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Work on Sabot-Projectiles - 1942-1944 - and Appendix 1 - 2)

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The work conducted on sabot projectiles by the University of New Mexico from 1942 to 1944 is summarized. Following a discussion of sabot mechanisms and materials of construction, several projectiles are described. These include armor-piercing sabot projectile for the 75-mm gun, armor-piercing and high-explosive sabot projectiles for the 105-mm Howitzer M3, armor-piercing sabot projectiles for the 75-mm pack Howitzer, armor-piercing sabot projectiles with tungsten-carbide cores for the 76-mm gun M1A2, designs for the 76-mm and 90-mm guns for construction by Remington Arms Co., Inc., and further developments in these designs.

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WORK ON SABOT PROJECTILES BY THE UNIVERSITY OF NEW MEXICO UNDER CONTRACT OEMsr-668, AND SUPPLEMENTS, 1942 - 1944

CONFIDENTIAL

Compiled by J. W. Greig

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Division 1

National Defense Research Committee of the
Office of Scientific Research and Development

WORK ON SABOT-PROJECTILES BY THE UNIVERSITY OF NEW MEXICO
UNDER CONTRACT OEMsr-668 AND SUPPLEMENTS, 1942 - 1944

by

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NDRC Report No. A-428
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Pertinent to Projects OD-52 and NO-26

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WORK ON SABOT PROJECTILES BY THE UNIVERSITY OF NEW MEXICO UNDER CONTRACT OEMsr-668, AND SUPPLEMENTS, 1942 - 1944

Compiled

by

J. W. Greig

Preface

This article gives a history of the research and development work done by the University of New Mexico on sabots under contract OEMsr-668 and supplements. This work began in 1942 and was terminated in 1944. Throughout, it was done under the auspices of Division 1, NDRC and under the direction of Dr. E. J. Workman, then head of the Department of Physics. The prime purpose of this article is to aid anyone in the Office of the Chief of Ordnance or in the Bureau of Ordnance who may be going over this work in connection with future development. To that end, information has been included that is not contained in the regular contractors' reports, a list of which will be found in Table VIII.

The reader will find that the article is more detailed in some parts than in others, and that this apparent emphasis is not related to the importance of the particular phase of the work emphasized. A word of explanation is in order. The work that resulted in this article was begun with an entirely different purpose in view, and a good deal of the information had been assembled, and much of the writing had been done, before the writer was asked to prepare this article. Time was not available to go over the ground again with the new purpose in mind or to rewrite what had been written. In addition, more detailed information was available to the writer about some phases of the work than about others.

The article is not intended as a critical survey of the work or thinking. Neither the time nor the technical files that would have been needed for this have been available. The article was prepared in spare time; on week ends and in vacation. The technical files that would have

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been necessary were no longer accessible; some of the files of classified documents had been returned, and others simply could not be located because of the disorganization resulting from a number of moves and condensations of the files of Division 1, NDRC.

The writer, acting as a consultant to Division 1, NDRC, had more or less familiarity with the work done by the University of New Mexico from the outset until September 30, 1944, during which period all the research and development was done. (After July 31, 1944 the contract was for testing only.) The information on which this article is based is contained principally in the reports made by the contractor to Division 1, NDRC, supplemented by information from the writer's correspondence files. Copies of the contractor's reports are on file in the Office of the Chief of Ordnance, in the Bureau of Ordnance, in Division 1, NDRC, and in the OSRD Liaison Office.

J. W. Greig

August 24, 1946

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WORK ON SABOT PROJECTILES BY THE UNIVERSITY OF NEW MEXICO UNDER CONTRACT OEMsr-668 AND SUPPLEMENTS, 1942 - 1944.

INTRODUCTION

When what was later to be known as Division 1, NDRC was first set up in the spring of 1941, as Section A of Division A of NDRC, one of its assignments was the achievement of practical high velocity projectile flight. One way that had long before been suggested to increase the muzzle velocity of projectiles fired from already existing guns was to use a sabot, and by this means fire a lighter projectile than the one normally fired from the gun. A sabot projectile consists of a projectile of smaller caliber than the gun held in a sabot that fills the bore holding the subcaliber projectile central in the bore and carrying the subcaliber projectile with it when it is driven forward by the propellant gases. When the projectile leaves the gun bore the sabot separates from the subcaliber projectile leaving it free in flight. When the subcaliber projectile is to be stabilized by spin this is transmitted to it through the sabot.

In the summer of 1942, a theoretical examination of the limitations imposed on the design and on the ballistic performance of such projectiles by stability requirements was made by Critchfield at the Geophysical Laboratory1/.

As a result of this study, it became evident that by firing subcaliber projectiles of high density and good armor penetrating

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1/ "Stability of Subcaliber Projectiles." Charles L. Critchfield. NDRC Report A-88, September 4, 1942.

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properties (non deforming), by means of sabots, much higher muzzle velocities, accompanied by stable flight, much increased armor penetration, shorter times of flight and flatter trajectories, could be realized with many existing rifled guns, provided the mechanical problems involved could be solved. Cemented tungsten carbide projectiles, or projectiles with cores of this material, had the density required and gave promise of satisfactory behavior against armor. Provided that the accuracy of this type of projectile could be made equal, or nearly equal, to that of the conventional projectile, it appeared to have several advantages over the latter in the attack of armored vehicles such as tanks. Not only could it defeat heavier armor, but also the chance of hitting with the first round or so would be greatly increased, because the shorter time of flight and flatter trajectory would require a less accurate estimate of lead and range.

Steel subcaliber projectiles offered less advantage in these respects than tungsten carbide or tungsten carbide cored projectiles. In some guns, indeed, steel subcaliber projectiles could not be used for the twist was too low to stabilize them. Nonetheless, in other guns a real advantage appeared possible by their use against tanks.

In the other fields considered, for example in the antiaircraft field, the advantages that could be gained immediately, by the use of sabots, did not appear to be as great as in the antitank field.

There was at that time an urgent need for better performance against tanks than the guns and ammunition in use were capable of. Moreover, antitank projectiles were among he simplest projectiles in use and antitank subcaliber projectiles could therefore be expected to put fewer restrictions on the sabot than most others, and such projectiles were of moderate size and would for this reason be easy to produce for experimental firings. If they could be successfully developed there need be no great delay in putting them into service as no modification of guns or of fire control equipment would be required. These considerations made the antitank field a good one in which to make a beginning with sabot projectiles.

Although the theoretical examination had shown that a very material improvement in actual performance against tanks was to be expected from the use of the sabot in existing guns, there remained a question about the extent of the limitation to the tactical use of such projectiles that would be imposed by the fact that the discarded sabot or its parts would follow different paths than the subcaliber projectile.

