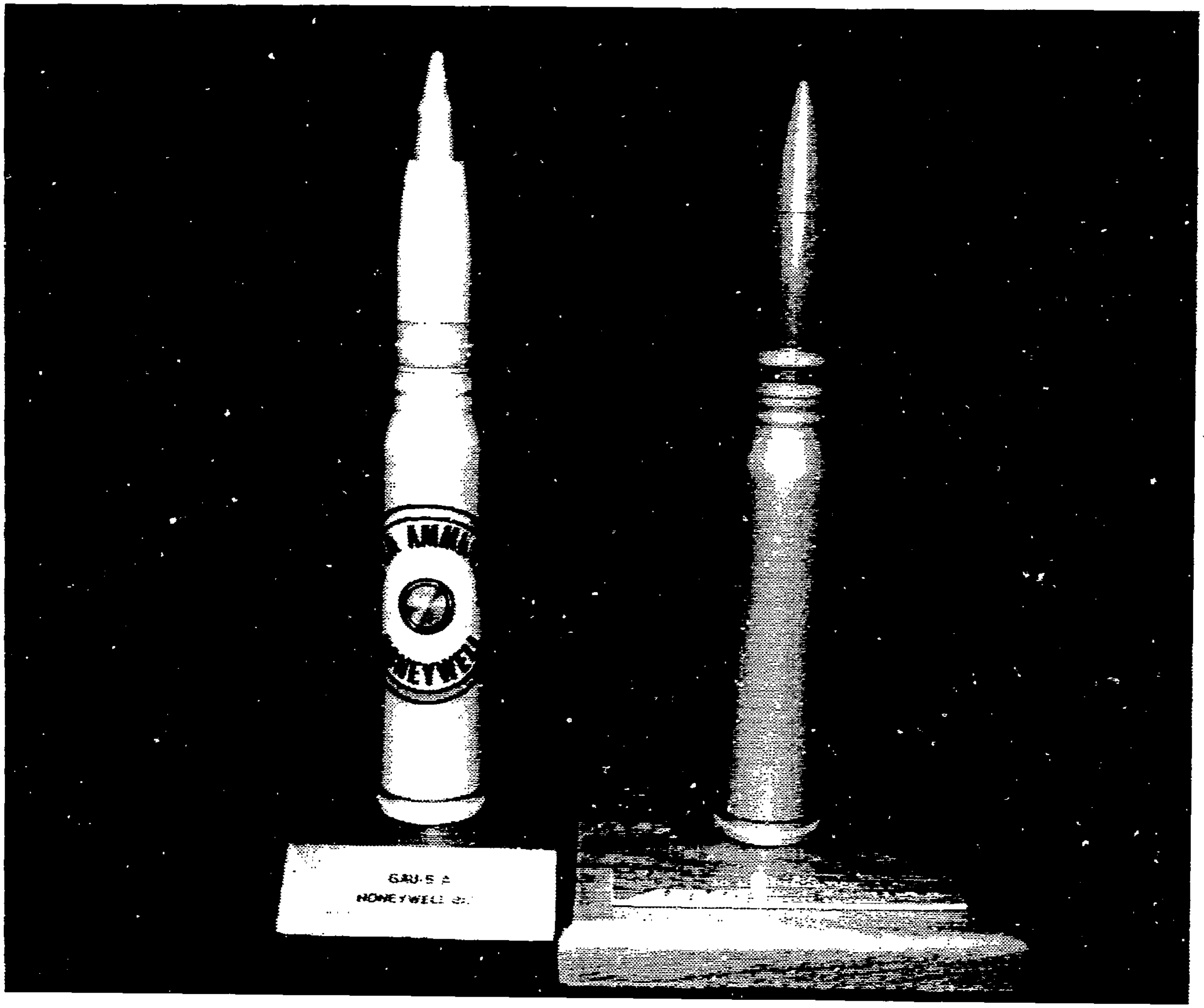


Figure 7. Honeywell and Aerojet Early Production GAU-8 Ammunition (About 1975)

performance requirements. Even after the ammunition was in production, they were allowed to make design changes in order to reduce costs or simplify production. This is best illustrated by looking at the two bottom projectiles of Figure 8, the lower being the target practice round as it was first produced and the second being of lower cost and simplified production yet equally suited to its purpose. Other similar but not so dramatic changes have been made to other production rounds by both manufacturers (see Figure 35).

Other 30 mm rounds of similar size to the GAU-8 which one may encounter are shown in Figure 9. The first, Figure 9(A), is the 30 mm Oerlikon round for the 302RK gun. The round and the gun were little more than a scale-up of the original German MG213. This round has a brass case and a narrow iron rotating band. It is dated 1950. Figure 9(B) is a later version of this basic round as modified for their later 304RK, a completely redesigned gun with only four chambers rather than five. This round, obtained by the author at the factory in 1971, has a lacquered steel case dated 1955 and a redesigned projectile with a much wider iron band. Aluminum cases were also made with what appears to be the same lacquer finish. The primer, like all European rounds, is a screw-in type, and, like all revolvers, is electrically initiated. The third round, Figure 9(C), is from Hispano-Oerlikon, now owned by Oerlikon, but previously known as Hispano-Suiza, and Oerlikon's major competitor. This round, dated 1972, is for the HS831L gun and is also used by the British in the RARDEN gun. Similar in outward appearance to the Oerlikon, it is slightly smaller at the base and larger at the shoulder with less taper. The rim is thinner, the extractor groove smaller and narrower, and the shoulder angle is different. It is percussion primed and has a lacquered steel case dated 1974. The fourth round, Figure 9(D), is an aluminum dummy

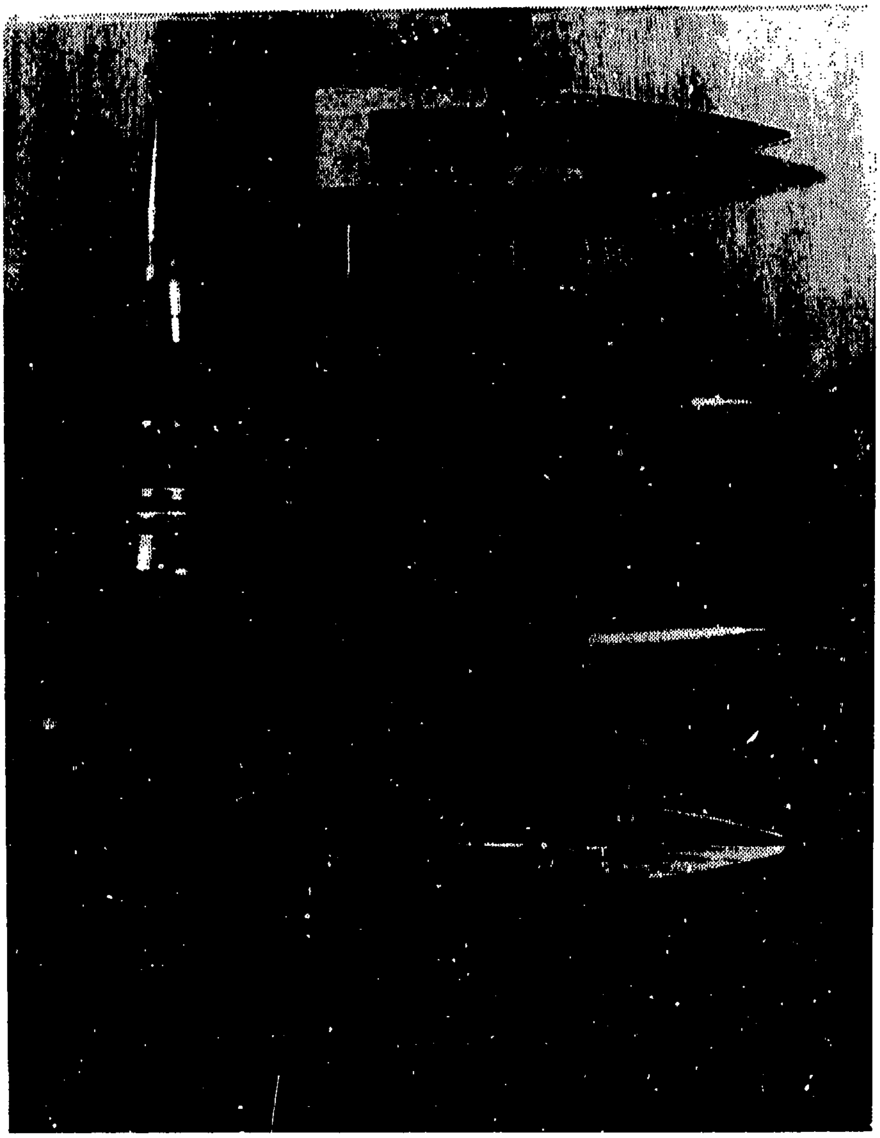


Figure 8. Honeywell GAU-8 Display Board (Early 1980's). Early TP Projectile added for Comparison

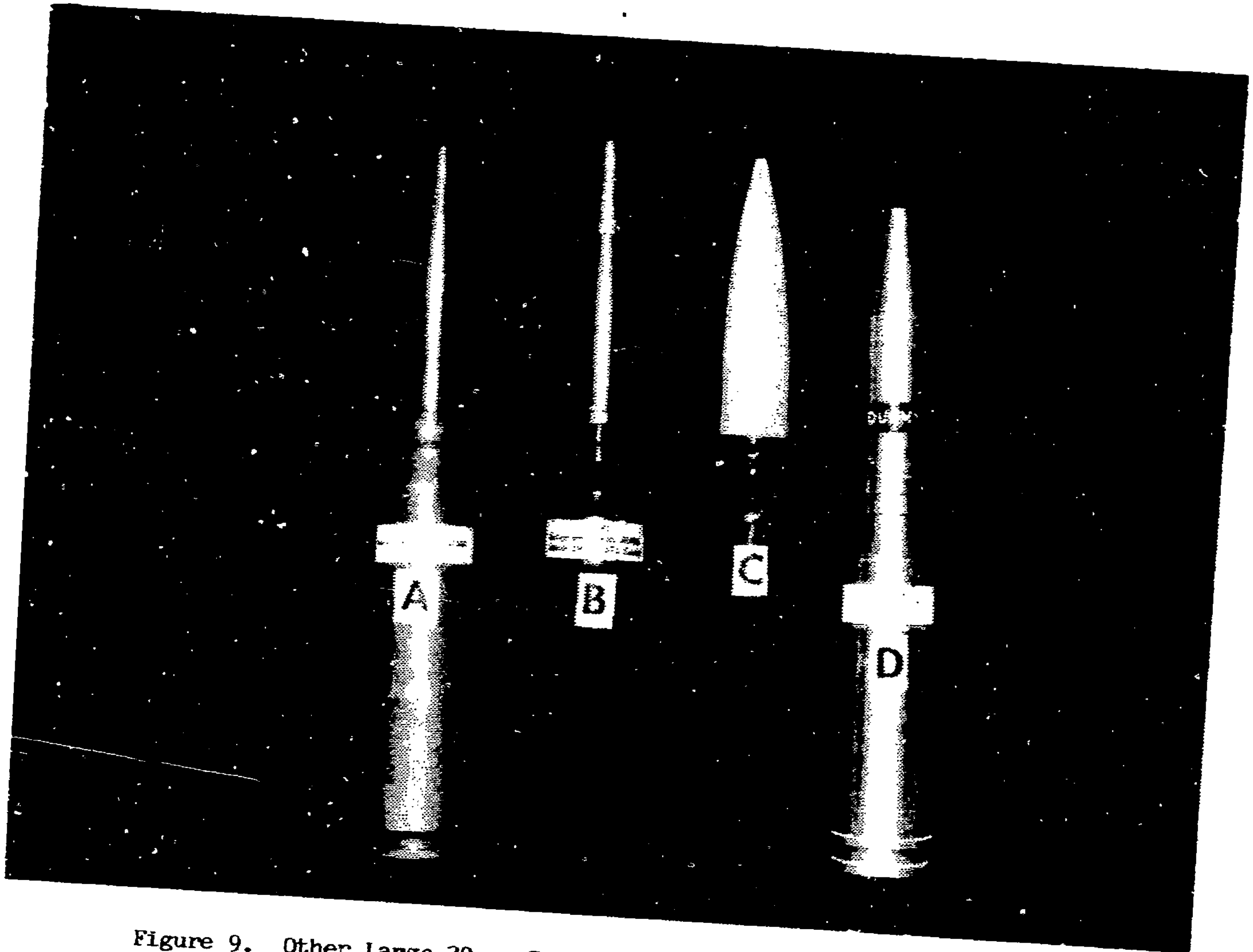


Figure 9. Other Large 30 mm Rounds
A. Oerlikon 302RK (1950), B. Oerlikon 304RK (1971),
C. Hispano-Oerlikon HS813L (1974), D. Russian "Alex 13" (1971)

made from a German language drawing obtained by the author in Europe in 1971. The gun, a unique recoil-operated weapon, was submitted as "Alex 13," a "Russian gun of Czechoslovakian origin." It is included for comparison purposes.

These and all other European rounds of 20 mm or over use screw-in primers while we use the much cheaper press-in type. An interesting sidelight is why Europeans insist on them. The author once asked a Swiss. He laughed and said, "Well . . . it seems that as ammunition ages in storage, the first part to go bad is the propellant. With screw-in primers we can remove the primer, dump out the old propellant, reload with new propellant and a new primer and have a new round. . . . Of course no one ever does it, but that is the reason."

SECTION VI

ALUMINUM CASES

Ever since the development of modern drawn cartridge cases, brass has been the material of choice, so much so that "cartridge brass" (70% Cu, 30% Zn) is a defined material listed in any reference of metal properties. Other materials have been tried, especially in time of war when brass becomes critical. The Germans developed moderately successful steel cases in World War I. Steel cases were in common use in World War II. Most production reverts to brass in time of peace.

Aluminum is a nice ductile metal which can be made with a wide range of physical properties. It is also light, and since 40% or so of a cartridge weight is the disposable brass case, aluminum becomes an interesting candidate for case material. Various agencies have tried, since around the turn of the century, to make aluminum cases, and although they were somewhat successful in making pistol and shotgun cases (5,000 to 20,000 psi), they were not too successful in high pressure (60,000 psi) weapons prior to the GAU-8. In the late 1960's when the Armament Laboratory was working on the preliminary design of what later became the GAU-8 system, it became apparent that if the cases were made of aluminum, rather than brass, a total system weight saving of over 800 pounds could be achieved. With this incentive, the Armament Laboratory personnel set about to develop aluminum cartridge cases suitable for use in a large 30 mm round operating at 60,000 psi.

At this time, several organizations were working on the aluminum case problem; Frankford Arsenal, Amron, Harvey Aluminum, and Oerlikon were doing the most significant work. There were two fundamental problems: either the case was too soft and stuck in or extruded out of chambers and sheared rims, or it lacked adequate elongation and split during firing.

When a brass or steel case splits during firing, there is usually minor gas leakage but no serious problems. (The author has fired Soviet brass ammunition when 30% of the cases split with no ill effects.) A split in an aluminum case is an entirely different matter and is, to say the least, spectacular. The situation is that although hot powder gas may leak through a split in a brass or steel case and slightly melt or erode the split, a similar leak in an aluminum case will ignite the aluminum which, under the pressure and flow velocity involved, will generate enough heat to melt or burn steel chambers and bolts. Although splits in aluminum cases, sometimes referred to as burn-throughs, are spectacular, the author was not able to locate a single GAU-8 sample to illustrate the point. This is a tribute to aluminum case success.

The Armament Laboratory realized that the problem was largely one of alloy development and awarded contracts to Harvey Aluminum and Amron to develop and demonstrate the technology required for high performance 30 mm cases. The AF did not specify a case configuration, only a required performance level, and the contractors were able to design the cases specifically to take advantage of, or compensate for, characteristics of aluminum. Figure 10 illustrates the Harvey and Amron designs. Note the Harvey Aluminum case, Figure 10(A), which is assembled with the "proof slug" they used to simulate the required 5,000-grain projectile. This Harvey Aluminum case weighs 2,627 grains and has a case volume of 11.6 cubic inches. The Amron case, Figure 10(B), weighs 2,260 grains and has a case volume of 12 cubic inches. Figure 10(C) illustrates an

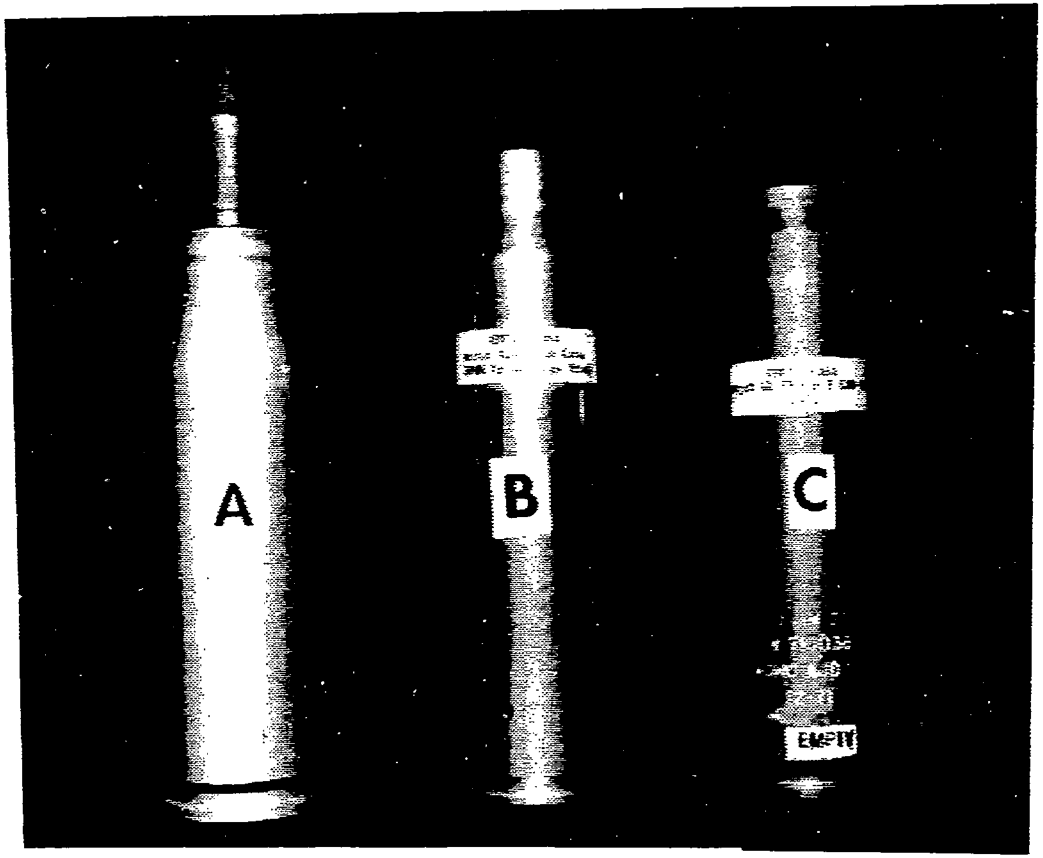


Figure 10. Early Aluminum Cases
A. Harvey Technology Study, B. Amron Technology Study, C. Aerojet GAU-8 (1971) for Comparison

early GAU-8 case for comparison. It weighs 2,202 grains and has a case volume of 10.7 cubic inches.

The Harvey Aluminum case was made from their own special 6000-series alloy developed for this purpose. They had difficulty obtaining the hardness and tensile strength required, but once they got this worked out, the case performed quite well. Harvey Aluminum had done other aluminum case work earlier, and after this program developed an aluminum case for the M50-series 20 mm ammunition, which reportedly met all requirements but was never standardized for production.

Amron, on the other hand, chose to work with the 7000-series alloys, specifically 7075. It was known that adequate physical properties could be developed in cases made of 7075; however, cases of this material were known to have a distinct grain and were prone to split along the grain. Alcoa, working with Amron, developed a high purity version of 7075 specifically for cartridge cases. It worked and is still in use for the GAU-8.

A word is required about case splits and the general use of aluminum cartridge cases. Although a split in an aluminum case is a serious defect and may, in fact, damage the gun, a certain number is inevitable. On a gun such as the GAU-8, which is remote from the operator, one split per hundred thousand rounds might be tolerated. However, if the gun were an M14 rifle, a single case split could blind or otherwise seriously injure the gunner, so one failure per hundred thousand or even per ten million is not acceptable. Aluminum cases should not be used for high performance individual or crew-served weapons unless all weapons capable of firing that cartridge are specifically designed and built to protect the user from occasional split cases.

Figure 11 illustrates the sequence of metal forming in the manufacture of a GAU-8 aluminum cartridge case. (The first three steps are significantly different from those normally employed for brass and steel which will be described later.) Figure 11(A) is the basic starting form which is either sheared or, in this case, sawed from rod or bar stock. It must be in an annealed form and meticulously cleaned of all surface contamination, especially oxides, and coated with a protective lubricant such as soap. It is then dropped into a die cavity slightly larger and deeper than itself. It is then "impacted" with a relatively slow moving punch which causes the metal to flow around the punch and back up out of the die cavity; hence, the terms "impact extrusion" or "back extrusion," resulting in the form shown in Figure 11(B). Note that the die cavity was smaller at the bottom, resulting in a base taper. The form must now be annealed again, cleaned, and relubricated. The next operation consists of placing this form into a smaller die of about base diameter and impacting it again. It is drawn down into the die cavity and extruded into the form shown in Figure 11(C). The next operation is to trim to length, Figure 11(D). Note that there is a considerable amount of material removed. This is done deliberately because this very top portion is likely to contain any seams, inclusions, or incipient cracks in the material. The next operation is a taper and first neck operation. A die is forced down over the form resulting in Figure 11(E). During this operation, in addition to the necking and tapering, the primer pocket is formed and additional material is moved into the rim area which, when later machined off, assures good homogeneous high density rims with good grain orientation. The next operation simply completes the forming started in the previous operation. The next operation, machining, again trims to length,

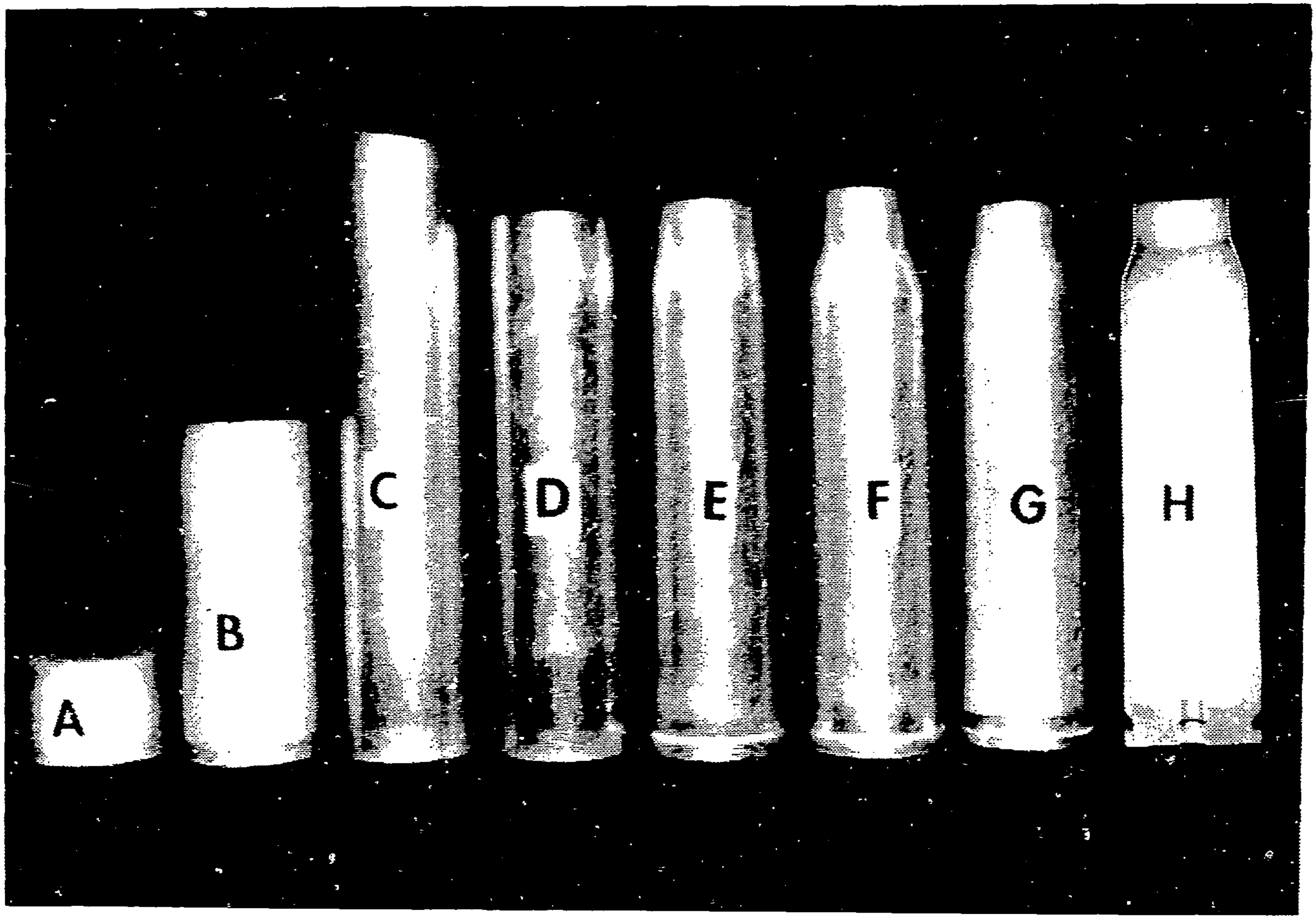


Figure 11. Extrusion Forming of Aluminum Case (Details in Text)

machines the rim and extractor groove, and drills the flash tube hole, resulting in Figure 11(G). Figure 11(H) is a sectionalized view of this final configuration. The case is now ready for final finish which generally consists of anodizing both inside and outside. Other finishes, lacquers, etc. may be used in addition to, or in place of, anodizing. It should be pointed out that it is advisable to have protective coating on the inside of the neck; otherwise, it may be severely burned, possibly burned through to the extent that it could damage the chamber.

No attempt has been made to give sufficient information to guide someone in making aluminum cases; only enough information is presented to allow one to understand, in general, how the cases are made. Several minor but important steps have been omitted, largely because they are not constant. Cleaning, relubrication, and various heat treatments are done differently and at different stages in different case shops and are considered trade secrets. The sequence illustrated here is virtually universal in aluminum case manufacture. The examples used were produced by Amron early in the GAU-8 program.

Mentioned earlier was the fact that the first three steps in the "impact extrusion" process was significantly different from the "blank, cup, and draw" process historically used for brass and steel. There are many arguments about the relative merits of the two processes which range from preferred grain orientation and structure through case hardness profiles to tooling and process cost. These are debatable, matters of opinion, and vary among different shops. Either process can be used with any material; it is purely a matter of developing technique. Here we will simply address the differences.

To illustrate the blank, cup, and draw operation, we have selected a 9 mm pistol case for two reasons: samples were available and it illustrates the universality of a process used for cases for pistols and rifles, up through automatic cannon to the largest artillery which uses cased charges. Figure 12 illustrates the sequence. Not shown is the first step or blanking operation in which a disc or blank of metal is punched out from a flat strip. Here is the first significant difference. In the extrusion slug, the grain ran lengthwise to the cylinder and the only scrap was the rod ends if the slug was sheared plus the saw kerf if it was sawed. In the blank, the grain runs normal to the cylinder axis and the scrap is the difference between the circle and the rectangle from which it is punched, at least 25%. The next operation is to center this disc (blank) over a hole in a die plate and punch it through, forming the cup illustrated in Figure 12(A). Many case shops buy this preform as their starting point, leaving the blanking scrap at the brass mill, with the decision being based on economics and facilities. This cup is then annealed and lubricated prior to the next or first draw operation. In drawing, as opposed to extrusion, the cup is placed over or into a tapered hole through a die plate and a punch descends to push the cup completely through the die in such a manner that the material is drawn back around the punch and elongated to the condition shown in Figure 12(B). This looks much like Figure 11(B) except that its base, being a free surface, becomes more rounded, whereas the bottom of the extrusion is configured to the shape of a closed die. This form is then annealed, lubricated, and drawn again, Figure 12(C). Being a short pistol case, it only requires two drawing operations; sometimes on longer cases a third draw is employed. The case is then length trimmed, Figure 12(D), and from here on the sequence is similar to the

Figure 12. Draw Forming of Brass Case (Details in Text)

previously described operations and varies from shop to shop. In this specific sequence, the primer pocket is upset, Figure 12(E); the base is formed, Figure 12(F); the case is tapered (necking not required), Figure 12(G); the rim is machined and the case is trimmed to length, Figure 12(H); and the flash hole is pierced, Figure 12(I). The specific samples illustrated here were produced by Israeli Military Industries.

SECTION VII

HIGH DENSITY PENETRATORS

Perhaps the most spectacular aspect of the GAU-8 gun is the effect of its high length-to-diameter ratio (subcaliber) depleted uranium penetrator upon striking armor. We started studying this technology before 1970 and had the technology in hand in time for full scale development along with the GAU-8 gun and its ammunition and production release in 1975. We thought we were pioneering in this area. Now it seems, or at least this author believes, that we have "reinvented the wheel," or at least reinvented high length-to-diameter ratio uranium penetrators. The Germans did it first in World War II.

It is well known that the Germans made considerable use of tungsten carbide, or "wolframstahl," which translates to tungsten steel, as armor penetrator cores. That uranium was substituted for tungsten during the war is apparent from the comments of Nazi Production Minister Albert Speer in his book, Inside the Third Reich, when he comments that the Germans had given up on the development of an atomic bomb and "In the summer of 1943 wolframite imports from Portugal were cut off, which created a critical situation for the production of solid-core ammunition. I thereupon ordered the use of uranium cores for this type of ammunition." He also notes in a footnote that "In 1940 twelve hundred metric tons of uranium ore had been seized in Belgium." This author recalls reading, in the early 1960's, a first hand report from a German serving on the eastern front in 1944 which contained a most striking description of the effect of new German anti-armor ammunition; this description can only be understood after one has seen the effect of a uranium penetrator. Figure 13 is a reproduction of pages 58 and 59 of Handbook of German Aircraft Ammunition, a compilation and translation done at Aberdeen Proving Ground and

AMMUNITION FOR MK 103, ELECTRIC FIRING
3 cm H-AP-T (SPECIAL CORE), NOT SELF-DESTROYING

(3 cm H-Panzergranatpatrone L'spur o. Zerl.)

A. Projectile

Weight	Projectile filler	Length of Tracer	Self-destroying	Fuze	Detonator
350 g	Special steel core in light metal casing	Approx. 1200 m	No	None	None

B. Cartridge case

Material	Propellant	Weight of Propellant	Primer
Brass	Nitro-cellulose tubular powder (3x3/0.5) + black powder igniter	116 g 4 g	C/22

C. Complete round

Weight	Muzzle Velocity	Packing	Number	Weight of loaded box
804 g	960 m/sec	Ammunition box 103 (Hermetically sealed)	50 rounds	Approx. 54 kg

D. Performance

Effect	Penetration	Use
Special armor piercing projectile with added incendiary effect. Effective only against targets with bare armor plate. On armor with obstructions the steel core tends to shatter	At 300 m on armor plate of 100 kg/mm^2 tensile strength 30° = 70 mm 0° = 100 mm	Exclusively for attacking medium and heavy tanks. Practice firing prohibited

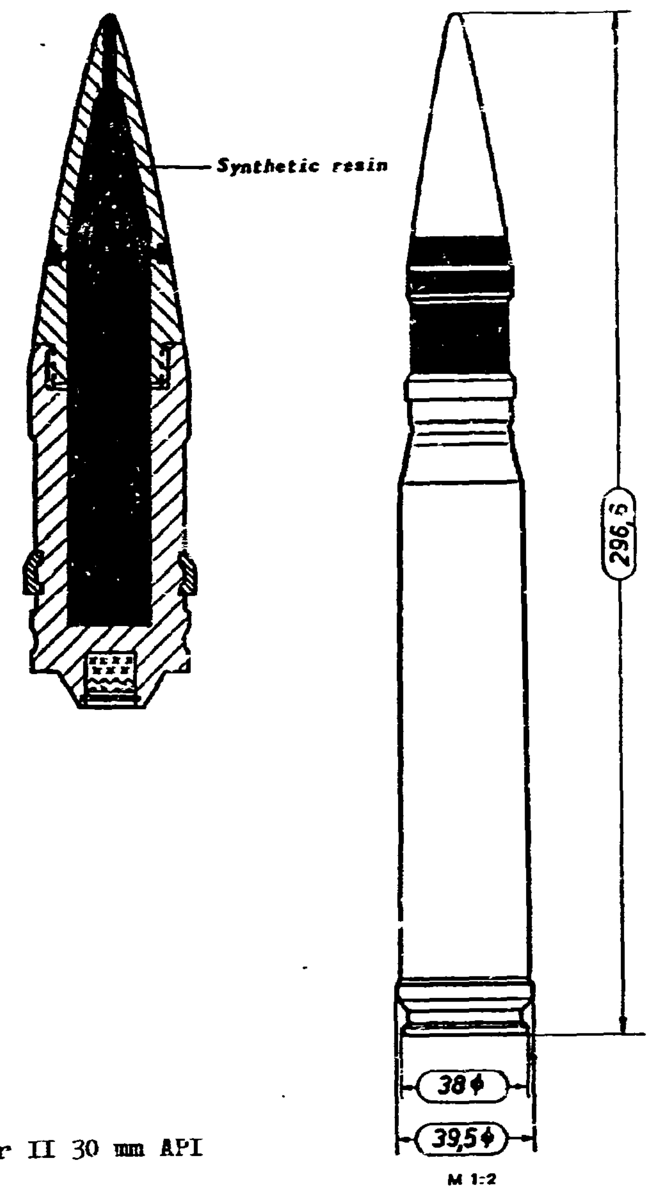


Figure 13. German World War II 30 mm API

published in 1956. At the time and until this writing, it was assumed that this was a tungsten cored round. Looking at it critically today one suspects that it was probably uranium. Points that indicate this are: (1) It was called an H-Panzergrenat-patrone, or "special armor grenade cartridge." Why grenade? There is no explosive or incendiary except if one considers the pyrophoric effect of uranium. (2) It is called a "special steel core." If it were tungsten, it would have been called "tungsten steel." (3) It is called a special armor piercing projectile with added incendiary effect. Where is the incendiary if not in the pyrophoric effect of uranium? (4) The capability of penetration of 100 mm of any kind of armor precludes it being any type of steel by US definition. It has to be either tungsten or uranium. (5) It is described as being "Exclusively for attacking medium and heavy tanks. Practice firing prohibited." This is the only German round known to have the restriction "practice firing prohibited." Why? Remember, German uranium was as refined; it was not "depleted uranium" as we know it. (6) This round was used by tank busting squadrons on the eastern front. There are no known reports of it being used on the western front. There are no known reports of uranium cores or the uranium effect on the western front. The Germans would have had no qualms about using toxic or radioactive materials against the "barbarians" on the eastern front; they may have hesitated about using it against the "civilized" people in the west. Also, they knew the British or Americans could copy it. Once compromised, they would have felt secure the Russians could not. (7) The round in Figure 13 was "Issued to Service" in June 1944, about a year after Speer "ordered the use of uranium cores for this type ammunition." Also this was about a year after they lost their source of tungsten.

In 1974, when we were about ready to introduce the GAU-8 into the inventory, this author was discussing uranium penetrators and the German use of them in World War II with personnel at the Federal Republic of Germany Ministry of Defense in Bonn. Their personnel were not aware of any wartime use of uranium for AP cores, but said they would look into it. In 1979 in a subsequent meeting and discussion, Peter Schopen in Bonn said they had been unable to uncover any records of uranium being used for penetrators even in R&D; yet from Speer's statements, it was a virtual certainty that they were aware of its effectiveness as early as 1943. Was all of the uranium penetrator work done in East Germany and the data not available to the west after the war? Probably so.

This author, at least, is convinced that the Germans did use high length-to-diameter uranium cores in World War II. In all probability, the 30 mm round in Figure 13 was uranium cored. The similarity between it and our current production round (top, Figure 8) is striking. In any case, we did not have access to this information, or at least did not recognize it at the time; so perhaps our reinvention is not unwarranted. It is interesting that we achieved the same solution.

In any case, we set out in the late 1960's and early 1970's to develop high length-to-diameter (L/D) spin stabilized uranium penetrators. The penetration capability and pyrophoric incendiary effect were well known to others; we were interested in maximizing the L/D ratio and the mass of the penetrator as a fraction of total projectile weight. We were also aware of the advantage of plastic rotating bands, so we chose to work with plastic encapsulated penetrators. Figure 14 illustrates several of the configurations which were examined between about 1968 and 1974. All of this work was done by

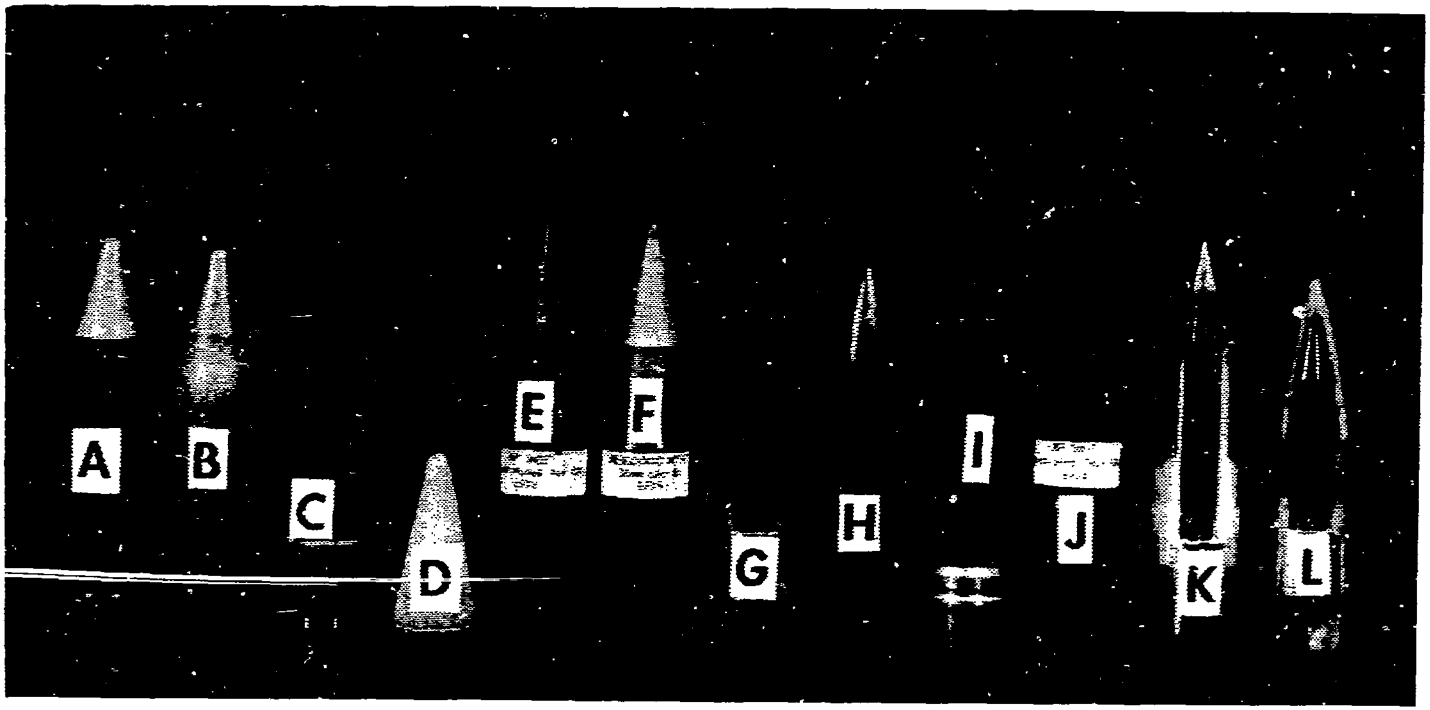


Figure 14. Plastic Encapsulated DU Penetrators
A. Early Design, B. Similar to A but with Blended Rotating Band, C. Terminal Ballistic Test Configuration with Gyro Ring and Steel Pusher Plate, D. Windscreen for C, E. Improved Configuration with Boat Tail, Sectioned, F. Aerodynamic Model, G. AF Specification Penetrator, H. Penetrator Test Model with Tungsten Carbide Core, I. Development Model, Honeywell Configuration, J. Penetrator Test Model, Probably for Honeywell, K. Section View of J, L. Another Test Configuration, Date and Purpose Unknown.

AAI Corporation, most under Air Force direction, and some under contract to Honeywell. Figure 14(A) is an early basic configuration with a 9/16-inch-diameter penetrator about 4-1/4 inches long with a classic double conical nose. It is completely encapsulated in glass-filled nylon, probably 41% glass as was used almost exclusively in this program. The base of the core is supported by an aluminum pusher similar to those shown in section in Figures 14(G), 14(K), and 14(L), as are all except Figures 14(C) and (I). One of the problems with the early designs was the tendency for the bourrelets to engrave, causing in-bore yaw, dynamic unbalance, bent penetrators, and flight instability. An early attempt to solve this problem is illustrated in Figure 14(B) where the rotating band was left full groove diameter for 1-1/2 inches, gradually tapering to bore diameter at a total band length of 2 inches. This helped but did not solve the problem. It was soon learned that although plastic makes fine rotating bands, it does not make good bourrelets. Also, it was noted that in order to stabilize the maximum L/D penetrator, a gyro ring, as shown in Figure 14(C), was useful. Figure 14(C) is a configuration developed and used extensively for penetration testing. It consisted of any desired penetrator, press fit into a machined glass-reinforced nylon body with a 3/4 inch by 1/8 inch thick steel gyro ring press fit in place. The steel pusher plate is bore diameter, about 5/32 inch thick, with a boss in the center of penetrator diameter which protrudes into the base of the body and butts against the core. Figure 14(D) is a nylon ogive which fits over the core and serves as a windscreen.

Since our intent was to obtain maximum armor penetration with a given muzzle energy, we worked on both the penetrator design and the projectile aerodynamics. Figure 14(E) is an evolution of Figure 14(A), wherein the ogive is lengthened and streamlined, the base lengthened, a bore rider/gyro added, and a longer tapered penetrator utilized. Figure 14(F) is a further refinement with a boat tail. This is an aerodynamic model only and is quite light, employing an aluminum "penetrator." Figure 14(G) is outwardly identical to Figure 14(F) but is a sectioned model to show the "optimum" penetrator configuration as it had by now evolved. During the course of this program, it was shown that maximum penetration could be obtained with a tapered rod. The tapered rod generated maximum unit pressure at the target interface and so long as the small end generated a hole in the plate of sufficient diameter to pass the base, it was a very efficient penetrator. This configuration by 1973 became the "Air Force specification penetrator," and the ammunition contractors, during GAU-8 full scale development, were charged with matching its performance. Figure 14(H) is a projectile dated April 1973 which had a tungsten carbide core which was shot for comparison purposes along with several different tungsten and uranium alloys about this time. Figure 14(I) is a model using the AF specification penetrator with an aluminum base to provide crimp grooves for correct bullet pull. Crimp grooves and rotating band are Honeywell configuration, probably late 1973 or early 1974. Figures 14(J) and 14(K) are external and sectioned views of test vehicles built to study the penetration of lower cost penetrators with long cylindrical bodies requiring less machining. These models contain steel bourrelets about 3/32 inch thick and thin steel sleeves with internal threads covering the base area. Figure 14(L) is another configuration with a shorter, larger diameter core without the steel base sleeve. It probably predates Figures 14(J) and 14(K).

Although several of these configurations achieved and even exceeded the required penetration and showed promise of meeting all other requirements, they were abandoned during full scale development of the GAU-8 in favor of the less costly aluminum body and crimped aluminum ogive shown in Figure 8.

There were some other investigations and trade-offs made during this time concerning uranium penetrators that should be mentioned. These concerned such things as comparisons with tungsten carbide and tungsten alloys, investigation of various uranium alloys, investigation of variations in hardness, study of manufacturing processes, general shape (L/D) investigations, and specific study of nose shapes. The following comments, at the risk of oversimplification, are offered to summarize the results of these studies.

The comparison of uranium and tungsten carbide and tungsten alloys can be simply summarized by saying uranium is as good as any and better than most. Tungsten carbide tends to penetrate undeformed or by classic kinetic penetration, whereas uranium tends to penetrate in a quasi-hydrodynamic mode. Tungsten alloys tend to be somewhat in between with ductile "mushrooming" of the point. Tungsten carbide and alloys are quality sensitive; uranium is much more forgiving.

During the early 1970's, the Navy standardized on a uranium alloy containing 2% molybdenum. The Army was working on "quad" and "quint" alloys containing four and five alloying agents in various ratios. We, at the recommendation of one of our contractors, chose a 3/4% titanium alloy. Arguments ensued and comparison testing was done. The results showed that as far as penetration was concerned, it didn't make much difference what the alloying agents were. Also, tests showed that U 2% Mo was prone to corrosion from atmospheric humidity whereas U 3/4% Ti is virtually stainless. The quint and quad alloys had no significant advantages over U 3/4% Ti. We stuck with our U 3/4% Ti, the Navy stuck with their U 2% Mo, and the Army stuck with tungsten alloys. Incidentally, the difference between the corrosion resistance of 2% Mo and 3/4% Ti is quite noticeable in samples left stored in unsealed boxes in air-conditioned buildings. Figure 14(G) is a 2% Mo alloy. The surface is rough, black, and scaly. Its next phase will be for a scale perhaps 0.015 inch thick to flake off, leaving a relatively clean surface which will again corrode. Figures 14(K) and 14(L) illustrate 3/4% Ti alloys. They have a tan color which is normally taken on during or immediately after machining with little or no evidence of further corrosion. In a gross sense, one might say that U 3/4% Ti is much less prone to corrosion than bare carbon steel, whereas U 2% Mo is many times more prone to corrosion than any iron alloy.

Investigations of the effect of varying hardness on uranium penetrators were conducted. Again, uranium was found to be very forgiving. Although maximum penetration occurred in the R_c 43-47 range, there was no great difference down to the low 30's or as hard as it could be made. Penetrators were made so hard that they broke if dropped on the floor. If launched without breaking, they still penetrated well.

Manufacturing processes were studied in order to produce the least expensive penetrators that would do the job. Again, it did not seem to matter if they were forged, machined, or investment cast. They all worked about the same.

Studies of penetrator shape did prove significant. The highest L/D is the best penetrator and the tapered rod is better than a straight one. The final selection was degraded from the best for reasons of cost reduction. From the tapered AF specification penetrator which was about the longest that could be stabilized, we evolved two similar configurations (Aerojet and Honeywell) which are basically cylinders with a tapered forebody and flat nose. A total penetration degradation of about 15% occurred.

Specific studies of nose shapes were made using conic, biconic, tapered, hemispheric, flat, etc., noses. Although this is an important point in hardened steel and tungsten carbide (nondeforming) penetrators, it is of no consequence in hydrodynamic penetrators and of little importance in quasi-hydrodynamic penetrators such as uranium. It quite simply doesn't make that much difference.

If the reader by now feels it doesn't make any difference what uranium alloy is used, what manufacturing process, what heat treatment, what shape, etc., are used, he has about reached the right conclusion. Uranium penetrators are very forgiving; it is hard to make a bad one. This is definitely not true for tungsten and its alloys.

SECTION VIII

IMPROVED 20 MM AMMUNITION

When the decision was made in the early 1950's that the new USAF ammunition would be caliber 60/20 rather than caliber .60 (see Figures 1(C) and (D)), it was also decided that the projectile performance would be considerably improved over the old M90-series. The several improvements included higher muzzle velocity, improved aerodynamics, increased explosive charge, and delay fuzing. Muzzle velocity of the 60/20 round was to be 3400 feet per second, about 700 fps faster than the M90-series. The improved aerodynamic shape is obvious by comparing Figures 1(B) and 1(D). The projectile was to be a thin-wall, high capacity shell weighing 1500 grains, and a delay fuze was to be developed.

There are often many changes between a good R&D item and what goes into production. This 20 mm shell is perhaps a classic example. The first proposed improvement to be negotiated out was the aerodynamic shape; this was easily justified by reasoning that at high altitudes, where it was assumed all future air combat would occur, aerodynamic shape was not critical. Besides the old shape is easier to machine and the fuze design is simplified. Next to go was the delay fuze. It simply was not developed in time. The thin-wall, high capacity shell did evolve, and its light weight (1560 grains) did permit the relatively high specification (measured at 78 feet range) velocity of 3380 fps or about 3400 fps muzzle velocity. Figure 15 illustrates the current M56A3 shell body compared to the old M97.

Bear in mind that this new round was developed for high altitude air combat as a replacement for the caliber .50 (12.7 mm) and in lieu of a caliber .60 (15.2 mm), both of which depended on an API round for effect. As a

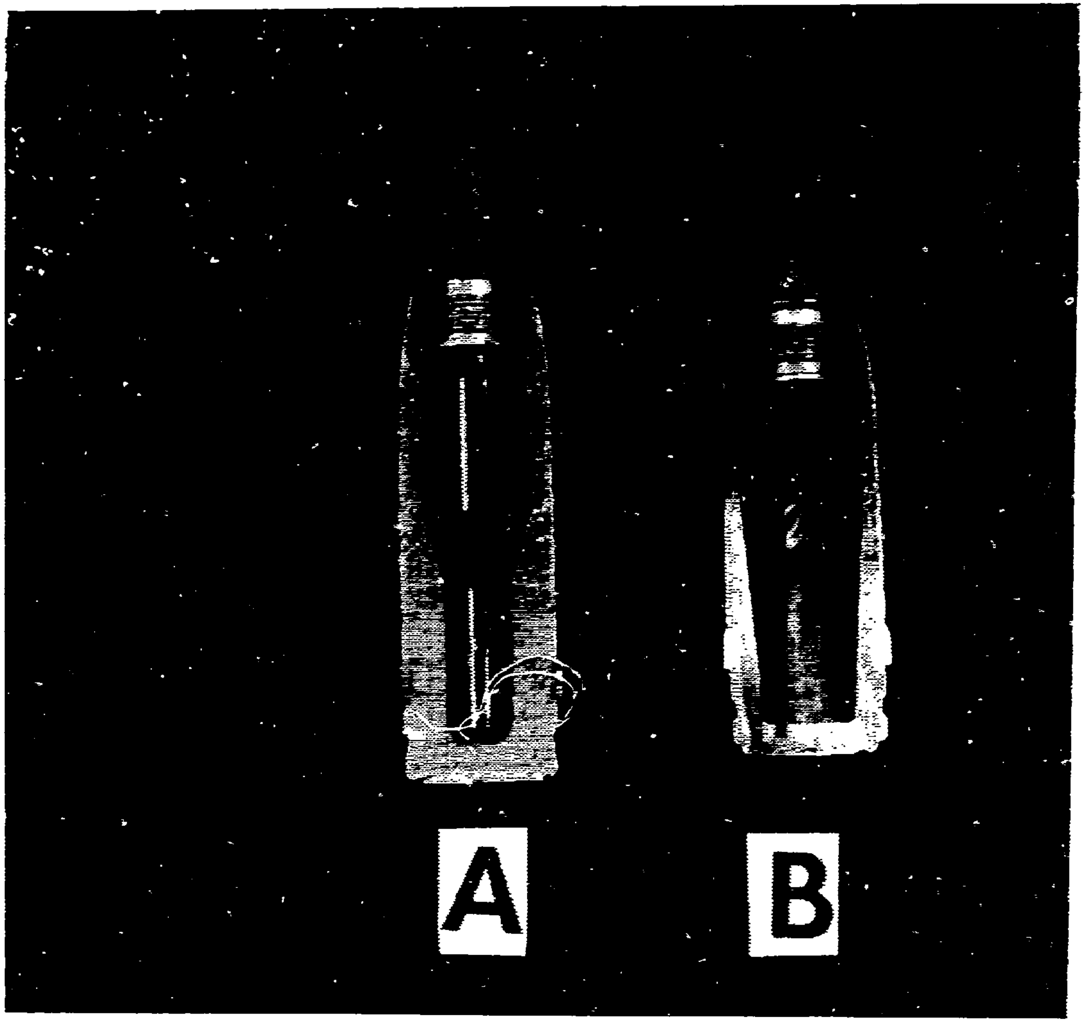


Figure 15. 20 mm M97 (A) and M56 (B) HE Shell

consequence, along with the M56 HEI shell, an M53 API shot was developed as well. As a matter of fact, at the time, the API was envisioned as being the more important of the two--after all we had won the war with the caliber .50 API M8! So we got the M50-series rounds, not perfect, but very good for their intended purpose. The only real deficiency was the lack of a delay fuze. They were standardized in 1955.

By the mid-1960's in the Southeast Asia conflict, we were using millions of rounds of 20 mm ammunition (Figure 16), not in the air-to-air combat for which it was designed but mostly for ground strafing! The users soon found out that the M53 API round designed to penetrate aluminum and thin steel aircraft armor at relatively short range was not too effective at long range against armored vehicles. Also, they found that the lightweight and high drag shape of these projectiles, although fine at 40,000 feet altitude, caused them to slow down at such a rate at sea level that the fuzes would not even function at a range beyond a mile or so. In the late 1960's, we undertook, at the request of the users, to develop some new 20 mm ammunition in the M50 configuration which was optimized for air-to-surface use.

The goal of increasing effective range and striking velocity infers as a minimum, increasing energy on target. With a predetermined overall round configuration, the muzzle energy is essentially fixed by the amount of propellent one can put into the case. Obviously then, in order to increase remaining velocity and/or kinetic energy on target, one must reduce the velocity decay in flight. The ability of a projectile to retain velocity is a direct function of the factor W/C_dA, where W is the projectile weight, C_d is a drag coefficient which is primarily a function of shape, and A is the cross-sectional area. Since A is determined by the caliber, the only way to

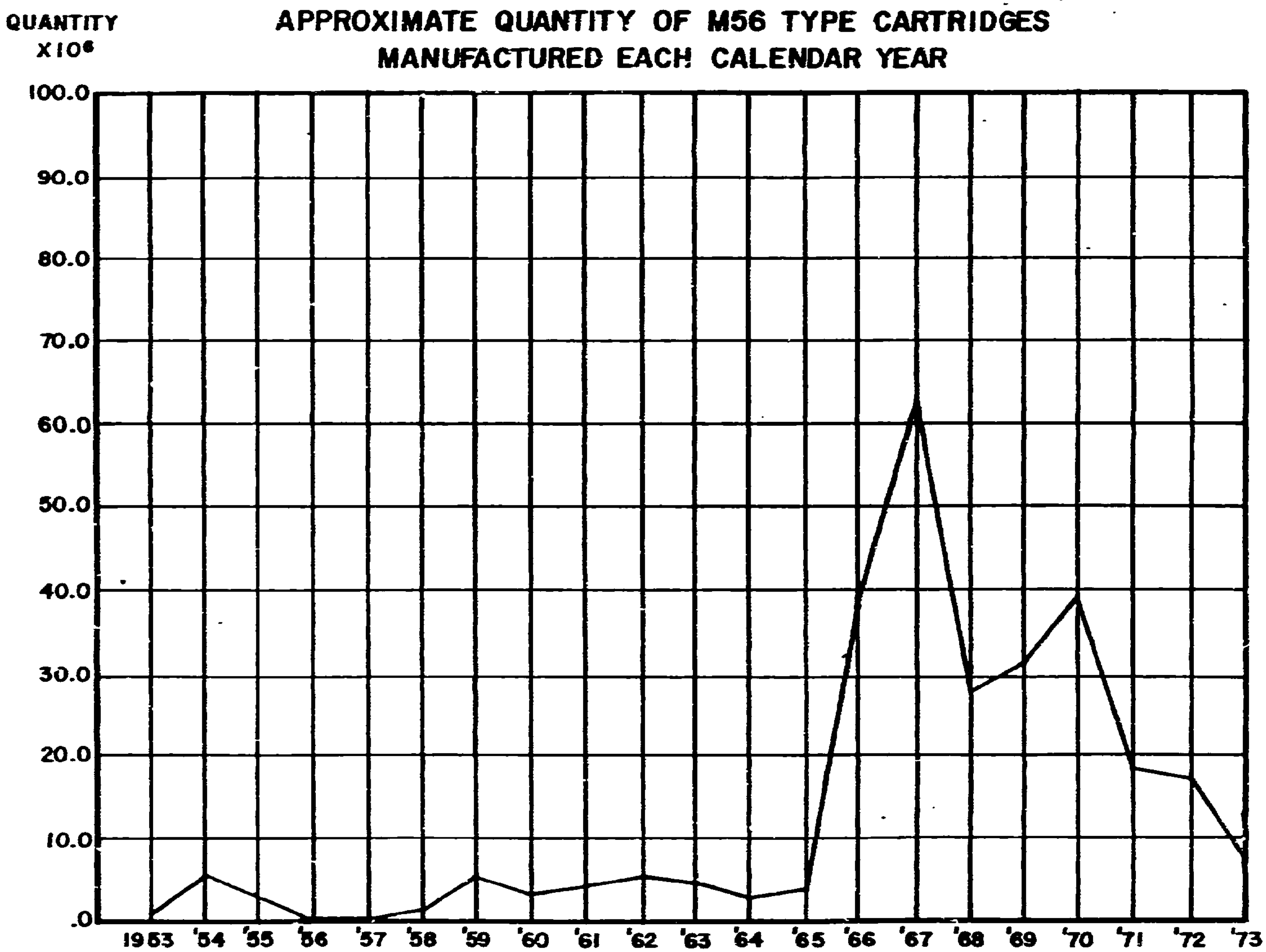


Figure 16. Annual Production of M56 Shell

increase lethality at long range is to increase the projectile weight and improve its shape.

A further objective was, of course, to increase the armor piercing capability and effectiveness against general ground targets. The decision was made to develop several new heavy projectiles as follows:

Type	Weight (gr)	Fuze	Penetrator	Muzzle Velocity (fps)
API	2500	None	WC or DU*	2650
SAPI	2100	None	Steel	2880
SAPHEI	2100	Base/Delay	Steel	2880
HEI	2100	SQ & Airburst	None	2880
TP	2100	None	None	2880

*WC = Tungsten Carbide, DU = Depleted Uranium

What was actually developed and demonstrated very successfully is illustrated in Figure 17. The first, Figure 17(A), is the armor piercing incendiary (API) projectile designed for maximum penetration. It contained a tubular tungsten carbide core (foreground), about 2-5/16 inches long, 9/16 inch in diameter with a 3/16 inch hole through the center and an added base cavity. This core is assembled to an aluminum nose and a steel base cup, with the hollow core filled with a conventional incendiary mix. The second, Figure 17(B), is similar in configuration with the entire body being of hardened steel with a soft steel nose plug, a steel base plug, and an incendiary filled cavity extending for 2-1/4 inches from base plug to nose plug, with a smaller incendiary core running a further 1/2 inch into the nose plug. This round lacked some of the penetration capability of the one in Figure 17(A); however, its cost would have been significantly less. These two rounds were developed by Avco under a contract with Frankford Arsenal for the Air Force. The third

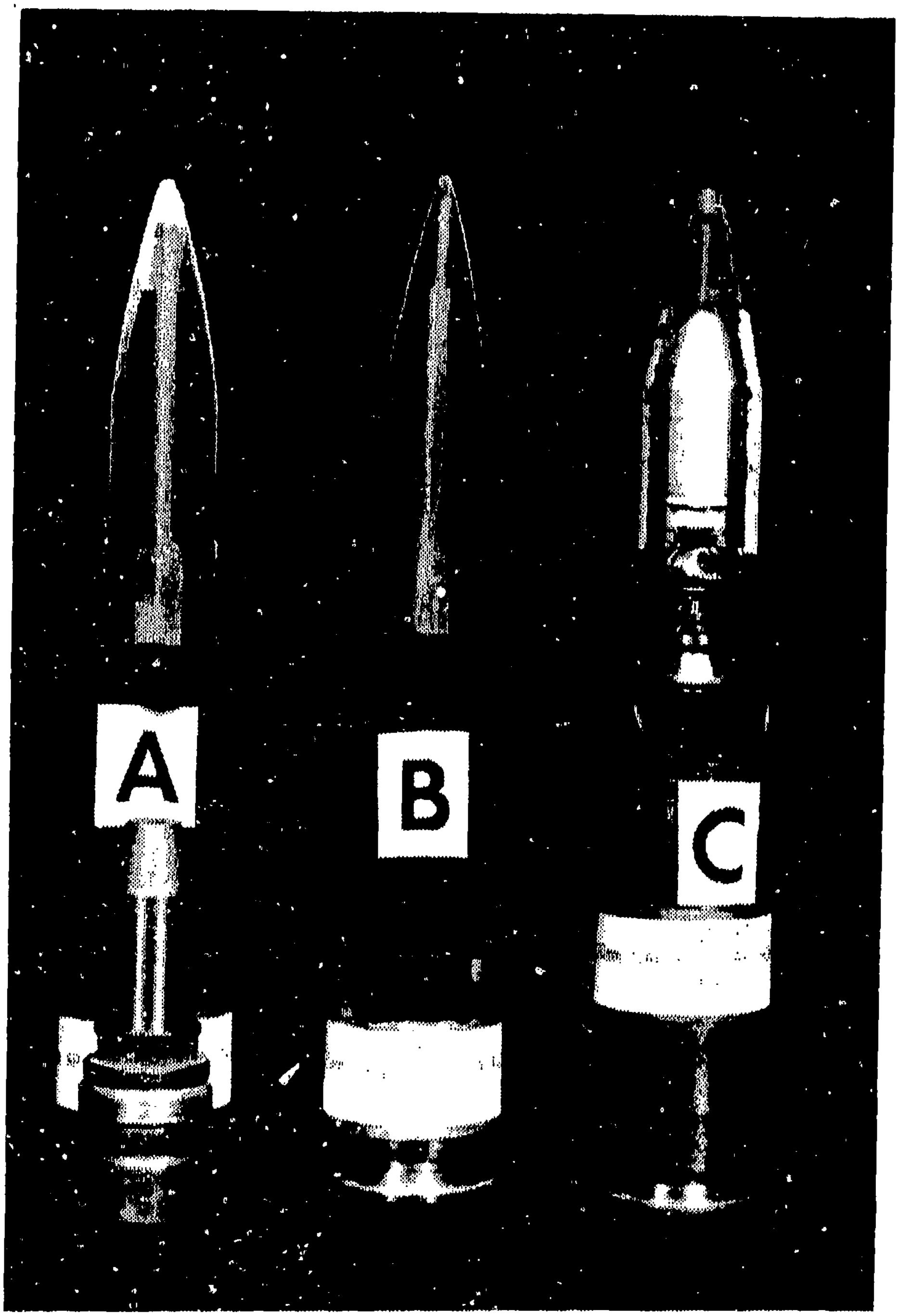


Figure 17. Improved 20 mm Air-to-Surface Rounds (all 1970)
A. High Density API with Tungsten Core,
B. API,
C. SAPHE

round in this series is as shown in Figure 17(C), and is at first glance a semi-armor piercing high explosive (SAPHE) round so common in Europe; however, it has two differences which were significant at the time. First, it utilized the same explosive as our HEI rounds, consequently adding incendiary to its capability, and more importantly, it contained an Air-Force patented all-angle base detonating fuze which was, and still is, unique. A brief explanation is in order.

Conventional base detonating fuzes operate on axial deceleration. As the projectile is slowed going through a target, a cylindrically guided inertial mass moves forward causing the firing pin to strike the initiator. In most cases, this works well; however, on glancing impact, the inertia weight may bind on the side of the tube so that the firing pin does not strike the initiator with enough velocity to fire it; the result is a dud. The all-angle fuze can best be understood by study of the section photograph in Figure 17(C). At the front of the fuze is a booster, followed by a conventional ball rotor, housing a detonator. The ball rotor is locked in place by a "C" clip and the firing pin which is held forward into the rotor recess against spring tension by the striker. The striker is seated on a soft aluminum crush washer. Upon firing, setback of the striker and firing pin crush the washer, retracting the firing pin from the ball rotor. Upon leaving the muzzle, the "C" clip, which was previously restrained by setback, expands, releasing the ball and the ball seeks its maximum moment of inertia, aligning the detonator with the shell axis. The firing pin and striker are prevented from creeping forward by spring force. The unique feature of this fuze now becomes apparent: the shape and mass properties of the striker are such that any deceleration force on the projectile, regardless of the angle at which it is applied, even up to an extremely high angle ricochet, will cause the striker to hit the firing pin dead center with minimum energy loss. Duds are virtually eliminated, and inertial delays are such as to delay detonation until after target penetration. This round of ammunition and the fuze were developed for us by Honeywell.

The target practice and high explosive incendiary rounds were not developed under this program, primarily because they were so straightforward that there was really no development to do--just draw them and build them. The user requirement for an airburst fuze for the HEI round was addressed. Two approaches were taken. A contract was awarded to General Electric Company to demonstrate its "eyeball" fuze, an infrared detector, which if linked alternately with impact fuzed ammunition would "see" the function of an impact round and function in the air. The other approach was a radar proximity device built by Motorola; it was not unique except for its small size. Both fuze concepts proved technically feasible, but neither was completed or produced because of cost and declining interest.

All of the developments for the improved air-to-surface 20 mm ammunition were successful; all feasibility was demonstrated and everything performed as advertised. All of the rounds could have gone directly into prototype fabrication, service test, and full-scale production. By this time, however, the Air Force had gun pods on the F-4C's and F-4D's and internal guns on the F-4E's. Since missiles were not the ultimate weapon they were expected to be, the Air Force was again using guns in air combat. Interest had now been lost in heavy, low-velocity, long-range shell for air-to-surface; interest was now diverted to lightweight high-capacity, high-velocity rounds for air combat! This interest reflected exactly what the M50-series was built for in the first place, except for one thing--fighting was taking place at 10,000 feet and less rather than 40,000 feet. Could we make an improved 20 mm for air-to-air? The answer, of course, is that you can always improve anything. The next question is whether the improvement is worth the cost--not just dollar cost, but by losses in alternate capability and added logistics. We had just found out, for example, that the Tactical Air Command (TAC) did not really want the improved air-to-surface round they had asked for.

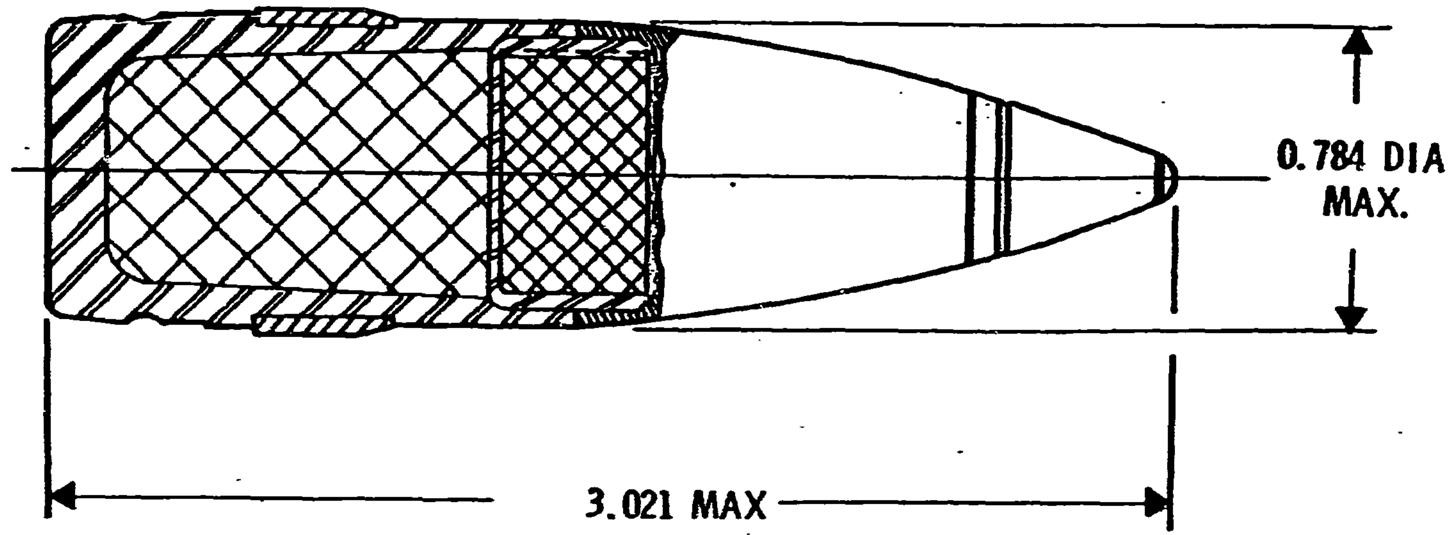
To improve the round for air-to-air use, one must increase velocity, improve aerodynamic shape, increase HE charge, and provide a delay fuze. These improvements were exactly what had been required in the late 1940's and early 1950's in improving the M97 into the 60/20. Of course, the delay fuze and the aerodynamic shape of the 60/20 had been lost in standardization to the M56 and could be regained, but how much additional improvement could be gained? Our analysis showed a total improvement of 10 to 15%, most of which was attributed to a delay fuze. After much study, analysis, briefing, and a direct order from the Air Staff (RDQ), it was decided to proceed with the development of the improved 20 mm. A significant impetus was added with the demise of the GAU-7 caseless 25 mm; some people seemed to think we could improve the 20 mm until it was as lethal as a 25 mm.

The design criteria for the improved round were to increase the velocity as much as possible, increase the HE charge as much as possible, improve the aerodynamic shape, and provide a function delay. It was required that the round be functionally interchangeable with the M56 round in the M61 gun and desired that it work in the M39 as well. The only target to be considered was the relatively light and thin-skinned MIG-21. Some elementary design work showed that, by lengthening and thinning the ogive, thinning the shell wall, and installing a plastic rotating band, the projectile weight could be reduced to 1200 to 1300 grains. This would permit a velocity of 3700 to 3800 fps. A function delay could be achieved (as was done in the GAU-7) by locating a heavy (brass, typically) firing pin at the front of an extended ogive on a modified M505 fuze, and by clever design of the front of the pin and/or a striker to control the impulse applied so that its travel time to the initiator would provide the desired delay.

With this background, let us examine some of the modifications that were tried in an attempt to improve the M56 for air-to-air use. One of the first proponents of this approach was Honeywell. In fact, their marketing efforts had a significant influence on the actual documentation of a requirement for this type round. Figure 18 illustrates an early 1972 Honeywell design which contained most of the features described above. It also contained an entirely new fuze with improved sensitivity, graze sensitivity, and self-destruct capability. It did not have a delay. Since we did not want to develop a new fuze and the improved 20 mm program was not yet approved, we did not buy this proposal. Honeywell's next approach was to modify the design to incorporate the "714" fuze they were developing for the Army. This projectile and fuze are illustrated in Figure 19(A). Since the Air Force was not interested in the Army's expensive and complex fuze, which still did not incorporate a delay, Honeywell's next design, Figure 19(B), contained a modified M505, much as was in the GAU-7, and, as it turned out, in the final improved 20 mm. Figure 19(C) was Honeywell's proposed companion target practice round. All of this work at Honeywell was done with internal funding.

When the improved 20 mm program was finally placed on contract, the contract was not awarded to Honeywell; despite Honeywell's extensive prior

20 MM HEI "QUICK" ROUND



OBJECTIVE:

- OPTIMIZE A-A CAPABILITY
- MAINTAIN CURRENT HEI CONTENT

Figure 18. Honeywell "Quick" Projectile (1972)

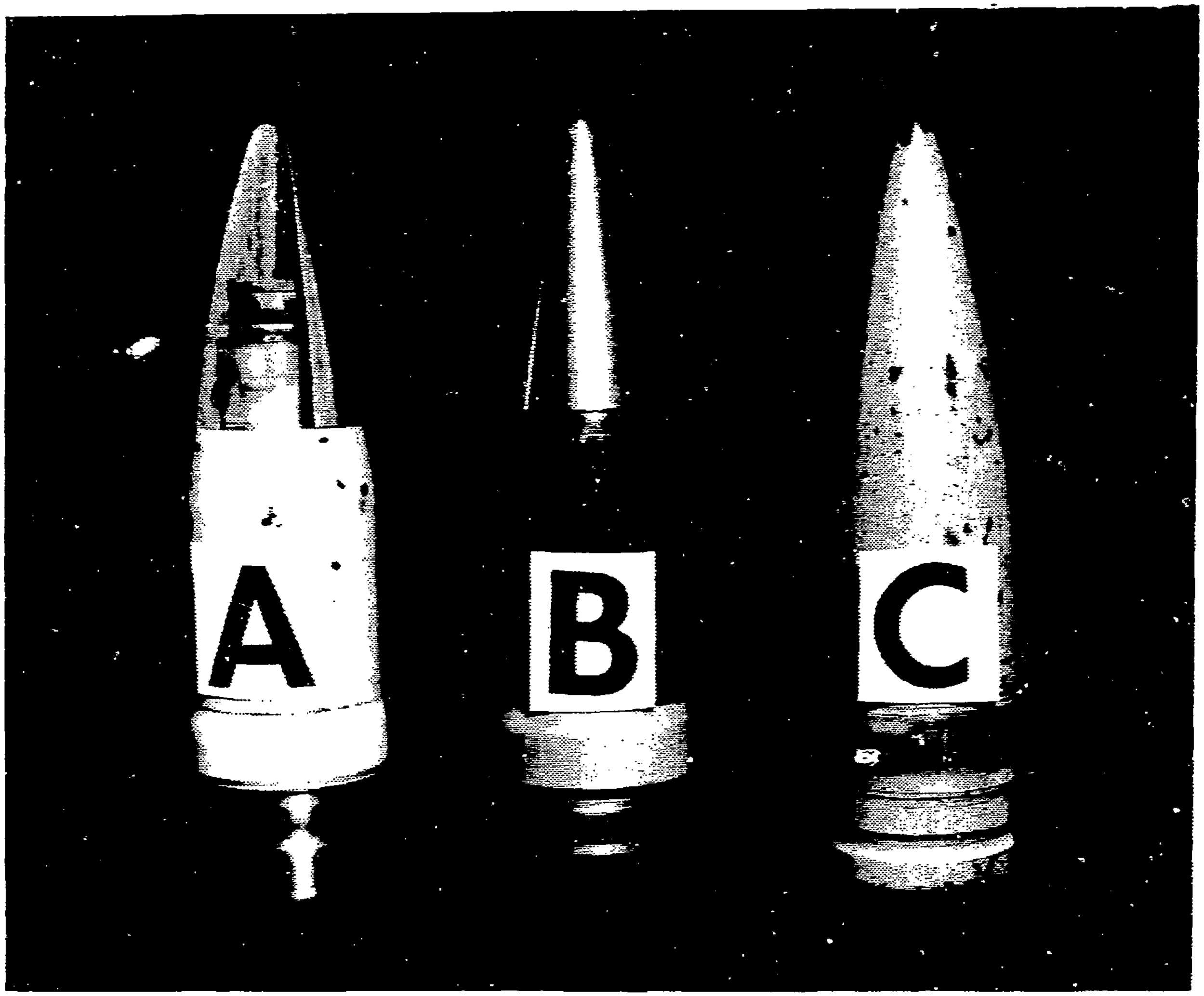


Figure 19. Honeywell 20 mm IR&D Projectiles: A. With 714 Fuze, B. With Modified M505 Fuze, C. Target Practice

work, Avco won the bid. Two of the desired characteristics of the new round had not yet been resolved: maximum HE charge and increased velocity (minimum time of flight). Figure 20 illustrates some of the available trade-offs examined during the early stages of the program. Figure 20(A) is the current M56 with the M505 fuze. Figure 20(B) illustrates the thinnest possible wall thickness for a M56 configuration round. It could only be made this thin by reason of some extreme design procedures and some new technology. First, the shell would not stand firing stresses without an HE filler, since it depends on the high-pressure pressed HEI filler to support the shell walls against chamber pressure. The plastic rotating band (not shown), being of the bonded type, requires only a very shallow band seat as compared to the copper band in Figure 20(A). Plastic bands require much lower engraving forces than copper so the supporting wall can be much thinner under the band. In actuality, this shell is an extreme case. It is not a practical design today. It has not, for example, been fired through a hot barrel, which might be 0.080 inch oversize, causing balloting resulting in deformation or fracture of the ogive. Also, there is no margin for faults in the steel which occasionally occur, especially during wartime.

Speaking of metal imperfections, note that this shell (Figure 20(B)) does not yet have its baseplate installed (as Figures 20(A) and 20(C)) although there is a flange provided to roll crimp it in place. This shell is simply not finished. Baseplates have historically been required on HE shell machined from bar stock because of occasional stringers and piping which, under firing stress, fail and/or permit hot propellant gases to impinge on the explosive charge causing a catastrophic in-bore detonation. Baseplates are not required on shell manufactured by drawing or extrusion methods (Figure 20(D)). Some

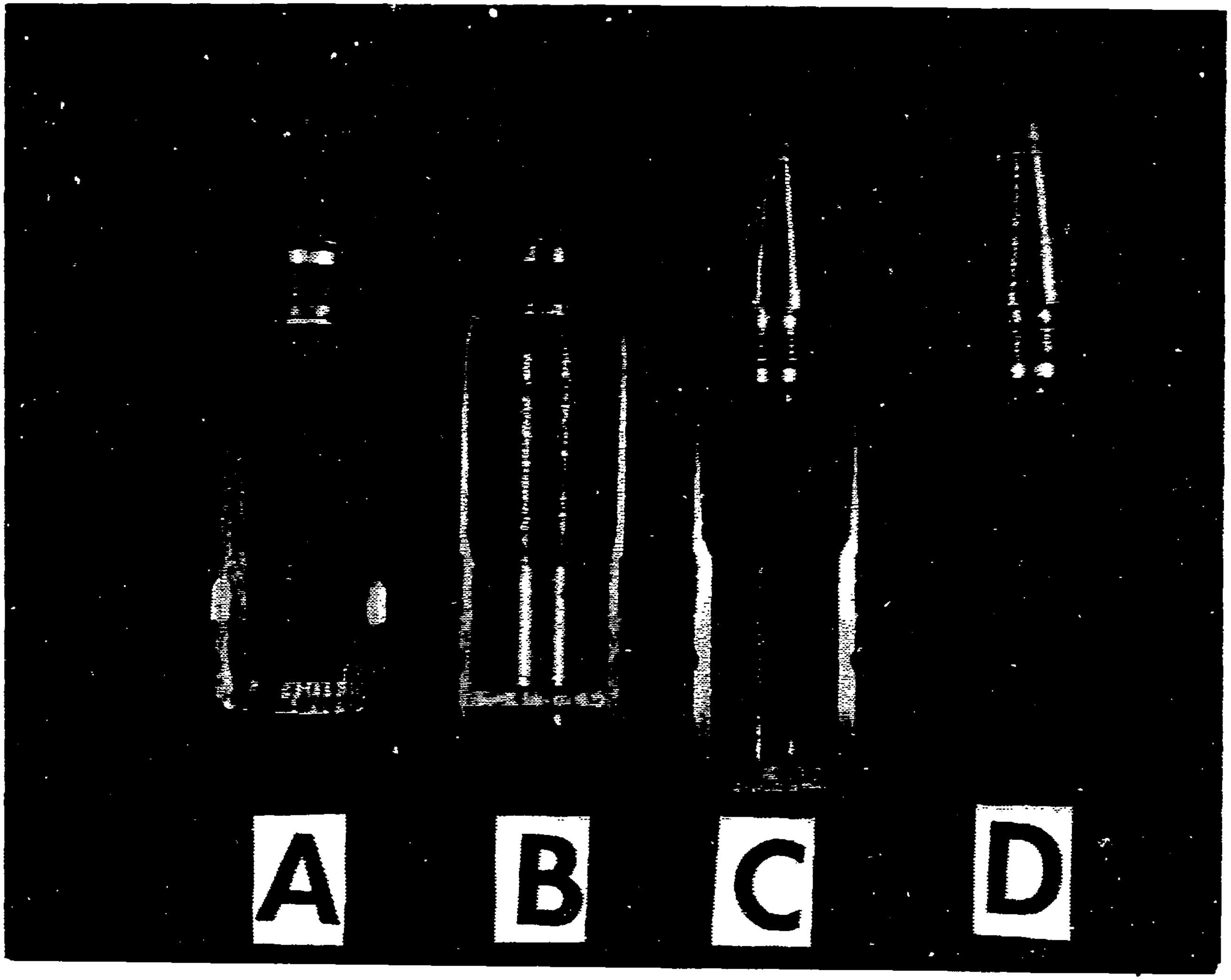


Figure 20. 20 mm Thin-Wall Projectiles
A. Standard M56, B. Maximum Capacity with M505 Fuze and M56 Length, C. Maximum Capacity with Improved Shape, D. Minimum Weight

work by the Army a few years ago has indicated that the precautionary baseplate may not be required in 20 mm with modern fills. Some relatively large holes (as compared to expected piping) were drilled through the shell base without experiencing detonation. This is probably because of the short residence time of the small (20 mm) caliber shell with a total action time of about 2.5 milliseconds and the insensitivity of modern fills. Large artillery with action times ten to twenty times as great and TNT fills are more critical.

Figure 20(C) illustrates another trade-off, an attempt to improve aerodynamic shape, maximize HE capacity, reduce weight, and achieve good muzzle velocity. The shell body is still the same length as Figures 20(A) and (B), but the longer ogive causes more of the shell to intrude into the case. This has two disadvantages: first, it occupies case volume which reduces propellant capacity and velocity and, second, it extends much of the shell aft of the rotating band where it is now subject to full chamber pressure and must be made thicker. This design ended up at higher weight and lower velocity than desired. Figure 20(D) shows a cold-formed shell body which is shorter than the M56 body, yet has higher HE capacity. Its overall length is equal to the M56. Its long streamlined ogive and light weight provide for maximum muzzle velocity and minimum time of flight. It is close to the final configuration developed under this program, differing in many minor respects and one major feature; it, as well as Figures 20(B) and (C), utilized bonded rotating bands whereas the final configuration utilized mechanically retained bands. Bonded bands simply were not ready. There was no nondestructive inspection or test that could separate a good bonded band from a bad one and no way to assure shelf life of the bond (see also Section XVII).

Figure 21 illustrates the final configuration of the improved 20 mm round, the one on the left being the TP, PGU-18/B and the one on the right being the HEI, PGU-17/B. They were completely developed, limited production runs made, and qualification and service tests completed. They were not put in production. The user really did not want an improved 20 mm after all; the M56 was good enough.

Incidentally, it should be pointed out that about 90% of the improvement demonstrated in the improved 20 mm could be obtained by substituting a delay fuze for the M505--and today we have such a fuze, known as the pressure-rise delay fuze, which is a modification to the M505 that can be made at very low cost.