In the spring of 1942, British and U. S. Army officers, familiar with British experience in Libya were consulted. They were agreed that this characteristic would not have limited the use of sabot projectiles in the tank battles in that theatre, and that such projectiles would have been most valuable because of their increased penetration. This led immediately to the commencement of experimental work aimed at finding a mechanically satisfactory type of spin stabilized armor piercing sabot projectile for use in existing guns, first at the Geophysical Laboratory, and soon after (August 10, 1942) at the University of New Mexico.

The work of the Geophysical Laboratory on sabot projectiles will not be discussed here. For information about it, reference may be made to the reports listed in the footnote[2]. Throughout the course of this work ideas were exchanged freely between the persons working on it at the Geophysical Laboratory and at the University of New Mexico.

The work done at the University of New Mexico has been reported in detail in Monthly Progress Reports, and a series of Final Reports has summarized the work done under the original contract and under the different supplements to that contract. In addition several special reports have been prepared. These reports are listed in Table VIII. The following notes will form a more or less connected outline of that work and will provide more background to some phases of the history of the work than appears in the reports. They may therefore be useful to anyone going over that work in connection with future sabot developments.

The work done by the University of New Mexico on the development of sabot projectiles may be divided roughly into phases on the basis of the immediate purpose of the work. In general these phases followed each other but there was a good deal of overlap. In describing the work, however, it will be convenient to divide it into these phases and to treat each separately. This plan is followed in these notes (See Table of Contents).

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2/ Division 1, NDRC has supplied the following list of reports on sabots from the Geophysical Laboratory. -

NDRC Report A-88 (OSRD No. 870), "Stability of Subcaliber Projectiles by C. L. Critchfield.

NDRC Report A-233 (OSRD No. 2067), "Development of Subcaliber Projectiles for the Hispano-Suiza Gun" by C. L. Critchfield and J. McG. Millar.

Part D of some monthly progress reports on contract OEMsr-51 from the Geophysical Laboratory.

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The first work done by the University of New Mexico was essentially an exploratory investigation of sabot mechanisms and of materials for their construction, in an effort to obtain a satisfactory sabot for use with an armor piercing antitank projectile. By the end of 1942 a basic design had been arrived at that was mechanically fairly satisfactory, and it had become evident that the work should now be aimed at making a definite projectile for a definite gun. Refinements of design to give improved performance could be expected as the work progressed.

The next phase was the development of a sabot by which to fire a standard 57-mm steel armor piercing projectile, the APC M86, from the 75-mm gun. So successful had the basic work been that the design and development of this projectile was carried out in a very hort time. A lot of seventy of these projectiles was supplied to the Ordnance Department. They were tested at Aberdeen Proving Ground in July 1943.

The next phase of the work was the development of an armor piercing, and of a high explosive sabot projectile for the 105-mm Howitzer M3. This work began in August 1943. It involved, not only the development of the two sabots, but also, the experimental determinations of the trajectories and the measurement of the stability factors of several projectiles. Lots of both types of sabot projectiles were made up, and then supplied to the Army for trial; the lot of high explosive projectiles in February 1944, the lot of armor piercing projectiles in March 1944.

The next phase of the work was the slight modification of the design that had been developed for the 75-mm gun, and the production, and supply to the Army, of a lot of sabot projectiles made to this revised design for use in the 75-mm Pack Howitzer.

The next phase was the development of a sabot projectile with a tungsten carbide core for the 76-mm gun fitted with a muzzle brake. This projectile had to pass through the brake without interference, then separate close to the muzzle. Twenty-five of these were made and supplied to the Ordnance Department for test.

After this had been done, the research and development work of the University of New Mexico on sabots was terminated because of the press of other work. However, aid was furnished to Division 1, NDRC in the procurement of additional sabot projectiles for the 76-mm gun.

Some work was also done in cooperation with Arthur D. Little, Inc. in exploring the possibility of molding plastic parts of sabot projectiles. This properly is a part of the first exploratory phase of the work.

EXPLORATORY WORK

Sabot Mechanisms and Materials of Construction

The first work at the University of New Mexico was the exploratory investigation of sabot mechanisms and materials of construction. The reports covering this[3/] show the evolution of the design that was later used in sabots for the 75-mm and the 105-mm Howitzers, and also

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3/ First Progress Report, covering the period up to the end of October 1942. Second Progress Report, covering the period November 1 - 28, 1942. Special Report, December 28, 1942. Fourth Progress Report, April 21, 1943. This report contains a review of that part of the earlier work leading directly to the sabot projectiles developed for service guns.

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the reasons why the materials used were first chosen.

During this period, two guns were available for experimental firing at the University of New Mexico's Proving Ground: a 20-mm (Hispano) automatic gun M2, and a U. S. Navy 6-pdr. Mk VII Mod. 2 4/. Almost all the firing was done with the latter gun.

The first style of sabot tried was the simple deep cup type in which air drag is depended on to bring about separation in flight. The First Progress Report, covering the work to the end of October 1942 contains drawings of several such sabots and statements of the results of tests. The first of these designs, 2-20, for the 20-mm Hispano, was a simple steel cup into which the rear half of the cylindrical section of the subcaliber projectile fitted. Two were fired. In one case the projectile tumbled, in the other it had not separated at 30' and no record was obtained beyond this. The next cup sabots mentioned, 2-57 and 2-57A, were of dural and for the 6-pdr. Mk VII. The first was a simple cup. Two models were fired. In the first model the subcaliber projectile was not fastened to the sabot. On firing, it punched through the base of the sabot. In the second model it was fastened in place. Separation did not occur. The second design 2-57A had a simple leaf spring release added. Two were fired and both separated. There is no statement about the yaw, but from other statements in the report both subcaliber projectiles presumably tumbled. Two other designs that might possibly be classified as cup

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4/ The 6-pdr. Gun Mk VII Mod. 2 has a bore of 2.244 in. (57-mm). Shot travel is 90.6 in. Chamber capacity is 50.10 cu. in. It fires a 6.03 lb projectile with a muzzle velocity of 2240 ft/sec using a charge of 560 grams.

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type sabots are described in this report. However, these designs tested the suitability of fibre and plastic materials rather than the operation of the deep cup sabot. The next experiments with deep cup designs that are recorded in the Progress Reports were made when working on the sabot for the 76-mm gun with muzzle brake.

Speaking of the deep cup sabot, the First Progress Report concludes (p 3):

> "..... it has, however, a high ratio of sabot mass to total mass, and is subject to the same compressive stresses as the base of the projectile."

The Fourth Progress Report summarizing the results with the deep cup designs says (p 7):

> "None were successful for two reasons: (1) The stress on the base of the sabot due to the projectile was greater than the material could stand without raising the ratio of sabot to total mass to a prohibitive value, (2) The release of the projectile was not smooth enough to avoid subsequent projectile instability. At this stage dural (17S-T) was being used for the sabots because of the high static strength - weight ratio."

The conclusion that the ratio of the mass of the sabot to the total mass, in this type, was prohibitive is evidently based on design studies, a number of which were made after the firings reported in the First Progress Report. The designs shown in that report were tried simply to investigate the operation, no effort being made to lighten them by removing metal where it was not needed.