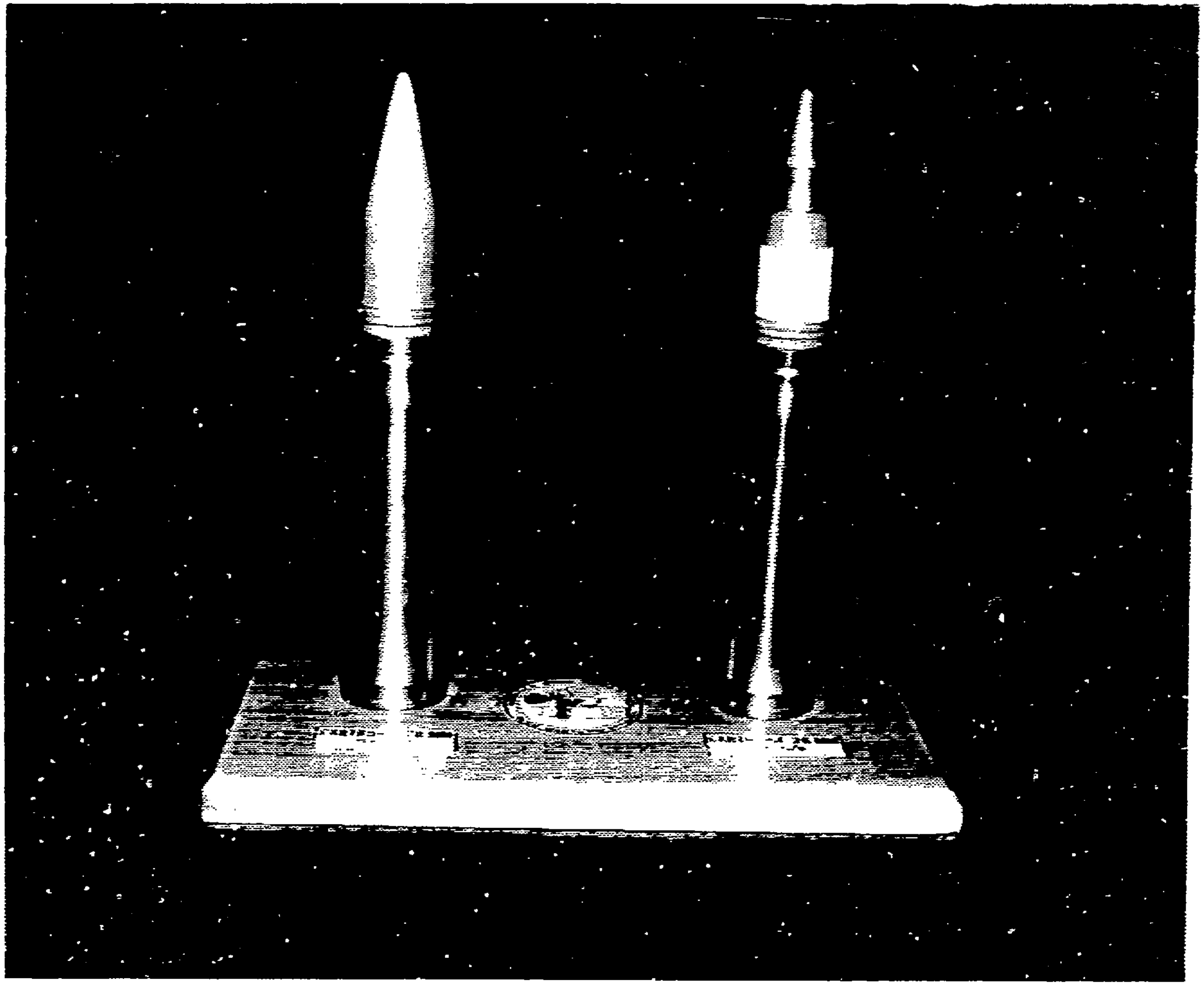


Figure 21. Improved 20 mm Rounds

SECTION IX

PLASTIC CARTRIDGE CASES

One of the great advancements in firearm history was the development of metallic cartridge cases. This development was essential to quick firing artillery, repeating rifles, and machine guns. In view of this, it may seem incongruous that ever since practical metallic cartridge cases have been around, people have been working to eliminate them. The fact is that metallic cartridge cases, especially brass, work and work well. An attendant fact is that they are heavy and expensive; depending on type and design details, percentages vary, but a brass case normally comprises about 40% of the weight and cost of a round of ammunition. Since weight is significant in logistics and a major problem in modern warfare, and cost of ammunition is also a major factor in modern warfare, it is obvious why anyone should be interested in reducing these by any significant fraction of the potential 40% that could be achieved if brass cases could be eliminated. During World Wars I and II, steel cases were developed to replace brass, primarily because brass became in critical short supply to all combatants. The fact that steel was both lighter and cheaper was not considered at the time; these are considerations today!

In the GAU-8 system, as described earlier, we did use aluminum cases to save several hundred pounds per flight on the A-10. Another area of investigation being pursued at the time, but not a serious contender for the GAU-8, was plastic or plastic/metal composite cases.

A cartridge case serves many purposes, one of which is to obturate or seal the chamber against the pressure developed by the propellant gas. In a conventional gun, the cartridge case is inserted into the chamber up to the extractor groove; the extractor groove and rim protrude from the barrel. The base surface, or at least the major part of it, is supported by the breech or bolt. In the annular area between the barrel and breech, the chamber pressure must be contained by the cartridge case and the cartridge case only. To make matters a little more difficult, the stress path between the barrel and breech face is somewhat long and the gap varies during the firing cycle, inducing significant strain in the case. With chamber pressures running from 50,000 to 70,000 psi, it is obvious that, in order to prevent the case from simply blowing out between the chamber and breech, the case must have a dynamic strength on the order of 70,000 psi to be used with conventional breech designs.

Figure 22 illustrates a number of attempts to make plastic or plastic composite cases with varying degrees of success. Figures 22(A) and 22(B) are two proposals submitted in the late 1960's. Figure 22(A) illustrates an attempt to construct a 20 mm case from plastic. It is electroplated with copper because the person who submitted it felt this would be necessary to assure function of electric primers with an all plastic case. He was right, of course, but what he did not recognize was the need for strength in the head area. Figure 22(B) was submitted as an all plastic case for the Army WECOM 30 round, a low pressure round at about 30,000 psi. So far as is known, it was never tried; it would not have worked even at this low pressure. Figure 22(C) is an attempt by General Electric to make an all plastic case. Personnel at General Electric Company correctly assessed the problem, deciding that in order to successfully use an all plastic case, it must be completely contained. They designed a breech with a form-fitting, 180-degree extractor which fit metal-to-metal against the barrel. Upon firing, even with an

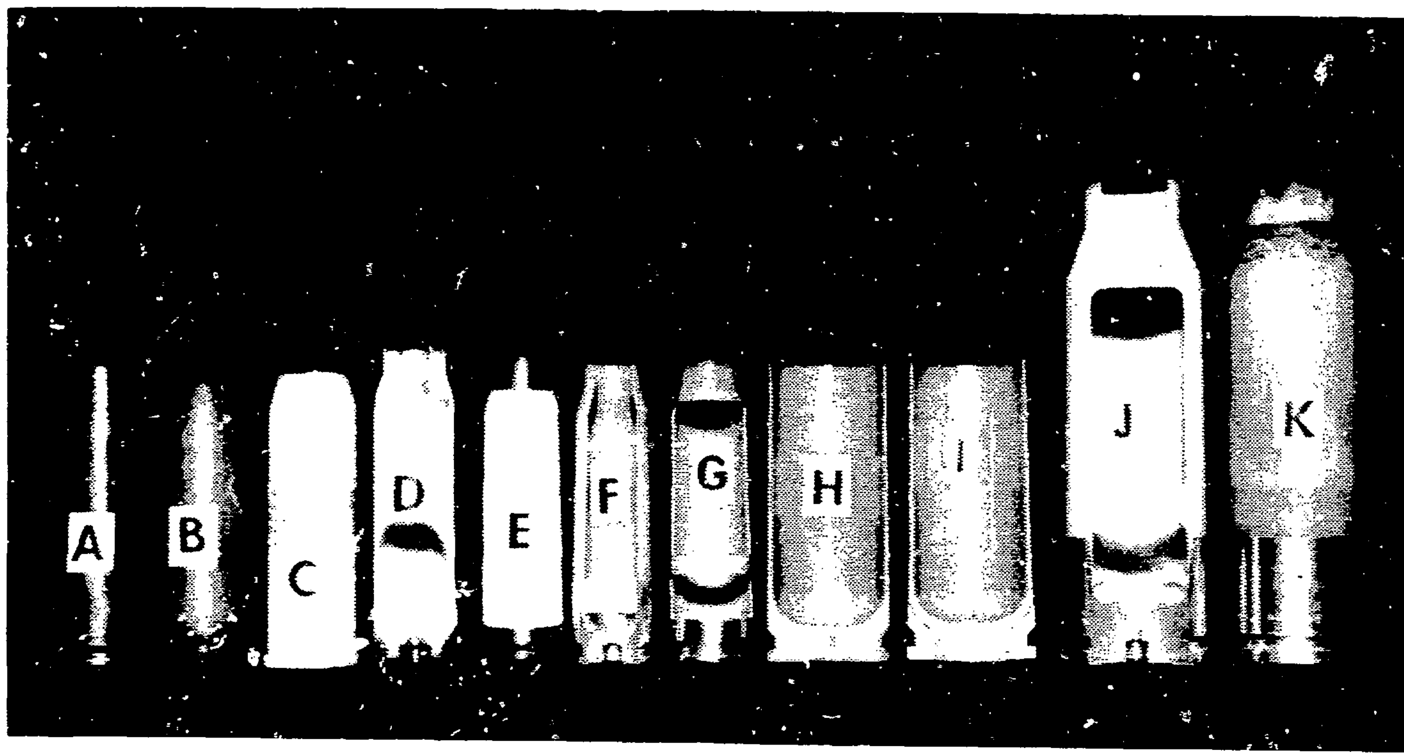


Figure 22. *Various Plastic Cartridge Cases*
A. Copper Plated 20 mm, B. Plastic WECOM 30, C. GE Experimental 20 mm, D. Remington 20 mm with Aluminum Neck Insert, E. Remington 20 mm with Steel Neck, F. AAI Plastic/Aluminum 20 mm with Ponded Joint, G. AAI Plastic/Aluminum 20 mm with Sawtooth Joint, H. Plastic Base of GAU-8 Configuration, I. Plastic/Aluminum Base of GAU-8 Configuration, J. AAI Plastic/Aluminum 30 mm, K. AAI 30 mm after Firing

exceptionally rigid test lock-up, the breech set back about 0.010 to 0.015 inch and permitted plastic to extrude radially outward about 0.040 inch into this crack. This extruded material is visible about 1/8 inch above the rim on the right side of this model. This is graphic proof of the need for tightly fitting breeches to virtually seal any plastic case. It is also graphic proof that it can be adequately done; this round was fired to M50-series specification performance. During this series of experiments, General Electric personnel learned, as did others about the same time, how difficult it was to prevent primer leaks in plastic cases. This particular case had an aluminum insert between the primer and plastic; it still leaked. This work was done by General Electric on internal funding in the early 1970's.

Figures 22(D) and (E) illustrate two of many configurations tried by Remington under contract to the Air Force to make plastic and metal composite cases. They worked with .221 Rem, 5.56 mm, 7.62 mm and 20 mm, in each case attempting to make a composite which was physically interchangeable with a brass case. In this program, one of the few exceptions to scaling laws become apparent. It was relatively easy to make functional small caliber cases but not so easy for 20 mm; the reason was time of application of stress. Plastic strength is extremely strain-rate sensitive. Whereas a .221 Rem round might have a one-millisecond action time and expose the plastic to stress above its static yield for 0.25 millisecond, the 20 mm, on the other hand, with 2-1/2 milliseconds action time might stress the plastic above static yield for a full millisecond. The plastic may flow in the 20 mm case, wherein it may not have time to respond in the .221 Rem. In any event, none of this work was totally successful, primarily because we were trying to make a case of plastic, steel, and/or aluminum which was a direct substitution for brass.

It proved difficult. On the other hand, it did become obvious that given the option to employ good design practice on the breech and the ammunition, successful plastic composite cases could be made.

Notable design features of Figures 22(D) and (E) are contained in the base and the neck. The base of Figure 22(D) is made of three steel components: first, the annular ring containing the extractor groove; second, the base washer forming also the rim; and third, the primer pocket which is also used as a tubular rivet to hold the other two pieces onto the plastic body. The base of Figure 22(E) is similar except that it includes an internal steel washer which is also held in place by the primer pocket rivet. The necks of these two rounds also carry metal inserts, a feature found necessary from earlier work in small calibers. A projectile, which is press fit or snap fit into a plastic neck so the plastic remains strained, will cause the plastic to at least creep, or, in most cases, to date; it will stress crack, causing loss of retention and loss of hermetic seal. Figure 22(D) employs a thin aluminum insert inside the plastic neck. In Figure 22(E), the entire neck is steel and the steel continues down about 5/8 inch inside the plastic case.

Figures 22(F) and (G) illustrate two of the last configurations of the development of a plastic aluminum composite case to replace the brass and steel cases for the M50-series 20 mm ammunition. This work was done by AAI Corporation under contract to the Air Force. The concept was to use an aluminum base machined from bar stock and an injection molded glass-reinforced nylon body. A design was quickly evolved which worked quite well in the M61 gun, a mechanism which is known for its easy handling of ammunition; however, these cases would not work in the M39, which is known for rough handling, impact loading, and slamming the case shoulder into the corner of the chamber during ramming. This first design had a case thickness at the shoulder of about 0.040 inch, thinning to less than 0.030 immediately behind the shoulder. In order to make the cases work in the M39 gun, a lot was made up in which the wall was increased to over 0.060 inch within this region and back to about 1-1/8 inches from the case mouth. They worked! The final configuration shown in Figure 22(G) extends this thicker wall all the way down to the base. About the time the cases began to function satisfactorily, "should cost" studies were run to determine how much money could be saved with these cases. It turned out that machining this aluminum base from bar stock would cost more than the entire metal case made by conventional cold-forming processes! An attempt was made to design a base which could be cold formed. Figure 22(F) illustrates a base with a smooth interior without the ratchet or sawtooth inner surface which normally retained the matching surface of the plastic body once it was snapped in place. The smooth surface required that the plastic be cemented or bonded to the base. It was not immediately successful and was abandoned. Figure 22(G) represents the final configuration which was technically successful. This particular case was fired before it was sectioned. It consists of a machined aluminum base with a double sawtooth mechanical retention for the injection molded 41% glass-reinforced nylon body. The body is about 0.060-inch thick throughout except for the neck which is molded to that thickness and machined out to admit the projectile. An internal ridge is left in the neck to snap into the projectile crimp groove and retain the projectile. The program might be described as a technical success but an economic failure. Figures 22(H) and (I) are preliminary studies of the base of a round in GAU-8 configuration. Identification of the designer has been lost, but they are presented anyway to show a different approach to the problem. Figure 22(H), of course, would not work; Figure 22(I) is a start, but has not considered primer pockets or sidewall stress concentration.

Figures 22(J) and (K) are successful plastic and aluminum composite cases which were used extensively in single shot firings at AAI during the development of the depleted uranium penetrator discussed in Section VII. At the time these were made, neither the Ford nor General Electric GAU-8 cases had been designed and built, so AAI built its own. This configuration is close to the original AF proposal (Figure 5(A)), including the too small extractor groove. For a few hundred or a few thousand cases, it is probably cheaper to make an injection molding die and machine bases than it is to make extrusion or drawing dies for conventional cases. Note that the junction of case and base has a three-sawtooth attachment.

In summary, several conclusions can be reached regarding plastic cartridge cases:

1. It is possible to make technically adequate plastic and metal composite cartridge cases, even with the constraint that they be functionally interchangeable with existing metal cases.

2. It would be relatively easy to make plastic and metal composite cases for a new system on which dimensional constraints of the case have not been set.

3. Conventional metal case forming is very inexpensive; the metal parts for a composite case must be simple and cheap in order to compete.

4. All-plastic cases cannot be made for existing high pressure guns.

5. All-plastic cartridge cases can be made but will require new breech designs which will seal and prevent the flow of the plastic case.

SECTION X

DUMMY AMMUNITION

Dummy ammunition has many and varied uses. In a sense, all of the ammunition illustrated in this report is dummy ammunition inasmuch as it is inert and is used for display or illustration purposes. The type of dummies described in this section, however, are somewhat different; they were specifically manufactured to be dummies.

There are many legitimate uses of dummy ammunition. The first type of dummy generally found for any cartridge is usually a simple turning (today usually of aluminum, formerly frequently of wood) which gives three-dimensional shape to an ammunition concept. The second type to appear is usually similar and is used to check out fit and function of a gun mechanism or model. Later dummies are used as display items, training aids, maintenance tools, ballast, trading stock, etc. Their uses are endless, and it seems that the required number is limitless.

As the uses of dummies are varied, so also are their configuration and construction. Some of the variations are shown in Figures 23 and 24. Figure 23(A) is typical of a machined early model intended to give three-dimensional visibility to a new design. It is machined from aluminum bar stock and is in more detail than most dummies of this type, including a simulated primer, a headstamp showing "HS831" at 12 o'clock and the figure "6" at 6 o'clock, and detail and painting of the rotating band and projectile. It is believed to have been made in 1966. Figure 23(B) is usually the second type of dummy made, this one also being an HS-831, consisting of an actual projectile and case, often (as in this instance) with a fired primer and assembled with a production crimp. This sample, dated 1974, was obtained by the author at the

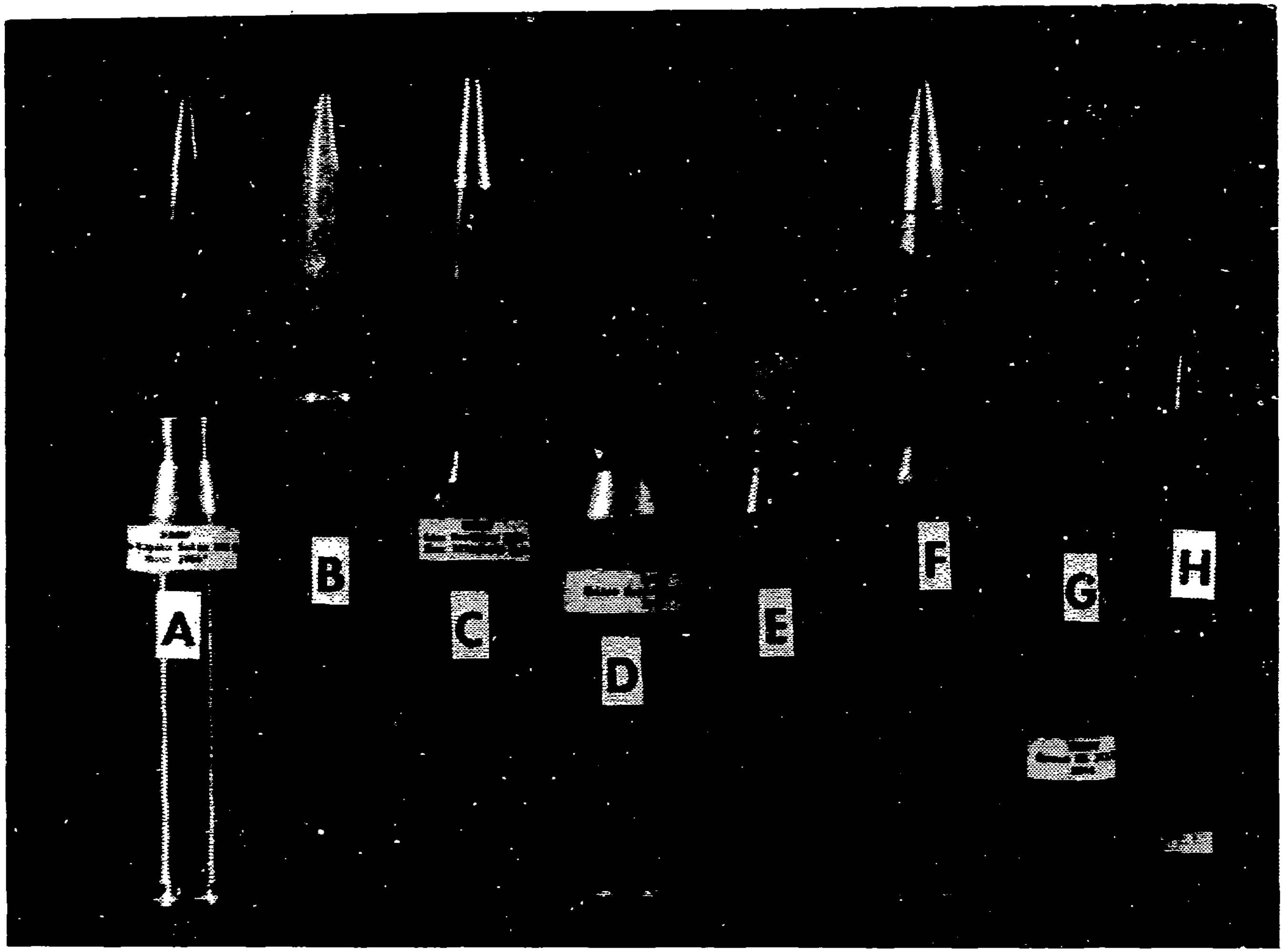


Figure 23. Classic Dummy Rounds
A. HS831 Solid Aluminum (1966), B. HS831 Crimped Components (1974)
C. 304 Oerlikon Thru-bolt (1971), D. Ford GAU-8 Crimped Components (1972)
E. Ford GAU-8 Thru-bolt (1972), F. GE/Aerojet GAU-8 Thru-bolt (1974),
G. MG213/30 Machined Steel, Hollow (1944), H. MG213/30

Geneva factory that year. Figure 23(C) is for the Oerlikon 304RK and is of the third type, commonly known as a "durable dummy," in which the projectile is more securely attached to the case so that it may be cycled through feed systems and guns without the projectile loosening in the case. In this instance, the base of the projectile is drilled and tapped, the base of the case is drilled and counterbored, and a large slotted head screw is used to assemble the round. The screw was obviously especially made for this purpose, having a head 22 mm in diameter and a slot 5 mm wide and 4 mm deep. The bolt may be contoured to simulate weight and balance of a loaded round. This dummy, assembled with a 1955 case, was obtained by the author at the Zurich factory in 1971. Figures 23(D) and (E) are Ford GAU-8 nondurable dummies and durable dummies, respectively. The nondurable dummy has a plastic button inserted in the primer pocket; case and projectile are crimped for assembly and the round is ballasted for weight and balance, probably with rice. Figure 23(E), in addition to being crimped, has a socket head cap screw counterbored into the base and threaded into the projectile. Its weight and balance appear to be close to correct, but no filler is evident and the cap screw appears to be a standard item. Both Figures 23(D) and (E) are dated 1972. Figure 23(F) is a durable dummy for the General Electric GAU-8. This round is not crimped and is also assembled with a countersunk cap screw. Ballast is not evident. This round shows some of the normal wear that occurs during cycling through guns and feed systems, especially dummies with aluminum cases. It is dated 1974. Figure 23(G) is a 1944 German MG213/30 dummy of the first type. It is unusual because it appears to be machined from steel, drilled from the base to simulate weight and balance, and closed with a plug which is staked in place.

Figure 23(H) is also an MG213/30 of 1944, second type, case crimped to projectile, primer pocket empty.

Figure 24 illustrates several of the many variations of 20 mm dummies made over the years. All except the first two are of M50-series configuration. The first two are included because they represent constructions which probably also exist in the M50-series but are not in the author's collection. Figure 24(A) is a typical example of a production steel case, roll crimped to a standard TP projectile with a brass button inserted into the primer cavity and retained by a ring stake. This sample is marked "20 mm Dummy for Gun MK-12." The case is dated 1953. Figure 24(B) is an M90-series dummy which utilizes a steel case, roll crimped and spot welded to the projectile in six places. It utilizes a very realistic simulation of an electric primer, ring staked in place. It appears to be finished with a satin chrome plate. The case is dated 1954; the projectile is dated 1953. Figure 24(C) is an unusual looking but not uncommon dummy made by crimping the M54E2 high pressure test projectile into a a brass case. A brass button simulates the primer and is held in place with a three-point stake. The entire assembly appears to have been finished with a cadmium plate and later painted blue with the word "dummy" stenciled in black. The paint was probably applied by some organization at their option. The projectile is dated 1957. In this as well as the next three samples, and other cases not illustrated, the projectile may have been soldered, brazed, or bonded to the projectile. Figures 24(D) and 24(E) are very similar and tend to point out many of the minor variations seen in 20 mm dummies. Both have steel cases, brass buttons for primers with three-point stakes, and a solid molded-in-place plaster or plastic case filler. Figure 24(D) appears to be cadmium-plated and has the designation "TG Dummy

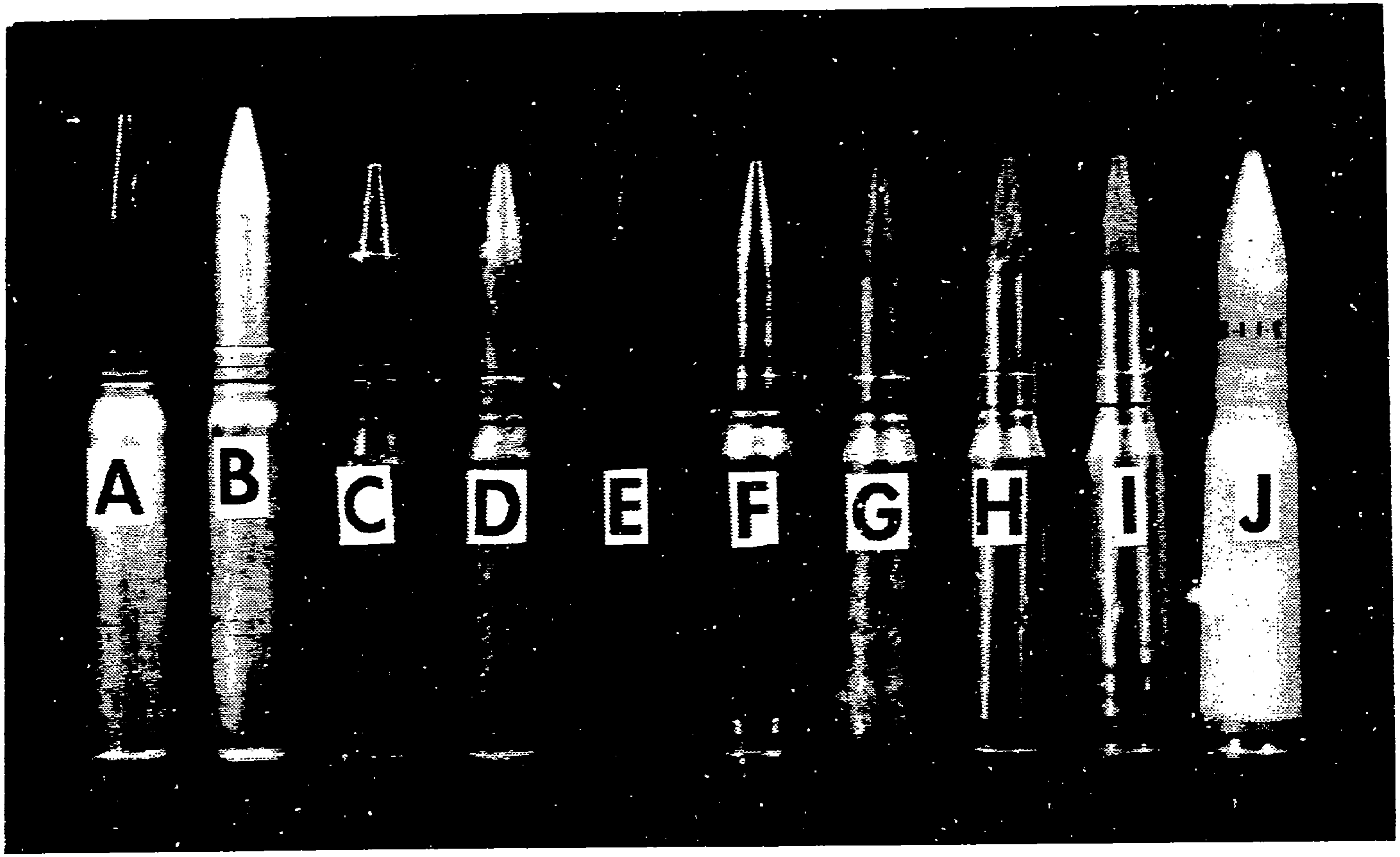


Figure 24. 20 mm Dummy Rounds
A. For MK12 Gun (1953), B. M90 Type, Spotwelded (1953), C. M54E2 (1957), D. TC Dummy 20M51E8, E. M51E8 (M51A1), F. Unidentified M50 Type, G. Steel/Aluminum with Spring Base, H. Steel/Aluminum 2nd Type, I. Steel/Aluminum Hollow Base, J. Steel/Plastic (1981)

20M51E8" and the date 1960 on the rotating band. Figure 24(E), on the other hand, has a parkerized case finish, and the projectile is painted blue. The stencil on the projectile is similar to that on Figure 24(D). The rotating band is not marked, but the shell body is stamped M51A1. No date shows. Figure 24(F) is yet another variation with no markings whatsoever. The projectile and rotating band appear to be machined integrally from steel. The case is steel and unusual in that it does not have a primer pocket. It is ballasted. Figure 24(F) is one of the first purpose fabricated dummies. Made of aluminum and steel, it was built to simulate M50-series weight and balance. It was designed to have long life when used to dynamically check out M61 guns and feed systems during manufacture, installation, and maintenance. It has a spring-loaded base plate which simulates "crush up" during ramming of standard ammunition. This round has obviously been used extensively and its major fault is apparent; the aluminum body in the vicinity of the extractor groove is significantly chewed up. This round is undated. Figure 24(H) has an obvious kinship to Figure 24(G), its only significant difference being that the junction between steel and aluminum has been moved forward to prevent the extractor from chewing up the forward edge of the extractor groove. Figure 24(I) appears to be identical to Figure 24(H). It is, except for the base. Both Figures 24(G) and (H) have perfectly flat steel bases, whereas the entire base of Figure 24(I) is concave, being recessed about 0.050 inch in the center. None of these steel/aluminum spring-loaded rounds are dated. Finally, Figure 24(J) illustrates the latest form of durable dummies. It has a steel base and a steel core which provide correct weight and balance. The base has a 3/8 inch by 0.050 inch dimple in the center to clear firing pins. The remainder of the round is a tough, durable, injection molded plastic which can stand almost limitless cycling through gun and feed systems. For maintenance and training on the system, it is perhaps the ultimate. This type, as well as the steel/aluminum composites have another advantage; they do not really look like 20 mm ammunition, so they are not nearly so apt to get stolen and given to girl friends and kid brothers. You do not see them in pawn shops and fleamarkets or decorating bars. A higher percentage stays in service. Also they, by their appearance, do not worry safety officers, wherever they may show up.

In summary, there are many kinds of dummy ammunition, and it is used for many purposes. In the beginning, a solid machined three-dimensional model will always be made and it will be useful. Also, there will always be a need for a certain number of dummies made of assembled inert components for display and educational purposes. When it comes to durable dummies, however, for manufacturing checkout, installation, service, training, ballast, etc., of gun and feed systems, the 20 mm M50-series has, over the past thirty years, gone through over a dozen configurations to reach a final excellent design. Any new system would be well advised to skip the intermediate forms and start with the plastic steel composite. In fact, this is exactly what the Armament Laboratory recommended to the A-10 SPO for the GAU-8 gun about ten years ago. They did not accept the advice; SPO's have a bad habit of not listening to good advice from experienced people.

SECTION XI

CASELESS AMMUNITION

The terms "caseless ammunition," "combustible case ammunition," and "consumable case ammunition" have each been given discrete meanings. Caseless ammunition infers a homogeneous molded propellant grain attached to a projectile with a primer inserted somewhere in its surface. Figure 25 illustrates four typical examples, from left to right: a Hercules 20 mm round from 1968, Frankford Arsenal 7.62 and 5.56 mm rounds of about the same date, all three with base primers, and a German 4.52 mm round of about 1974 with the primer visible on the side. Combustible case ammunition infers a case of some energy-producing material, typically felted nitrocellulose fibers, used in place of a conventional case. Consumable case ammunition infers a case of some material which burns or sublimes during the combustion cycle but contributes zero or negative energy. Although these distinctions do exist, all three types share most of their theoretical advantages and shortcomings, and present much the same problems to the gun and ammunition designer. All three types are frequently referred to as "caseless ammunition" and the distinction ignored.

In an article entitled "Airborne Guns and Rockets", published in the March-April 1973 issue of Ordnance magazine, this author wrote:

> "A word about caseless systems is in order, Cases serve many purposes; they seal the chamber, protect propellant from contamination, serve as flame barriers, accept and transmit handling loads, serve as heat sinks, etc. In caseless systems, other provisions must be made to serve these functions. At present this requires somewhat complex mechanization."

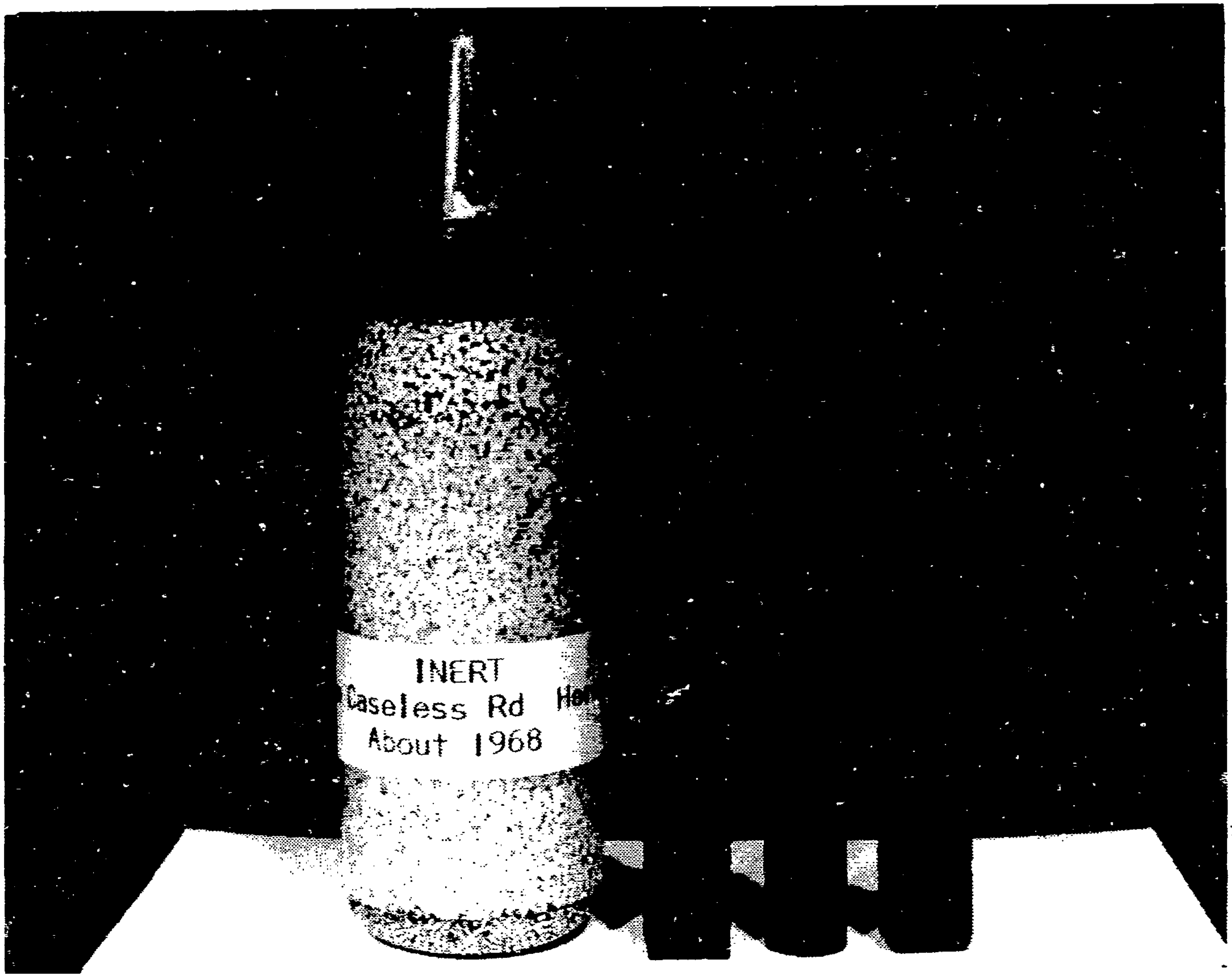


Figure 25. Typical Caseless Rounds
L to R, Hercules 20 mm, Frankford Arsenal 7.62 mm, Frankford Arsenal 5.56 mm, German 4.52 mm

"Such complexity is warranted when - and only when - weight and volume are sufficiently critical, as in air superiority aircraft. Once we develop compact lightweight plastic cases and weapons to handle them we should expect them to replace caseless ammunition as well as the metallic cased variety."

At the time this was written, we were working on the development of the 25 mm GAU-7 caseless (or more precisely, combustible case) gun system for the F-15 air superiority fighter. As it turned out, vulnerability to fire propagation in the ammunition bay caused a requirement to encase the round in a flame-retardant sheath which was stripped off prior to the round entering the gun, in effect, a "case" which only served part of the functions of a case. The funding and manpower required to develop this entirely new technology was taken from ammunition development; consequently, the problems of atmospheric humidity and inconsistent interior ballistics were not solved in time to get the GAU-7 gun on the F-15 aircraft and the program was cancelled.

It is the opinion of this author today that there are probably no circumstances where caseless ammunition makes sense.

SECTION XII

TELESCOPED AMMUNITION AND TELESCOPED CASELESS AMMUNITION

Telescoped ammunition, as we know it today, is credited to Bill Smith of the Armament Laboratory at Wright Air Development Center in 1954. Figure 26(A) is reputed to be one of the first models, typical of the Air Force patent drawings. (This particular model is missing a screw-in aluminum base plug which housed the primer.) This early model contains or makes provision for all of the essential elements of a successful telescoped round, which may be described as follows. The projectile is seated into a cylinder of base diameter and would be crimped or staked in place. The section behind the projectile contains a propellant charge which is communicated to the primer through the flash hole (not shown). Once the primer is fired, it ignites this charge which accelerates the projectile to a few hundred feet per second while it is traveling the 5/8 inch or so to release the flame to the main charge. The main charge, in this case granular propellant, is located in the annular volume between the outer case and the projectile/inner sleeve. The projectile is guided in this initial motion by a "consumable" inner sleeve, which in this model appears to be cloth-reinforced phenolic. After the projectile leaves the base cylinder, the flame enters the propellant zone through a 1/8-inch gap between the sleeve and base cylinder. The projectile, moving rapidly, enters the barrel breech and seals it before sufficient pressure rise occurs in the propellant bed to collapse the sleeve and blow by in front of the projectile. The full charge now ignites; the sleeve is crushed and burned and the projectile accelerated down the bore. From the instant of firing, the base is forced rearward against a standing breech, and the base flange is forced outward against the case and, in turn, the cylindrical chamber wall. As the pressure in the propellant bed rises, the forward seal is likewise forced forward against the base of the barrel and outward against the case and chamber. Here we see one of the requirements of telescoped ammunition and guns: some provision must be made to seal the chamber at both ends. This particular configuration is designed for what is known as a lateral split breech gun. In this mechanization the round is inserted between the barrel and a standing breech, and two short cylinders are then moved over the case from front and rear, leaving another joint to be sealed, this one being at the middle of the case and accounting for the internal and external belts or seals on this model. These central rings were also the location of links and the transmission of handling loads. The projectile is the typical 3200-grain 30 mm from the T204 round for the T121 gun.

This ammunition concept and guns to handle it were worked on for two or three years by Pachmayr Corporation, American Machine and Foundry, and Armour Research Foundation. The Armour Research Foundation concept was a combustible case design utilizing cotton gauze and potassium perchlorate as major constituents of the case. Many single shots and several short bursts were fired "demonstrating the feasibility" of telescoped caseless ammunition. The program was terminated with the decline of interest in aircraft guns around 1957.

Figure 26(B) is another type of telescoped round also developed during the mid-1950's, one of several designs proposed for the T154 gun design requirement. In this instance, done by Winchester, the case is also the chamber, consisting of an aluminum tube and high density filament wound glass fiber outer layer. The glass fiber wrap had a design strength of 300,000 psi and contained the chamber pressure. Sealing and function of this round are

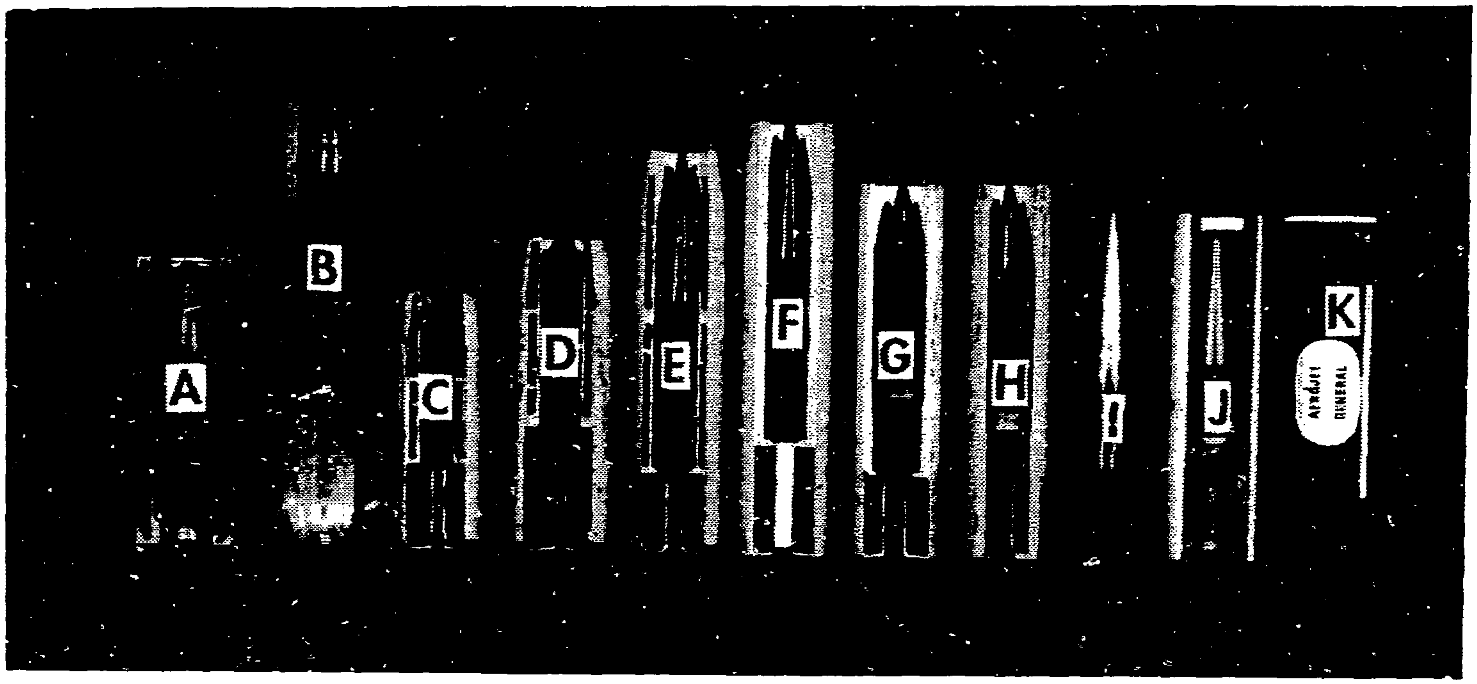


Figure 26. Telescoped Ammunition
A. First Telescoped Round (1954), B. Winchester Case/Chamber, C. IITRI 20 mm Combustible Cartridge, D. IITRI 25 mm Combustible Cartridge, E. IITRI 25 mm GAU-7 Proposal (1968), F. IITRI GAU-7 Phase I (1968), G. Philco-Ford/IITRI GAU-7 Phase II (1969), I. GE/Hercules GAU-7 Phase II (1969), J. GE/Hercules GAU-7 Phase III (1970), K. Aerojet GAU-7 Proposal (1970)

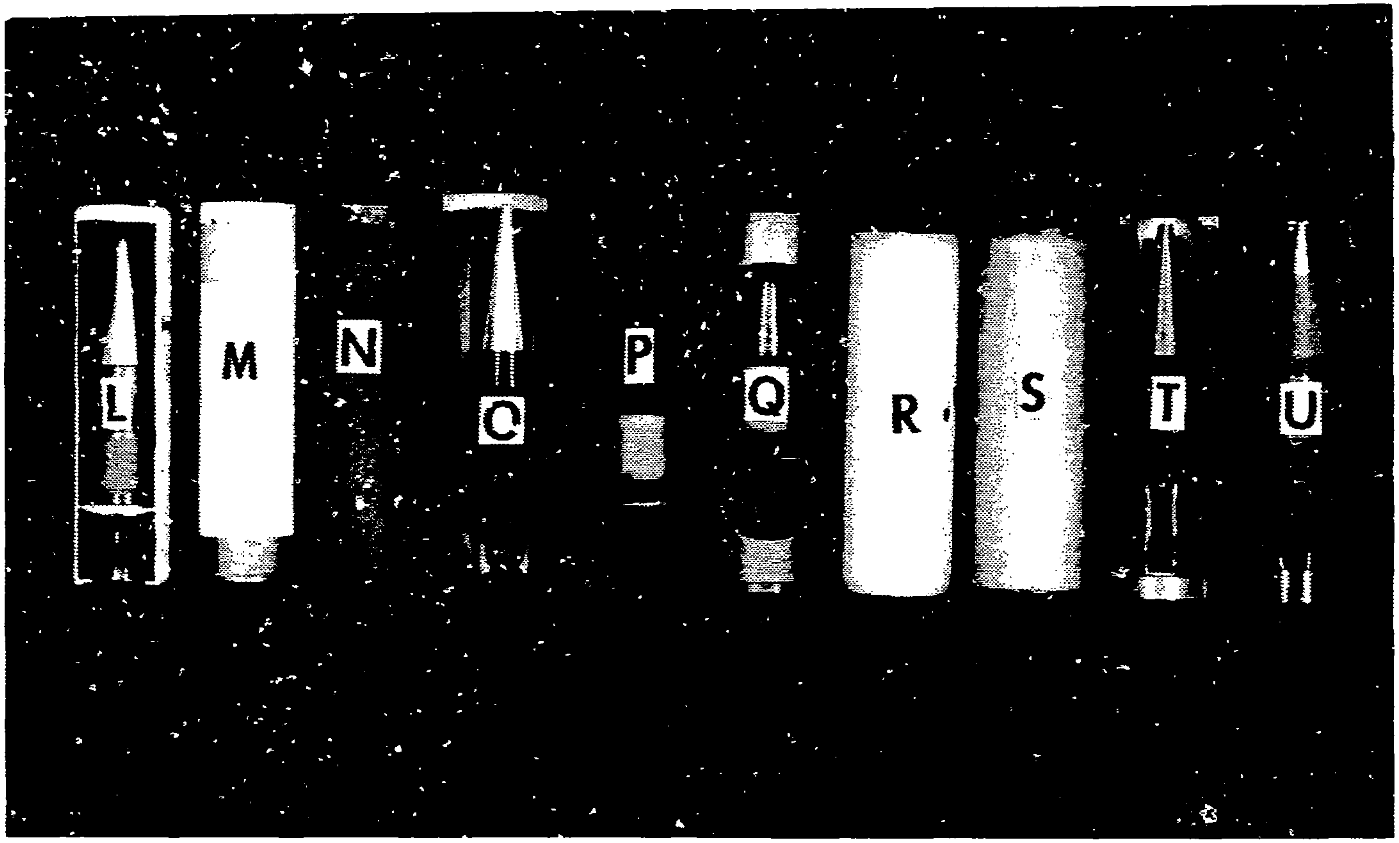


Figure 26. (Continued)
L. Ford/Brunswick GAU-7 (1972), M. Cased GAU-7 (mid-70's), N. Cased GAU-7 (mid-70's), O. AMCAWS-30 (mid-70's), P. Ford Control Tube Round (1976), Q. Ford High Performance Control Tube Round (1977), R. Plastic Case (late 70's), S. Plastic Case with Metal Seals (late 70's), T. Control Tube, Plastic Case (early 80's), U. Control Tube, Split Case

obvious from inspection. The projectile is the typical T154 specification 4900-grain 30 mm.