It may be noted here, with respect to the separation of sabot and subcaliber projectile in flight, that a good many firings of deep cup sabots had been carried out by the Geophysical Laboratory and that no design of this type tried there had given satisfactory operation 5/.

5/ During the fall of 1942 and the spring of 1943 the Geophysical Laboratory fired a good many sabots of this type in an effort to achieve (Concluded on page 9)

In the period covered by the First Progress Report some attention was paid to projectiles designed to be stabilized by placing the center of pressure well behind the center of mass. By applying the thrust from a sabot at some point, or points, well in front of the base of the subcaliber projectile the compressive stress in the walls of the projectile at a given acceleration is made less than if the thrust from the sabot were applied on the base. In this way the

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5 - Concluded/
successful operation in the 20-mm Hispano. A great deal of trouble was experienced that was believed to be due to large yaws before separation. The centrifugal type of sabot was found to be so much more reliable than the deep cup or axial type that the latter was abandoned. "Of all the designs of axial sabots, there were none that were successful. It was found that it is possible to have the sabots separate either by drag alone, by gas pressure, or by a small charge of black powder, but in each case the sabots usually separated with a large yaw." NDRC Report A-233 (OSRD 2067) p. 38.

Later, after the adoption of muzzle brakes for British guns, the development of deep cup or pot type sabots was begun in Canada at Valcartier by the Artillery Proof and Development Establishment. In order to minimize the effect of initial yaw on the subcaliber projectile during separation, these sabots were designed so that only a short relative motion of the subcaliber projectile and the sabot was required to separate the two to such an extent that they could be inclined several degrees relative to each other before they interfered. Separation was aided by the expansion of propellant gas caught in a small chamber in the base of the sabot. This was done so that separation might take place with a minimum of interference when the projectile was yawing. The writer saw some of the early models fired at Valcartier in the fall of 1943 and their performance was encouraging. Considerable development work was subsequently carried out on sabots for the 6-pr. and 17-pr. and reports were issued covering the work. These reports are not at hand at this time, however, hence the writer is unable to say how well these designs function when the gun is worn and there is considerable initial yaw.

Later, in December 1944, the Remington Arms Company, who had been working on centrifugally operated sabots for the 76-mm and 90-mm guns, abandoned them in favor of deep cup type sabots, and developed such a sabot for the 90-mm. They appear to have been strongly influenced in this choice by the results obtained with this type at Valcartier, and by the experience there with proof firing of British 6-pr. and 17-pr. sabots. The Remington work will be referred to in more detail later.

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length of projectile that can withstand a given acceleration may be increased, and long narrow projectiles can be fired by means of a sabot. ~~[illegible]~~ The retardation of such a projectile can be made less than that of the normal spin-stabilized projectile of the same mass, and consequently the range for any given MV can be increased. Such projectiles cannot be spin-stabilized. Stability must be obtained by getting the center of pressure behind the center of mass. When fin-stabilized they should receive, at most, a very small spin[6/]. Two projectiles designed to seal the bore but to transmit very little spin to the main body of the projectile are described. Spins as low as 12 r.p.s. at an MV of 2160 ft/sec, and 4 r.p.s. at an unstated MV were obtained with these projectiles fired from the 6-pdr. Mk VII. Some firings of long narrow projectiles were also made, but none were successful. Projectiles of this shape are, of course, not adapted to punching holes through armor, but they have application in carrying high explosive. No further experiments of this kind were reported in subsequent Progress Reports.

The first sabot projectile that resulted in satisfactory flight was fired on November 2, 1942. This was a projectile designed so that the sabot was thrown off in parts, by centrifugal force, on emerging from the muzzle. The sabot consisted of two segmented steel

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6/ Some small spin appears to be advantageous in reducing dispersion. Without any spin, an asymmetry in the projectile that did not itself produce spin would continuously bend the trajectory in one direction. Spin would result in a corkscrew motion instead.

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rings, fitting into grooves in the body of the subcaliber projectile, and held in place there by copper bands, of which the rear formed the rotating band, and the forward the bourrelet. When this design gave satisfactory results, attention was directed to improving it. The first improvement was to change the bourrelet surface, bearing against the bore, from copper to steel. Next, because the forward groove in the body of the projectile would be particularly bad for an armor piercing projectile, it was eliminated. The bourrelet was now supplied by a sleeve surrounding the subcaliber projectile, from the rear segmented steel ring forward to the beginning of the ogive. This sleeve received its thrust directly fom the segmented steel ring at the rear. Various materials were used successfully for the sleeve, dural, wood, plastic. The first sleeves were segmented and held in place by steel bands that burst under centrifugal force. Later they were partially segmented by slits from the inside, and the metal bands were omitted.

The rear segmented steel ring was now modified. Instead of cutting a deep groove in the projectile to hold the ring, the projectile was threaded and corresponding threads cut on the ring. This decreased the weight of the sabot and greatly reduced the depths of the cuts in the projectile. The threaded steel ring was now in some cases completely segmented and held together by the rotating band as before. In other cases it was partly segmented by radial slits cut from the inside, and was held together by the steel remaining between the slits and the outer surface. Copper wire was hammered into these slits to seal them against gas.

This design led directly, by a modification in the arrangement of the slits that partially segmented the threaded base ring, to the designs used later for the 75-mm and 105-mm sabot projectiles supplied to the Army for test.

The testing of materials during the early experimental work resulted in the adoption of steel and plastic, and the abandonment of dural as materials of construction. It is of interest to examine the record to learn the reasons for this so far as they concern dural and plastic.

At the outset, because of the importance of getting a light-weight sabot, dural (17S-T) was experimented with. After a number of disconcerting failures, however, its use was soon abandoned (First Progress Report, November 1942), except as a sleeve type bourrelet. Later, this use was also discontinued and plastic was used instead, "because of the unfavorable weight of Dural as compared with plastic or wood" (Second Progress Report, December 1942).

The tests that resulted in the abandonment of dural except as a material for bourrelet sleeves were of two kinds: first, actual firings of experimental projectiles in which dural was used, and second, measurements of shear strength.

Let us consider the firings of experimental projectile first. The record of these is contained in the First Progress Report. It is stated on page 4: "It appears from our tests that the strength of Dural is markedly reduced by exposure to the breech temperatures with the result that complete failures of Dural have occurred under stresses far below its static yield point.(6) Samples of sabots have been recovered in which the yield had the appearance of thermo-plastic flow.(7)

This point requires further investigation." The reference (6) refers to tests of designs 22-57, 27-57R, 2-57, and 18-57, while (7) refers to tests of design 22-57.

Let us consider the projectile tests referred to.

18-57. This was a test of dural as a material from which to make rotating bands. The projectile was a standard steel projectile for the 6-pdr. Mk VII with a cup of dural, on which the band had been formed, threaded to the base. The projectile was recovered and examined. The band failed to seal properly. This experience is in agreement with experience elsewhere that dural is unsatisfactory as a rotating band. The surface of the dural in contact with the bore almost certainly melts, and if any gas under high pressure can escape past the band it erodes badly.