Figures 26(C) and (D) are Illinois Institute of Technology Research Institute (IITRI), formerly Armour Research Foundation (ARF) "combustible cartridges." They were built by IITRI during the mid-1960's to capitalize on the resurgence of DOD interest in guns and their previous experience with the combustible case T154. As a matter of fact, it was the earlier success and current technology at ARF/IITRI that encouraged the Air Force to embark on the GAU-7 gun program. Figure 26(E) is also an IITRI round, dated 1968, and designed specifically for the GAU-7 program whose specification inferred a 3000-grain 25 mm shell at 4000-fps muzzle velocity. These three rounds (Figures 26(C), (D), and (E)) are obviously similar featuring cases and structural components fabricated from resin hardened felted nitrocellulose fibers (guncotton). The voids are filled with conventional loose propellant. Figure 26(F) is a later evolution, also dated 1968, which was proposed for the GAU-7 program. Note that much of the loose granular propellant has been replaced by more felted guncotton. Undeterred guncotton, of course, burns much too rapidly for use in guns, but in this application it was lanned to utilize the deterrent properties of the resin used to stiffen the felt to control combustion rate. Figures 26(G) and (H) are subsequent designs each bearing the designation "Philco-Ford/IITRI caseless round." They are GAU-7 Phase I rounds dated 1969.

Competing with Ford/IITRI team for the GAU-7 program were General Electric/Hercules. Figure 26(I) is the Phase I General Electric/Hercules design as of 1969. This is a true caseless round consisting of a deep cup of bonded conventional propellant with a small charge of fast burning conventional propellent to eject the projectile prior to the breakup and ignition of the main charge. Note that this projectile is unique in that the rotating band is at the junction of the ogive and the cylindrical body and appears as an oversize ogive. The final evolution of the General Electric/Hercules design is shown in Figure 26(J). This dummy is not a very realistic simulation of the real round, but it does show that by 1970 General Electric/Hercules had reverted to a more conventional projectile and recognized the need to close the nose and, in this case, with a styrofoam disc. Not clearly shown here, but remembered by the author, is that several protective outside surface coatings had been tried by this time and were considered essential for moisture protection. A sprayed-on rubberlike film was a common configuration.

Throughout the GAU-7 program, the Air Force technical people were never fully convinced that the ammunition development was firmly inhand. The prime contractors were encouraged, and several subcontracts were awarded, to pursue alternate approaches. One such study conducted by Aerojet is shown in Figure 26(K). In this instance, an attempt was made to capitalize on rocket technology. The entire hollow cylindrical propellant charge was molded of fast burning rocket propellant which had 208 core holes running axially through the grain. The function sequence was that, when the primer fired, it ignited a booster charge which propelled the projectile out of the case and into the barrel. This action broke a frangible front cover, exposing the core holes which were doped with a rocket igniter. After the projectile passed out of the grain, the booster propellant gasses ignited the grain which burned simultaneously from all core holes. It worked with some degree of success; however, it was deemed impractical since the fire issuing forth from the cores impinged on the breech face of the barrel and would have caused cook-off problems if, in fact, it did not literally burn up the breech end of the barrel. This model is dated 1970.

The final form of the GAU-7 round is closely represented by Figure 26(L). Since many thousand rounds of this were made and successfully fired and a few hundred were unsatisfactorily fired, it warrants an accurate description and a discussion of what was right and what was wrong.

The outer case was felted nitrocellulose fibers. It was impregnated with resin for stiffness and combustion deterrent. The case was about 1/16 inch thick and had the appearance and feel of very stiff cardboard. The front of the round was sealed by a thin mylar or similar film held in place in this model by an "L" section ring cemented in place. In some models, the case was made slightly longer and crimped over in front, similar to a roll crimp on a paper shotgun shell. The 25 mm projectile weighed 3000 grains, had a 1-inch-wide bonded plastic rotating band, and was retained by a multi-layer combustible retainer ring of celcon or nitrocellulose snapped into a 3/32-inch wide by 3/32-inch deep retainer groove. The main propellant charge consisted of two molded propellant grains, the front charge being generally more dense and slower burning. The grains were both made by a solvent bonding process wherein a predetermined amount of solvent was added to a fixed charge of conventional granular propellant which thereupon was put into a mold and compression formed into the grain. It was then dried. Varying amounts of propellant were then machined from the outside base of the base grain as a means of charge adjustment. The primer consisted of a conventional stab primer mix in a felted guncotton body which was glued into the case. Forward of the primer was a blackpowder ignition booster sealed into an aluminized mylar moisture barrier. When the round was well made and fired under the right conditions, it behaved well giving a muzzle velocity of about 4000 fps, an acceptable and reproducible action time, and a chamber pressure of 60,000 psi.

The key words in the last sentence are "well made" and "right conditions." These rounds were made by Brunswick at Sugar Grove, Virginia, and although extreme caution was exercised, the potential for process variation was great in every step of fabrication. Starting with the first step of felting the case, which is essentially a batch process and by definition varies from the first to the last case drawn in each batch, and ending with the assembly which consisted of hand assembly and glueing components together, each step had the potential for variations. After the rounds were assembled, they faced their biggest problem: variations in atmospheric conditions. Although the rounds behaved fairly well at Ford's San Juan Capistrano Range in California, the exposure of the round to only a few hours of the normal Eglin Air Force Base, Florida, atmosphere rendered them completely unpredictable and unacceptable. In looking back, it can be said that it was not unexpected that climatic variations had an adverse effect on the ballistics of caseless telescoped ammunition; what was unexpected was the magnitude of the effect.

Based on the long and expensive experience of the GAU-7, and recognizing the many important functions served by a cartridge case, it is this author's opinion that caseless ammunition in any form is probably not a worthwhile goal. Reducing the weight, cost, and complexity of a case is, however, quite appropriate.

By the time the GAU-7 program was terminated, everyone had realized that the user (Tactical Air Command (TAC), in this case) would probably never tolerate the vulnerability of caseless ammunition and, in fact, in this instance caused us to wrap up each caseless round in a fireproof disposable plastic case until the time it was fed into the gun. If we had to case the round any way for fire protection, why not leave the case in place all the way through the gun and solve some other problems such as fore and aft chamber seals and firing pin seals? Figures 26(M) and (N) are fired plastic cases demonstrating this concept. Figure 26(M) is believed to be a General Electric Company attempt using Lexan for the case with an aluminum base ring for corner reinforcement. Figure 26(N) is believed to be a Ford design using what appears to be 41% glass-filled rylon. Both appeared to have worked reasonably well, yet both exhibit the typical failure associated with cylindrical cases of this type: under firing, they must expand both radially and in length, which invariably causes failures at the base corner, at the front corner, or both, unless some design provision is made to accommodate the axial motion with a slip seal. Such a development path was reasonable; however, at this time, the Air Force was spending all their available R&D funds on 30 mm GAU-8 and improved 20 mm ammunition, so the idea was not pursued.

Figure 26(O) is the odd one in this series, being the only one of Army origin; all the others were either Air Force or IR&D for, or related to, Air Force application. This round is for the Army Materiel Command Automatic Weapons System 30 mm gun (AMCAWS-30). It is interesting here for several reasons. First, note the extreme similarity between this and the original telescoped round (Figure 26(A)) of 1954; perhaps this is not too unexpected since Bill Smith was at this time working for the Army Materiel Command. Second, it is a tapered case, smaller at the base and designed for front loading; all other cases are essentially cylindrical. Third, and most significant, it was designed to operate in a "stop mode" whereas none of the others were deliberately made to fire that way. An explanation is required.

One of the reasons why telescoped ammunition is so volume efficient is that is uses the volume occupied by the projectile twice: once to store the projectile, and later for combustion chamber or "boiler room" to burn the propellent. One of the most fundamental problems in developing satisfactory telescoped ammunition is devising a method of getting the projectile part way into the barrel bore before igniting the main propellant charge, so as to utilize the volume for boiler room and to prevent blowby of propellant and gasses ahead of the projectile. Once the projectile has sealed the bore, it is desirable to instantaneously ignite the entire propellant charge so that a normal ballistic cycle ensues. This is the problem that was never satisfactorily solved for the GAU-7. It could be solved for some conditions, but at extremes of temperature, humidity, etc., it was inconsistent, resulting in wide variations in velocity, pressure, and action time. The Army in the AMCAWS-30 proposed to approach the problem by only giving the projectile enough initial impulse from the primer/booster to propel the projectile into the forcing cone where it would stop. The main charge could now smoulder a few milliseconds until it had ignited sufficiently and developed enough pressure to set the projectile in motion again. Such behavior had been observed much earlier in telescoped ammunition and was generally avoided because it resulted in long and uncertain action times, which were unacceptable for high rate externally powered guns. The Army, however, was only interested in low rate self-powered guns, so the idea of exploiting the "stop mode" interior ballistic cycle appeared promising. Unfortunately, it did not work. The problem of getting the projectile to hit the forcing cone and stop in a consistent manner turned out to be as difficult as any other approach and the idea was abandoned. This work was done in the mid-1970's.

About this time, the Air Force set about to solve the interior ballistics problems of telescoped ammunition. We solicited industry for its ideas and funded two contracts. Since the Air Force had surplus barrels, projectiles, and breeches from the GAU-7 program, it was decided to use them insofar as possible to reduce costs. Very few other restrictions were placed on the contractors. They were not to concern themselves with gun design or compatibility with known designs. They were not to worry about extraction and ejection. They were not even to worry about muzzle debris at this time. They were quite simply to develop a telescoped round design which once and for all demonstrated that the telescoped concept was valid and that it could be made to provide satisfactory interior ballistics with short and reproducible action times over the full military specification temperature range.

The contract that produced the best results was with Ford Aerospace and is known today as the control tube concept. Interestingly enough, the solution to the problem turned out to be functionally very similar to Bill Smith's original design, the value of which had really not been appreciated for two decades. Figure 26(P) illustrates the round that evolved. It utilized a steel case and machined steel end caps. (After firing, it had to be driven out of the chamber.) A "control tube", a rather complex and expensive steel machining, was screwed into the base. This control tube housed the primer, a piston located over a booster charge, and three radially oriented ignition charges. It also held the base of the projectile in place and retained it with a plastic snap ring. A cloth-reinforced phenolic tube surrounded the projectile, and the annular space between the case and all these central components was filled with loose propellant. The functional sequence is as follows.

Once the primer is fired, it ignites the booster charge. This pushes against a hollow piston which, in turn, pushes against the projectile. Once sufficient force has been generated to shear the plastic retaining ring, the piston and, in turn, the projectile are accelerated forward by this relatively high pressure booster charge. After about 5/8 inch of travel, the piston and projectile have reached a velocity of a few hundred feet per second, and the piston uncovers three ports communicating radially to the ignition charges. These charges ignite and, in turn, begin to ignite the main propellant charge. The projectile, now moving rapidly, enters the barrel and seals it off before sufficient pressure is generated in the propellant bed and transmitted forward to cause blowby. The propellant now continues to burn, collapsing the phenolic tube, and blowing it and the piston down bore after the projectile. The entire case volume is available as "boiler room," the projectile is accelerated in a normal manner, and the piston and phenolic are ejected as muzzle debris. The round functioned well ballistically throughout the required temperature range; pressure, velocity, and action time were reasonable and reproducible. The round was, of course, not usable since it could not be extracted or ejected from its chamber, and it produced unacceptable muzzle debris, but it had served its purpose. It proved telescoped ammunition to be fully ballistically feasible. This model was made in 1976.

The Air Force at this time was again trying to define the optimum gun system for future air superiority fighters. Again, as usual, it was found that one of the most dominant characteristics was low time of flight, therefore high muzzle velocity. Maximum velocity infers maximum charge-to-mass ratios. Maximum charge for a given volume begs for consolidated molded propellant. A thin-wall lightweight projectile is desired. It was decided to extend the previous work at Ford Aerospace to see if telescoped ammunition could be made to work with molded propellant. (It had contributed to the problems of the GAU-7.) The GAU-7 TP projectile was cut down to 2300 grains for this program. The development was successful, resulting in the model shown in Figure 26(Q). Ballistic reproducibility, although not as good as in the loose propellant round, was quite acceptable. Muzzle velocity was close to 5000 fps. The control tube was simplified and reduced in cost. The round still would not extract, and the piston still appeared as muzzle debris. This round is dated 1977.

Since the interior ballistics of telescoped ammunition appeared to be in hand, it was decided to demonstrate extraction and eliminate muzzle debris. The debris problem was simple: use a combustible tube rather than cloth-phenolic and attach the piston to the base of the projectile. The biggest problem appeared to be to build a case which would expand in both length and diameter during firing yet relax sufficiently to be easily extractable. The first thing tried was to improve upon the plastic case of Figure 26(N). This case, Figure 26(R), was only partially successful. It failed under firing loads especially at cold temperatures. The failures were mostly at the base and around the front seal. Steel bases and seals were added which improved matters considerably, Figure 26(S). The seals were later changed to fit outside the plastic rather than inside, and the performance became generally satisfactory although occasional failures still occurred at cold temperature in the dynamic test fixture. Figure 26(T) illustrates a loose propellant round in this configuration.

The steel cases tried earlier did not fail or leak; they simply expanded plastically during firing and became tight in the chamber. A Ford Aerospace engineer proposed a split steel tube with a lap or scarf joint which would expand easily under firing loads and also relax after firing to permit it to extract. It worked. Figure 26(U) is of this type. Also, note that Figure 26(T) is a loose propellant round, and Figure 26(U) is a compacted molded grain round. Both types have been made in both plastic and steel cases. Both are presently satisfactory from a ballistic standpoint, especially in the steel case. The loose propellant round has a muzzle velocity of 4,500 fps; the molded grain round has a muzzle velocity of 5,000 fps. They are strong candidates for future high performance gun systems.

SECTION XIII

GAU-7 PROJECTILES

The GAU-7 program began in 1968 and ran a little over five years. It was notable as the first serious attempt to develop, and put into the inventory, telescoped caseless ammunition. The previous section gives a general overview of the ammunition. During this time hundreds of variations were made in the rounds in order to achieve the desired characteristics. In the process, many variations of the projectile were tried, nineteen of which are illustrated here. These are not all that were tried, but they are a good representative sample. Two prime contractors, General Electric and Philco-Ford, worked on the program. Many ammunition subcontractors were involved including Avco, Olin, General Motors, Hercules, Honeywell, Brunswick, Aerojet, and IITRI; however, not all made projectiles. In retrospect, the actual manufacturer of all projectiles cannot be determined.

General Electric used three distinctly different projectiles and several variations during their participation in the GAU-7 program. Figures 27(A), (B), and (C) illustrate the three types; they are also identified with Phases I, II, and III of the R&D program. Hercules was prime ammunition contractor to General Electric during this period, and all three projectiles can be identified in Hercules ammunition. The first, Figure 27(A), is unusual in that the rotating band appears to be a continuation of the ogive and is totally forward of the cylindrical section. This chrome-plated demonstration model appears to be machined from a solid bar of steel; however, it is not. It only weighs 3000 grains. Drawings from the time show a steel base cup, a copper rotating band, and an aluminum nose extending into the cup almost to the base

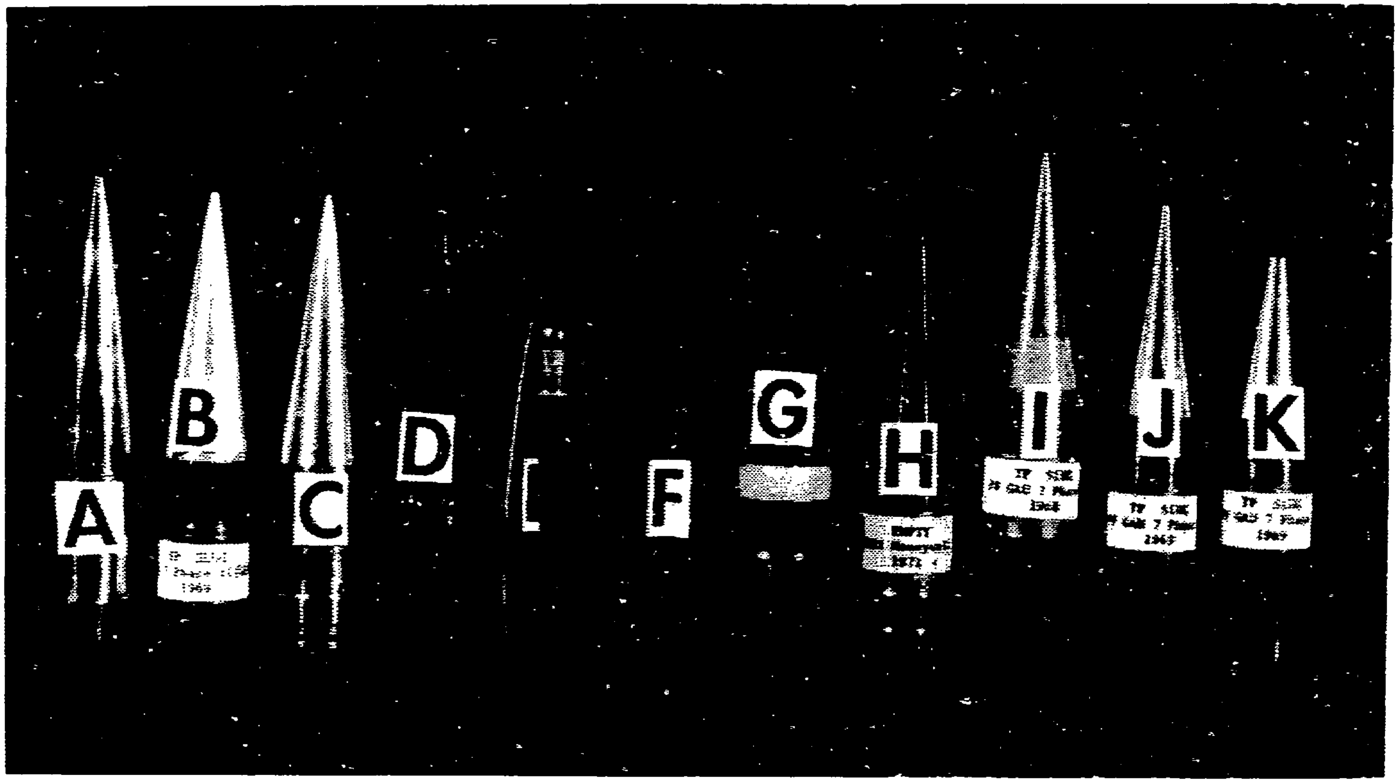


Figure 27. GAU-7 Projectiles
A. GE/Hercules Phase I (1968), B. GE/Hercules Phase II (1969), C. GE/Hercules Phase III (1971), D. Avco TP External (1971), E. Avco HEI (1971), F. Avco TP Section (1971), G. Aerojet TP (1970), H. Honeywell SAPHE (1971), I. Philco-Ford Plastic Jacket (1968), J. Philco-Ford Phase II (1969), K. Philco-Ford Phase II (1969)

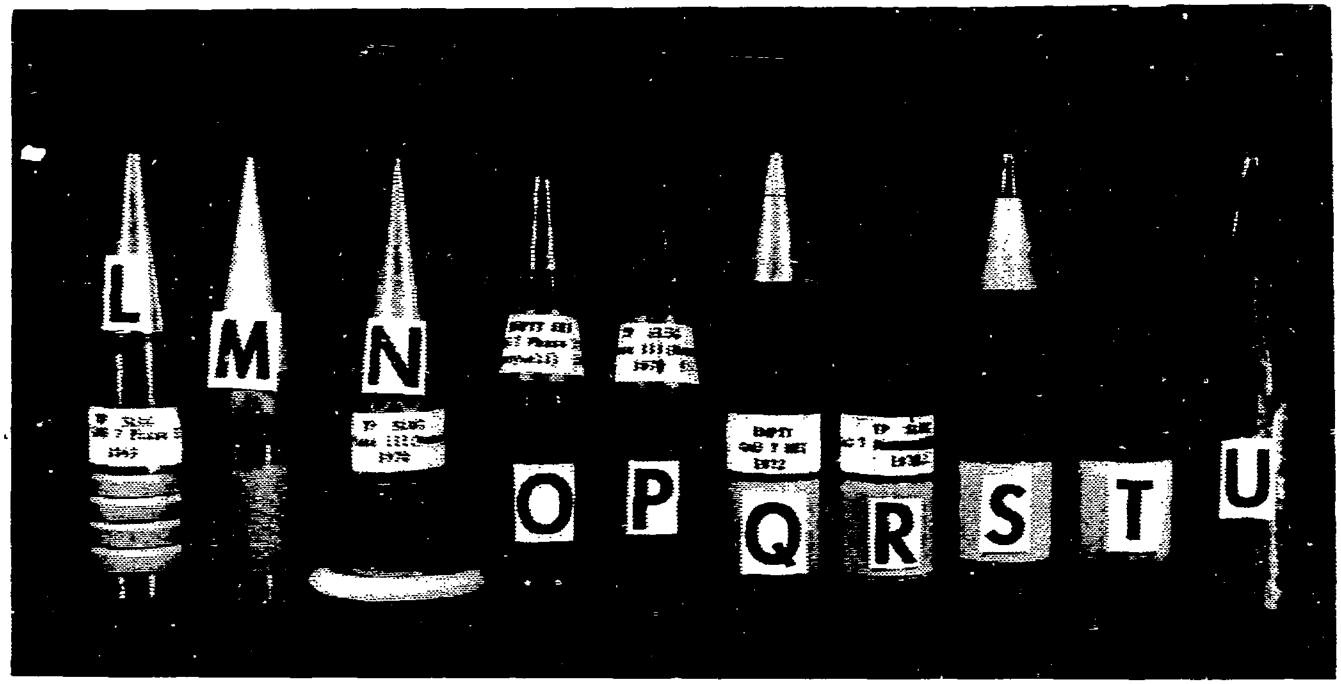


Figure 27. (Continued)
L. Philco-Ford Phase II (1969), M. PF/Honeywell Phase III (1970), N. PF/Honeywell Phase III (1970) O. Honeywell HEI (1970), P. Honeywell (1970), Q. Ford HEI (1972), R. Ford TP (1972), S. Ford HEI (1973), T. Ford TP (1973), U. Ford TP Sectioned (1973)

of the round. This projectile was only 24 mm in diameter. It was made in 1968.

Figure 27(B) is somewhat more conventional; the rotating band has been moved behind the ogive. The rotating band is a welded copper overlay. A square groove near the base is used for retention. This feature was later adopted by Ford Aerospace and remained to the end of the program. This particular projectile has been fired, as can be seen from the engraving of the rotating band. It dates from 1969.

The final configuration of General Electric projectiles is seen in Figure 27(C). It is virtually identical to the previous one except that the welded overlay band has been moved aft and narrowed slightly. The base is steel and is drilled and tapped to accept the aluminum nose. This Phase III projectile is from 1971.

During 1971, General Electric subcontracted with Avco Corporation to develop an effective HEI combat projectile and a compatible target practice round. This was done, and they are illustrated in Figures 27(D), (E), and (F). Both projectiles share the external configuration shown in Figure 27(D); a very low drag shape about 5 calibers in length with a 3-caliber ogive, 1-1/2 calibers of cylindrical body, and a 1/2 caliber boat tail. The welded overlay band is about 1/2 caliber wide.

The combat HEI version of the round is shown in section in Figure 27(E). It is a classic high capacity shell with thin walls in the forward section which thicken at the rotating band and aft in order to stand engraving and chamber pressure. The advantage of welded overlay rotating bands is apparent, not requiring an undercut which results in thicker walls. The fuze is an

M505, unmodified in function but with a new body and windscreen to provide improved aerodynamics.

Figure 27(F) is the matching target practice round in section. Essentially, it is a piece of steel tubing swaged over an aluminum core. This is believed to be the first time this construction was used for TP shot; it was later adopted by Ford Aerospace and continued to the end of the program. It is a good design, and if proper tooling is available, it is inexpensive.

The next round in the sequence, Figure 27(G), is the one used by Aerojet Corporation under subcontract to Ford Aerospace. It is important in this discussion because it has two rotating bands: a plastic one forward and a copper one aft. The aft band is, of course, conventional. The forward one was put there for two purposes: first, to serve as a guide to prevent balloting of the projectile within the cartridge body and, secondly, to seal the bore immediately upon entering. Although this is the only projectile in this series which shows an auxiliary forward band, the effect was obtained in other instances by having the band well forward, in others by the use of extremely wide bands, and in still others by making a temporary forward band by wrapping tape around the bourrelet. Of course, the tape bands were cut through by the rifling and were shed at or before muzzle exit, as was this Aerojet band, especially since it was used in gain twist rifling.

Another interesting and uncommon projectile from the GAU-7 era is the Honeywell-designed base fuzed round shown in Figure 27(H). Commonly referred to as a SAPHE round, this model is about 4-3/4 calibers in length with slightly less than 3 calibers of ogive. It has a narrow copper band and a crimp groove generally more suited to a cased round. There is a threaded joint sealed with a copper washer immediately in front of the band which permits the round to be charged, fuzed, and assembled. This model is believed to have been made in 1971.

The remainder of the sequence in Figure 27 is in chronological order and all evolved from the Ford Aerospace (then Philco-Ford) GAU-7 program. These, however, are not all of the projectiles used by Ford Aerospace; as a matter of fact, the standard Phase I design is missing. It was a simple cone cylinder configuration 5-1/2 calibers long with the cone being slightly less than one-half of the total length. It had a steel base cup about 1-3/8 inches long, with the remainder being aluminum. The rotating band was copper, about 7/32-inch wide located about 1 inch from the base. Near the end of Phase I, at the suggestion of the Air Force, some of these projectiles were coated with plastic out to band diameter. This coating prevented balloting of the projectile prior to bore entry and sealed the barrel immediately after the ogive had entered. They worked well, although the plastic always shed at muzzle exit. Figure 27(I) illustrates one of these projectiles. It was made in 1969.

During Phase II, the projectile was shortened to about 5 calibers with the cone being slightly more than half the length (Figure 27(J)). The steel base cup was 2.7 inches long, and a 0.4-inch wide electron beam welded copper rotating band was 0.8 inch from the base. At some later date, this projectile was shortened to 4-1/2 calibers by cutting off the nose, as seen in Figure 27(K). This length varied only slightly for the remainder of the program. Both of these Phase II projectiles have a groove at the base of the rotating band which was used for projectile retention.

At about this time, interest in plastic bands began to increase. Figure 27(L) is an obvious Phase II projectile which has been modified by the addition of a 1-inch-wide plastic rotating band. This band appears to be some type of filled phenolic. It is believed to have been made in 1969 or 1970.

Phase III began still using copper bands but had many variations in projectiles and bands. Figure 27(M) is typical of many bonded plastic band designs. Figure 27(N) is similar but uses a different plastic and bonding technique. It is included here for two reasons: first, to show the ring gate used to mold the band and, second, because it has, for the first time, a retainer groove machined near the base (not visible in this photograph) as in the General Electric Phase II design. This is believed to have been built by Honeywell, Inc., in 1970.

During 1971 and early 1972, Honeywell, Inc., under contract to Ford Aerospace, developed some HEI projectile configurations. Figures 27(O) and (P) are typical. They utilize the wide plastic band which later became standard, yet otherwise bear little resemblance to the two previous projectiles. The projectile in Figure 27(P) is unusual in that it weighs 4500 grains, fully 50% more than standard. It appears to be solid steel. Its purpose is unknown.

The remaining 5 illustrations in this series show both TP and HEI versions of the last two designs. As one would expect, they utilize the best features of all previous designs. After Ford Aerospace won the competition (end of Phase III), all General Electric and subcontractor data was made available to Ford Aerospace for full scale development. These shells (Figures 27(Q), (R), (S), (T), and (U)) resulted. Actually all 5 have the same shape, being 4.6 inches long with a 1.8-inch cylinder and a Von Karman ogive.

Figure 27(Q) is the 1972 version of the HEI shell. It is of rather conventional construction except for the 1 inch bonded plastic rotating band and the square cut retaining groove. The fuze is a modified M505 with a heavy brass firing pin located well forward. The mass of this pin and the distance it must travel provide a function delay against most targets. Several different fuze/body interfaces were tried to reduce fuze wipe-off at high obliquity.

Figure 27(R) is the TP version of this round. It utilizes a simplification of the construction used by Avco Corporation illustrated in Figure 27(F). It is also from 1972.

Figures 27(S), (T), and (U) are the final configurations of the GAU-7 projectiles, identified by now as HEI, PJU-2/B and TP, PJU-3/B. The rotating band has moved forward slightly from the previous design. The fuze interface has been settled; it is conventional M505. Figure 27(S) is the HEI; Figure 27(T) is the TP. Figure 27(U) shows the simple design used for the TP - a piece of steel tubing, reamed slightly at the front, swaged down over a piece of soft aluminum, then finish machined and banded. These items are dated 1973.

SECTION XIV

THIN-WALL STEEL CASES

Brass has been the material of choice for cartridge cases for well over 100 years. It is so common that any reference book on metals will list "cartridge brass" as such, being 70% copper and 30% zinc. Even today there is no material that is functionally better. Anything else is generally considered a substitute.

This is not to say that brass is the perfect case material; it is not. It is heavy, relatively costly, and in times of war it becomes a critical supply problem. Substitute steel cases have been used with varying degrees of success since World War I. Aluminum cases have been tried since the turn of the century, with some success in low pressure rounds. The GAU-8 is the first fully successful high pressure aluminum case. As discussed in Section VI, this was developed for reasons of weight.

A typical aluminum GAU-8 case weighs 2200 grains (143 gm, 0.315 lb) made of cartridge aluminum with a density of 2.75 gm/cc. It occupies about 3.12 cubic inches. If it were made of brass to the same dimensions, it would weigh 6838 grains (444 gm, 0.977 lb); if it were made of steel, it would weigh 6286 grains (408 gm, 0.896 lb). For the A-10 aircraft with a design load of 1350 rounds, the aluminum case saves 893 lb over brass or 787 lb over steel. It is easy to see why aluminum was chosen. These figures, of course, assume a simple substitution of one metal for the other with the same case dimensions, which is, more or less, the way it is generally done.

Frank Marquardt, while working for the Navy in the late 1960's, spent considerable time trying to promote redesign of the 20 mm steel case to take advantage of the strength of steel by building thin-wall steel cases and increasing chamber volume by 10% to 15%. This idea was revived in the late 1970's on the GAU-8. It was reasoned that steel could be made three times as strong as aluminum, consequently only 1/3 as much should be required. Since steel is less than three times as heavy as aluminum, it was postulated that it might be feasible to build a steel case as light as an aluminum one, and in the GAU-8 gain as much as 2 cubic inches of chamber volume as well. This was a goal which no one expected to achieve; however, the objective of our program was to derive the thinnest, lightest steel case possible. Also, since steel is much cheaper than aluminum, a cost saving was expected to result. This was tried under contract to Amron Corporation.

Figure 28 illustrates a cross section of the production aluminum case and the first two design iterations of a thin-wall steel case. Design of cartridge cases, in spite of modern computer-aided design techniques, still involves a lot of art and a good bit of cut-and-try. Not unexpectedly, these first two designs, which weighed about the same as aluminum (0.315 lb), did not work. They experienced case separations near the base, and the mouth was too thin to develop the required bullet pull. After several iterations a design evolved which worked in a Mann barrel, but as expected, failed when fired in the more elastic automatic gun. A few more iterations, gradually adding metal at points of failure and experimenting with finishes, produced a case at about 0.53 lb which worked and still added about 1.25 cubic inches to usable chamber volume. It could probably be made cheaper than the aluminum case, but would add 260 lb to the current 1200-round ammunition complement. (As a point of reference, a steel case for the Oerlikon 304RK from which the GAU-8 round derived weighs 0.77 lb.) This case may or may not be produced, but the technology is there if needed.

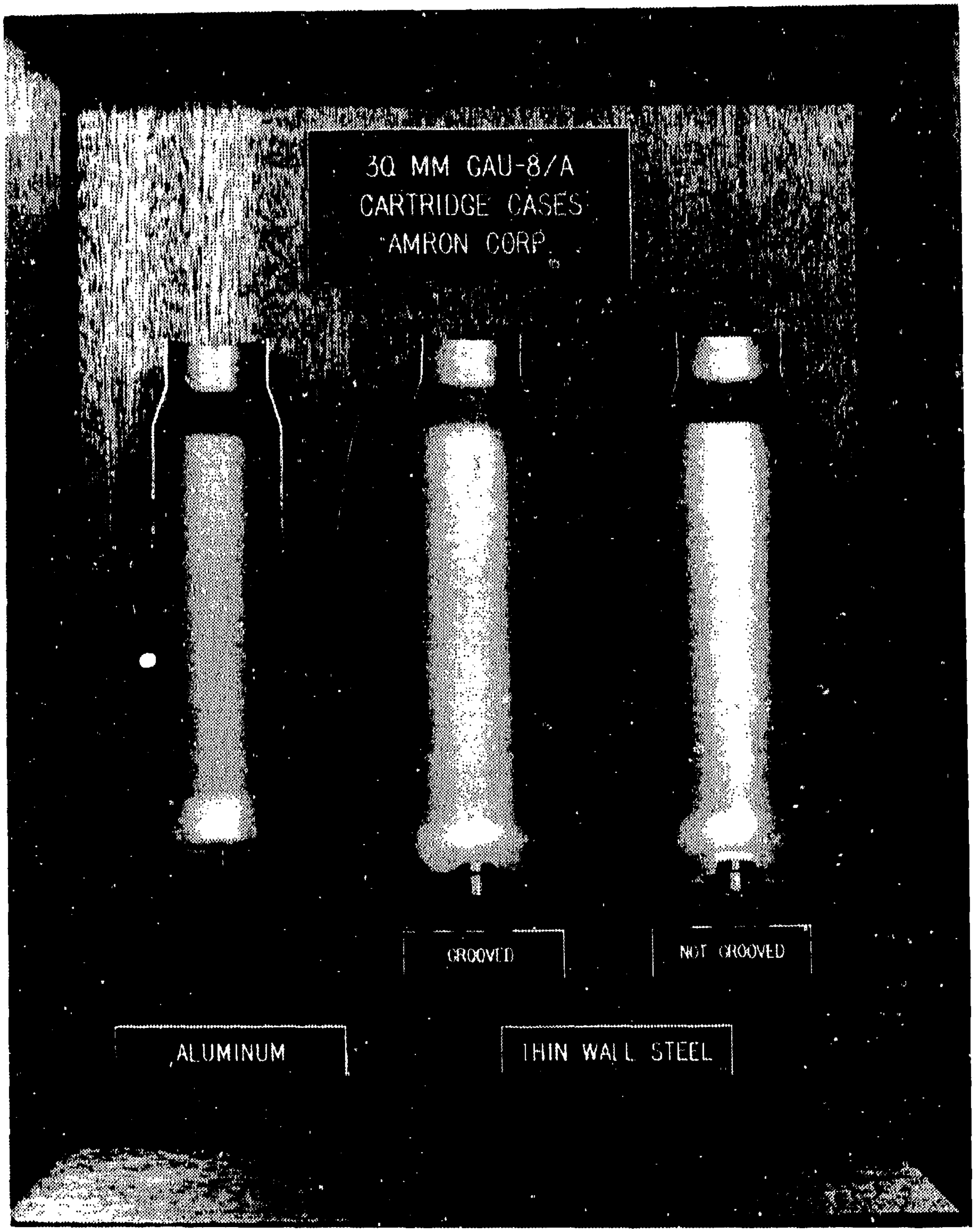


Figure 28. Thin-Wall Steel GAU-8 Cases

SECTION XV

FLECHETTES

Flechettes, a French word, means literally little arrows. The word first came into its present military meaning in World War I when the French dropped finned steel darts from airplanes as a means of strafing. The type of flechette ammunition of concern to automatic cannon caliber guns is the single flechette round which has been made in the US in recent years in virtually every caliber from 5.56 to 120 mm. As we know it today, this ammunition was derived from work done by Irwin "Winn" Barr at AAI in the early 1950's, although it also bears a relationship to the 210 and 280 mm "Rochling" or "Arrow" projectiles used by the Germans during World War II.

Flechette ammunition has two characteristics which make it interesting, both of which derive from its high sectional density. First, it is a good armor penetrator; this, of course, is true of any high length-to-diameter (L/D) ratio penetrator and occurs because of the high sustained unit pressure at the target interface, especially at high velocity. Secondly, the high sectional density reduces the effect of aerodynamic drag, enabling the flechette to retain more of its initial velocity and further enhancing penetration.

Flechette ammunition by its nature must be sabot launched. Herein lies another advantage and its major disadvantage. The advantage of sabot launch is, of course, that the projectile has a low sectional density while in the gun bore and can be easily accelerated to velocities not readily attainable with conventional shot. The disadvantage of sabots is that they must be discarded at muzzle exit, and these rapidly decelerating sabots pose an unacceptable hazard to launching aircraft. For this reason, flechette ammunition has never been used from forward-firing aircraft. It can be used on side-firing gunships.

Sabots have been made of wood, light metals, and plastic. Conventional ordnance today may use aluminum, magnesium, plastic, or a combination of these materials. In attempting to make flechette ammunition suitable for aircraft use, plastic and non-metallic composites are used. The first approach was to design the sabot such that it separated into many small particles at muzzle exit hoping these small lightweight pieces of plastic would not damage an aircraft as it flew through them. The critical question then became what would happen to a turbojet engine when this junk went through it. A test was run, and it was determined that the plastic melted and fused onto later stage compressor blades, disrupting their aerodynamic shape and causing loss of efficiency and power.

The next step was to devise a "sabot diverter" which would stop the sabots, break them up, and discharge them under the aircraft. This was done in 20 mm around 1970 and in 30 mm ten years later. These are heavy ungainly devices which must be attached to the gun, airframe, or both. They are around 95 percent efficient and realistically can allow flechette ammunition to be fired from aircraft.

Like any ammunition design problem, the design of a flechette round is a series of trade-offs. Significant trades are length-to-diameter ratio, muzzle velocity, spin rate, etc. Unfortunately, barrel rifling exit angle is usually set before the flechette round enters development and has a profound effect on the design. The ideal rifling angle would be on the order of 1/2 to 2 degrees, or a smooth bore with a short rifled "sabot stripper" at the muzzle. The 20 mm round shown in Figure 29(A) was designed for a barrel of

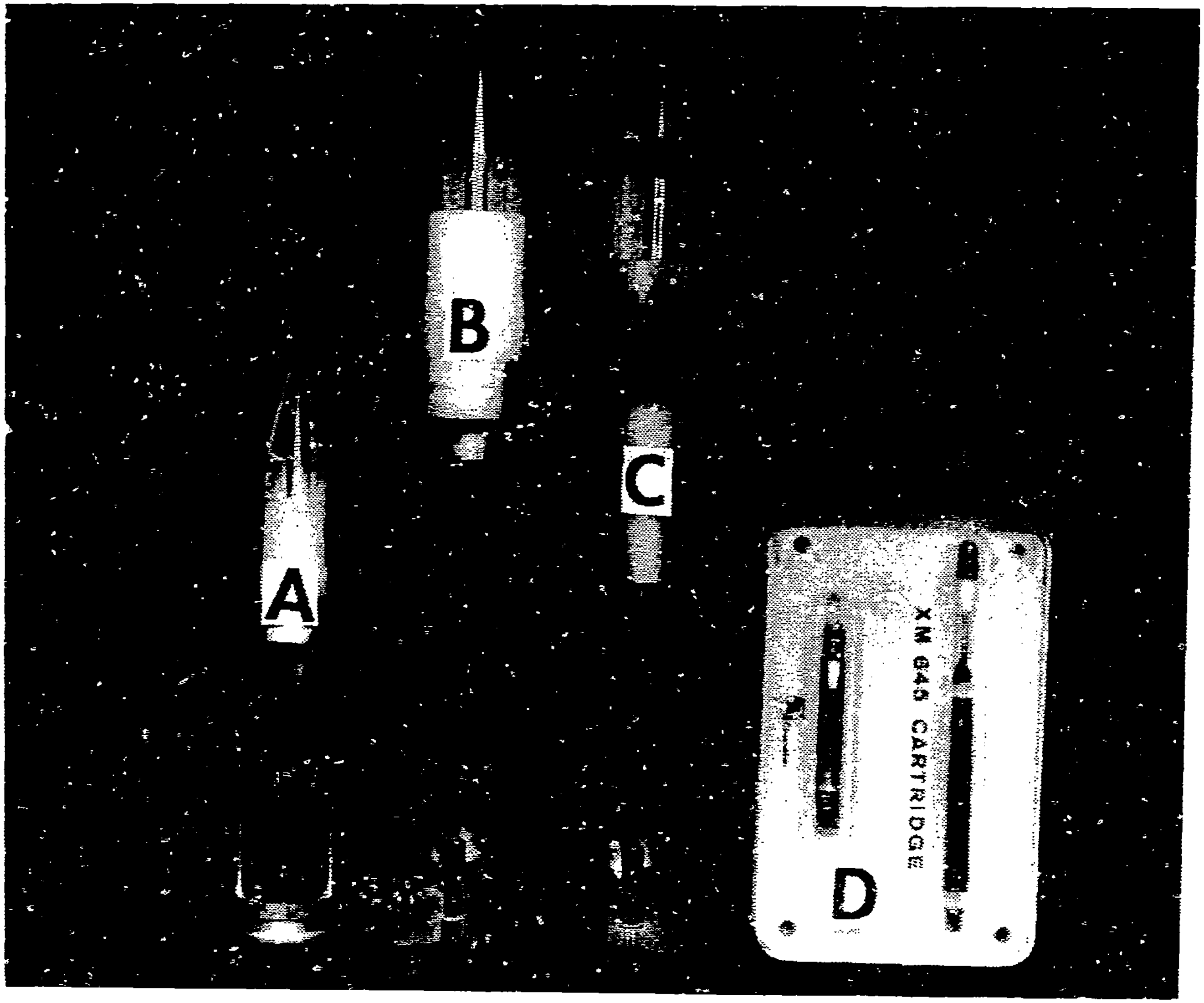


Figure 29. Typical Flechette Rounds
A. 20 mm Steel Flechette, B. 30 mm DU Flechette,
C. 30 mm DU Flechette, D. 5.56 mm Steel Flechette

slightly less than 8-degree exit angle, and has a fairly high L/D ratio steel flechette traveling at moderately high velocity. When made in uranium, the L/D had to be reduced. The 30 mm DU flechette shown in Figure 29(B) is further reduced, largely because the rifling angle is near 10 degrees and the higher spin rate, coupled with any in-bore asymmetry, causes penetrator bending.

Recognizing the relationship between spin rate and allowable rod length, a technique of using slip seals to prevent the package from spinning up to rifling rate has been devised. This works well in artillery where zero to nominal spin is acceptable; however in this application, spin must be significantly above zero in order for the sabot stripper to work but significantly below rifling angle rate to prevent bending of the relatively long DU penetrator. In other words, the seals must slip, but only so much. In order for this to work, friction must remain relatively constant over the complete range of atmospheric and ballistic conditions - usually a high risk. How well it will work remains to be seen. Figure 29(C) illustrates such a round.

All three of these designs utilize what is known as a "puller sabot." Chamber pressure acts on the tapered aft sabot section forcing it down against the penetrator, generating sufficient friction to "pull" it along as the sabot is accelerated down the bore. To illustrate part of the range of sizes through which this technique has been successful, Figure 29(D) has been included. This, as well as those shown in Figures 29(A), (B), and (C) was made by AAI and is the Army's 5.56 mm Special Purpose Individual Weapon (SPIW) round of the late 1960's and early 1970's.

SECTION XVI

ROCKET-ASSISTED PROJECTILES

Whether guns or rockets were first used as weapons depends on whose version of history one accepts. In either case, both have been around for over 600 years. The two systems are in many ways similar yet vastly different. The idea to make a gun-boosted rocket or a rocket-assisted projectile must certainly date back for centuries. The idea to combine the two technologies to utilize the advantages of both systems is appealing to the ordnance man today, especially to one who is relatively new in the field.

A little closer examination of the situation and some simple calculations will show that, if starting at the beginning with a requirement to deliver a given payload to a given target with a given set of terminal conditions, one can always design either a gun or a rocket, or in some cases one of each which will do the job better, and certainly at less cost than the hybrid. Also one must consider that in combining two technologies in order to yield the advantages of both systems, he may also harvest the disadvantages of both. That is not to say there is never justification for the hybrids. There may be cases where they are useful.

First, let's differentiate between a gun-boosted rocket and a rocket-assisted projectile. A gun-boosted rocket is generally defined as being something more than a closed breech rocket launcher, wherein a relatively small amount of gun propellant is burned at low pressure to give a boost of a few hundred feet per second to a rocket. The pressure is held low so that the rocket does not have to be made excessively strong and can maintain a good mass fraction. The disadvantages of such a device are the launcher is heavy (relative to an open tube), the rocket must be stronger (heavier) in order to sustain the boost, and the system is more complex and usually more expensive than a conventional rocket, and the launcher is now subject to recoil and a recoil system must generally be provided. In most all cases, a straight rocket is a better solution.

A rocket-assisted projectile (RAP) is generally an afterthought add-on to a conventional gun-fired projectile and usually comes about because someone is not satisfied with an existing gun and wishes to extend either its range or striking velocity. The most common application is in artillery, an application which the Germans practiced in World War II and the US Army has since utilized. The application generally consists of utilizing one-half to two-thirds of the shell volume for a rocket motor. The net result is a longer range with a much smaller payload with increased shell complexity and cost. As a typical example, the Germans extended the range of the 28 cm K5 gun from 68,000 yards to 94,600 yards with a RAP shell, a quite impressive increase. It should also be noted, however, that the sabot-launched arrow shell fired from the same gun had a range of 160,000 yards.

After the GAU-8 program got underway, some people began to realize that the time would come when increased armor penetration capability and longer range would be desirable. As a growth potential for the GAU-8, we decided to investigate RAP rounds. According to our usual procedure, we wrote up a statement of work and went out to industry for proposals. None of the proposals we received were exactly what we wanted, but Thiokol submitted the best one, and we contracted with them, thinking we could guide or direct them around to doing what we wanted done. We couldn't, or at least we didn't.

The Thiokol proposal was for a tandem projectile with the penetrator in front and a rocket motor behind. We wanted a coaxial design with a long rod penetrator surrounded by a rocket grain. When the contract was completed, we had the tandem round shown in Figure 30(A). Thiokol was more concerned with the problem of designing a motor to withstand the 80,000 g's of axial acceleration, 100,000 rpm spin rate and 60,000 psi chamber pressure of the gun launch than in developing what we wanted. The round shown has a centilevered tungsten alloy penetrator, a phenolic ogive, a steel body, and a central nozzle. It worked in a Mann barrel. The motor survived and functioned. The net result was a complex expensive high technology round that was just about as good a penetrator as the standard GAU-8. It was never fired with a DU penetrator in a hot or worn barrel. If it had been, the phenolic ogive would probably have been engraved by the rifling and the unbalanced penetrator would have bent or broken off at the cantilever. At least we proved that a properly supported grain would withstand the launch forces and burn predictably.

We tried again, and this time AAI had done its homework and produced a proposal to do exactly what we wanted done. Figure 30(B) illustrates the results of that contract. It contains a long rod penetrator, actually longer than in the production GAU-8 round. It is housed in a monocoque steel shell which supports it rigidly fore and aft to prevent in-bore bending. The coaxial motor is an end burner, inhibited on both internal and external surfaces, vented through four nozzles. The windscreen is plastic. The rotating band is bonded plastic, a technology not yet perfected when this job was done. It works as expected providing a significant increase in penetration at nominal ranges, or alternately, it will provide as much penetration at 6,000 feet as the standard round will at 4,000 feet. The technology is now in hand, but it is obvious, comparing this round to the GAU-8 API in Figure 8, that the RAP round will be more expensive and will only be produced if the

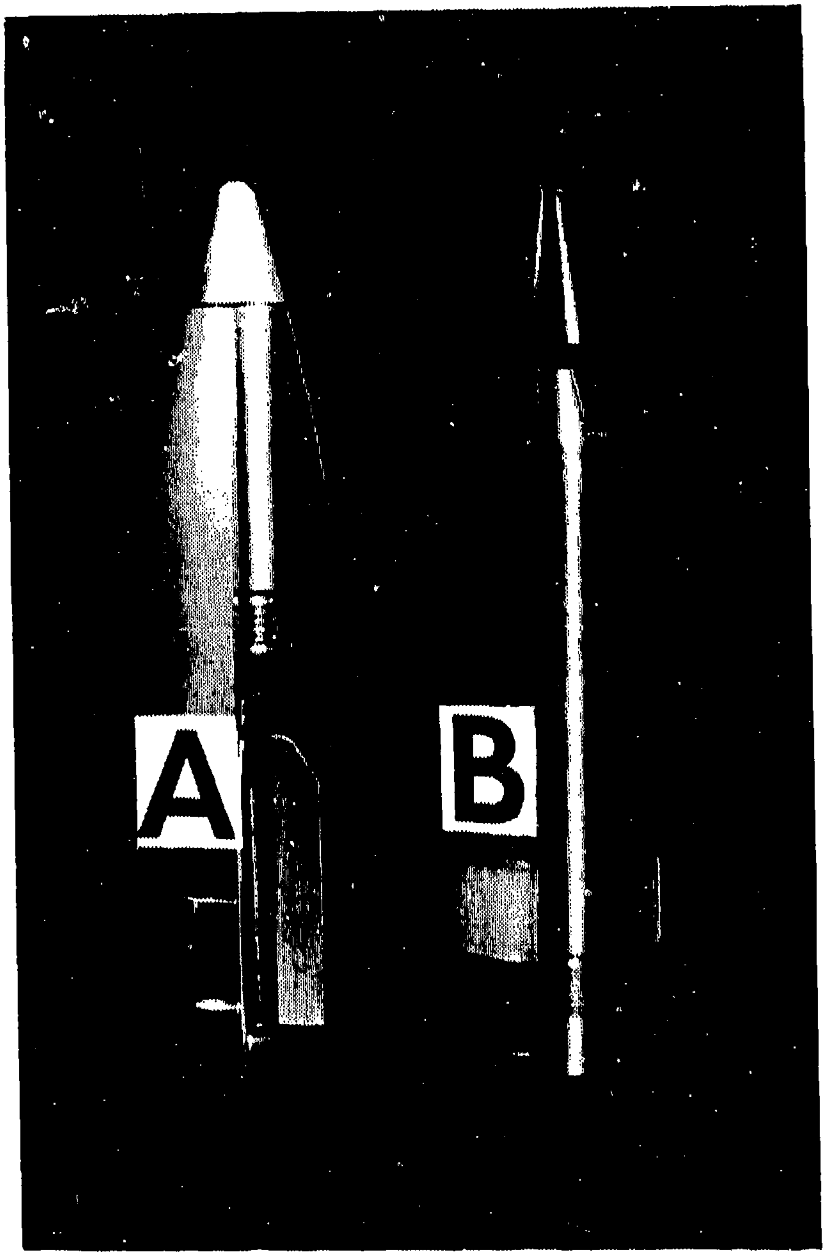


Figure 30. Rocket-Assisted Projectiles
A. Thiokol 30 mm RAP, B. AAI 30 mm RAP

standard round becomes inadequate. The AAI round is dated 1976. The Thiokol round is perhaps three years older.

While on the subject of RAP rounds, it might be worthwhile to mention tracers, fumers, and other items which expel gas from a projectile base. It should first be noted that in a well-designed shell something on the order of 50% of the drag is nose drag, 10% is skin friction, and 40% is base drag. As a simple explanation, one might say that the base drag is caused by the partial vacuum created at the base simply because air cannot fill in the void swept by the shell in flight. The first thought of the novice is to streamline or taper the base back to a point, or at least to a smaller area. This has been done and is known as boattailing. It works pretty well on subsonic or low supersonic velocities. As speed increases, the boattail effect decreases. Boattails are common on long range bullets or shells where the last part of their trajectory is at low velocity.

It has been observed that tracer projectiles exhibit less drag than conventional shot, especially in rifle caliber where tracer diameter is large relative to the projectile diameter. This is not unexpected since the tracer products exhaust into the void reducing the vacuum. The next logical step is to provide a pyrotechnic in the projectile base specifically to generate gas and reduce drag. This is commonly referred to as a "drag-reducing fumer" and was used in the early days of the GAU-8. It was eliminated as a cost reduction.

If the fumer generates enough gas and it issues from the base at significant velocity, it will generate impulse and might be construed to be a nozzleless rocket. It may have sufficient energy to totally eliminate the 40% drag associated with the base and also provide additional thrust, perhaps equal to total drag. In this case, the projectile velocity remains constant or nearly so and the fumer has become a sustainer rocket. If we have by now added nozzles and more pyrotechnic (fuel), we have a RAP round and the thrust/time profile can be tailored to our specific requirement.

SECTION XVII

ROTATING BANDS (PLASTIC IN PARTICULAR)

Rotating bands, driving bands, or sealing bands are generally interchangeable terms which describe the part of an artillery projectile which is largest in diameter and normally seals the bore preventing gas blow-by, and engages the rifling to transmit torque to the projectile. From the early days of rifled bores, lead was commonly used for this purpose. It apparently worked adequately up until muzzle velocities approached 2,000 fps, at which time gilding metal was substituted for lead. Gilding metal (90-95% Cu, 5-10% Zn) is a satisfactory band material up to at least 3600 fps, and depending on propellant and other variables up to about 4,000 fps, until it begins to intolerably "copper" the barrel (as lead begins to "lead" the barrel at 1200 fps and must be hardened with tin or antimony up to about 2000 fps).

Early attempts to replace gilding metal stemmed from two sources: criticality of copper in wartime and coppering of bores. The earliest attempts to replace copper followed the same logic as switching from lead to copper: use a metal, that although still ductile, had a higher melting temperature. The solution was to use relatively pure iron: electrolytic iron or ingot iron. This solution is used today in many European weapons. Two "tricks" are used which make these bands functional and even give longer barrel life than copper bands on weapons using moderate firing cycles. First, the bores are nitrided to provide hard surfaces to resist friction wear. Second, the band, before installation, has a chevron cross section which is pressed into an undercut band seat sufficiently to flare out into the undercut but not enough to eliminate the void. This void ring under the band gives displaced metal somewhere to go during the engraving process.

The advent of powder metallurgy, especially oil-impregnated powder metal bearings, led several people to try sintered iron and copper bands with little or no success. In the early 1950's, this author was testing sintered bands at Aberdeen Proving Ground which were manufactured at Frankford Arsenal. They invariably separated at muzzle exit. Some simple stress analysis showed they had to fail; centrifugal force strained them to well over their ultimate strength. He wondered why Frankford Arsenal would send such obviously flawed material to Aberdeen to be tested. It was then that he learned a basic lesson: an organization doesn't do anything; people do. Although Frankford Arsenal was a venerable organization, someone up there was doing out-and-try engineering. As far as is known, there are still no successful high performance sintered bands.

It is not known who first tried plastic rotating bands or when. The first functionally successful bands, however, were believed to have been made by the Navy in the early 1950's for the MK12 and MK11 guns. This author tested them at Aberdeen, and although functionally satisfactory, they were not operationally satisfactory. The MK12 gun fired from a closed bolt and the MK11 was a revolver, both of which stopped with chambered rounds. A round left in a moderately hot chamber would have a soft band which would subsequently shear upon firing. Figure 31(A) is one of these bands made in 1954. In the early 1970's the Air Force found that the Navy still had several hundred of these banded bodies in storage. We obtained them from the Navy and fired them under various conditions including muzzle velocities of up to 4,000 fps. After nearly twenty years of storage, they still worked perfectly. This band is made of nylon with no reinforcement. It works largely because of the design

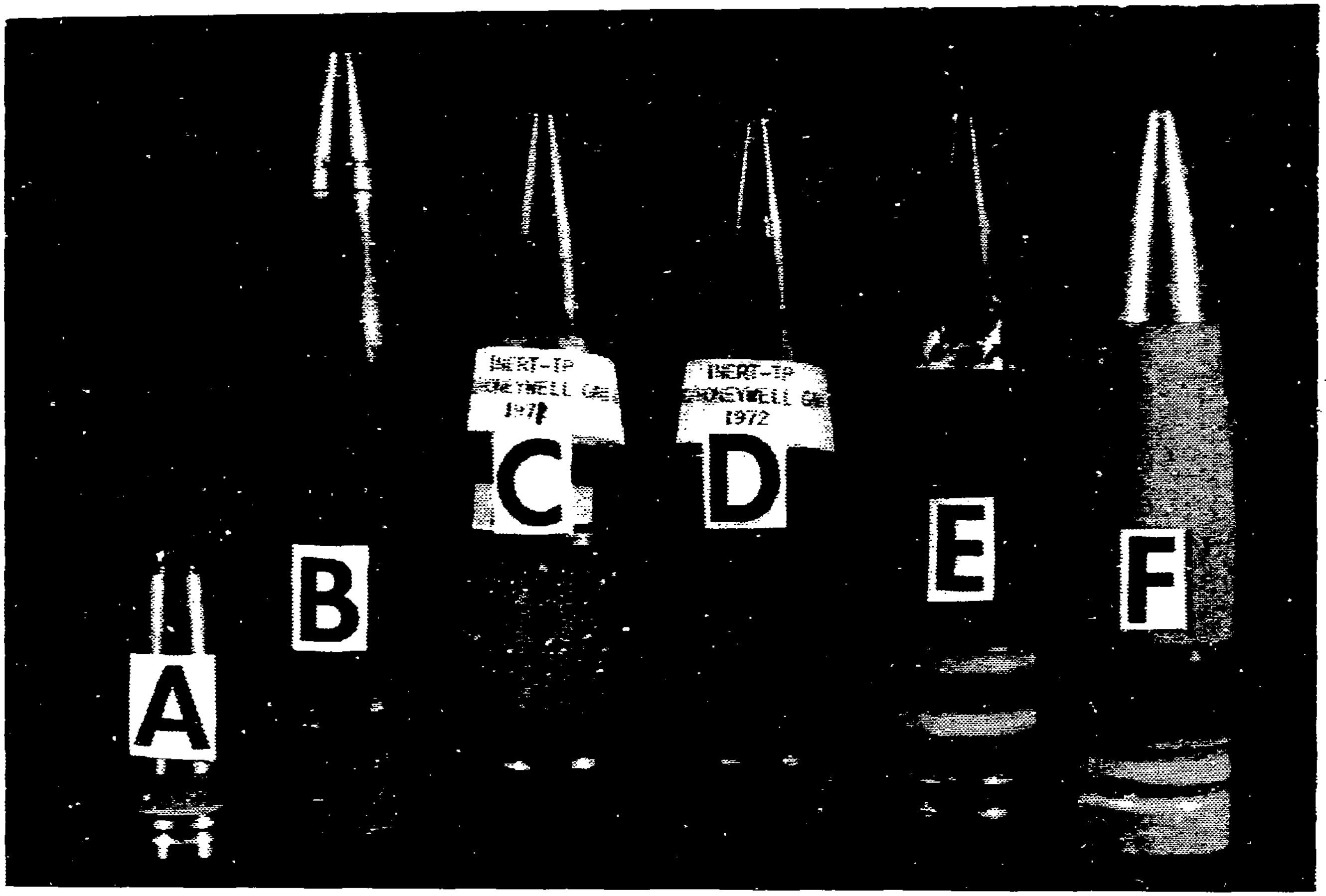


Figure 31. Plastic Rotating Bands
A. Navy 20 mm Nylon Band (1954), B. Navy 30mm Nylon Band (1955),
C. Ford/Honeywell GAU-8 Prototype (1971), D. Ford/Honeywell GAU-8 (1972),
E. GE/Aerojet GAU-8 (1975), F. GE/Honeywell GAU-8 (1974)

of the band seat which functionally consists of three dovetail grooves separated by two knurled ridges.

The Navy people did not give up because nylon would melt in contact with a hot chamber. They were working on a unique 30 mm round with two bands identical to the single 20 mm band, but with the cartridge case extended forward to completely cover the bands. The crimp groove was forward of the front band. This projectile, illustrated in Figure 31(B), is dated 1955. It is assumed that its demise came about as a result of the deemphasis of guns in favor of missiles in the mid-1950's.

The early work by the Air Force on the GAU-7 plastic bands was discussed in Section XIII and illustrated in Figure 27 and will not be discussed further here. The GAU-8 development followed the GAU-7 by about two years, and Ford/Honeywell, being involved in plastic bands for the GAU-7, committed to plastic bands immediately. General Electric, on the other hand, being generally ultraconservative, opted for copper bands as a primary design with plastic as a growth option. An early Ford/Honeywell band is shown in Figure 31(C). It is a bonded nylon band in a shallow band seat utilizing the same technology being applied to the GAU-7 at the time. The ammunition delivered to the Air Force for test in 1972 had bands as shown in Figure 31(D), being black nylon with two grooves molded in place making in effect a triple band. There was one unusual feature about these bands, or more correctly about the barrels in which they were fired. Only the first few inches of the bore were rifled, and this at a high angle, e.g., 20 degrees. The shell acquired its full spin during this travel, and then entered a tapered section where the band was wiped smooth. The balance of the bore was smooth. The rifled and tapered sections were replaceable inserts designed to save costs of complete barrel replacement. The idea was not new, being a standard item on the Navy 20 mm MK11 gun; nor did it work particularly well. As a matter of fact, the contractor's own figures showed it to be more costly in the long run than standard barrels. These two Ford/Honeywell shells are dated 1971 and 1972.

In addition to the standard copper band, General Electric/Aerojet developed a backup plastic band for their GAU-8 candidate round. After they had clearly won the competition, they staged a demonstration wherein they fired several thousand rounds using plastic bands in two barrels and copper bands in the other five. This was the first really dramatic and uncontestable demonstration of the advantages of plastic bands. Three points became very clear:

1. Normal barrel erosion is virtually eliminated with plastic bands. After the barrels firing copper bands were completely shot out, the barrels using plastic bands looked almost new.

2. The muzzle velocity of the barrels firing copper bands increased slightly for the first hundred rounds or so and then decreased as erosion permitted blowby. The muzzle velocity for the barrels firing plastic bands remained constant throughout the test.

3. On an extended burst the muzzle velocity of copper-banded projectiles decreased as the barrel got hot and expanded permitting blowby. Plastic-banded projectiles maintained constant velocity.

After this demonstration, it became obvious that our new gun should have plastic bands. Figure 31(E) is the production Aerojet configuration that evolved. It has two glass-reinforced nylon bands about 9/32-inch wide molded into deeply undercut grooves. Figure 31(F) is the General Electric/Honeywell band as it entered production. It is a low glass content band about 5/8-inch wide retained by four raised knurled ribs of essentially the early Navy patent configuration. These two band designs went into full scale production in the mid-1970's and have been made in quantities measured in tens of millions. They have been quite satisfactory. Being mechanically retained, however, they require a fairly deep machined, undercut, and knurled band seat.

There are some cases such as the high capacity HE shell, RAP rounds, and thin-walled tubular projectiles (Figure 49), where the need or desirability of a thin wall does not permit the use of deep seats and mechanically retained bands. This was the reason for welded copper overlay bands used earlier. A technical need for a good reliable bonded plastic band still existed in the mid-1970's.

A lot of work was done by a lot of people in the late 1960's and through the 1970's on plastic bands for many applications. Most of this work was done on bonded bands because it seemed to show the most promise for universal application, and it was felt that it should ultimately be less expensive since it eliminated the need for several machine operations. Figure 32 shows a few of the many experiments that were conducted with varying degrees of success. Most of this work was done in 20 mm caliber because it provided a readily available and inexpensive test bed. Much of the work had to be done experimentally because of the lack of information on the dynamic physical properties of plastics. Most plastics, unlike metals, are easily deformed at moderate loads if the loads are slowly applied, yet become much stronger and sometimes brittle under suddenly applied loads. Also plastics are much more influenced by the military temperature extremes of +165°F to -40° or -65°F than are metals. The properties of plastics were not and are not known at the required loading and temperature extremes.

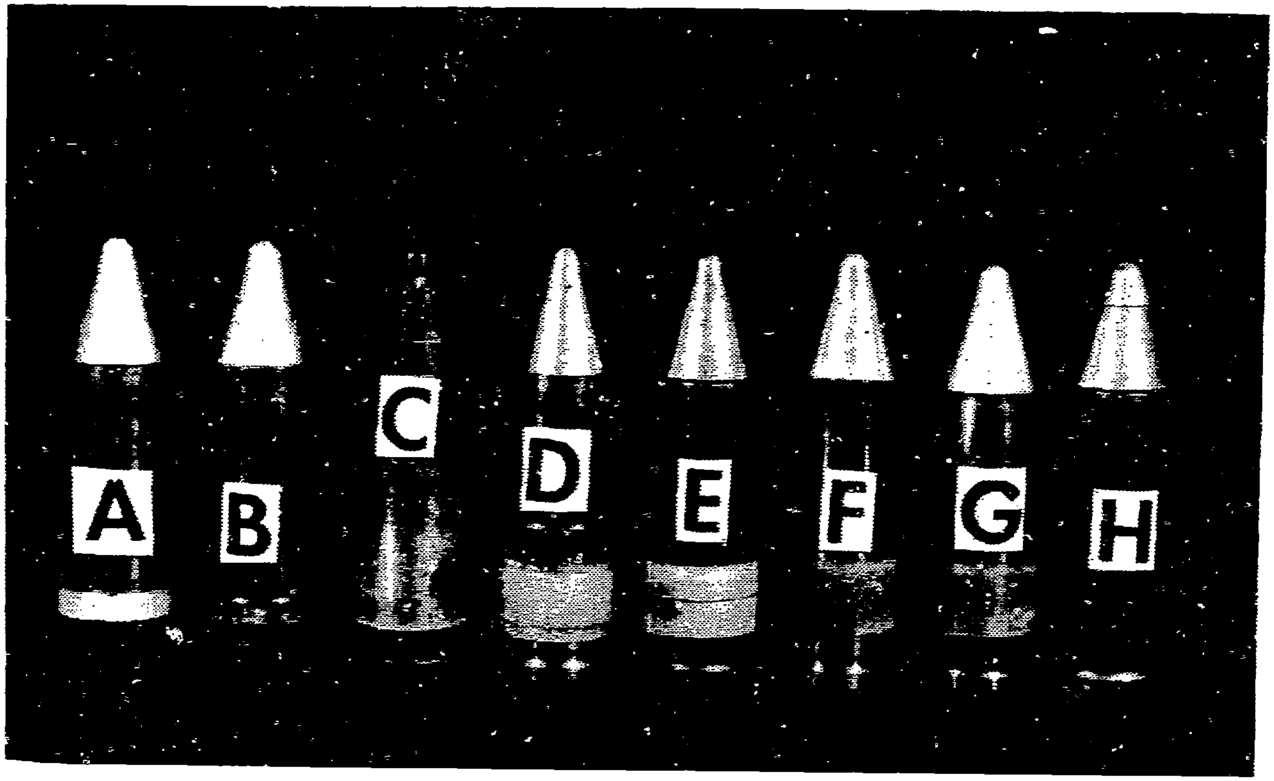


Figure 32. Plastic Rotating Bands
A. Nylon Band in Standard Seat, B. Polycarbonate Band in Standard Seat, C. Jacket Type Band, D. Wide Two-Stage Band, E. Wide Bonded Band, F. Configuration Test, G. Configuration Test, H. M50-Series Configuration

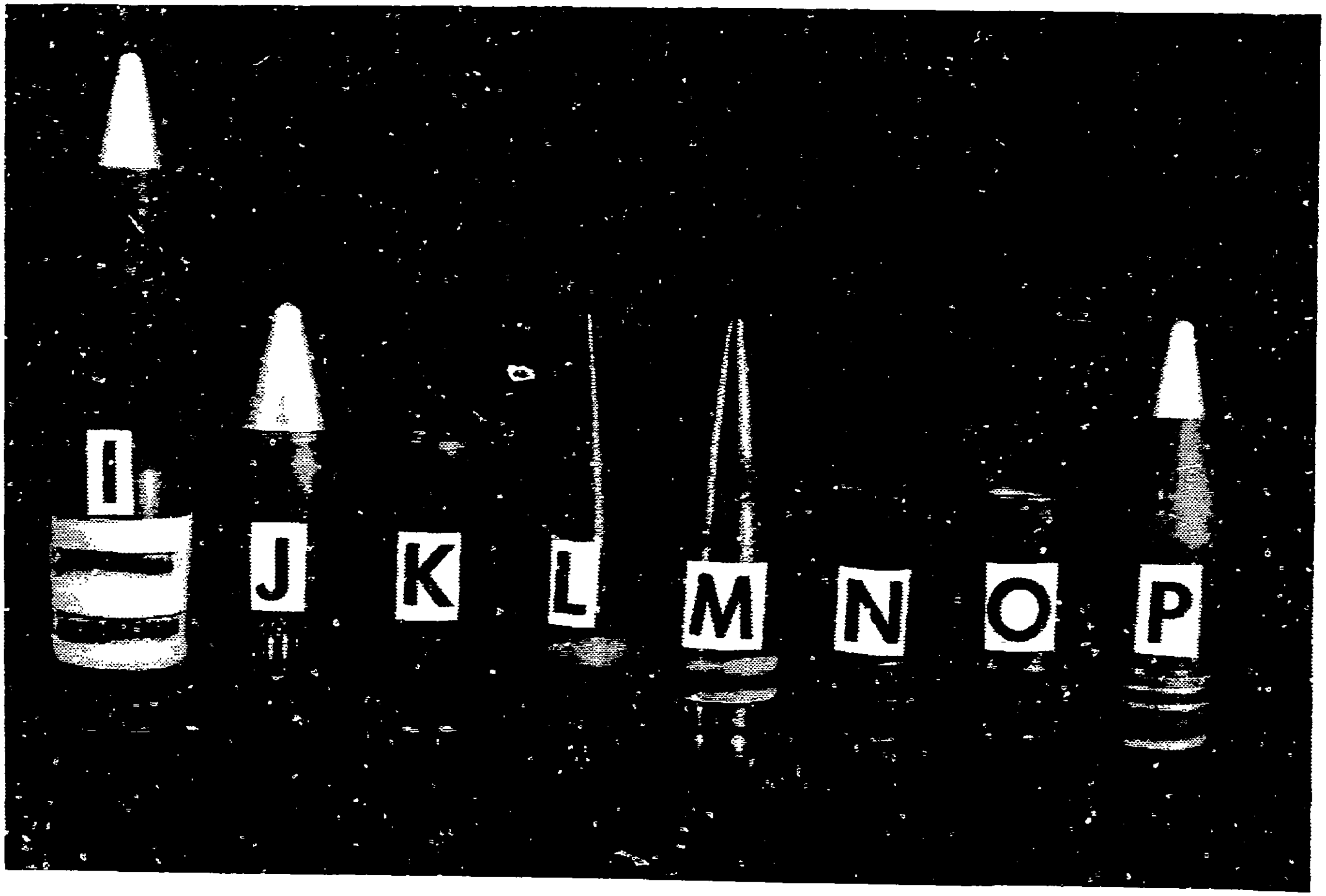


Figure 32. (Continued)
I. GAU-7 Band Test, J. Band Test, K. Band Test, L. Honeywell "Quick" Round, M. Honeywell Proposal, N. Avco R&D, O. Avco R&D, P. Avco Final Design

Although the 1954 Navy bands worked, they required somewhat expensive band seats. Plastics had improved since 1954, and an attempt was made to see if some modern plastics would work in standard band seats. Figures 32(A) and 32(B) are nylon 6-12 and polycarbonate, respectively, molded to dimension on M55 projectile bodies. The nylon was simply not strong enough and sheared; the polycarbonate stress cracked, as can be seen in the photograph. No further work was done.

In some of the early attempts to make a bonded band, it was thought that a wide band, almost a jacket, might be molded in place on a clean body and due to its width generate enough resistance to transmit the required torque and sufficient adhesion to resist centrifugal force. Figure 32(C) is such a projectile. It did not work. It would spin the projectile but invariably shed at the muzzle. Also, it did not protect the shell body from rust. Rust can be clearly seen through the band in this photograph. For some reason, someone tried a two-stage band where the first half was bonded to a seat, perhaps 0.015-inch deep and the aft portion possibly 0.045-inch deep (Figure 32(D)). The band appears to be polyethelyne which serves well for sabots and light gas gun pistons but did not work in this case. The band seat appears to have been grit blasted and primed with a bonding primer, but adhesion is nil. The next round (Figure 32(E)) has a similar appearance but is actually much different. It was obviously grit blasted, dip primed, tape bonded, and used a high glass content nylon. Similar to the final configurations of the GAU-7, it probably worked, suffering, as did the GAU-7, from the inability to maintain quality control. It is not known who made it, but it is dated "7-16-75."

Somewhat earlier than this we were having some degree of success with dip priming and applying various bonding agents prior to banding and curing the bond. It appeared full success was imminent. We began to look for optimum band configurations to provide long barrel life, a factor of safety, and prevent drag causing fringing of the bands by the rifling. Of course, a wide band would provide a factor of safety, and there is no penalty from an undercut for a bonded band, so a moderately wide band was chosen, as shown in Figures 32(F) and (G). These bands are about 1/2-inch wide. The major difference is in the length of the front and rear chamfers on the band. It was found that a long rear chamfer gave the plastic displaced by engraving somewhere to go and reduced fringing. Figure 32(G) is probably close to an optimum configuration. Of course, one can do anything in R&D, but sometimes is constrained by other factors when putting it to application. In the improved 20 mm ammunition program, it was required that the new ammunition function in existing chambers, so the band had to be narrowed down to about 5/16-inch width (about 50% wider than the standard copper band), as shown in Figure 32(H).

Upon examining these last three projectiles, it is obvious that the bonding on Figures 32(F) and (G) is beginning to fail from both front and rear and on Figure 32(H) from the front. In fact, random nonsystematic failure of bonds, the inability to define what will produce a good bond, and the lack of a nondestructive test to measure a good bond is what has precluded, to date, putting bonded bands in inventory. The GAU-7 program is a good example. Of the several thousand bands made, many are good today; many are not. Figure 32(I) is a GAU-7 projectile which has been subjected to a test. In this case, trying to peel the band off with a 1/4-inch wood chisel is not very scientific, subject to judgement, but in this particular case, showed good adhesion. After 10 years in Florida humidity, most of this bond is still good except for about 1/8-inch of the forward edge on the opposite side of the shell.

A lot of work was done during the 1970's to evaluate bands and bonds without having to go through expensive firing tests at high and low temperatures and after temperature and humidity cycling. Of course, firing tests would ultimately be required, but some simple reproducible screening tests would be useful. One such test is illustrated in Figures 32(J) and (K). Rationale for this test was that as the projectile was propelled into the tapered origin of rifling, the engraving force on the band appeared as a radial impact driving the rifling land into the band. A drop hammer test was made to do this. Figure 32(J) illustrates a projectile which survived this test. Figure 32(K) illustrates a failure where the band has spalled off in a brittle failure 1/32 inch to 3/16 inch on both sides of the land.

The improved 20 mm program for air-to-air got fully underway after the demise of the GAU-7 and the successful demonstration of the value of plastic bands on the GAU-8. Plastic bands were an early requirement. Figure 32(L) is the Honeywell "quick" round (Figure 18) on which the band is too wide for inventory M61 barrels. Figure 32(M) is one of many variants tried by Honeywell which would fit existing barrels. As mentioned earlier, Avco won the competition and developed the PGU-17 and PGU-18 rounds (Figure 21). They also made many attempts at bonded bands. Figure 32(N) is one such attempt and shows obvious rust streaks under the band. Figure 32(O) looks good but as usual had problems after temperature-humidity cycling. Their final solution, Figure 32(P), used a mechanically retained band of polyethersulfone, a tough plastic which they market as Avlon®. At first glance, it looks like the early

Navy band but is much different. The plastic is, of course, different. The band seat is undercut but not as deep. Instead of having two raised ridges knurled on top to provide three dovetails, this round has one raised ridge, hit with a "V" shaped roller to provide two dovetails. The knurling is in the grooves. It works.

We had reached the late 1970's and still did not have a bonded plastic band which worked under all required conditions; what looked so easy was elusive. The need for one still existed, in fact, was stronger than ever; we were working with thin-walled shell at velocities of 4,500 and 5,000 fps. We were looking for new band ideas that would work under these conditions yet give satisfactory barrel life. Honeywell, under contract, evolved two new band concepts. The first was to use thin metallic fins with plastic in the voids and the second was to build up a band area with porous sprayed metal and fill the pores with plastic. When Honeywell personnel briefed these two ideas at Eglin, it immediately became obvious that the porous sprayed nickel was the solution to the problem--not as they proposed but as a surface over which to install a bonded band. It would prevent corrosion under the band and would give a porous surface to allow a bonded band to get a mechanical grip. It was tried, and it worked under all conditions. The only disadvantage is that the process is somewhat expensive, but since it is the only thing that works flawlessly at 4,500 to 5,000 fps, it is used.

An example of the versatility of this technique is shown in Figure 33. In this case, a thin-walled 25 mm shell to be fired from a telescoped round was designed to be completely encapsulated in plastic, with the idea that if there were no edges to initiate bonding failure, then bonded bands would stand a better chance of working. Conventional bonding techniques did not work; they

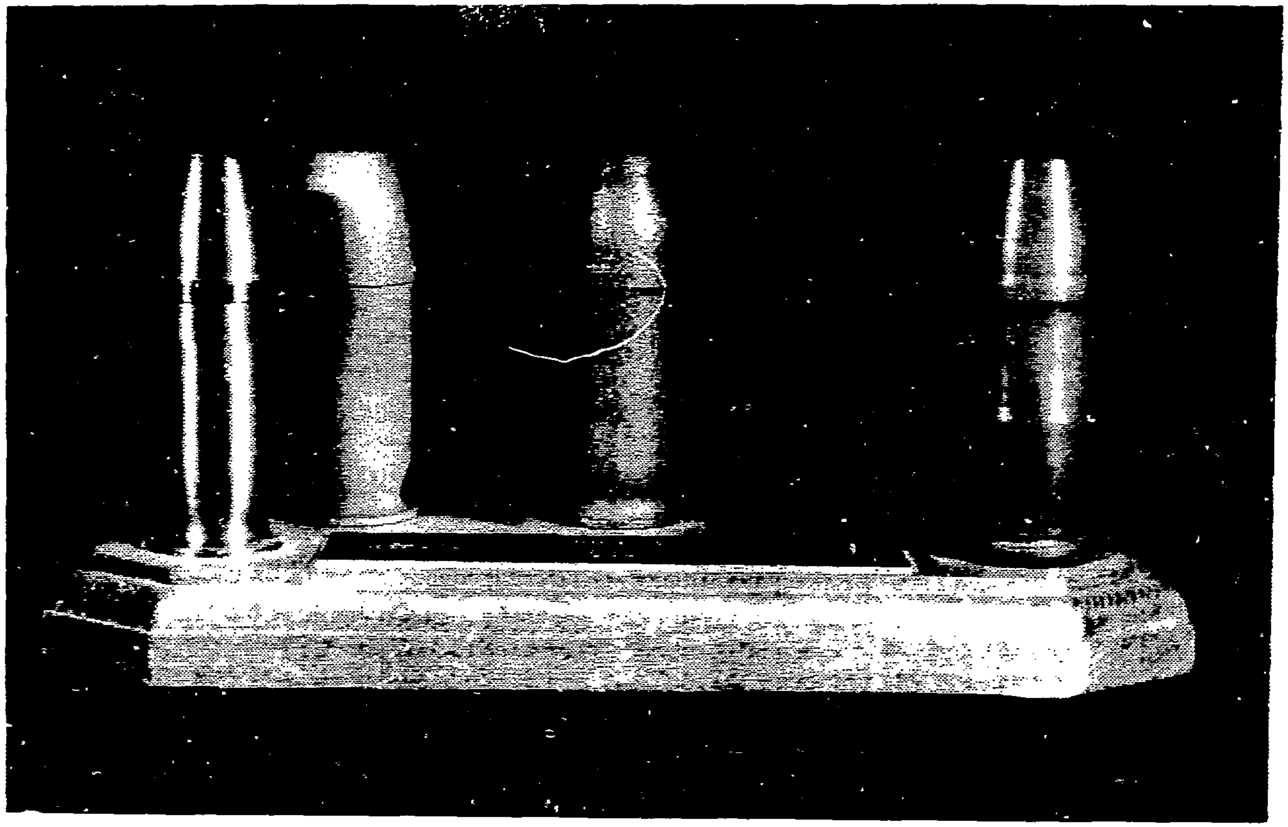


Figure 33. Plastic Encapsulated Projectiles

shed the jackets in large chunks. When the metal spray technique was used to prepare the surface, the bonded jacket was totally satisfactory. This work, done by Avco, utilized polyethersulfone (PES) as a jacket material. The four steps of application are illustrated in Figure 33. From left to right, the first is the shell body supplied by the Air Force. It is cleaned and sprayed as seen on the second shell and then dipped in solvent-thinned PES. Next, it is put into a mold using the fuze thread for centering and completely encapsulated. It is then machined to the desired configuration. Of couse, further development has allowed the band to be molded to net or near net dimensions, eliminating the gross machining shown.

Plastic bands have come of age. For normal projectiles which allow for machined band seats and have velocities up to around 4,000 feet per second or so, simple injection molded bands, 50% (or more) wider than conventional copper band will suffice. It can be made of any one of several types of nylon or stronger plastics with or without reinforcing fibers. For thin-wall projectiles such as high capacity HE shell, RAP rounds, tubular projectiles, etc., a metallic nickel spray followed by a solvent reduced primer and a molded band has proven successful at muzzle velocities up to 5,500 fps.