2-57. This was a simple dural cup sabot with a lead-wieghted steel subcaliber projectile. The subcaliber projectile punched through the base. However, in this case the subcaliber projectile was not fastened in place in the sabot. In a second test, with the projectile fastened in place, this did not occur. If, as appears quite possible, the base of the subcaliber projectile was not seated against the sabot when firing occurred, the force exerted would be increased and the subcaliber projectile might then punch through the base without the strength of the base being in any way below the rated strength. This appears to have occurred in much later work at the University of New Mexico. It happened a number of times at Aberdeen Proving Ground in firing 90-mm sabot projectiles with steel base plates.

22-57 and 27-57R. These projectiles were essentially alike except for the length of the subcaliber projectile. The sabot here consisted of a rear ring of dural, the outer surface of which was formed into a rotating band, and a forward ring of dural that acted as the bourrelet. At each end of the subcaliber projectile a section had been turned down and threaded. The dural rings were threaded to these reduced sections and screwed up tight against the shoulders. The rear ring was then flush with the rear face of the projectile, and a steel piece, the full diameter of the subcaliber projectile, was attached to the rear of the subcaliber projectile so that it covered the junction between the dural ring and the subcaliber projectile. Although the drawings do not show it, the rings were presumably partly segmented from the inside, so that they would be broken up by centrifugal force once they left the gun. One model of 27-57R was fired. The Report reads: "Recovery of fragments of the rings showed definitely that the sabot collapsed in the gun. The Dural appeared to have melted or to have sheared in a semi-fluid state. From this test, that on 22-57, and on 18-57 (q.v.) it is evident that dural (17S-T) is not a dependable material for use when exposed to powder temperatures and may (see 2-57) have a much lower shear strength under suddenly applied loads than under static conditions."7/

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7/ Although a great deal of work was done during the war both in U.K. and U.S.A. in determining the change of strength of various metals and alloys with change in rate of loading, and many reports on the work were published, very little information on this subject was available at this time to those working on sabots at the University of New Mexico. This was in part because much of it had not yet been published, in part because the application of the regulations compartmentalizing classified information effectively prevented the wide and rapid dissemination of such information among those needing it.

The writer has seen a number of papers on this subject but, so far as he can recall, none of those seen dealt directly with shear and none gave any indication of a reduction in strength of dural such as suggested here.

(Concluded on page 15)

It was not proved that the failure of the dural was the cause of the failure of 22-57. This was surmised because of the proved failure in the case of 22-57R.

There is a characteristic of dural that, at the time, was probably not known to the men doing the experimental work, that may possibly explain the failure of 27-57R, and that almost certainly does explain the appearance of the recovered fragments. When hot

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7 Concluded/

A list of NDRC reports on "The Behavior of Metals under Dynamic Conditions" is given under project NRC-82 in OSRD Report No. 6604.

Work on this subject was also done in U.S.A. by the Naval Research Laboratory and possibly also by other organizations.

For British reports on this subject, the reader may consult the Subject Heading List of British Reports being prepared by the Liaison Office, O.S.R.D.

Mention may be made of a few reports:

OSRD Report No. 4343, November 1944, "Behavior of Metals under Dynamic Conditions (NS-109), Mechanics of the Dynamic Performance of Metals," by D. S. Clark, D. H. Hyers, D. S. Wood, and P. E. Duwez, gives a theoretical discussion of the subject.

OSRD Report No. 3837, April 1944, "Progress Report on Behavior of Metals under Dynamic Conditions (No-11) (NS-109), Influence of Impact Velocity on the Tensile Properties of Some Metals and Alloys," by P. E. Duwez and D. S. Clark, gives data on the tensile strength of 17S-T and 24S-T. These data show a slight increase in ultimate tensile strength under dynamic conditions over that under static conditions, 7 percent for 17S-T, 5 percent for 24S-T.

Naval Research Laboratory, Mech. and Elec. Div. -- Ballistics Section Report No. O-2531, May 1945, "Bend Testing at Ballistic Speeds, First Partial Report Problem O-46, Technique and Survey of Typical Results," by Herschel L. Smith and Arthur E. Ruark. Confidential. This paper contains an appendix "Survey of Work on Dynamics of Plastic Flow.

Naval Research Laboratory Report No. O-2532, which is the second partial report on Problem O-46, "Tests of Magnesium Alloys and 24S-T." Confidential.

It is understood that a third paper, N.R.L. Report O-2700 by H. L. Smith and Edwin Burns, is in preparation.

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powder gases stream over dural at high pressure and velocity they erode the dural with extreme rapidity. Great quantities of the metal may be removed[8] and the surface of the remaining metal will appear washed and melted. If this movement of the gas over the surface is prevented by adequately sealing the gas, no such effect occurs. It is by no means clear from the drawings that the dural rings were effectively sealed against the passage of the gas. If not, erosion may well have weakened them to the point of failure.

The firings of experimental projectiles, then, did not actually show that the strength of the dural was lowered.

The second type of test of dural was the measurement of shear strength. This was carried out (1) statically, and (2) by applying the pressure, developed in the chamber of the 6-pdr. Mk VII on firing, to the shearing of 0.05" thick dural, (a) with the dural protected from the gas, and (b) with it exposed directly to the gas. The following results are quoted from page 37 of the Fourth Progress Report, April 21, 1943.

Exposed to powder gases	strength less than 11,000 p.s.i.
Protected from powder gases	strength between 22000 and 33000 p.s.i.
Statically	42000 p.s.i.

The report contains a drawing of the device used for holding dural so that a series of circular areas of different sizes were exposed to the pressure, but gives no other details of how the experiments were performed.

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8/ See the results obtained at the Geophysical Laboratory in testing the erosion resistance of metals using a vent through which the gas from a charge of powder exploded in a small chamber was allowed to escape. "Metals Tested as Erosion Vent Plugs" O. H. Loeffler, G. Phair, and H. S. Jerabek, NDRC Report A-148.

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Later greater thicknesses were tested. NDRC Report A-234, page 56, reads as follows:

> "Attention should be drawn to some unsuccessful attempts to use dural for sabots. This material naturally recommends itself to the sabot designer by its high strength-weight ratio. However, this high ratio is not maintained at elevated temperatures. Tests made at the University of New Mexico show that (at least in sections up to the order of 0.125 in. thickness) the shearing strength of dural exposed to the powder gases is only one-fourth the shearing strength it exhibits under static loading at room temperature. The effect is possibly due to two things: (i) ordinary heat conduction into dural from the hot powder gases, and (ii) a thermitic type of reaction between the dural and the powder gases that apparently liberates large quantities of heat at the surface of the dural. If the dural is insulated from the powder gases, neither effect occurs, and successful insulated sabots of this type have been made. Also, if the dural is in massive sections it is probable that neither of these effects will materially weaken the sabot.
>
> In this connection it is only fair to point out that other designers, notably C. L. Critchfield[9], have used dural with some success even when it is exposed directly to the powder gases."