Plastic bands require a smooth bore surface; otherwise, they are quickly abraded to failure. Conventional hard chromium plating has proven to work well. Plated barrels used with plastic bands have extremely long life, at least three times as long as the same barrels with gilding metal bands. The mechanism of this extension of bore life is not known. This author feels there are three interactive mechanisms at work:

(1) Plastic bands do not stress the chromium in the forcing cone and the origin of rifling to the extent that gilding metal does, thereby reducing

the incidence of cracking of the plating.

(2) The plastic is extruded into the plating cracks, preventing propellant gasses from entering and eroding the substrate.

(3) The plastic smears onto the bore providing an ablative film which momentarily protects the bore surface from hot propellant gasses.

SECTION XVIII

TARGET PRACTICE PROJECTILES

Target practice (TP) projectiles, sometimes called ball or simply practice projectiles, although seldom used in combat (in cannon calibers), are an important part of a gun system. They are used almost exclusively during gun development and later are used for gun function testing, boresighting and gun/sight harmonization, and for the majority of training. In fact, most guns during their life fire more TP rounds that any other kind. The cost of TP ammunition is a significant part of the total life cycle cost of a gun system.

The design requirements of TP projectiles are quite simple: they should be inexpensive and closely simulate the combat round(s). Simulation of combat rounds includes both interior ballistics (for gun function) and exterior ballistics. Simulation of exterior ballistics requires that the trajectories should closely match out to the longest expected combat range. For surface-to-surface, surface-to-air, and air-to-surface firing, this requires, as a maximum, that mass and drag coefficient should match. For guns firing from highly maneuvering aircraft, aircraft turret-mounted, or otherwise firing such that the muzzle velocity vector is not directly into the relative wind, it is necessary that mass, drag coefficient, center of pressure, center of gravity, axial moment of inertia, and transverse moment of inertia be reasonably well matched.

Many foreign manufacturers solve the problem of TP projectiles quite simply; they manufacture HE shell bodies, fill them with an inert simulated high explosive, screw in an inert simulated fuze, and paint them with a TP code color. Simple? yes; effective? yes; expensive? yes.

Starting now with the concept of a functionally perfect TP projectile, let's look at some of the value engineering, to use a current expression, that was done on the 20 mm M55 TP and the 30 mm GAU-8 TP in order to arrive at functionally acceptable yet low cost TP projectiles, as illustrated in Figures 34 and 35, respectively. Figures 34(A) and 35(A) and (D) illustrate the 20 mm M56 HEI, the 30 mm Honeywell HEI, and the 30 mm Aerojet HEI which it was desired to simulate.

Looking first at the 20 mm, Figure 34(B) illustrates the classic standard M55 TP round that has been in production for thirty years. It is obviously cheaper to manufacture than the M56 HEI. Both nose and body are screw machine parts. The solid aluminum nose approximates the steel bodied, but partially hollow fuze, and judicious selection of drill diameters and depth allows the steel body to approximate the mass, center of gravity, axial moment of inertia, and transverse moment of inertia, not perfectly, but adequately. Figure 34(C) is a cost reduction proposal entertained in the early 1970's, substituting a polycarbonate nose piece for the aluminum one. It was made in R&D quantities and functioned satisfactorily, but the savings, if any, were insufficient to warrant the change. Figure 34(D) is a production TP body taken off the line before the band and crimp grooves were cut and used in one of our plastic band programs. It is not included here because of the plastic band, but because the steel body was manufactured by a blank, cup, and draw operation rather than machining. Correct configuration of the forming punch provides correct mass properties. The aluminum nose is the same as in Figure 34(B). Continuing the cold forming logic still further, there is no need to produce a separate nose piece. Figures 34(E) and (F) are the last two forming steps of projectile bodies made completely by cold forming, starting

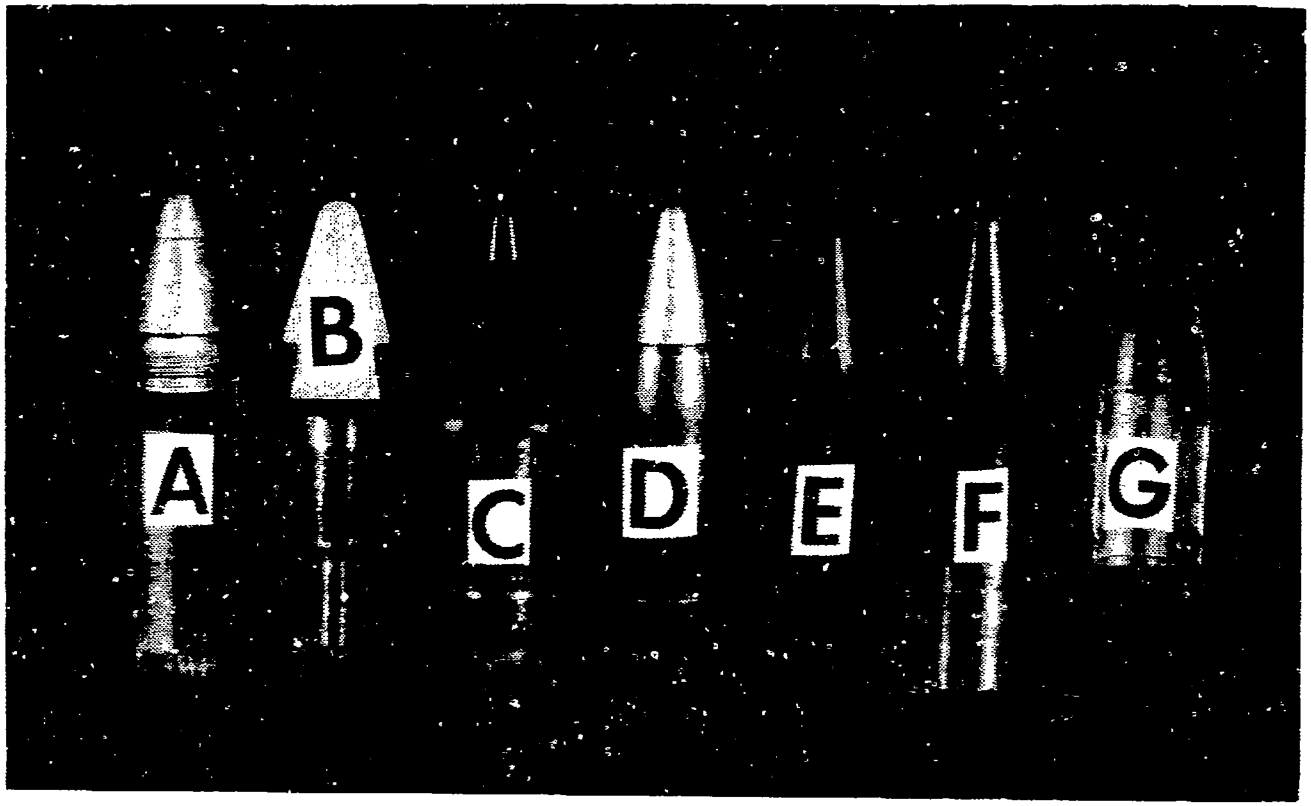


Figure 34. 20 mm M50-Type Projectiles
A. HEI M56, B. TP M55 "Standard", C. TP M55 with Plastic Nose, D. TP M55 with Drawn Body, E. TP M55 in Draw Process, F. TP M55 Drawn in Final Form, G. TP-T M220 Impact Extruded

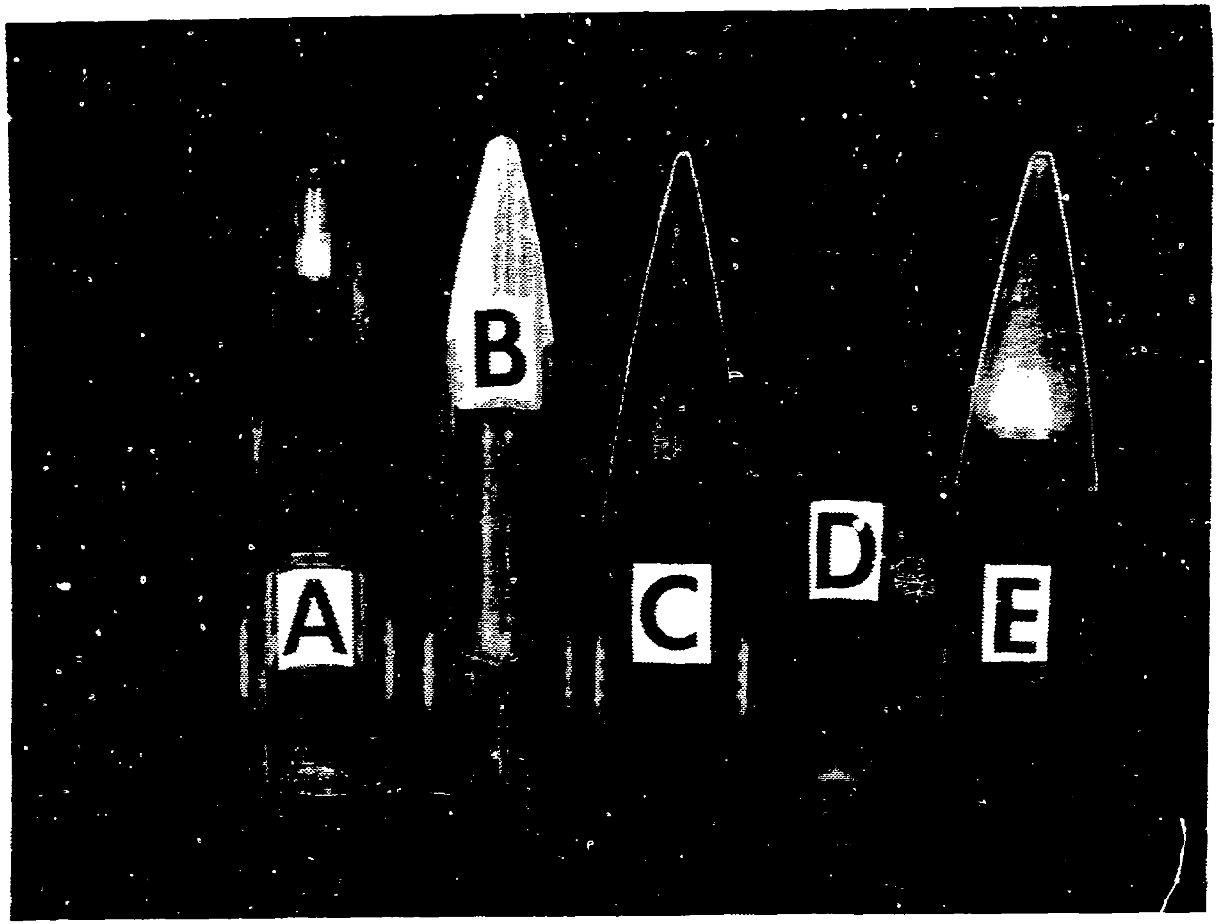


Figure 35. 30 mm GAU-8 Projectiles
A. Honeywell HEI, B. Honeywell TP (early), C. Honeywell TP (current), D. Aerojet HEI, E. Aerojet TP (current)

with a blank, cup, and draw. Of course, bodies can also be made by impact extrusion. Figure 34(G) is the Army M220 target practice tracer (TP-T) round which is impact extruded on both ends. Obviously, there are several ways a satisfactory TP round can be made, and it is a good idea to have several acceptable alternates because the least expensive method cannot be predetermined; it depends on what type of plant capacity happens to be idle when we ask for bids.

The GAU-8 situation is a little different from the 20 mm story in two ways. First, it was not intended for crosswind firing, so mass properties did not have to match as well; in fact, the mass properties of the two combat rounds, API and HEI, varied greatly. Second, although the TP round started out to be a simulation of the HEI round, it was changed to a simulation of the API round which is the primary combat round. Figure 35(B) is the initial production design of the Honeywell TP round which simulates the HEI on its left. A value engineering change proposal (VECP) resulted in the design shown in Figure 35(C), which is obviously more economical in material and machining than its predecessor. Aerojet likewise initially simulated its HEI round with a design similar to Figure 35(B) (not shown), but by VECP changed to the current configuration shown in Figure 35(E). The TP projectiles shown in Figures 35(C) and (E) are about as inexpensive projectiles as one can get and are quite satisfactory for both the GAU-8 and GAU-13 for which they are intended. They are not all-purpose TP designs. They would not adequately match an HEI round in the bomber defense role and probably would not adequately match when fired from a fighter in a high "g" maneuver. Also, they would not be satisfactory for firing from most reciprocating-type gun mechanisms where the ramming portion of the firing cycle is frequently accomplished by camming the projectile nose off of the chamber wall. (As a matter of fact, the API round would not work here either.)

So much for the TP projectiles that are in our inventory. Now let us look at some of the things that have been tried in recent years but did not get into the inventory. The GAU-7, of course, is treated in Section XIII and will not be covered here. What is of interest are the various 20 mm and 30 mm concepts that have been proposed, studied, and prototyped that can be described as "frangible," "non-ricochet," "low cost," or all of the above.

A hazard of air-to-surface gunnery training is that projectiles fired at ground targets are apt to ricochet into the air and strike the strafing aircraft as it passes over and beyond the target. This is not an everyday occurrence, but it does happen frequently enough that the aircraft repair bills run to hundreds of thousands of dollars annually. There are several recorded instances where such mishaps actually caused the loss of multi-million dollar aircraft. If one could magically assure that no projectile would ever ricochet, this still would not solve the problem for often the offending projectile is an old one lying on the range which was knocked into the air by incoming rounds. This is evidenced by the rusty corroded projectiles sometimes recovered from damaged aircraft.

Another ricochet problem was introduced along with the 30 mm GAU-8 gun: designed for much longer combat range than the 20 mm, it also had a much longer ricochet range. The area of firing ranges required to contain the new projectiles was more than quadrupled. Not all ranges in use were sufficiently large.

The ideal answer to the ricochet problem would be to have the projectile break up into dust on impact, a proposal which sounds reasonable until one realizes the projectile must be strong enough to stand 80,000 g's (30 mm) to 120,000 g's (20 mm) of acceleration in the gun bore, and the centrifugal force generated by spinning at 120,000 rpm at the muzzle. Projectiles of this strength simply do not disintegrate upon striking earth. There are several things, however, that come to mind that might reduce, if not eliminate, this problem: Design the projectile such that it marginally stands the gun-induced loads but will fail, breaking into chunks under any greater load; make the projectile of rather brittle material so that if it hits or is hit by another projectile on the target range, it will break rather than fly intact into the air; design an anisotrophic projectile that will stand axial acceleration and spin loads but will fail under axial deceleration and transverse loads; design the projectile so that upon hitting the target, it becomes stable in the target medium (earth) and buries itself. All of these and other things have been tried with varying degrees of success, some of which will be described. Of course, there was another requirement that the new projectiles not cost more (user) or cost less (SPO) than the standard TP round.

One projectile did partially satisfy the non-ricochet and low cost requirements and it got into the inventory. The slug and nose cap 30 mm TP projectiles are shown in Figures 35(C) and (E). As mentioned earlier, they were introduced into the inventory primarily because of their reduced cost; however, the slugs, once the ogive is broken off, should be stable in loose earth and will tend to bury rather than ricochet. Also in the event that it does strike something hard and ricochet, the ogive will have been broken off and the theoretical maximum ricochet range reduced significantly from the earlier type TP shown in Figure 35(B).

One of the most frequently proposed methods for producing low cost frangible projectiles is through powder metallurgy, specifically sintered iron. By controlling density, alloying ingredients, and heat treatment, a wide variety of physical properties can be obtained, from very fragile to extremely hard. Figure 36 illustrates a concept for a low cost non-ricochet TP projectile developed by Honeywell under Air Force contract, starting in the late 1970's. It is made of three sintered iron parts and two injection molded plastic parts assembled by press fit. It is designed to fail under transverse loading on impact, yielding irregular high drag fragments. It is further intended to be fragile enough that if any large fragments are struck by subsequent rounds, they will fracture rather than being kicked up into the air. This projectile has not gone into the inventory; however, there is still some interest in it and some manufacturing technology studies are being done. Some variation of this design may some day be in service.

Zinc is one of the world's least expensive non-ferrous metals. It is inexpensively die cast into relatively complex forms with high precision. It is also fairly fragile, with little (5-10%) elongation, as anyone familiar with the "pot metal" bright work on automobiles and appliances of the pre-plastic era can attest. Zinc die casting looked like a natural way to make really low-cost frangible projectiles. Such a proposal was received from Ford Aerospace. It was tried. Figure 37 illustrates two attempts to make such a projectile in 20 mm. The first attempt consisted of a net die cast hollow body with an inserted aluminum nose. The body included an integral rotating band. It did not "lead" or "copper" the barrel, but it did "zinc" it. The next attempt used a plastic band, but the major problem only became more evident; the soft zinc ogive was engraved by the rifling, causing a general

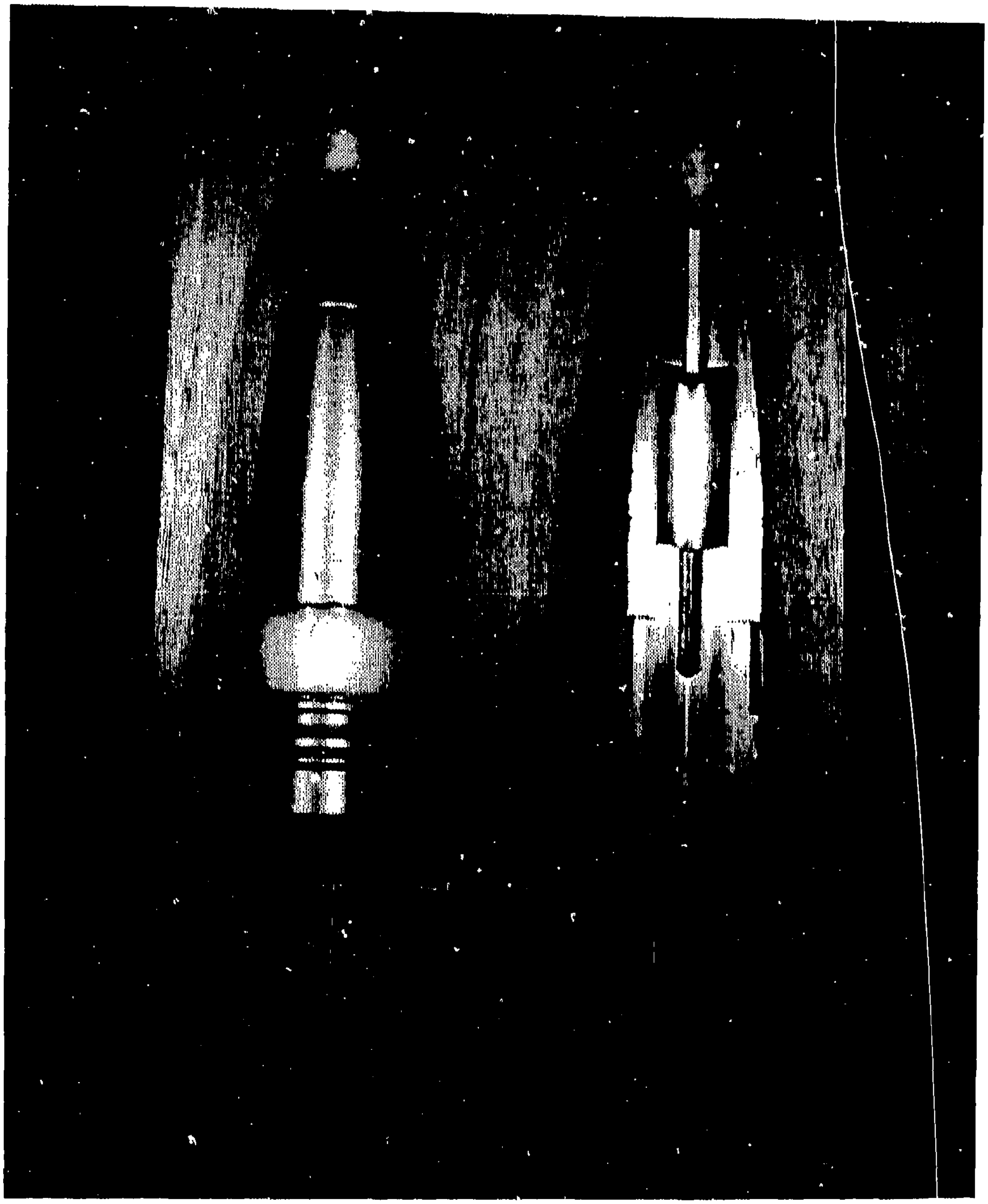


Figure 36. Sintered Iron TP Projectiles

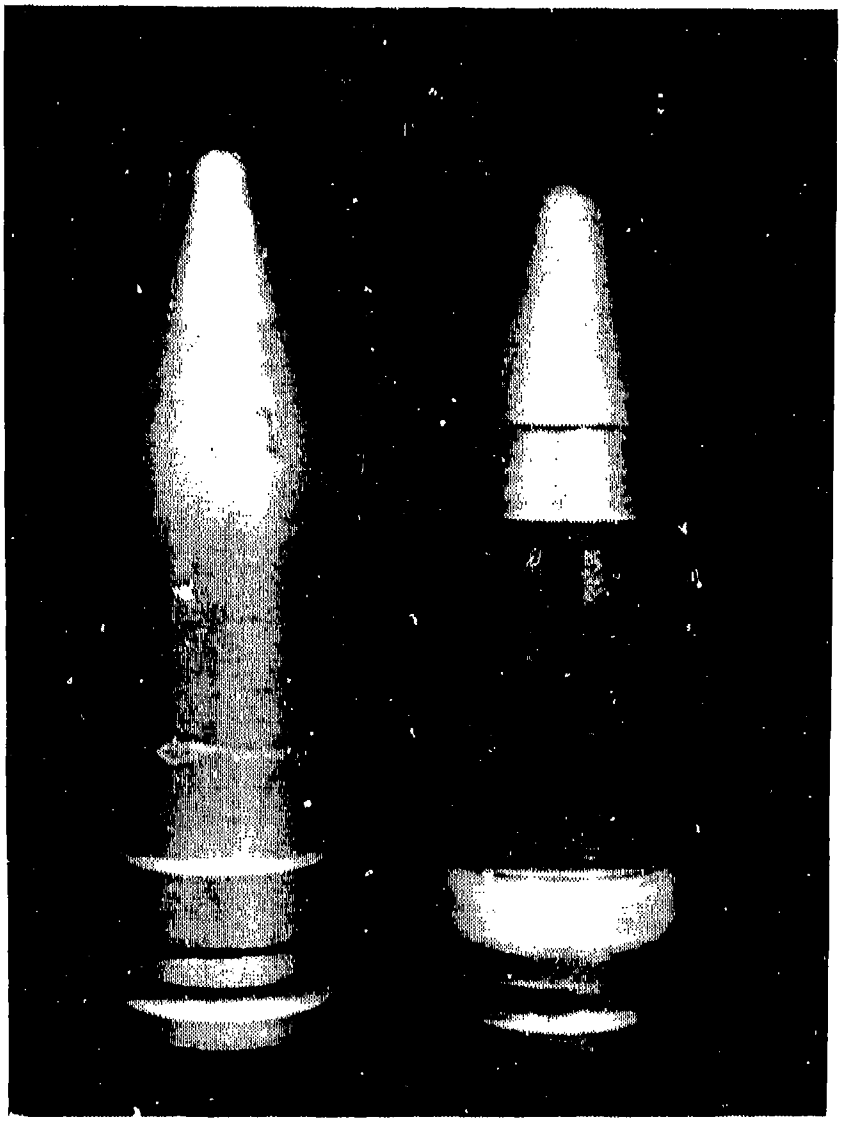


Figure 37. Zinc Die Cast 20 mm Projectiles

ballistic mess. A steel bourrelet insert would be needed; so much for a good idea for a cheap projectile. The project was abandoned.

Avco submitted a proposal to design a projectile that would withstand in-bore acceleration, yet break up on rapid deceleration. At the time they were working on, or had just completed, the improved 20 mm air-to-air ammunition, so their proposal took that form. Figure 38 illustrates what was developed. It consists of a steel base cup which can be completely cold formed except for the band seat, an injection molded glass-filled plastic body filler and nose, and a mechanically retained polyethersulfone rotating band. When the projectile hits a target, the plastic is driven back into the body cavity such that hydraulic shock pressure opens up the steel body in "banana peel" fashion. The fingers so formed are either broken off, leaving only the short cylindrical base, or are left partially attached, leaving a ragged piece of junk, either of which is a high drag shape which will not travel far. This development was completely successful. If the user actually wanted a low cost reduced ricochet projectile, this design could be tailored to M50-series, GAU-8, or any other form.

A very intriguing idea for a frangible projectile was conceived by one of our engineers several years ago when he was investigating plastic-bodied projectiles for various uses (see Section XIX). He proposed a plastic shell with a cavity to be filled with washers or thin steel punchings. It was felt that such a projectile would readily stand axial acceleration and spin, yet would readily disintegrate when subjected to transverse shear loads. Some preliminary tests in 20 mm of the item illustrated in Figure 39(A) indicated the idea might work. At the time, our primary interest was in 30 mm GAU-8, so

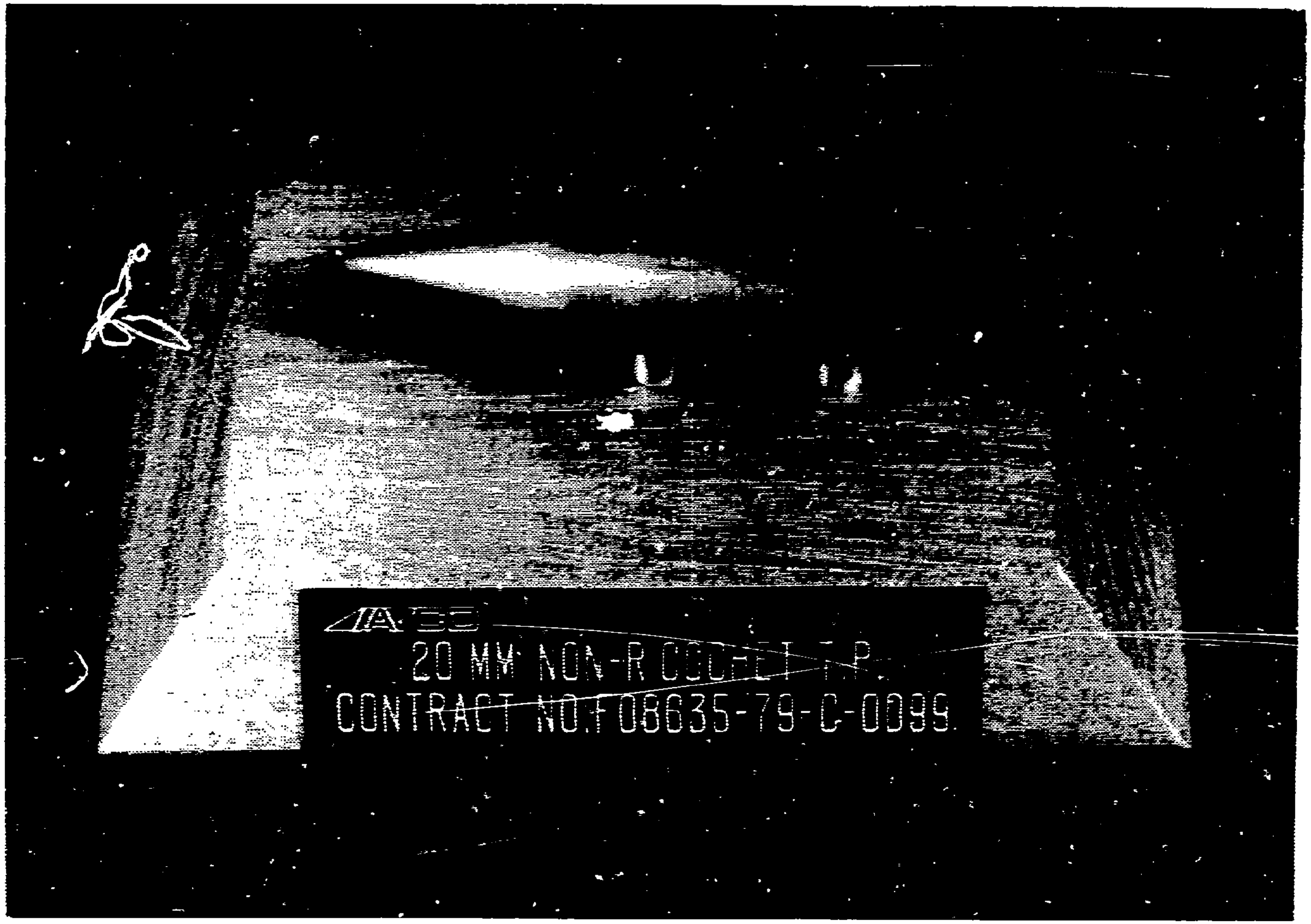


Figure 38. Non-Ricochet TP Projectile

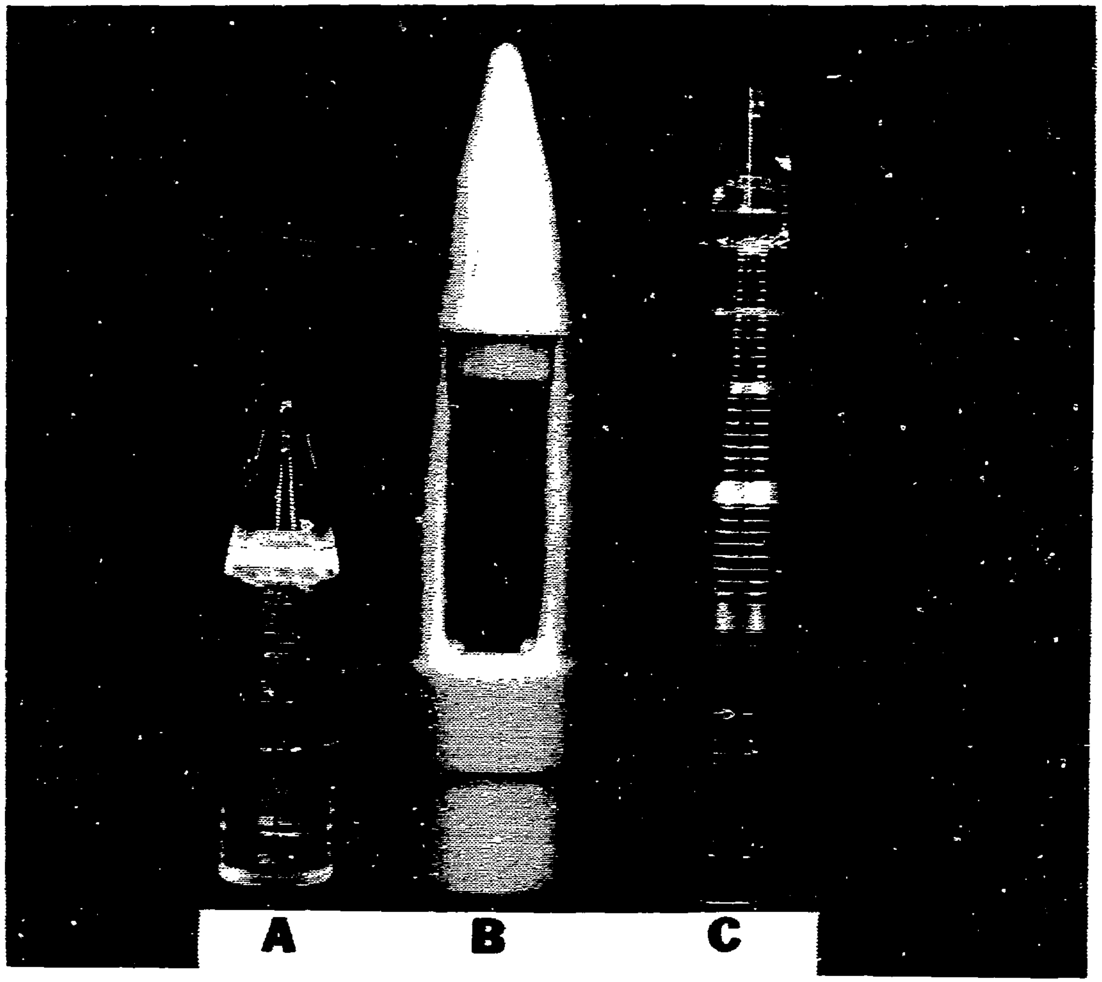


Figure 39. "Washer Stack" Projectiles
A. 20 mm Platelet Stack, B. 30 mm Platelet Stack,
C. 30 mm Washer Stack

it was decided to try to develop the concept in that caliber. A first scale-up attempt was made by AAI utilizing dies remaining from the earlier plastic encapsulated DU penetrator work illustrated earlier in Figure 14. This design, still using octagonal plates, is shown in Figure 39(B). A later version, developed under contract to DeBell and Richardson, is shown in Figure 39(C). This version contained a stack of commercial steel washers with the plastic body molded in place. About this time the problems began to appear. The bourrelet engraved, causing in-bore yaw. The cantilevered nose, now offset and spinning at high rate, broke off in the bore. After much trial and error over several years, a design evolved which would work. It required steel bore riders fore and aft and a thin-wall high strength steel tube through the center of the washer stack to handle bending loads. It was now much more expensive than the original concept, but at least it stayed intact and could be fired to assess its behavior on impact. Tests were run at high obliquity impact into sand to simulate low angle strafing. The projectiles did break up well, but the washers tended to sail like frisbees, traveling long distances, reaching significant height, and remaining airborne for significant time. It was our assessment that the hazard from the washer stack projectile was probably at least as great as that of a conventional TP. So much for another good idea.

SECTION XIX

MISCELLANEOUS: INCLUDING THINGS THAT NEVER WERE, SHOULD NOT HAVE BEEN, OR WERE AHEAD OF THEIR TIME

Anyone who has been in the research and development business for any significant length of time knows that very few of the items one works on are ever put into production. If 10% of your ideas make production stage, your percentage is high. Occasionally an R&D project will be a technical success, but for one reason or another, not be put into production, only to be borrowed, stolen, or reinvented by someone else years later. (A good example is the Navy plastic rotating band adopted by the Air Force some 20 years after the Navy abandoned it.) Other items never get into service in the form studied but serve as an inspiration or starting point for another program. Still others had best be entirely forgotten except for the fact that someone else at a later date will come up with a similar idea and if data is not available, will waste time and resources on it. This section will contain some items in each of the above categories.

A. Improvements or Modifications to the GAU-8

Whenever anything is put into the inventory, there are always dozens of people who immediately know how to improve it or adapt it to some other application. In the case of the GAU-8, several improvements have been made (reduced cost TP projectile, for example), several are under consideration (e.g., steel cases), and several have been rejected or ignored. Some of these items have been discussed in earlier sections; some will be discussed here.

The GAU-8 gun and its ammunition were developed and optimized for the air-to-surface role; as such, it utilizes relatively heavy (5,000- to 6,600-grain) projectiles at moderate (3,300 fps) velocity. It was inevitable that someone would decide to see how the round might be improved for surface-to-air and air-to-air application. Improving a round for use against soft maneuvering targets generally consists of increasing muzzle velocity and explosive capacity and decreasing projectile weight and drag coefficient. Some simple calculations show that if the projectile weight was reduced to 4,000 grains, muzzle velocity could be increased to 4,000 fps. At 3,500 grains, 4,250 fps could be expected and at 3,000 grains, 4,500 fps would not be unreasonable. Of course, the projectile shape should also be changed to provide minimum drag for these new high velocity rounds. The first such round to appear is shown in Figure 40 and is an Aerojet proposal of the mid-1970's for the Army Division Air Defense (DIVADS) requirement. It is not known how many were made and fired (if any) or the exact projectile weight or performance. This model is identified as an HEIT, has a secant ogive, boattail, and dummy tracer element. It is obviously a model as it weighs 6,530 grains!

In 1979 the Air Force awarded two contracts to study the air-to-air optimization of the GAU-8 round, feeling that we might be directed to use this round for our next air combat gun. The Honeywell solution shown in Figure 41 is a thin-wall design with a spherical base (and an aerodynamic flow separator), a variation of the pressure rise delay fuze, and selective body embrittlement for fragmentation control. The projectile was in the 4,000-grain class. Muzzle velocity was in excess of 4,000 fps. The other contract was awarded to Avco, and the solution is shown in Figure 42. The rather unusual design of the nose and fuze had two purposes: first, to reduce total weight and, second, to reduce ricochet and fuze wipe-off which are persistent problems in air combat where the average angle of obliquity at impact is on the order of 80 degrees.