In this the idea that the strength of dural may be lower under rapidly applied than under static loads, which was earlier considered as a possibility, has been dropped, and an increase in temperature is considered to be the cause of failure. No calculations of the probable temperature gradient within the dural appear to have been made. In their absence one may remain doubtful that the temperature of the thick sections involved in the sabots could be raised significantly through thermal conductivity in the short time available.

Much later, in the work on a sabot for the 105-mm Howitzer M3, dural was again tried as a ring to transmit thrust and torque, and was again abandoned because of mechanical failure. In these designs,

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9/ At the Geophysical Laboratory, C.I.W. See C. L. Critchfield and J. McG. Millar, "Development of Subcaliber Projectiles for the Hispano-Suiza Gun," NDRC Report A-233 (OSRD No. 2067).

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however, the factor of safety was very low indeed (Report of 10 March 1944).

The following data on alloy 17S-T have been extracted from the Aluminum Company of America's booklet "Aluminum and Its Alloys" 1946. In calculating the forces acting on the projectile, the pressure values obtained with copper crusher gauges must be multiplied by a factor which for the service type of gauge is usually nearly 1.2 and for the copper ball gauges used in the early work at the University of New Mexico is probably still greater.

Table I

Mechanical Properties of Alloy 17S-T

	Yield Strength (set 0.2%) lb/in^2	Ultimate Strength lb/in^2	Elongation %	Shear lb/in^2
Typical values	40000	62000	22	38000
Minimum values for specifications rolled rod 0.125" - 8.00"	32000	55000	16	
Typical values at elevated temperatures (after prolonged heating at testing temperature)				
75°F	40000	62000	22	
300°F	35000	41000	18	
400°F	11000	17000	33	
500°F	7000	10000	50	
600°F	4000	6000	80	
700°F	3000	4000	100	

Modulus of elasticity 10.3×10^6 lb/in^2 (approx.)

Density 0.101 lb/in^3

The use of dural as a material for the sleeve type bourrelet was at this time considered to be successful, but was discontinued because of the unfavorable weight of dural as compared with plastic. (Second Progress Report.)

Wide experience with dural has shown that when used as a bourrelet it has little resistance to deep engraving which occurs especially when the gun becomes somewhat worn. However, a steel band over the dural, to act as a bearing against the bore, removes this difficulty. This arrangement has been used successfully on both U. S. and British service projectiles. It was adopted later by the University of New Mexico indesigns of all metal sabots for the 75-mm gun and howitzer and for the 105-mm howitzer. It was also used in experimental sabot projectiles for the 76-mm Gun M1A2. In this case however, Dowmetal proved satisfactory and was adopted because of its lower density.

Plastic was tried first as a sleeve type bourrelet. It was found that certain plastics used in this way showed no tendency to fail in the gun and did not engrave deeply. A good deal of effort was then put into investigations of plastics for use as sleeve bourrelets and even as complete sabots.

Information and samples were obtained, in many cases by interviews with plastic experts in government bureaus and other organizations, and tests were made both statically andin the gun. The Fourth Progress Report lists a number of plastics tested and states (p. 38): "As bourrelet material, serving solely to guide the projectile in the gun, it was found that almost all material listed would serve satisfactorily, from dural to wood. The laminated phenolics, particularly Dilecto C, proved most satisfactory. If, however, the entire sabot is to be made of plastic, very few materials appear to have adequate strength combined with a suitable low density. The laminated phenolics, with laminations perpendicular to the axis of the projectile are the most satisfactory."

A table listing shear strength of eight plastics is given and another listing the shearing strength of threads cut in various plastics, 10, 20, and 40 threads per inch.

The tests of plastics reported in the Progress Reports, at this time or later, are all either firing tests or tests of mechanical strength. No long-term tests of dimensional stability are reported, and none appear to have been made. One short-term immersion test on paper laminated phenolic tubing ASTM type XX (Textolite) was made about the middle of February 1944. The piece tested was several inches long. The inside diameter was 2.9", the outside diameter 4.153". It was boiled in water three hours, then let dry and cool at room temperature for one and one-half hours. The outside diameter was then 4.156". It was then submerged in water at room temperature for 21 hours and let dry at room temperature for two hours. The outside diameter was then 4.155".

A good deal of effort was spent both by the University of New Mexico and Arthur D. Little, Inc. in attempts to make all-plastic sabots. This is treated separately in the next section. Efforts were also devoted to producing sleeve type bourrelets and complete sabots by molding plastics. This is also treated separately.

All-Plastic Sabots

During the fall of 1942 and the first half of 1943, a good deal of work was done in an effort to develop an all-plastic sabot 10/. The idea appeared attractive. If it could be accomplished it would result in a light sabot, and if the sabot could be molded in place it would be easy to manufacture. The idea was to have the thrust transmitted from the sabot to the subcaliber projectile over the whole length of the sabot. To this end, the subcaliber projectile was grooved or threaded over the full length of its cylindrical section, and corresponding grooves or threads were formed on the plastic sabot. The rotating band was usually of copper and was attached directly to the plastic, but in a few cases plastic rotating bands integral with the sabot were tried.

The first sabots tried were machined from block or tubing. Later Arthur D. Little, Inc. made a number by molding. The results of firing tests were erratic, and the work was stopped without the reason for the failures being definitely determined. Under these circumstances and because of the availability of the two NDRC reports referred to above, a detailed account of the work will not be attempted here. It is in order, however, to consider some of the problems that confronted the efforts to develop such a sabot.

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10/ The chief sources of information on this part of the work are:
4th Progress Report Contract OEMsr-668, April 21, 1943.
Progress Report for June 1943, July 8, 1943.
Progress Report for July and August 1943, September 7, 1943
Final Report Contract OEMsr-668, Supplements 1, 2, and 3, March 10, 1944.
NDRC Armor and Ordnance Report A-234. This was written July 1943.
NDRC Armor and Ordnance Report A-278 (OSRD No. 3832), "Molded Sabots for Projectiles," by Arthur D. Little, Inc., June 6, 1944.

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Table II

Properties of Phenol-Formaldehyde Plastics[1]

	Compressive Strength lb/in^2	Tensile Strength lb/in^2	Modulus of Elasticity in Tension lb/in^2	Water Absorption[2] percent	Specific Gravity
Laminated					
Cellulose Paper Base	20-40x10^3	7-25x10^3	4-30x10^5	0.3-9.0	1.30-1.36
Cotton Fabric Base	30-44	8-12	3.5-15	0.3-9.0	1.30-1.36
Glass Fabric Base	42-47	11.5-40	10-20	0.3-2.3	1.4-1.8
Cast					
No Filler	4-25	2-9	4	0.02-2.0	1.26-1.335
Mineral Filler	29-34	4-9		0.12-0.36	1.68-1.70
Asbestos Filler	6-10.5	1.8-2.5	10		1.6
Molded					
No Filler	10-30	7-10	7-10	0.1-0.2	1.25
Wood Flour, and Cotton Flock Filler	24-32	6.5-9.5	10.5-12.5	0.4-1.0	1.32-1.47
Macerated Fabric and Cord Filler	15-30	6-8	9-14	0.5-1.8	1.34-1.47
Sisal Felt Filler	10-35	7-12		0.5-15.0	0.7 -1.35
Pulp Preformed	15-35	4.5-12	9-15	0.2-1.2	1.39-1.45

(1) Data from Plastic Properties Chart -- Modern Plastics Encyclopaedia 1946.
(2) Measured on strips of 1/8" thickness, after 24 hours immersion.

The strongest plastics available when the work was done were laminated phenol-formaldehyde plastics, with a base of cellulose paper, or of cotton or glass fabric. The glass fabric base material was not then available in any quantity, and mechanical tests made on it did not indicate a mechanical superiority over the organic base materials. The most of the machined sabots were made from the cotton fabric base material. The compressive strengths of the materials actually used for the machined sabots were not measured but an idea of the maximum strengths can be had from an examination of Table II, where the maximum values listed are 40,000 and 44,000 lbs/in^2.

For the molded sabots nothing quite so strong was available. The A. D. Little report gives the manufacturers' figures for the compressive strength of two of the molding materials used as 25,000 lb/in^2, and it will be seen from Table II that in all probability the third material was not materially higher in compressive strength. It appears likely that the stress required to cause failure of a plastic depends on the rate at which it is applied, and on its duration. About this, however, no information is at hand.

The pressures to which a sabot would be exposed in urrent U.S. Army tank and anti-tank guns are in excess of the compressive strengths of these plastics. Table III lists the rated chamber pressures for a number of these guns. These rated pressures are the maximum pressures that the ammunition will develop when the propellant is at 70°F. Some lots of propellant will give the rated muzzle velocity, at 70°F, with a lower pressure, but these pressures will be developed at 70°F by other lots. As the temperature of the propellant goes up the pressure developed increases. In the case of the 76-mm gun, which is fairly representative of guns of this type, the pressure-temperature relationship is almost linear, the increase in pressure being 125 lb/in^2 per 1°F increase in temperature[11]. There was a requirement that ammunition

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11/ "High and low temperature ballistic research. First Progress Report, Firings in 76-mm Gun M1," B. E. Anderson and W. S. McGilvray, Ammunition Development Branch, Ordnance Department, July 3, 1943.

Table III

Rated Pressures for Selected U. S. Army Guns, Propellant at 70°F.

Gun	Ammunition	Pressure lb/in^2 Copper	Pressure lb/in^2 Actual (approx.)
37mm gun M3A1 (A.T.)	APC M51	50,000	60,000
57mm gun M1 (A.T.)	APC M86	44,000	52,800
75mm gun M3 (Tank)	APC M61	36,000	43,200
76mm gun M1A1 (Tank) and M1A2 (Tank)	APC M62	43,000	51,600
90mm gun M3 (Tank)	APC M82	38,000	45,600
105mm Howitzer M2	HE M1 (5th zone)	30,000	36,000

The rated pressure is the maximum pressure at standard temperature developed by the round in question. It is given in terms of copper gauge readings. Actual pressures are approximately 1.2 times copper gauge pressures. The figures in the last column were obtained by multiplying those of the preceding column by 1.2. Some lots of ammunition will give the rated muzzle velocity with a lower chamber pressure. Increase in temperature of the propellant will increase the pressure above rated pressure.

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should function properly at temperatures as high as 135°F, and actually temperatures in excess of this may be developed in a round that has been left in the chamber of a hot gun, or even exposed to the sun in some localities. The pressure in the 76-mm gun at 135°F would be 8125 lb/in^2 above the pressure at 70°, i.e., the maximum pressure would be 51125 lb/in^2. These pressures are stated in terms of copper gauge readings and must be multiplied by a factor of about 1.2 to get true pressures.

This raises the maximum pressure at 135°F to approximately 61500 lb/in^2. The base of the sabot, behind the rotating band, is exposed to the pressure of the propellant gas; however, the pressure at this point is somewhat less than the pressure at the breech end of the chamber, as some or all of the propellant is being accelerated.

The rotating band on the projectile exerts a pressure against the bore of the gun, and likewise of course against the projectile. The peak of this pressure occurs during engraving which, in a new gun, begins immediately after the projectile starts forward, and in any case considerably before the peak chamber pressure is reached. The peak band pressure, in the case of standard projectiles is likely to be materially in excess of the peak chamber pressure. No systematic information on this subject is at hand but the following data will show the magnitude of the pressure to be expected. In all cases the pressures stated are averaged over the whole width of the band. Local peak pressures may be considerably greater. In the case of the 37-mm gun M3 a band pressure of 83000 lb/in^2 when firing was measured[12/]. Band pressures measured when firing nine HE shell Mk XXVII Mod. 3 from the US Navy 3" A.A. gun ranged from 59000 to 71500 lb/in^2, averaging 65500 lb/in^2. The average of five measurements of band pressure in the 75-mm gun T22 firing He shell M48 E2 was 65100 lb/in^2, the high value being 71500 lb/in^2, and the low value 51500 lb/in^2. In this case the gauge was about 2" beyond the forcing cone. Pushing projectiles through instead of firing gives

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12/ "Stresses in Gun Tubes. Band Pressure Characteristics of 37-mm M3 Gun 770-Tube No. 2928," R. Beeuwkes, Jr., Watertown Arsenal Laboratory, Experimental Report No. WAL 730/95, May 5, 1944.

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values 10% - 30% lower than those obtained from measurements made during firing the same projectile. Pushing the 75-mm AP M72 shot through the M1897 tube gave a band pressure of 108300 lb/in^2.13/ The band pressure is higher for the solid A.P. shot M72 than for the M48 E2 shell, presumably because the AP shot being solid gives a less yielding support to the band than the rather thin wall of the M48 shell. The small difference between the band pressures generated when firing and when the projectile is pushed through suggests that the band pressure in firing will not depend greatly on the chamber pressure.

A decrease in the diameter of the band, or what is equivalent to it, improper seating of the band, leaving a space between it and the bottom of the band seat, results in much lower band pressure. It seems likely, therefore, that the pressure developed by a copper or gilding metal band on a sabot of the type under consideration would be materially less than the pressure that would be developed by the same band on a standard steel shot, for there is some play between the sabot and the subcaliber projectile, and, in the case of the machined sabots, there is also play in the threads between the band and the sabot. In addition the plastic is more compressible than steel. Each of these factors will lower the pressure. There is a limit, however, to the lowering that is

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13/ The information about the 3" and 75-mm projectiles was given the writer informally by Prof. Karl F. Herzfeld. For details see his paper, NDRC Report A-455 in course of preparation.