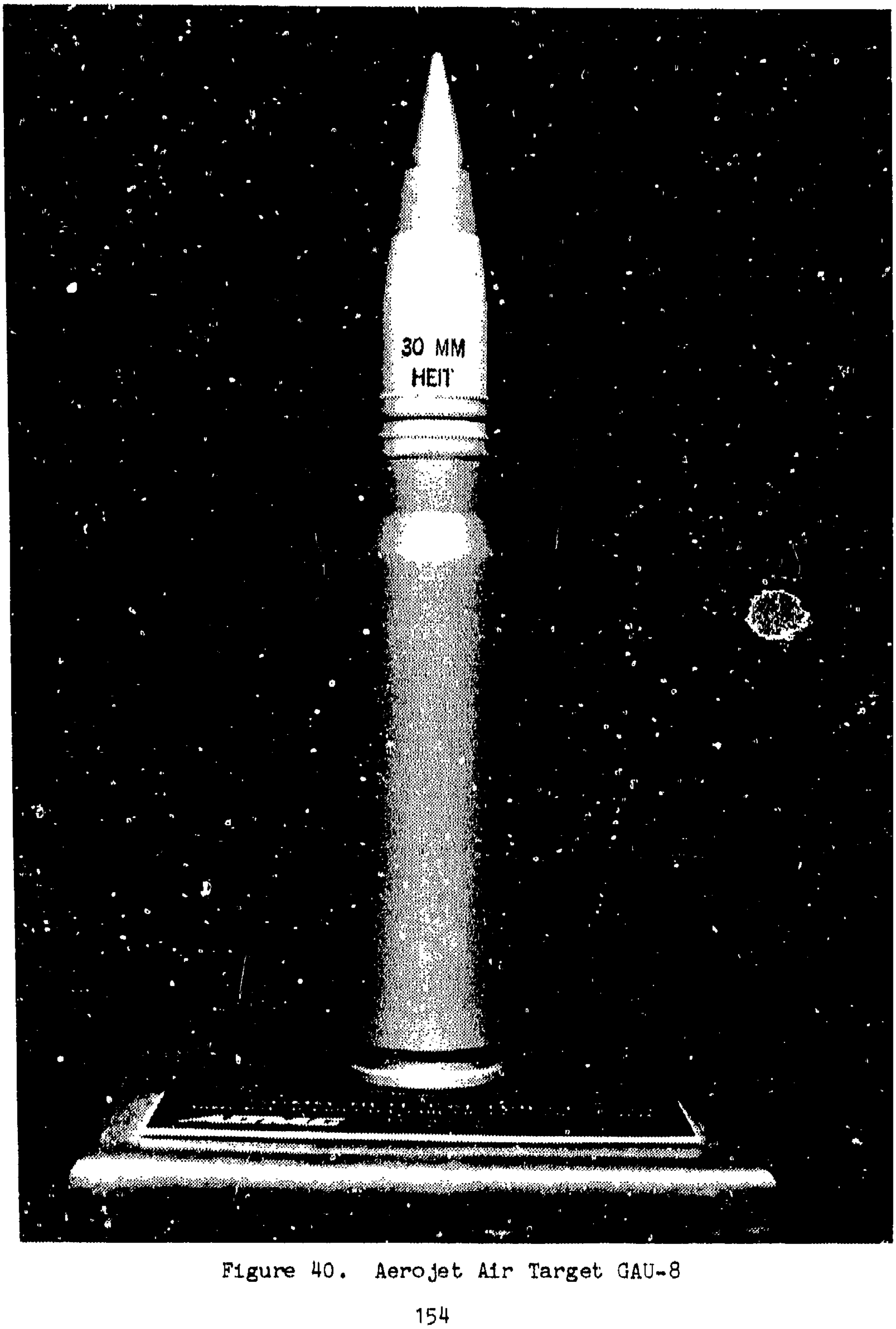


Figure 40. Aerojet Air Target GAU-8

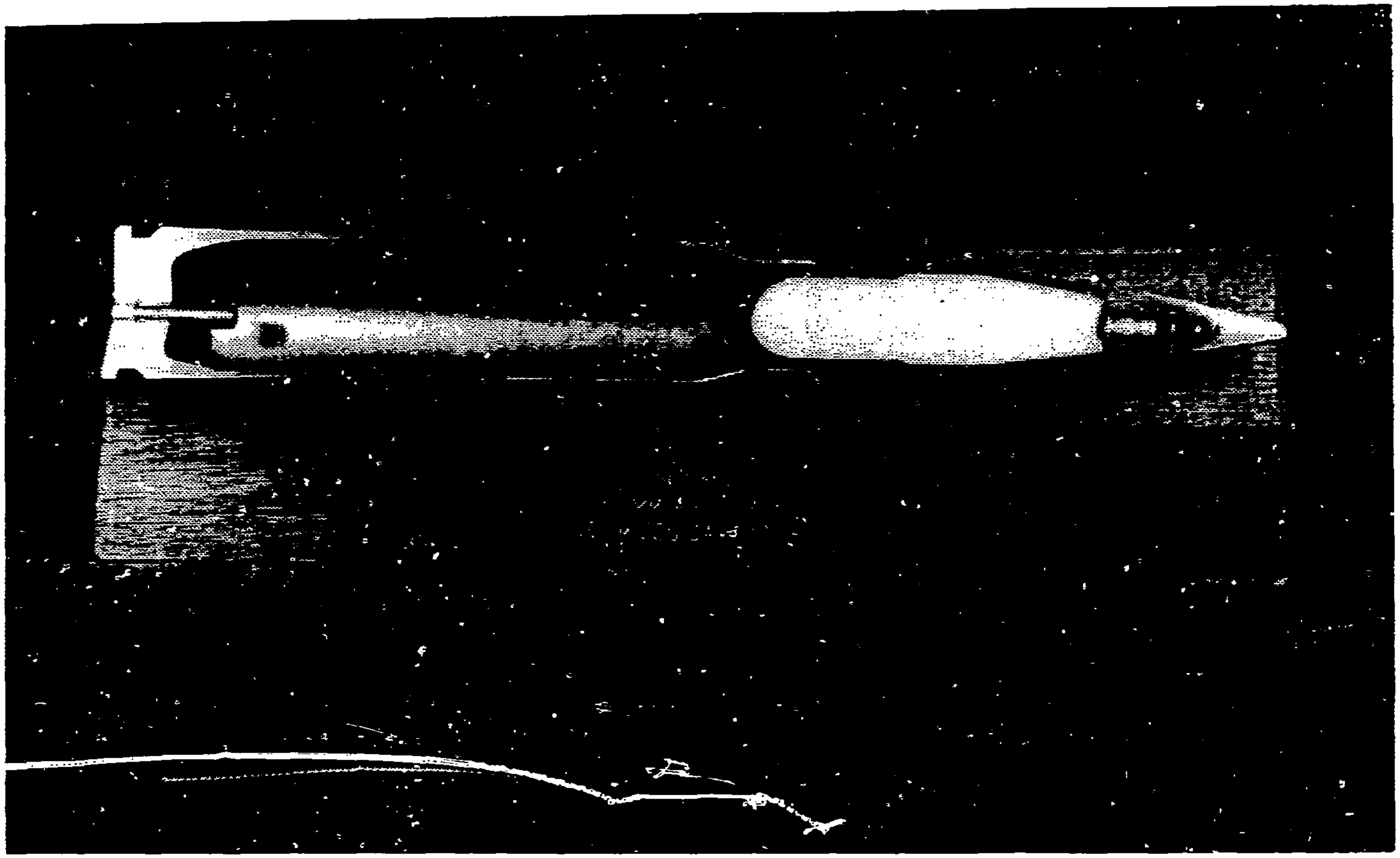


Figure 41. Honeywell Air-to-Air GAU-8

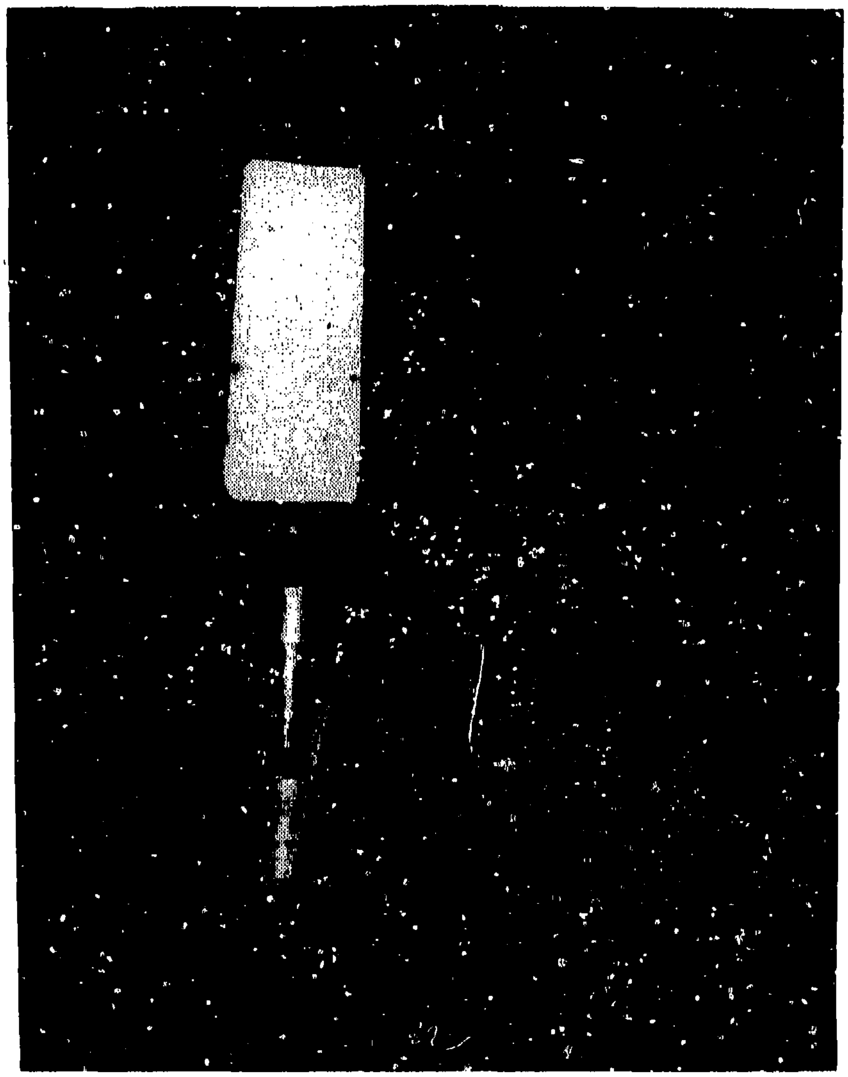


Figure 42. Avco Air-to-Air-GAU-8

A few words about the optimum design of the HE shell are in order. Although we are specifically talking about automatic cannon caliber shells, the same discussion can, for the most part, be applied to bomblets, grenades, mortar shell, pipe bombs, or any other explosive device intended to obtain the maximum part of its lethality from fragmentation. It can easily be shown that the lethal efficiency (defined as the summation of the mass of the fragments multiplied by the velocity of the fragments raised to the 3/2 power divided by the total weight) of a cylindrical device with common explosives reaches a maximum when the device has a charge to mass (C/M) ratio of about 1.0. This efficiency is within 90% of its maximum at C/M ratios of 0.5 to 2.5. When one considers that further lethality is added by blast and incendiary effect, it is obvious that the C/M should be biased toward the high side, i.e., greater than 1.0. The only time the C/M should be less than one is if the shell wall becomes so thin it will not withstand firing and impact loads, or it would break up into fragments too small to be effective against the intended target. The use of controlled fragmentation techniques has been shown on several occasions to be a waste of time and money. Because of the wide variance of hardness in target aircraft components, it was found (in the GAU-7) that random fragmentation (so long as the fragments were not too small) was as good as, or better than, controlled fragmentation. A correct conclusion can easily be drawn from this discussion: An optimum shell for use against aircraft or other soft targets can be designed simply by making the shell wall as thin as practical to stand firing and target impact loads, heat treating or cold working to provide maximum fragment size, filling it with an HEI mix, and equipping it with a delay fuze. Although not commonly used in the US, a base fuze is probably better than a nose fuze since the fuze is not as apt to wipe off on impact and the shell is not as prone to break up.

B. GAU-8/25 mm

With the demise of the GAU-7, which failed because of undesirable characteristics of caseless ammunition, there was still interest in a gun (and round of ammunition) which could fire 3,000-grain 25 mm shells at a muzzle velocity of 4,000 fps. We took some GAU-8 cases (which are nominally 6.8 inches long), shortened them, necked them to 25 mm, and installed GAU-7 projectiles. Shown in Figure 43 on either side of a GAU-8 round are two versions, one with a 6-inch case and a 10.1-inch overall length and the other with a 5.65-inch case and a 9.75-inch overall length. Both rounds were capable of 4,000 fps muzzle velocity, matching the GAU-7. If the same techniques were applied to the current 2,300-grain 25 mm shell used in today's telescoped ammunition (Figures 25(Q), (T), and (U)), one could expect a muzzle velocity of 4,500 fps and an overall length of 9.0 inches. At the time this work was done (mid-1970's), the F-15 was committed to the M61; and as is typical in peacetime, no one was willing to invest money in guns or ammunition for future fighters, so nothing further was done.

C. Other 30 mm Ammunition

There are four 30 mm rounds of ammunition that should be mentioned because they have some historical interest or relationship to other ammunition. Because of this relationship, three other inventory rounds must also be illustrated.

Figure 44(A) (see also Figure 5) illustrates the 30 mm DEFA/ADEN round derived from the German MG213/30 of World War II. It is used in a revolver gun in more different types of free world aircraft than any other round. It

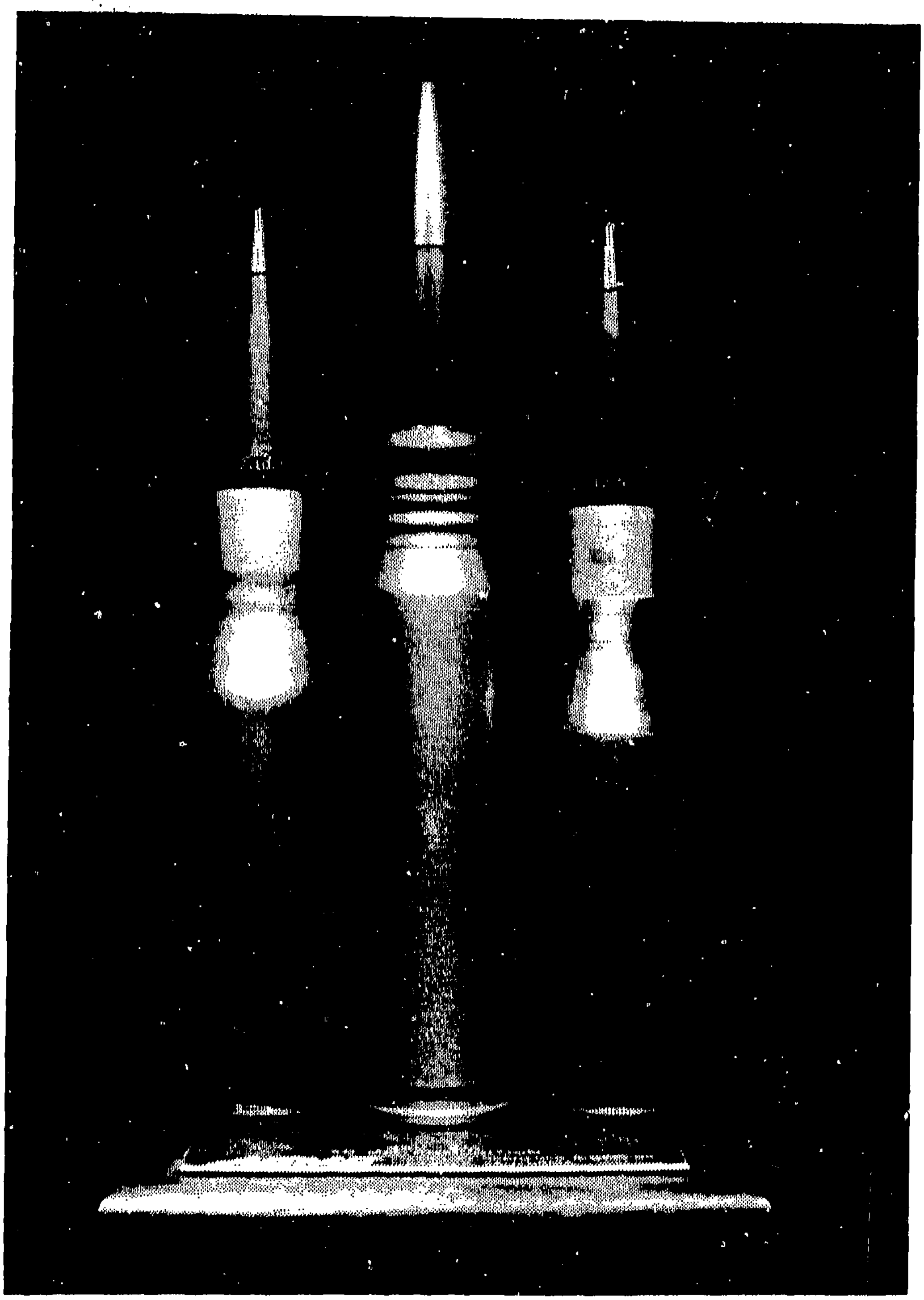


Figure 43. GAU-8 and GAU-8/25 mm Rounds

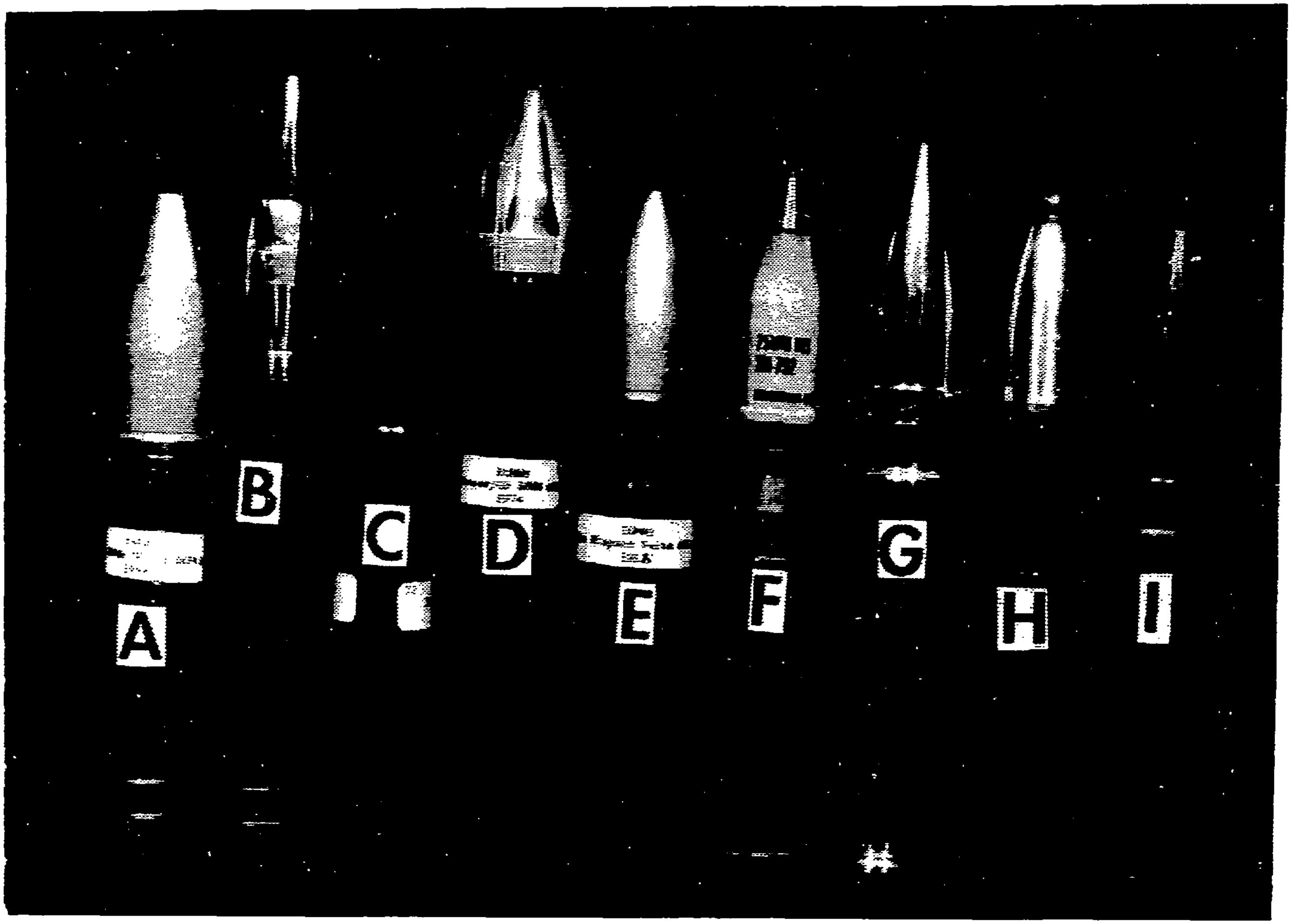


Figure 44. Miscellaneous 25-30 mm Rounds
A. 30 mm DEFA (1968), B. 27 mm Mauser (1971), C. 27 mm Mauser Case (1972), D. 30 mm Mauser/GD (1974), E. 30 mm Hispano-Suiza 825 (1956), F. 25 mm Bushmaster (1977), G. 25/30 Aluminum Dummy (1977), H. 25/30 Dummy (1978), I. 30 mm T168 (1953)

is perhaps only natural that the Germans should use this round as the basis for their new 27 mm Mauser round for the German/Italian/British MRCA aircraft gun. Figure 44(B) is a cigarette lighter given to the author by Mauser some years ago, represented to be a dummy of the MRCA round. Its dimensions, except for length and neck diameter are essentially identical to the DEFA. Figure 44(C) illustrates a later version of the Mauser case dated 1972 and obtained through independent sources. Its obvious difference is in the dimensions of the belt. Not so obvious is the fact that the case is 2 mm longer and 1.5 mm larger in diameter than its predecessors, minor dimensional changes on the surface, but sufficient to add 9% to case capacity, hence energy. This 27 mm round is mentioned here only because it forms the basis of the 30 mm round shown in Figure 44(D) which is the result of collaboration between Mauser and General Dynamics/Pomona on a new round for use in a Close-In Weapon System (CIWS) for the defense of ships at sea against incoming missiles and low flying aircraft. General Dynamics/Pomona designed and built the Phalanx system now in use which mounts the M61 gun and fires an armor piercing discarding sabot (APDS) round. This new round was an attempt to upgrade the existing system in range and lethality. This round is dated 1974.

One of the earliest attempts to design an optimum cartridge for air combat must be credited to Hispano-Suiza of Geneva, Switzerland. The round they developed in the mid-1950's is illustrated in Figure 44(E). It fired a 3,500-grain projectile at 3,600 feet per second muzzle velocity. Designated the HS825, it was well ahead of its time, being unquestionably the best air-to-air round of its day. Not only that, it is better than any air combat round used by any nation today, almost thirty years later. The reason it is included here is that we bought and tested these rounds in the mid-1950's. There was, and is, nothing wrong with the round. The only problem was that the gun designed to fire it was junk! The gun was a gas-operated affair wherein the gas pistons acted on two spur gear pinions which were engaged with a fixed rack in the receiver and a movable rack on the bolt body. This design, operating at a mechanical disadvantage of 1:2, provided a motion multiplication of the bolt relative to the gas piston of 2:1. Rack and pinion gears simply do not work well under impact loading, especially under the backlash, clearance, deflections, and binding normally associated with an operating gun.

Recognizing that the 30 mm GAU-8 round was really too big to be seriously considered for a pure air-to-air role and that the M50-series 20 mm was really too small, the author began in 1976 to design a conventional cased round of ammunition which might be politically and logistically supportable in this role. Of course there was the HS825 mentioned in the previous paragraph, but it did not seem logical to tout a 20+ year-old round of foreign ammunition as being the best we could do. There was also the Army 25 mm "Bushmaster" round (Figures 44(F), 2(A), and (4)) which was dimensionally in the range desired, but it had iron rotating bands (unsuitable for our firing rates), and the HE capacity was considered to be too small. The approach taken was to utilize the 25 mm case (existing tooling) necked to 30 mm, with a high capacity lightweight 30 mm shell and a pressure rise delay fuze. All of the design work was done in-house, and a round of ammunition was defined having a projectile weight of 3220 grains, a 944-grain HEI filler charge and a muzzle velocity of 3,600 fps. A turned aluminum dummy of this configuration is shown in Figure 44(G). Honeywell was aware of what we were doing and built some dummy projectiles, complete with pressure rise fuzes, and inserted them into Bushmaster cases with expanded necks. Figure 44(H) is such a round and looks right except that the shoulder is too far aft. None of these rounds were built and fired; however, their design was within the state-of-the-art and the computed performance could be guaranteed. About this time, however, it became obvious that the Tactical Air Command was interested in expanding the encounter envelope to all angles and extended ranges with emphasis on deflection shooting. This required muzzle velocities of 4,500 to 5,000 fps and conventional cartridge cases as large as, or larger than, the GAU-8. We renewed our emphasis on telescoped ammunition in order to get the desired performance within cartridge volumes which could be accommodated on our aircraft. So much for another good idea!

No discussion of USAF-developed 30 mm aircraft ammunition can be considered complete without including the reverse tapered case round designed for the T168 gun, as illustrated in Figure 44(I). This unusual configuration is not for any ammunition or ballistic reason; rather, it was done to accommodate some unusual gun features. At this time (early to mid-1950's), one of our major gun applications was for bomber defense on our almost sacred (at that time) strategic bombers. For turret mounts, it was desired to keep guns as short and compact as possible. Also, it was desirable to pivot them near their center of gravity, and for purposes of simplifying feed chuting, it was desirable to feed them as near the elevation pivot as possible. Revolver guns, in vogue at the time, were all wrong. The feed, rammer, chuting, etc. were all aft of the drum. The center of gravity was at or forward of the drum. If the drum could be fed from the front rather than from the rear, the gun could be shortened to only slightly longer than the combined length of barrel and drum. The feed belt could enter at the center of gravity through a hollow trunnion, and the whole bomber defense turret would be simplified. This was done in the T168 gun and resulted in the round shown. Being a contemporary of the T182 gun and the T204 round (Figure 5(G)), it shared both projectile (3,200 grains) and ballistic performance (2,700 fps). It also shared in the demise of all gun and ammunition development during the late 1950's. Incidentally, the Russians, who still put defensive gun turrets on all of their bombers and transports, are rumored to have a similar gun and ammunition in their inventory for the same reasons.

D. Plastic-Bodied Projectiles

Two earlier sections treat the use of plastic bodies on projectiles for specific purposes: armor piercing projectiles and frangible target practice projectiles. During the late 1960's and early 1970's, other attempts were made to take advantage of cheap injection molded plastic projectile bodies. Some typical examples in 20 mm are illustrated in Figure 45. These were all done by AAI Corporation at the suggestion of the Armament Laboratory. They are in two series: base loaded and nose loaded. There are also two types of projectiles in each series, frangible TP and what might be termed "structural and incendiary damage." Figures 45(A), (B), and (C) illustrate one of the first washer stack projectiles, showing (A) the washer stack, (B) plastic core and base filler which is inserted into the washer stack before they are inserted into the plastic jacket, (C) and closed with the base plug. About this same time, we were investigating the incendiary effects of mischmetal and had also observed that many plastics, being chlorinated or florinated hydrocarbons, tended to be good oxidizers, apparently releasing florine or chlorine when subjected to explosive or high

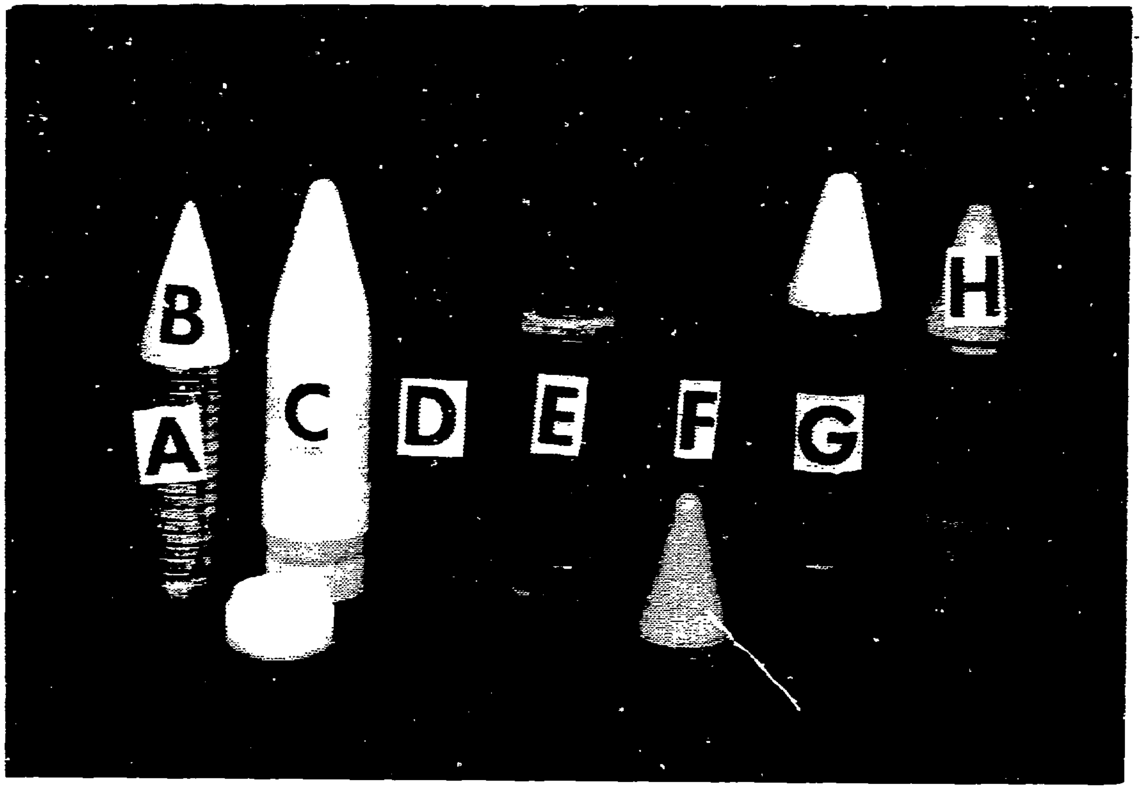


Figure 45. Plastic-Bodied Projectiles
A. Washer Stack, B. Nose Filler and Core, C. Jacket and Base Plug,
D. Mischmetal Core, E. Octagonal Platelet TP, F. Octagonal Cored Projectile,
G. Mischmetal Cored Projectile with Teflon® Nose, H. Keyed Disc TP

velocity impact loads. It was only a natural step then to substitute a mischmetal insert (Figure 45(D)) for the washer stack and core filler. The configuration of the plastic body was later changed, eliminating the base plug and moving the joint to the nose. The body cavity was changed from cylindrical to octagonal and octagonal platelets substituted for the steel washers in the TP round (Figure 45(E)). Of course, this redesign also required an octagonal mischmetal core (Figure 45(F) and an enhancement of incendiary effect was obtained by substituting a teflon® nose plug (Figure 45(G)). The last illustration in this series (Figure 45(H)) is unique and may have been a transition between the base plug cylindrical cavity models and the nose plug octagonal version. This figure has a cylindrical cavity with four internal ribs running full length. The platelets are punchings with four equally spaced notches which key them to the body. This model is different from the others also, as it has what appears to be a 41% glass-filled nylon body.

Some general words about plastic-bodied or plastic-jacketed projectiles is in order. It is quite possible to make a few R&D models of something as shown here, fire them in a Mann barrel, and have them behave fairly well. However, when plastic-bodied projectiles are fired in dynamic guns with barrel whip and oversize, overheated barrels, the bourrelet and base become engraved, in-bore yaw results, causing as a minimum unacceptable dispersion and, quite frequently, projectile break-up. When constrained to existing conventional chamber designs, the only solution is to resort to installing steel bore riders fore and aft on the projectile. If one were starting from the beginning or were free to modify the chamber, a less expensive solution would be to make the entire cylindrical portion of the projectile groove diameter (as is done in small arms), or put a groove diameter rotating band on both front and rear of the projectile.

E. Structural and Incendiary Damage

The term "structural and incendiary damage" was used in the preceding section to describe the type of damage one might expect from a certain projectile. Actually, Structural and Incendiary Damage (SID) was a project name and the name of a specific projectile type in the early and mid-1950's. The work was done by Denver Research Institute through Frankford Arsenal for the Air Force. Although there are no samples of this round in the author's collection, it is easily described as being an M56 shell body (Figure 34(A)) filled with steel balls with an incendiary mix in the interstices. The projectile was, of course, heavier than the standard rounds and its terminal effect, although different, was judged to be less lethal than the standard HEI M56 or the API M53.

F. Armor Piercing Projectiles

The evolution of armor and armor piercing ammunition is a continuous see-saw. The improvement of one forces a requirement for the improvement of the other. There have been many different types of armor piercing shot and shell, and the goodness of each must be judged in light of the known or intended target and of the time it was developed. By today's technology, the best armor penetrator is considered to be the fin-stabilized discarding sabot-type discussed under flechettes above. The second best is the spin-stabilized discarding sabot-type used on the Army 25 mm Bushmaster round and the Navy 20 mm Phalanx system. To date, we have been unable to tolerate sabots on aircraft guns, so we have been precluded the use of best armor piercing technology.

Another armor penetrating technology that has enjoyed great popularity since World War II is the shaped charge. It has seen only limited use in aircraft guns for two reasons: aircraft guns are generally small caliber, limiting shaped charge effectiveness; and the high spin rate required to stabilize high velocity forward-firing ammunition causes sufficient Coriolis acceleration to drastically degrade jet formation and penetration over an equivalent non-spinning cone. The Army did utilize shaped charges in the high explosive dual purpose (HEDP) shell for the WECOM 30 and also has an HEDP shell for their DEFA/ADEN configuration round for the Chain Gun on their new Advanced Attack Helicopter (AAH). Also GE, some years ago, investigated a German-designed "flat cone shaped charge" which was professed to suffer less degradation than conventional liners. It was tested and compared to the GAU-8 and found, in general, to be less effective. Other than these two cases, kinetic energy penetrators carried in full caliber shot or shell have been the standard for anti-armor aircraft guns.

Some typical examples representing the large range of AP designs tried and/or used are illustrated in Figures 46 and 47. The first, Figure 46(A), is the AP core from the 20 mm M53 round. It is short and stubby and not very effective by today's standards. It looks like just what it is: a shortened version of the pre-World War II designed 20 mm M95. It is shortened because the M95 projectile weighed 2,000 grains and the M53 weighs 1,546 grains. Although not an outstanding penetrator, it is quite effective for what it was intended to do: punch holes through aircraft structure, engines, and seat armor. During the late 1960's and early 1970's, Lake City Arsenal, the procurement agency for 20 mm ammunition, developed, under Product Improvement, some more effective API designs. Figure 46(B) was designated LC-34-P, and

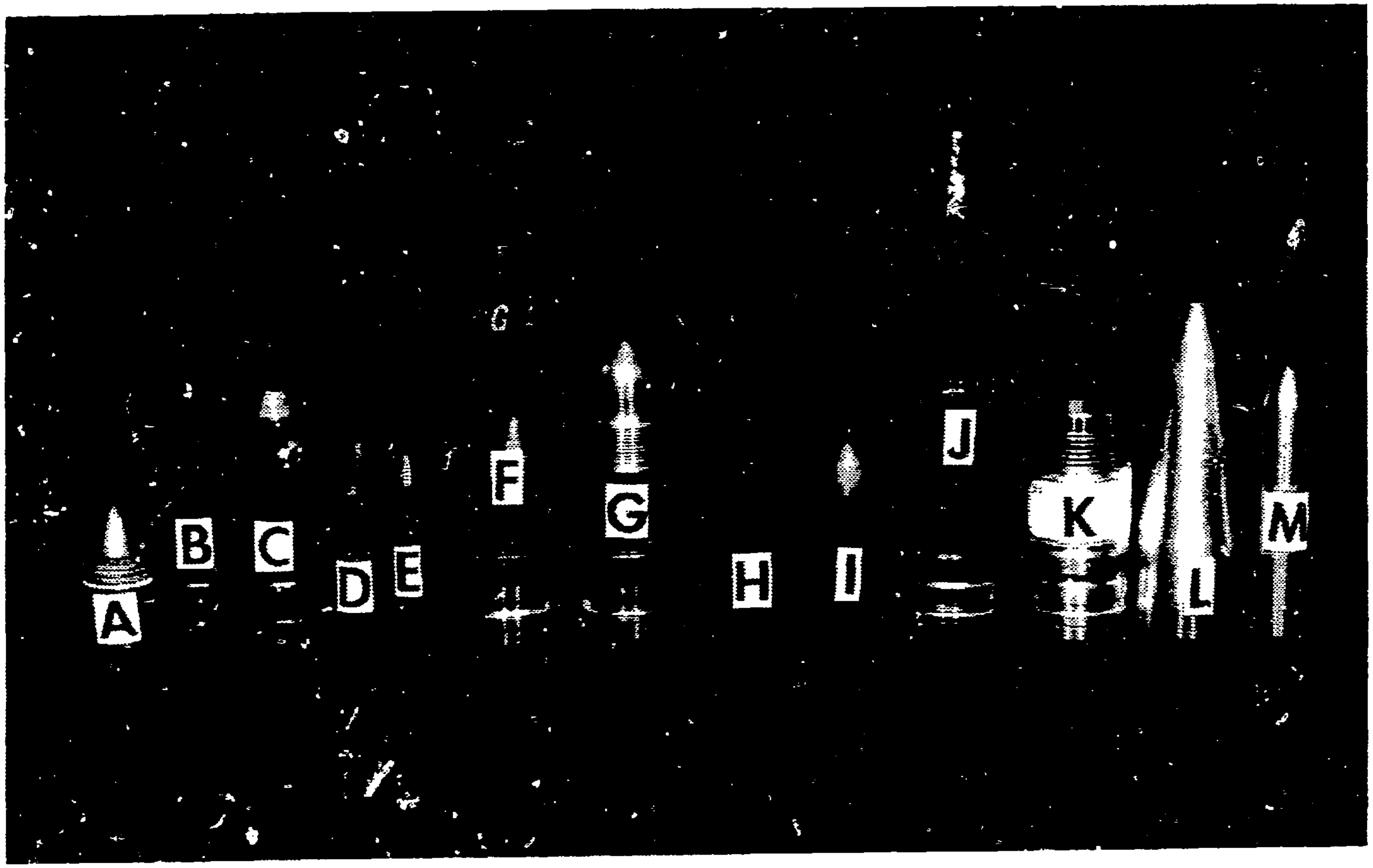


Figure 46. Armor Piercing Projectiles
A. 20 mm M53 Core, B. 20 mm LC-34-P, C. 20 mm LC-59-P, D. Tungsten Core, E. Tungsten Core, F. 30 mm ADEN AP MK/1Z Projectile, G. ADEN MK/1Z less Windscreen, H. ADEN Windscreen, I. ADEN Tungsten Core, J. 30 mm GAU-9 AP Projectile, K. GAU-9 AP Base and Connector Sleeve, L. GAU-9 Forebody, M. GAU-9 Tungsten Core

Figure 46(C) was designated LC-59-P. They are dated 1970 and 1974, respectively. They are aluminum-capped full body penetrators with base cavities for incendiary fills. These designs are acceptable ballistic matches to the M50-series rounds. Other improved AP shot and shell, developed by the Armament Laboratory about this same time frame, are discussed in an earlier section on Improved 20 mm Ammunition and illustrated in Figure 17. Still other independent work was done, including the sub-caliber tungsten cores shown in Figures 46(D) and (E). Such cores as these could be expected to maximize the penetration of 20 mm shot, but to what advantage? They still would not penetrate heavy armor, and the less expensive steel penetrators will defeat the vast majority of realistic targets. There simply is no use in developing ammunition to defeat targets that do not exist. The origin of these two cores is unknown.

The next four illustrations, Figures 46(F) through (I), illustrate the sub-caliber tungsten carbide-cored British 30 mm MK/1Z projectile for the ADEN gun. The shell body and nose cap are both aluminum; the rotating band is copper. All-up projectile weight is 4,190 grains; the core weight is 2,255 grains. Being a reasonably well designed projectile but a low velocity gun, the author would estimate it to penetrate about one inch of homogeneous armor at zero obliquity from nominal ranges. Enough for armored personnel carriers, not enough for tanks. The next four illustrations, Figures 46(J) through (M), show the GAU-9 AP projectile as submitted by Hughes for competition against the GAU-8 in the early 1970's. It is probably very close to, if not an exact copy of, the Oerlikon 304RK (KCA) round, as, in fact, the GAU-9 was a slightly modified Oerlikon 304RK. Both front and rear body sections are aluminum, joined by an internal steel sleeve threaded to both halves. The core is supported by a loose slip fit on both ends and has an interference fit in length. An incendiary mix was inserted between the core and body in the front section. The total projectile weight without incendiary filler is 5,680 grains; the tungsten core weighs 3,475 grains.

The sequence of projectiles and components shown in Figure 47 evolved during the early phases of the GAU-8 program. During this time, the contractors were charged only with the development of steel AP shot and SAP shell. The high density DU penetrator work was being done separately; it was considered sufficiently critical and specialized to warrant a separate program (see Section VII). Figures 47(A), (B), and (C) are the components of an early design done under the Ford contract. It consists of a steel base cup, a high L/D steel penetrator, and a plastic windscreen. The penetrator is centered at the base by a press fit of the knurled base of the penetrator into a recess in the cup. The penetrator is centered at the front of the cup by a ring shown in Figure 47(B) which is a slip fit over the core and inside the cup. In this model it is held in place by a rubber "O" ring; there is no apparent means to prevent it moving aft under setback except that the aft section contained incendiary filler. Obviously, this is a concept model, not a functional round. Another problem that would have occurred with this round, especially in a hot (oversize) barrel, is that the front part of the penetrator, being cantilevered, would probably bend in the bore due to centrifugal force and in-bore yaw. The next model, shown in Figures 47(D) and (E), utilizes a machined steel body and penetrator, hollowed out at the base, and a plastic windscreen. The concept of this round was that the total inertia of all metal parts would be concentrated on the relatively small spike penetrator, producing high and sustained dynamic pressure at the interface. In-bore

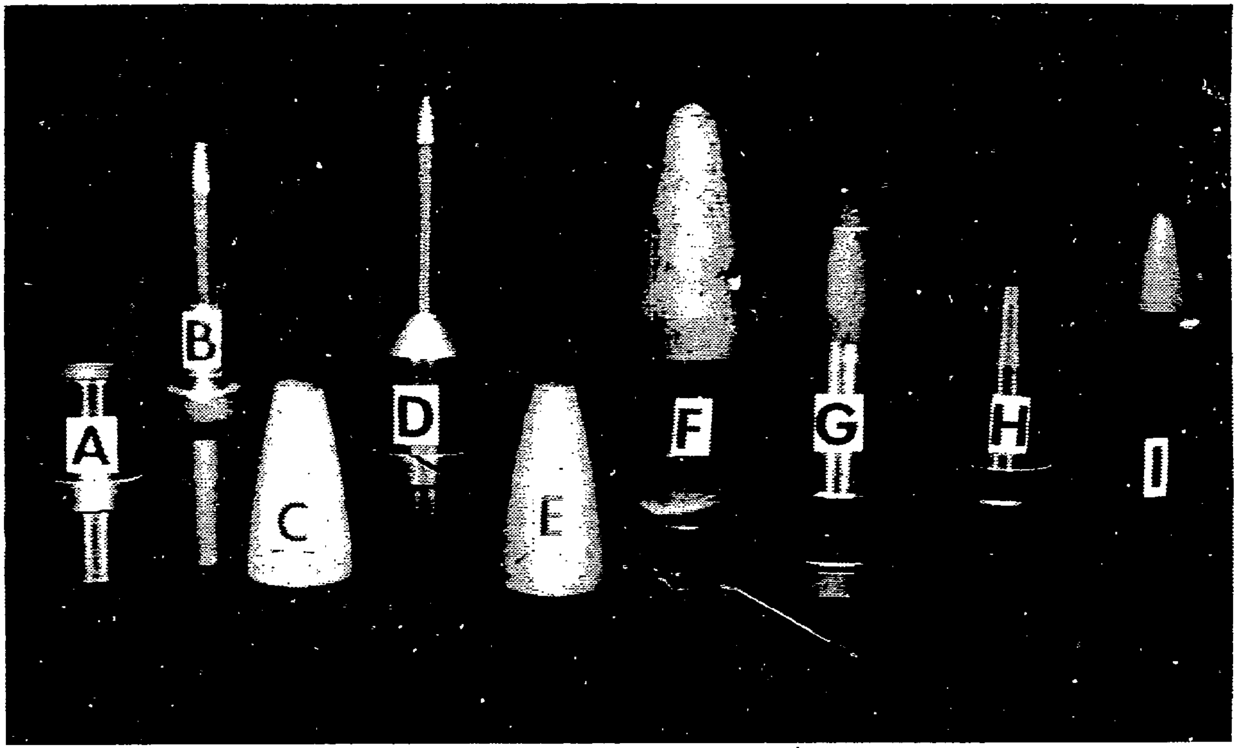


Figure 47. GAU-8 R&D AP Projectiles.
A. Base Cup, B. Rod Penetrator, C. Plastic Windscreen, D. Body and Penetrator, E. Plastic Windscreen, F. Steel and Plastic Shot, G. APHE Shell, H. API Shell, I. API Shell Windscreen

bending of the cantilevered spike could have been a problem here also. Figure 47(F) is a still later design from the Ford program consisting of a solid steel nose stepped down to about 3/4-inch diameter, knurled, and with a plastic rotating band and base molded over the knurled portion. The center of gravity of this projectile is so far forward it might have been unstable. It is not known whether these three projectiles were actually designed by Ford or by its subcontractor, Honeywell.

The next two shells, illustrated in Figures 47(G), (H), and (I), were believed to have been made by Aerojet for General Electric. Both are obviously demonstration models, as the one in Figure 47(G) has no windscreen or provisions for one, whereas the shell in Figure 47(H) has a windscreen shown in Figure 47(I), but it has no crimp groove. The model in Figure 47(G) was obviously designed to contain an HE load, as it has an aluminum base plug which can be screwed out to reveal a fuze. The model in Figures 47(H) and (I), on the other hand, was intended to be API only as indicated by the color code and the fact that although the projectile is hollow from the base, it is closed by a base plug which is obviously not a fuze. The APHE shell in Figure 47(G) weighs 5,375 grains; the API shell weighs 5,500 grains.

During full scale development (engineering development) of the GAU-8 system, the prime contractor (GE) was given responsibility for integrating our separate DU penetrator technology work into the GAU-8 system. Our contract with AAI had developed a projectile and penetrator, Figure 14(G) (see also Section VII), which were capable of defeating the required armor; and General Electric, through their ammunition subcontractors (Aerojet and Honeywell), was charged with delivering that penetrator on target. They chose not to use the plastic encapsulation technology; rather, they wished to use an aluminum base with the penetrator pressed in place and covered by a windscreen. (See Figure 8 for the final Honeywell configuration.) When this long tapered penetrator was mounted in such a fashion, slightly over three inches of it was cantilevered; as a result, imbalance, centrifugal force, and low modulus of elasticity caused catastrophic in-bore bending of the penetrator. The contractor's solution, approved by the A-10 System Progam Office (SPO), was to make a shorter, stubbier, less efficient penetrator compatible with their preferred carrier design. At the Armament Laboratory, we worked on an alternate design that would carry the preferred penetrator. Our concept called for supporting the penetrator at the nose and base within a monocoque steel shell and supporting the midsection with a plastic filler. The shell was made by modifying dies for a 20 mm cartridge case (Figure 48(A)). The base was then machined (Figure 48(B)) to center the penetrator. (In production, this would have been cold formed.) The core was inserted, a plastic filler dropped down over it, and the ogive necked down to retain an aluminum nose piece which centered the penetrator nose. Figures 48(C) and (D) show two minor variations of this design. Although this work, which was done by Amron, was a technical success, it did have problems. First, of course, bonded banding technology was not in hand. Second, the extreme cold working of the steel near the nose resulted in excess work hardening and occasional cracking. By this time, however, the A-10 SPO had accepted the GAU-8 ammunition designed with a shorter penetrator, so our work was stopped.