The 75-mm gun T-22 was rifled differently than the M1897, M2, or M3. The rifling was rectangular, the land width 0.1444", the groove width 0.1866", the groove depth 0.0305". The bore diameter was 2.951". The shell M48 E2 was fitted with a plain band 3.020" diameter on the cylindrical section. The length of the cylindrical section was 0.61" and of the tapered section 0.25".

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practicable for there must be enough pressure to insure that the band is properly engraved and it seems quite likely that the band pressures may equal or exceed the strength of the plastic.

In the all-plastic sabots described above, as in all other sabots experimented with, the forward thrust of the propellant against the sabot is not distributed along the length of the sabot but is applied at the base. Therefore, because of the great difference between the plastic and the steel in respect to the amount of strain produced by a given stress, the forward thrust of the sabot on the subcaliber projectile cannot be distributed at all uniformly along the sabot. Speaking of this, in connection with the stress analysis of the all-plastic sabots designed at the University of New Mexico, and comparing this analysis with that for the threaded base ring sabot of steel, the authors of NDRC Report A-234 say on page 53 of that report: "Another essential difference is due to the samll modulus of elasticity of plastics (E is of the order of 10^6 lb/in^2 for plastics, as compared to 30×10^6 lb/in^2 for steel). This means that the strain for a given stress is about 30 times as large for plastics as for steel. Hence the stress in the threads holding the sabot to the projectile is concentrated in the threads toward the base of the projectile, rather than distributed over the entire length of the threads. The amount of this stress concentration is difficult to predict, but the use of a safety factor of about 2 has resulted in successful designs of this type."[14/]

14/ "Sabot Projectile for Cannon," NDRC Armor and Ordnance Report A-234 (OSRD No. 3010), W. D. Crozier, H. F. Dunlap, C. E. Hablutzel, Lincoln LaPaz, and D. T. MacRoberts. The words "successful designs" evidently mean that individual sabot projectiles made to the design were fired successfully.

When one considers the stress concentrations that are likely to occur from the complex stress distribution in the rear part of sabots of this type it seems most improbable that any of the plastic materials available when the work was done are strong enough to work in the guns listed in Table III.

The work on all-plastic sabots was begun while the 6-pdr. Mk VII gun (57-mm) was the only test gun in use and the sabots were consequently for that gun. The subcaliber projectiles used were solid steel, 1.2" in diameter, and of various lengths from 3.7" to 4.55". They were threaded or grooved along the full length of the cylin drical section, usually 10 per inch, as tests showed that the shear strength of the plastic used was higher at 10 than at 20 per inch. The length of the sabot depended on the length of the cylindrical section of the subcaliber projectile, so was of various lengths from 2.0" to 3.1". The rotating bands were usually of copper, threaded onto the plastic from the rear; the pitch of the thread being almost always 20 threads per inch. A few sabots with integral plastic bands were also tried. The report of April 21, 1943 lists, round by round, the results of firing 85 all-plastic sabots from the 6-pdr. Mk VII. These include 35 separate designs. In most cases only one or two projectiles made to a given design were fired. In no case was the number greater than 10. The results were erratic both in respect to chamber pressures and flight characteristics. The only cause assigned at the time was variation in the plastic. It seems at least as probable that differences in the stresses set up from round to round in the plastic, which at best must have been stressed nearly to failure, account for the unpredictable differences in behavior.

The molded all-plastic sabots prepared by Arthur D. Little, Inc. were also for the 6-pdr. Mk VII. The steel subcaliber projectile used was 1.2" in diameter and 4" long grooved along the cylindrical section 10 grooves per inch. The plastic sabot was 2.5" long. The copper rotating band was placed in the mold and so was attached during molding.

The results of firing these projectiles at the University of New Mexico Proving Ground are given in NDRC Report A-278. The velocity, the chamber pressure (copper), and the flight characteristics based on the amount of yaw, are stated for each round. The mass of the projectile was essentially the same in all cases, and the same powder and weight of charge were used throughout. A greater proportion of the projectiles failed in the gun than had been the case with the machined sabots. In the table in the report the rounds are grouped according to the plastic used and other variants. Again the results were quite inconsistent. "Generally speaking, some of each group gave good flights and others gave poor flights thereby making it impossible to compare intelligently one feature with another."[15]

It is possible, however, to see some system in the behavior. From a plot of the pressure against velocity, for the rounds for which these data are given, it is evident that the normal pressure with this charge and these projectiles was about 24,000 lb/in^2 (copper), i.e., above the compressive strength of the plastic, and the normal velocity about 3850 f/s. This is a much lower chamber pressure than that used in current tank and anti-tank guns. Although the normal pressure appears to be about 24000 lb/in^2, there is a wide spread to the

15/ NDRC Report A-278, p. 22.

pressures listed, some being as high as 56,000 lb/in^2. This sort of thing is not infrequently met with when using standard projectiles and is usually assigned to faulty ignition of the propellant.

The pressures stated for the individual rounds have been averaged according to the flight characteristics and the values so obtained are listed below in Table IV. The extremes of pressure and the number of rounds included in the data are also listed.

Table IV

Pressure, and Flight Characteristics of A. D. L. All-Plastic Molded Sabot

Flight	Stated Chamber Pressure in lb/in^2 (copper)			No. of Rounds
	Average	High Value	Low Value	Included
Very Good	25,000	26,000	23,000	3
Good	28,350	56,000	22,500	13
Fair	28,400	32,000	20,000	4
Tumbled	43,300	56,000	32,500	5
Failed in gun	39,710	55,000	21,500	7

The data show a very definite association of successful flights with quite moderate chamber pressure, and of failures, i.e. failure in the gun or tumbling in flight, with high chamber pressure. There are notable exceptions to this, however. Rounds that developed 45,000 lb/in^2 and 56,000 lb/in^2 gave good flight, and one round where the projectile broke up in the gun developed only 21500 lb/in^2.

The writer of the Arthur D. Little report attributed the erratic pressures to cocking in the bore. He says (p. 22):

> "In nearly all cases of failure, the chamber pressure was exceedingly high. We are convinced that the cause of failure is primarily in the geometrical proportions of the sabot, which is 2.5 in.

long and 2.24 in. in diameter, that is, with a ratio of length to diameter of about 1 to 1. Such a cylinder can easily get cocked in the bore, momentarily plugging it and causing the high pressure. The high pressure in turn in dislodging the shot may well start failures of the material, which would never occur in normal operation. Many of the test firings of the similar sabot-projectiles made by the Universityof New Mexico were subject to the same erratic behavior. It was therefore agreed to discontinue further work on this size of projectile and sabot."