The development of a 30 mm RAP projectile (see Section XVI and Figure 30(B)) by AAI by 1976 had inadvertently resulted in a monocoque round similar to what we had been attempting to do. Since the Improved 20 mm program had HEI and TP rounds but no API, we contracted with AAI to demonstrate a 20 mm

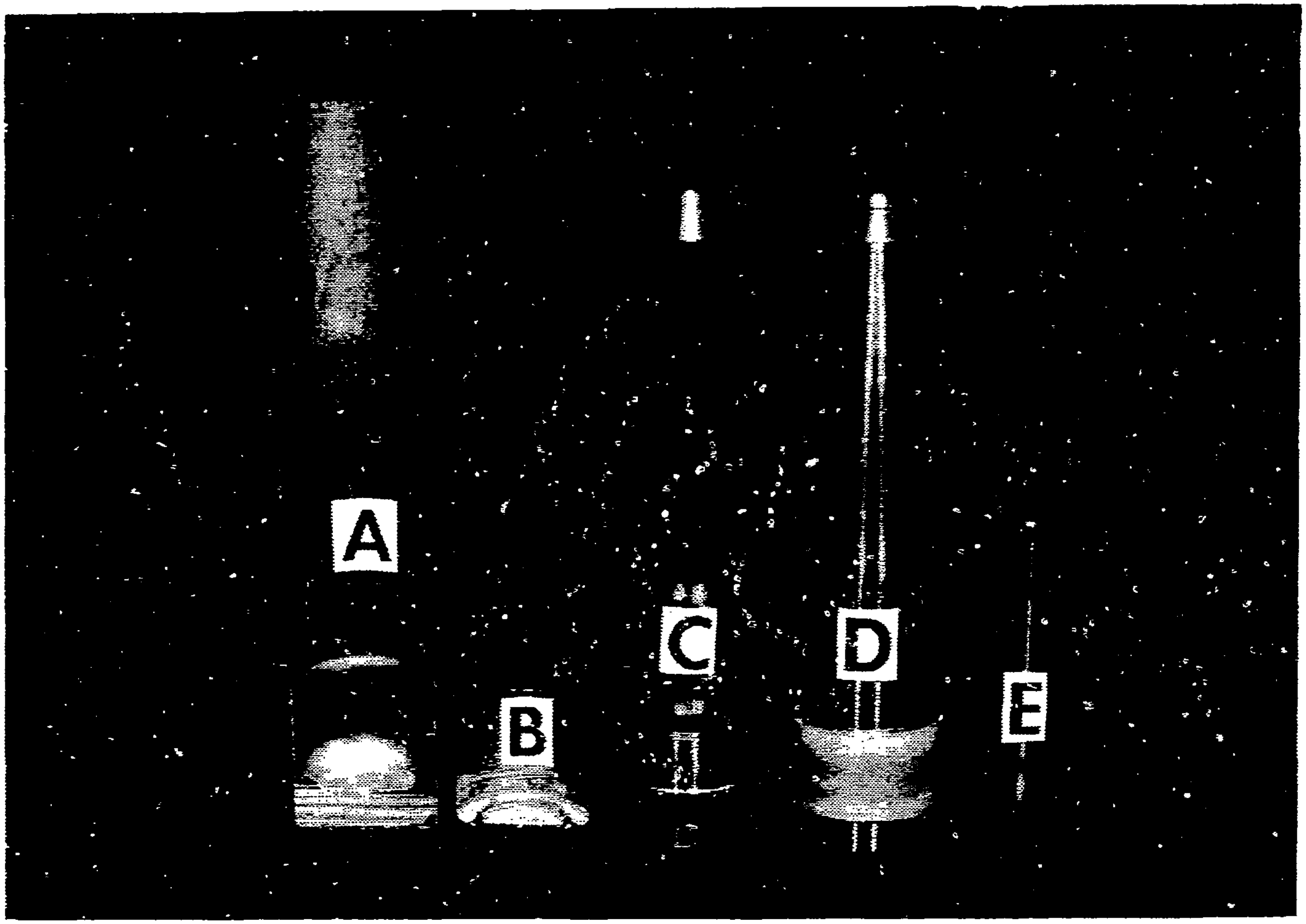


Figure 48. Monocoque Projectiles
A. Drawn Casing, B. Base Detail, C. Unbanded Assembly,
D. Variation with Band, E. AAI 20 mm Monocoque

API monocoque projectile ballistically similar to the Improved 20 mm but using a DU penetrator to maximize penetration. Figure 48(E) is the result of that contract. This projectile is dated 1979. Although this R&D model is all machined, it is obvious that a similar design could be made inexpensively from cold formed metal parts. The monocoque design has three major advantages over the production GAU-8 design: it permits the delivery of longer penetrators because of better support; it permits an increase in ratio of axial to transverse moments of inertia, thus stabilizing longer rods; and it eliminates the possibility of rifling engraving on the aluminum body used in the GAU-8 round. Some variant of these monocoque designs is the best non-sabot AP technology available today.

G. Tubular Projectiles

The ability of a projectile to retain its launch velocity is a direct function of the ballistic coefficient W/C_dA, where W is the weight, C_d is a drag coefficient which results from shape and finish, and A is the cross-sectional area of the projectile. For at least the past 100 years, possibly as long as we have been firing spin stabilized projectiles, someone has periodically suggested drilling a hole axially through the projectile to "let the air through" or, in practice, reduce the cross-sectional area. Another way of looking at it, even with modern knowledge, is that if 50% of a projectile's drag is nose drag and 40% is base drag, then eliminating much of the nose and base should significantly reduce drag. Over the years, this had been tried many times. Even as late as World War II, this was tried at BRL with the 20 mm TP M99 projectile. It never worked as expected. The reason was quite simple. No one understood supersonic aerodynamics, especially supersonic flow through tubes. The flow would choke so that the flow through the tube was subsonic, much below the projectile velocity. The resulting drag was higher than it would have been had the projectile not been drilled!

The idea was resurrected again in the 1970's. By this time, the Armament Laboratory had a good aeroballistic range and personnel knowledgeable in supersonic aerodynamics. In the mid-1970's, we ran a series of experiments by varying diameter ratios, nose and base angles, and area ratios in convergent and divergent nozzles. We were able to specify conditions under which supersonic flow could be established and maintained through the tube. Many people and organizations became excited with this new technology. Many different designs were built and tested for many applications varying from short range target practice (they could be made light and designed to choke at will) through antiaircraft (they were light, could be fired at high velocity, and cut big deep holes) to armor piercing (high sectional density yields good penetration). Figure 49 illustrates one model tested by the Armament Laboratory. It weighs 2,300 grains, and even with a stable pusher/base plug, it could be launched well over 4,000 fps from the GAU-8. Some work is still being done on tubular projectiles. Some of the past work is classified. So far as is known, none are in inventory. Like so many technological phenomena of academic interest, it is difficult to find a real application for it.

H. Squeezebore Projectiles

People are always trying to "wicker" the ballistic coefficient one way or another. A low ballistic coefficient makes a projectile easy to accelerate, whereas a high ballistic coefficient enables it to sustain velocity after launch. This accounts for sabot-launched projectiles, both fin- and spin-stabilized, as well as the tubular projectiles just discussed. It also accounts for the squeezebore design attributed to Professor Hermann Gehrlich

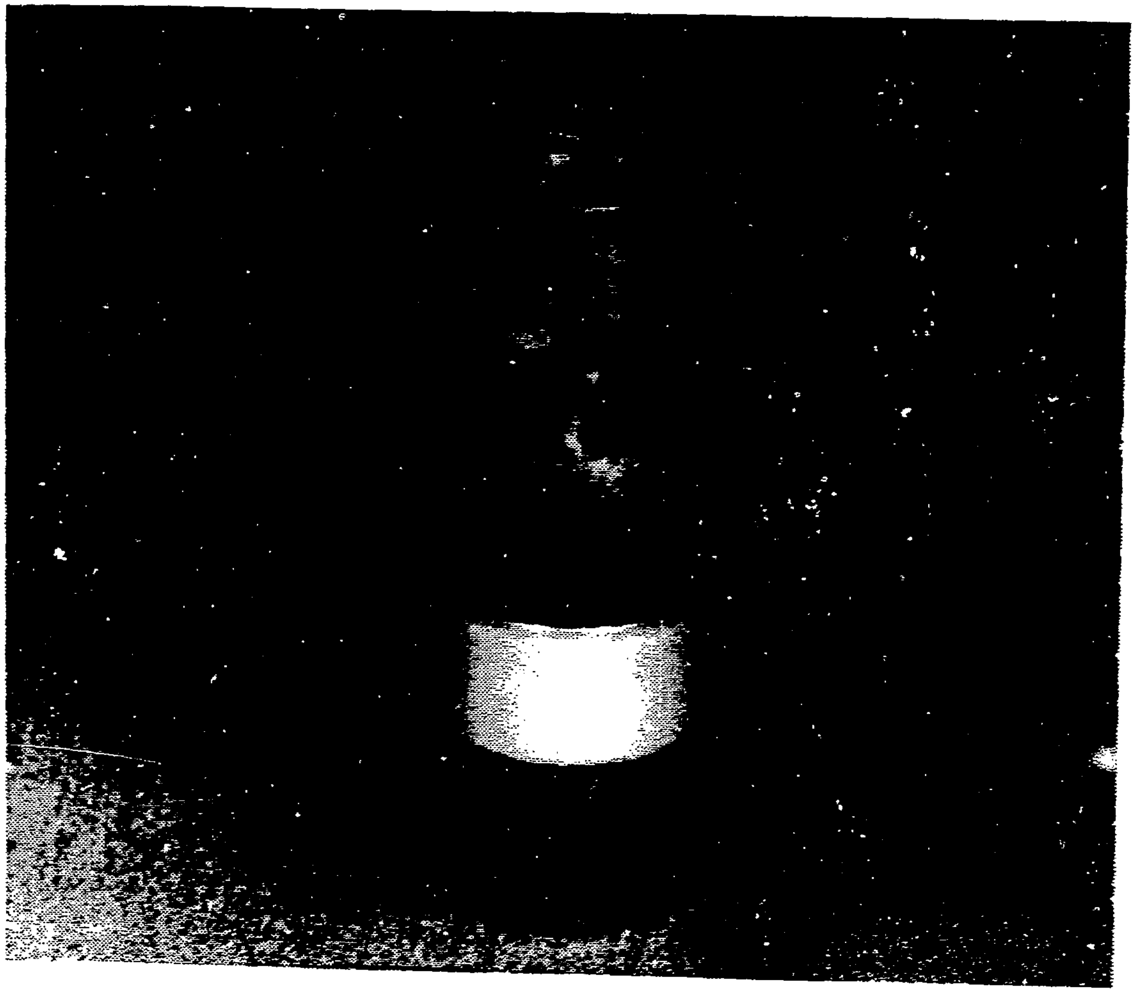


Figure 49. Tubular Projectile

(or Gerlich). The first recorded knowledge of this design in the US was when the German Halger-Ultra rifle was tested at Aberdeen in December 1932. It utilized a projectile similar to, but probably smaller than, the 35/28 caliber Gehrlich projectile illustrated in Figure 50. The concept, of course, is simple; the skirted projectile presents a large area to the propellant gas for in-bore acceleration and is squeezed down to a small area prior to muzzle exit for reduced aerodynamic drag. The Germans produced and fielded at least two weapons using this technique during World War II in 28 mm and 75 mm initial calibers. All such ammunition had problems, one of the major ones being inaccuracy attributed to the fact that the skirts never collapse symmetrically, yielding a dynamically unbalanced projectile.

Like all "good ideas," this one surfaces from time to time. In the early 1970's, we contracted with Colt to investigate the use of extrudable plastic in place of deformable skirts. It was felt that if the major caliber bore rider was made of plastic and the projectile body designed with voids into which the plastic could be squeezed, a symmetrically balanced projectile might result. Several different designs were tried; that shown in Figure 50 in 30/25 mm was the most elaborate. It did not work. Plastic, under rapid loading, simply is too strong to squeeze where you want it to go. So much for another "good idea."

I. Fin-Stabilized Full Caliber Projectiles

In the late 1950's, we were concerned about defending our strategic bombers against a new invention--the guided missile. To summarize, we wanted to fire a relatively large shell filled with small shot toward the missile and scatter the shot in the missile's path. We did not want to use spinning shell or the shot would disperse too rapidly. We developed a fin-stabilized shell

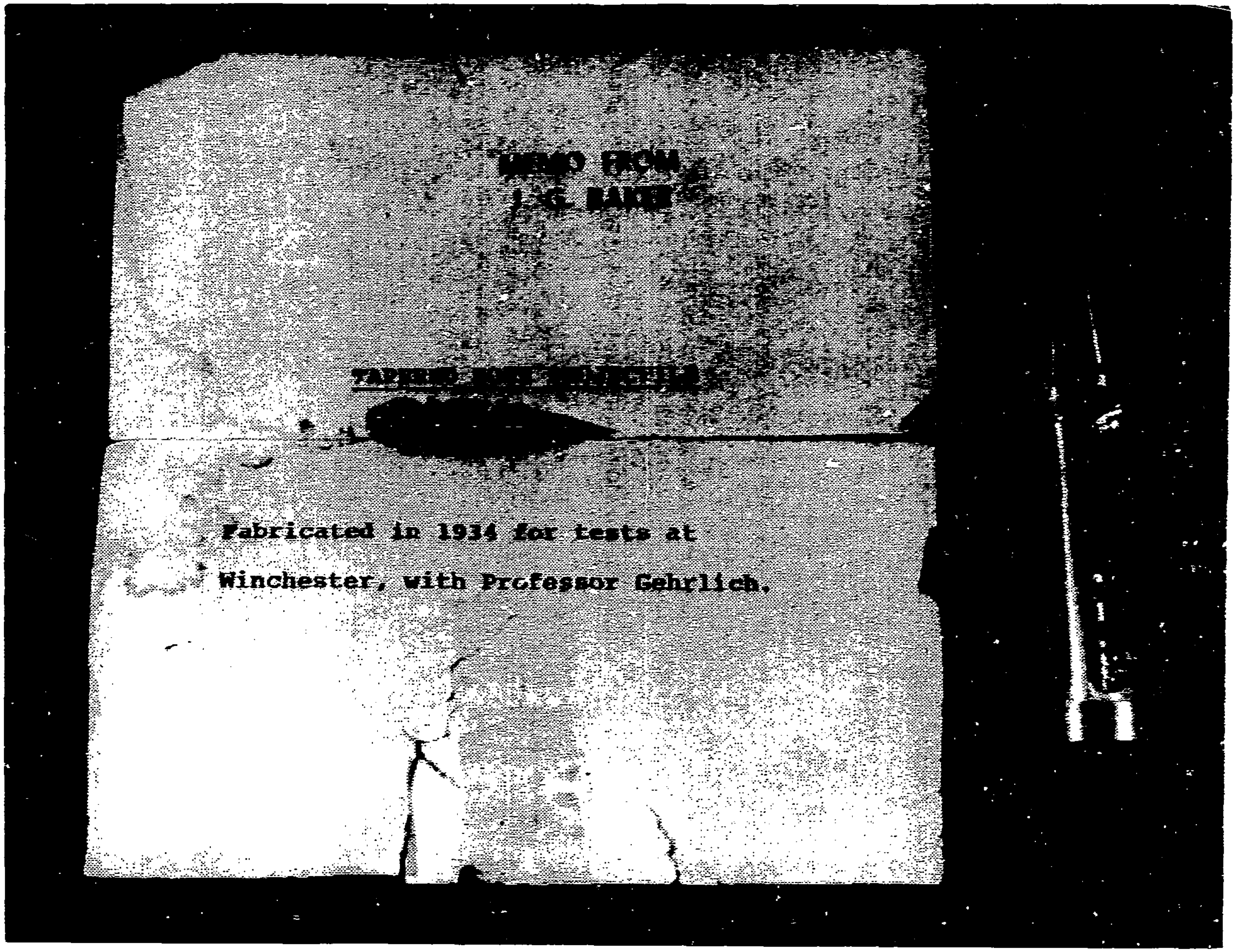


Figure 50. Squeezebore Projectiles

which was compatible with the T239-type round (see Section IV and Figures 5(K) and (L)) and the T182 or T212-type guns. Two variants of this shell are shown in Figure 51. The program was successful as far as it went, but was terminated because it did not have sufficient range to defend against a missile with a nuclear warhead and equipped with a "dead man" fuze.

J. Ablative Cooling Ammunition

Many things have been added to, and in the vicinity of, the propellant charge to modify internal ballistics, prevent coppering, reduce flame temperature, reduce barrel erosion, etc. One idea which we tried was submitted to us by Calspan around 1970. It consisted of placing a bladder of silicone fluid between the propellant and the projectile. When the charge was fired, the bladder broke and smeared the thick silicone fluid over the bore surface, protecting it from the heat of the propellant gas. Being nonflammable itself, it did not cause muzzle flash or interfere with propellant stoichiometry. Figure 52 illustrates such a round in 20 mm. It worked. It had two drawbacks: the ablator displaced propellant, requiring hotter propellant to compensate; and upon firing, a black greasy residue replaced the normal smoke fouling around the muzzles. About the time this technology was perfected, plastic bands were perfected also. The plastic bands were a cleaner solution to our problem at the time. The ablative technique might still be useful at some future date.

K. Recoilless 20 mm

This author is fully convinced that if you wait long enough, someone will propose anything. At one time in the early 1970's, someone felt it would be a good idea to convert the 20 mm to a recoilless system. Figure 53 is a proposed recoilless version of the M55 round. Of course, it could be done.

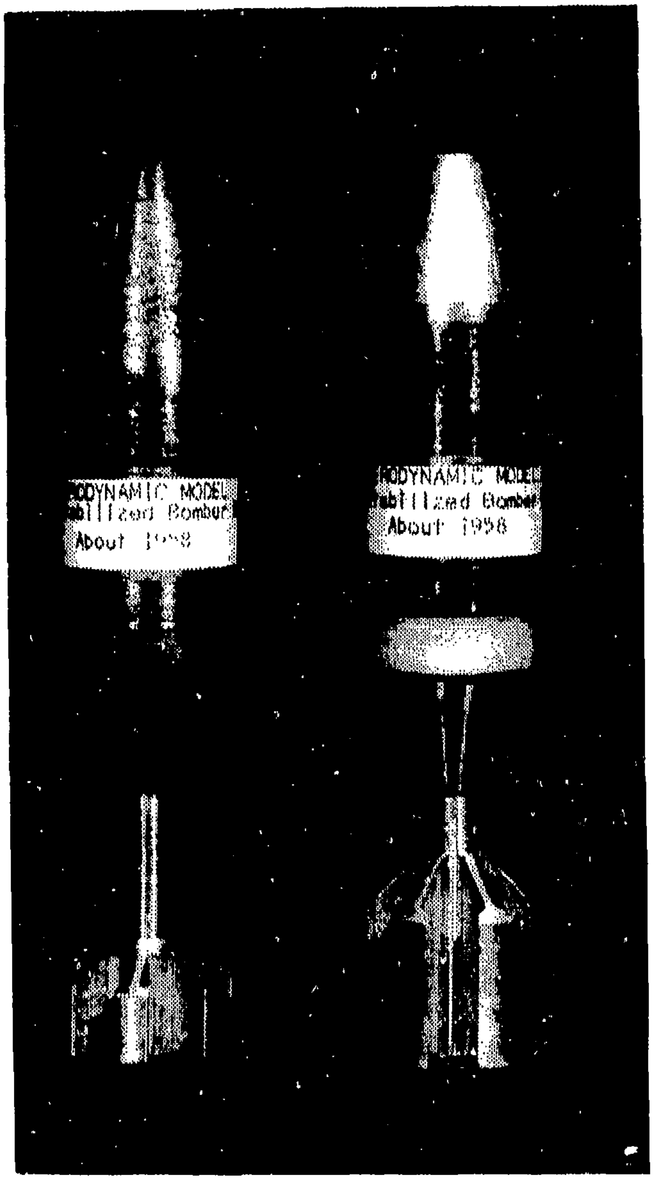


Figure 51. Fin-Stabilized 30 mm Shell

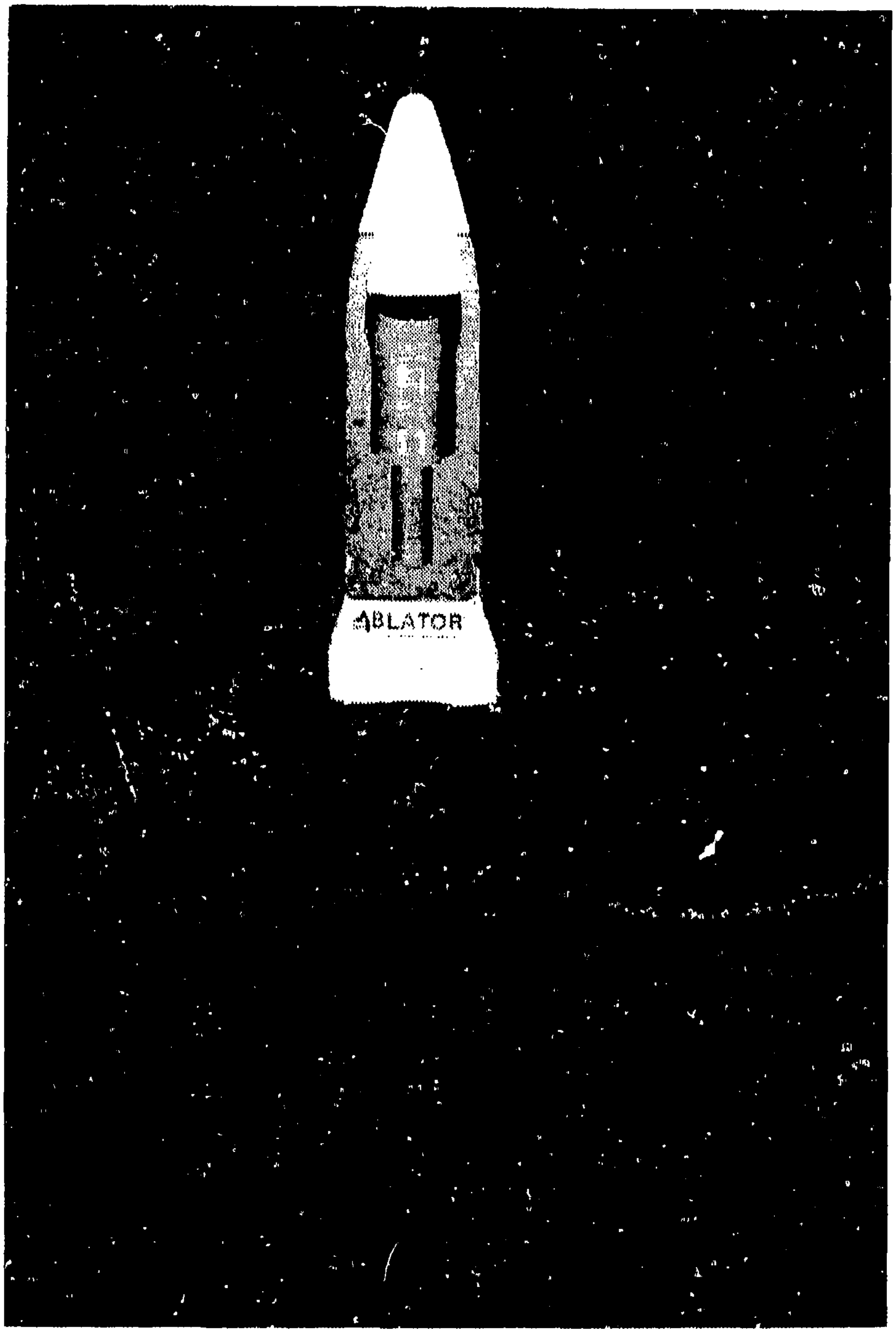


Figure 52. Ablative Ammunition

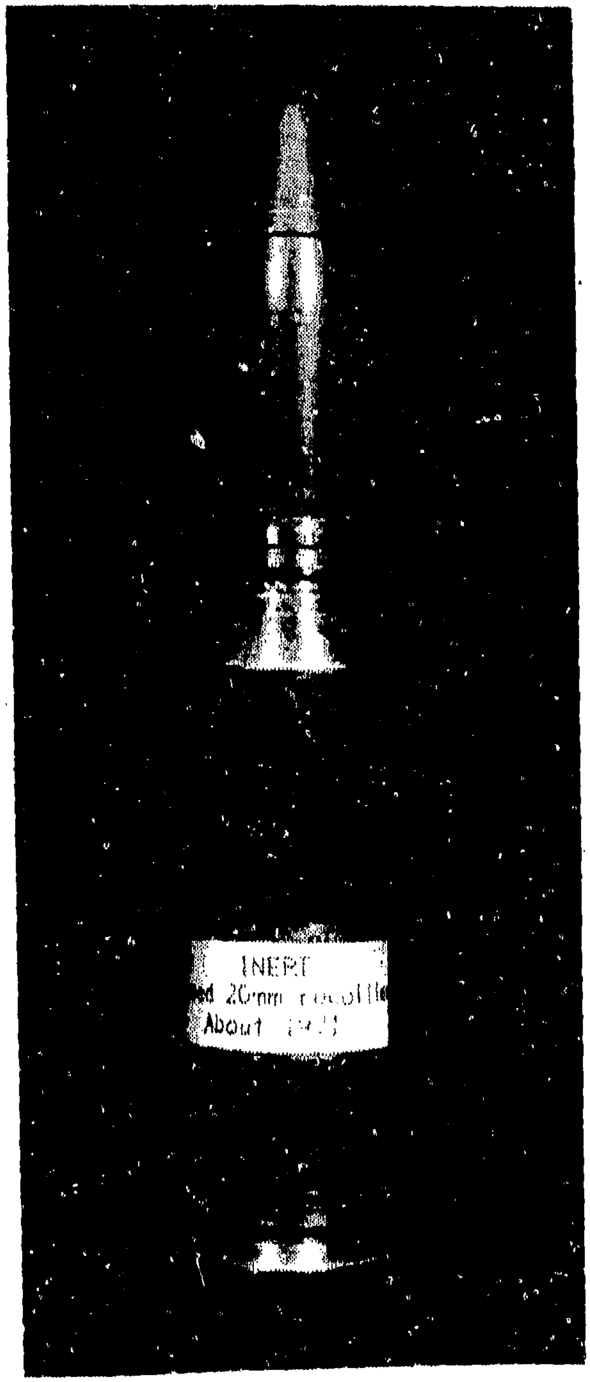


Figure 53. Recoilless 20 mm Cartridge

The muzzle velocity would be 1,500 to 1,800 fps. But why?

L. Automatic Light Gas Gun

With the advent of the space age in the late 1950's, we were encouraged to examine our current technology to see what might be useful in space. Of course, being in the weapon's business, we looked to space weapons. Space bore the connotation of long ranges and high velocities, suggesting "hypervelocity weapons," whatever that term might mean.

One form of hypervelocity launch device in daily use at the time was the two-stage light gas gun. The question arose as to whether it would be possible to redesign this cumbersome piece of laboratory equipment into a reasonably light and rapid firing weapon. We contracted with General Electric to find out. Their goal was to take the 20 mm M50-series round, the M61 gun, and devise an automatic light gas gun with a muzzle velocity in excess of 10,000 fps. They did. The cartridge required is shown in Figure 54. It uses a standard 20 mm cartridge case and a projectile/carrier/piston replacing the standard projectile. It is chambered in the 20 mm breech of a two-stage 20/7.62 mm barrel. "O" rings (missing from model) located in the two deepest grooves provide a low pressure seal within the bore. Helium is induced in the region of the holes in the projectile/carrier. The projectile (mounted in front of the aluminum carrier) and the carrier are transported up the 20 mm bore and seated against the breech of the 7.62 mm barrel. Helium pressure is then raised to the desired level and the induction port sealed. The main propellant charge is then fired, driving the plastic/aluminum piston down the 20 mm tube, raising the helium pressure until the projectile retainer shears, and the 7.62 mm projectile is accelerated down the launch tube by the expanding helium. The piston comes to a stop against the carrier and is driven

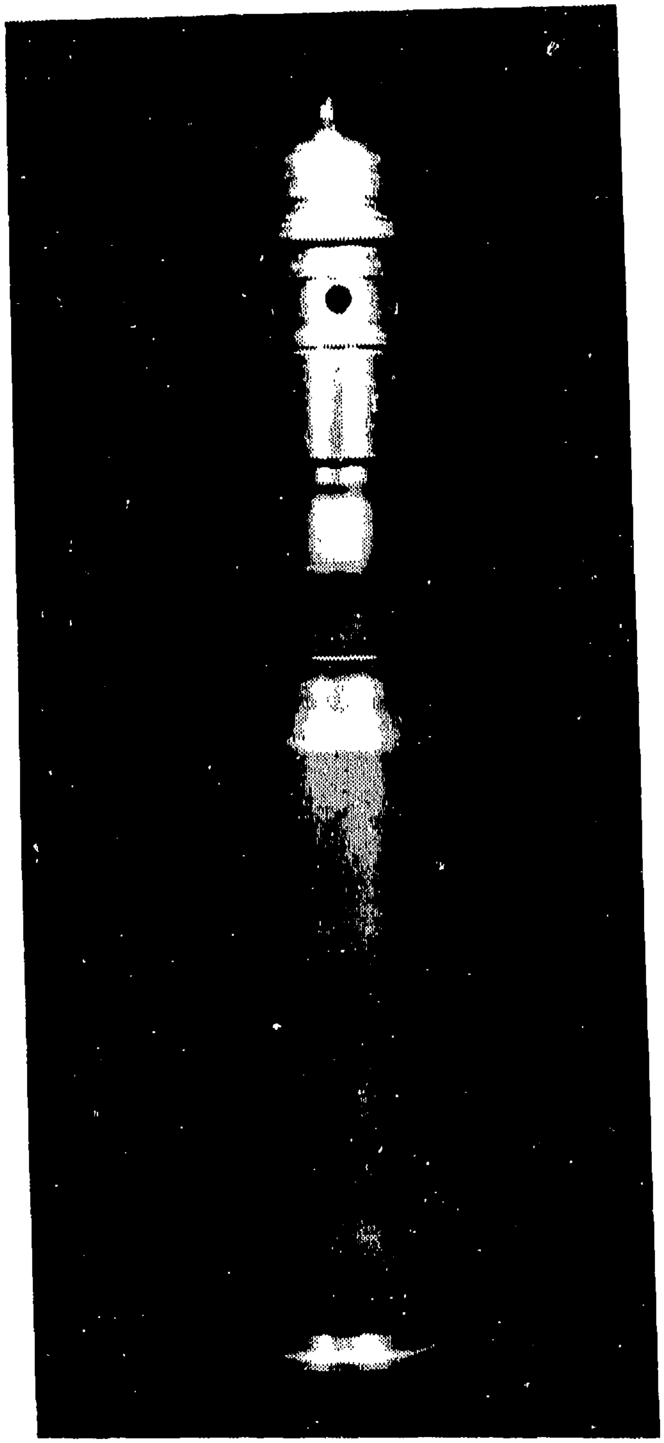


Figure 54. Automatic Light Gas Cartridge

part way into its hollow base such that they join together. After projectile exit, the launch tube is sealed and gas is injected into it to drive the carrier and piston rearward into the cartridge case where the entire assembly is extracted and a new one loaded. It was somewhat complex, but it worked. It was the first automatic light gas gun. If anyone needs an automatic weapon longer and somewhat heavier than a 20 mm gun that will fire lightweight 7.62 mm projectiles in excess of 10,000 fps, it can be built. Velocities up to 30,000 fps are feasible with this technique. The mechanism is scaleable.

M. Lockless Telescoped System

During the late 1960's, Maury Golden of Hughes Tool Company (now Hughes Helicopters) came up with a new idea in cartridge and breech design. Now, really new ideas in the gun business do not come every day, and this one had some merit. So we funded some investigation of it (as did the Army). Basically, the concept was a flat telescoped cartridge and a breech which consisted of a slot milled through a barrel (with breech plugged), into which the cartridge was inserted and a pressure sleeve slid over the barrel. The sleeve then withstood the pressure; the reaction force was handled by the stirrups left from the barrel walls. No breechblock or lock was required. Plastic cases were normally used, and it did not make any difference if they split since the chamber was sealed by conventional piston rings between the barrel and sleeve.

The round was tried in virtually every caliber from 5.56 to 40 mm, proving again that scaling laws are valid. It can provide a simple light-weight gun system for moderate rates of fire. The sealing sleeve is a rather heavy reciprocating mass for a really high rate gun. The system has promise and should not be forgotten. Figure 55 illustrates two versions of this round. The 25 mm can be recognized as being a contemporary of the GAU-7 as it utilizes a copper banded projectile with what appears to be a polyethelyne sleeve extending from the rotating band to about 1/2 inch onto the ogive, typical of procedures of the day. It was also intended to be caseless in the pure definition. It is dated 1970.

The 30 mm version is plastic cased, designed to fire a GAU-8 projectile. It is made of glass-filled nylon and is designed to split down all four corners during firing. Dating from the mid-1970's, it reportedly worked quite well.

This weapon and concept has had several nicknames, including the "chicklet gun" and the "baloney slicer."

N. Reverse Tapered Plastic Case

At one time in the mid-1970's, we advertised for ideas for cartridges and breeches utilizing all plastic cartridge cases. The requirement was that the case be enclosed such that it would not split, leak, or extrude through any breech joints. General American Transportation (GATX) presented a proposal for a reverse tapered round which was seated into a chamber. This chamber had a device similar to a poppet valve in its base which served to positively prevent plastic flow and also served as an extractor/ejector. It worked and was satisfactorily fired in both single shot and automatic mode. Figure 56 illustrates the cartridge as it was made in 20 mm. It was not very volume efficient, the large plastic forward seal/projectile retainer occupying a lot of nonproductive volume. The total round volume is much larger than the M50-series rounds which it ballistically simulates. Even with its large bulk of glass-reinforced plastic, it still illustrates the potential of plastic cases for weight saving; the total weight of plastic parts is 1,490 grains

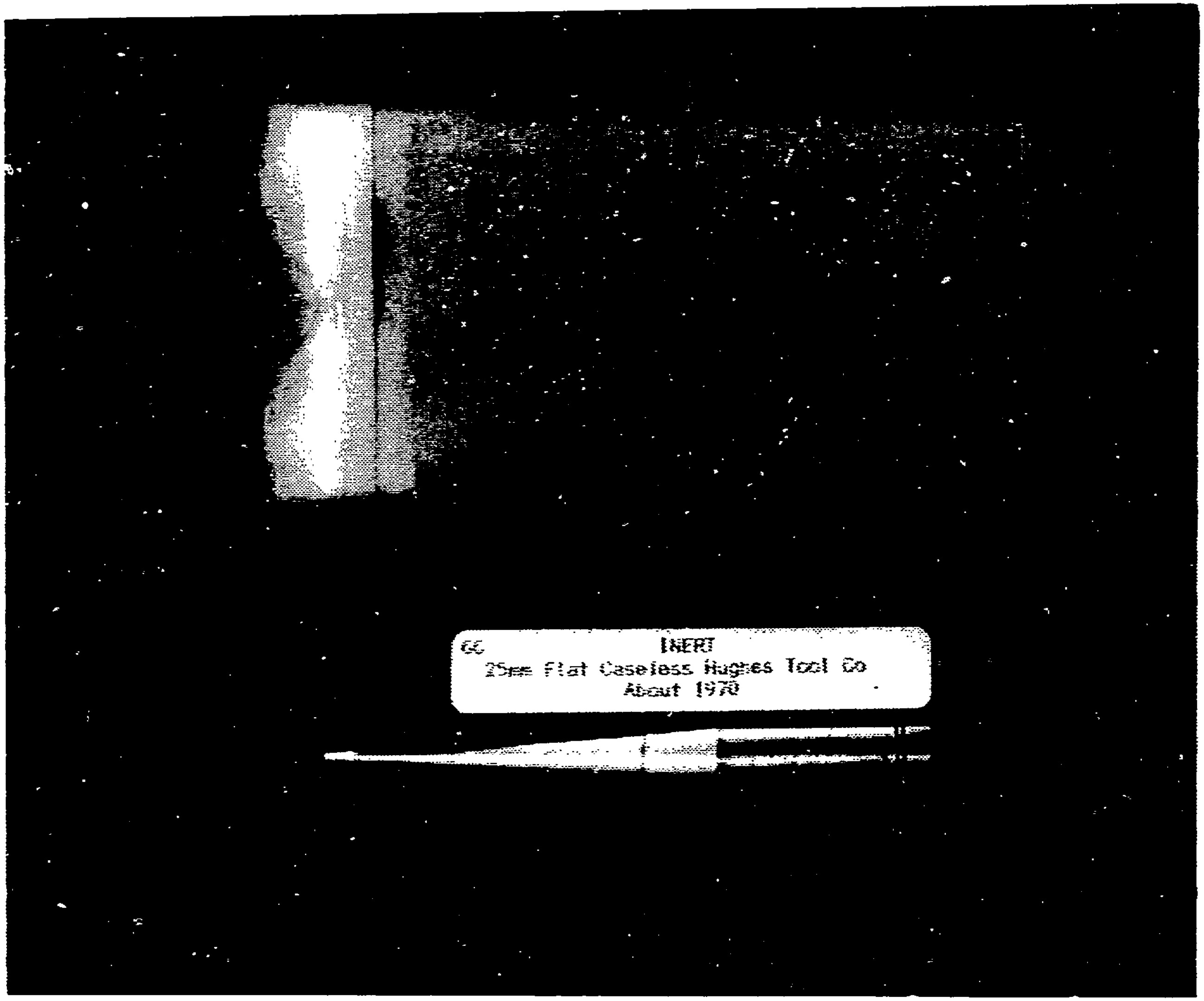


Figure 55. Lockless Telescoped Ammunition

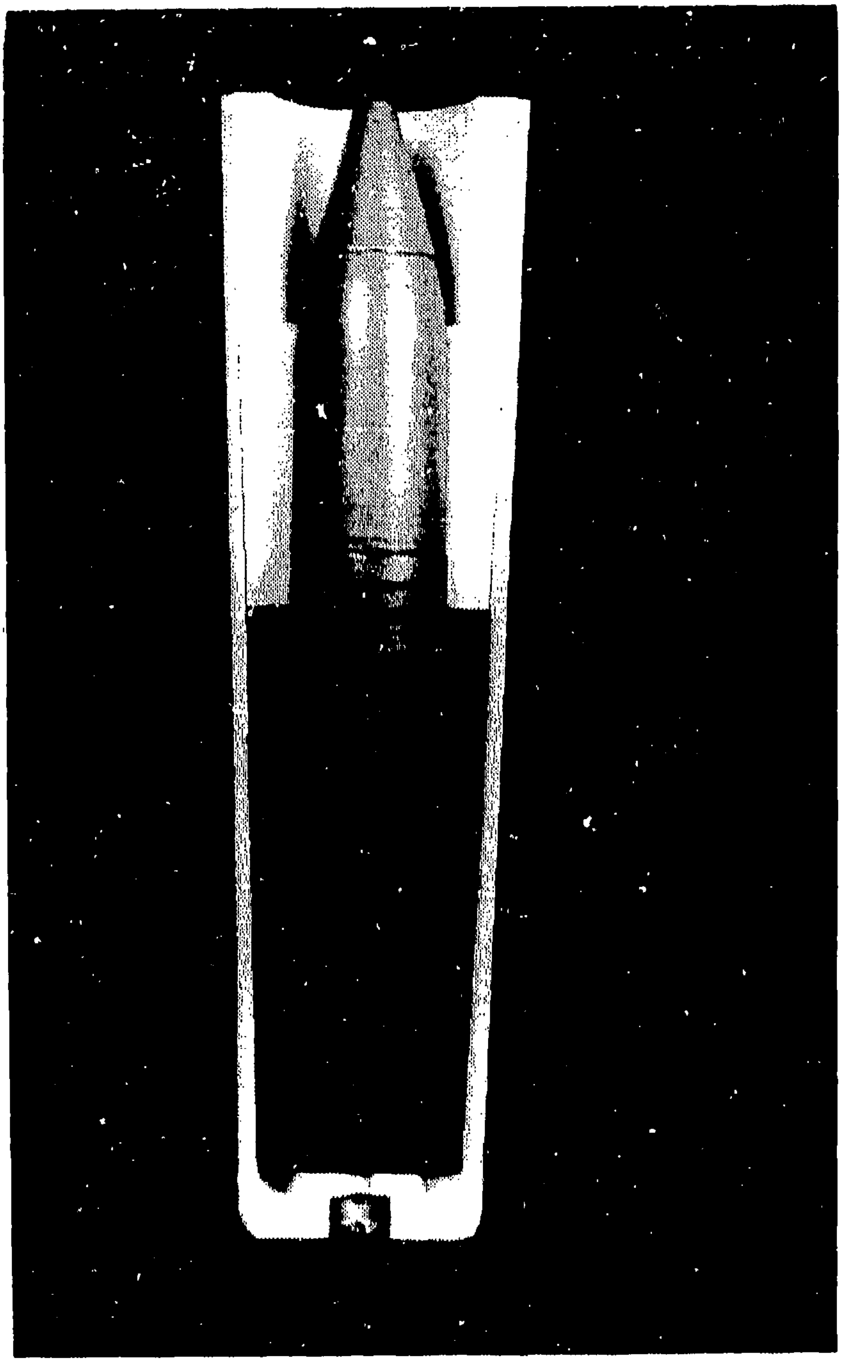


Figure 56. Reverse Tapered Plastic Cartridge

compared to 1,850 grains for the conventional 20 mm brass case and 1,775 for the steel case.

SECTION XX

SUMMARY AND CONCLUSIONS

As stated in the introduction, the goal of this report was to assemble, classify, photograph, and describe the significant items of the several hundred dummy rounds of ammunition and ammunition components the author has collected in over thirty years of research and development in guns and ammunition. This has been done. In no case has the treatment of any single item been complete or exhaustive, nor was it intended to be. In most cases, the descriptions, reasons, and results are from the author's admittedly imperfect memory. In many cases, the opinion of the author is also evident. This opinion, however, is backed up by very extensive and diversified experience in automatic cannon caliber guns and ammunition; the extent and diversity are a function of his position within the Air Force R&D community and the "systems approach" used by the Air Force, wherein responsibility for all phases and components of gun and ammunition resided in one office under this author's technical direction for the majority of that thirty plus years.

If anyone reading this report is encouraged to embark on a particular course of R&D, or for that matter abandon some proposed project, he is cautioned not to do so on the basis of this document alone because of its admitted cursory nature. Rather he should use this as a guide to aim him in the right direction to conduct a full literature search of his subject. Virtually everything herein is documented in one or more government technical reports. The contractors mentioned, as a rule, also have complete documentation of their work, in many cases more detailed than the government reports.

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