Any increase in the resistance offered by the projectile to movement up the bore during the early stages of the burning of the powder will, by increasing the pressure on the powder, increase the rate at which it burns. This will in turn give rise to an increase in the peak pressure. No calculations have been made to find an approximate figure for the increase in "starting pressure" that would be needed to raise the peak pressure from 24000 lb/in^2 to 56,000 lb/in^2 and it is by no means clear that cocking in the bore[16] could do so. Considering the strength of the plastic, and /in the absence of pressure data obtained from firing a series of standard projectiles cut down to the weight of these sabot projectiles, using the same charge, showing that this charge would in fact give uniform pressures with a normal projectile of this weight, it does not seem necessary to appeal to this mechanism to explain the erratic results.

After the lot of projectiles made to design, 28-75 D had been sent to Aberdeen, some more work was done at the University of New Mexico on all plastic sabots, this time for the 75-mm gun, M3. The Final Report, Contract OEMsr-668, Supplements 1, 2, and 3, contains drawings of two designs, and the record of firing tests of each. Both these designs had a partially segmented bourrelet with a copper rotating band threaded

16/ Among the projectiles tried during the development of an armor piercing sabot projectile for the 105-mm howitzer were some whose ratio of length to diameter was only slightly greater than that of the molded all-plastic sabot projectiles.

to it, 20 threads per inch. In one case the projectile was solid steel 1.6" dia 5.1" long. In the other case it was the 57-mm APC M86 projectile threaded 10 threads per inch for 2.7" forward of the base. The plastic extended beyond the threaded portion having a total length of 4.5". Both models were unsuccessful. The projectiles tumbled in flight. The report states: "The results of these and other tests were so unsatisfactory that further consideration of all plastic designs for the 75-mm gun was suspended."

The 75-mm sabot 2-75 D with the M86 subcaliber projectile did not differ significantly in dimensions from many sabot projectiles with plastic bourrelets, steel sabot rings, and the same subcaliber projectile, that had been fired successfully from the 75-mm gun. This eliminates the matter of the cocking in the bore as a possible cause of the failure. In some of the 2-75 D projectiles, the forward part of the bourrelet was a separate piece of plastic of a kind used successfully many times for bourrelets for part-steel-part-plastic sabots. Failure of this portion of the sabot could hardly have occurred. Although some of the steel projectiles used in the firings from the 6-pdr Mk VII must, judging from their dimensions, have had at best but a small margin of stability, the M86 when fired with full spin from the 75-mm gun at the altitude of the University of New Mexico Proving Ground (approximately 5000') has a good margin of stability, so that tumbling indicates that the projectile did not receive full spin. It appears likely that the plastic of the rear part of the sabot failed under the band.

From the experimental work it is evident that the plastics used would not stand up to the stresses encountered in either the 6-pdr Mk VII or the 75-mm gun M3. From a comparison of band pressures and chamber pressures with the compressive strength of laminated plastics (Table II) it appears improbable that these plastics are strong enough to be used in all-plastic sabots for spin-stabilized projectiles to be fired from present day guns.

Molding Plastic Parts

Following a conference in the Engineering and Transition Office of the OSRD on February 9th, and on the strong recommendation of that office, Arthur D. Little, Inc. was contracted (Contract OEMsr-886) to help in the sabot program of Division 1, NDRC by investigating plastics for use in sabots, and suitable production methods for use with them. A considerable amount of work was done co-operatively by that company and the University of New Mexico in investigating the possibility of molding the plastic parts of sabot projectiles designed by the University of New Mexico; both plastic bourrelets and all-plastic sabots. The experimental work, done by the University of New Mexico on this program, consisted essentially of making firing tests. The work has been covered by the final report of the Arthur D. Little Company[17], and need not be considered in any detail here. However, certain conclusions may be stated. The following are quoted from page 1 of that report:

(1) "There are few materials among the non-metals that are satisfactory for making sabots.

(2) "The phenolic plastics are suitable, at least for the sleeves or bourrelets of sabots.

17/ "Molding Sabots for Projectiles," NDRC Armor and Ordnance Report NA-278 (OSRD No. 3832), Arthur D. Little, Inc., June 6, 1944.

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(3) "An entirely satisfactory all-plastic sabot design was not obtained, but on the other hand it was not proven that such a design was not possible.

(4) "For all but the smallest size projectiles it appears more feasible to mold the sabots separately and attach them to the projectile than to mold directly onto the projectile.

(5) "The completed sabot of phenolic plastic is sufficiently stable in dimensions."

In explanation of item (5) it appears from page 4 of the report that the writer had in mind that dimensional changes should not be over 1/3 of 1 percent, i.e., 0.01" in 3"[18/]. Actually, a change of 1/3 of 1 percent is not tolerable. The diameter of the bourrelet shown on University of New Mexico designs 28-75 D, dated 5-27-43, and 28-75 D revised, dated 3-2-44 is 2.945" - 0.005". The diameter of the bore of the 75-mm is 2.950" + 0.002". An increase in diameter of 0.0033 x 2.945 is 0.0098" which would make a bourrelet, originally 2.945" in diameter, 0.0048" greater in diameter than the bore of the gun. In this case, the tolerable expansion is only one-half of what they considered acceptable.

After investigating the practicability of molding the sabot or the bourrelet around the subcaliber projectile, it was concluded that it was not practicable. The first experimental attempt was to mold all plastic sabots for the 6-pdr. Mk VII gun (57-mm). The subcaliber projectile was 1.2" in diameter. It was found that shrinkage of the molded part during cooling gave rise to dangerously severe stresses in it. Many of the moldings cracked, some soon after coming out of the mold, some several days later, without any apparent abuse. Others cracked on rough handling.

18/ There is no indication that long term immersion tests or long term tests at high and at low humidity were actually carried out.

Another difficulty, experienced in trying to mold the sabot on the projectile, arose from the fact that the projectile about which the sabot is to be molded must fit firmly and exactly into a receptable in the mold. This would require the projectile dimensions involved to be held within extremely close limits.

Still another difficulty that was anticipated, if an attempt were to be made to mold around the 57-mm APC M86 projectile, arose from the fact that to handle inserts as long as this would require presses with a longer stroke than is commonly used.

All attempts to produce sabots molded directly around the projectile were abandoned. However, quite a number of all-plastic sabots for the 6-pdr. gun were molded and later assembled to the subcaliber projectiles.

A mold was also made in which plastic bourrelets for sabots for firing the 57-mm APC M86 projectile from the 75-mm gun weremolded.

It was found impracticable to mold the parts to the final dimensions because of (1) the taper required in the mold and (2) the variation in the dimensions of the finished moldings which was about 0.003 inch per inch under carefully controlled conditions. It was therefore recommended that the moldings should be made oversize and the final surface be obtained by turning in a lathe.

Following this plan, the recommendation for the construction of projectiles to the 28-75 D design was to mold the bourrelet, using transfer molding, with both outside and inside dimensions oversize. The molded bourrelet would then be assembled to the projectile. The space between the subcaliber projectile and the bourrelet would be filled with a liquid resin that would cure or polymerize in place to a solid. This would cement the bourrelet in place and would also eliminate play between the bourrelet and the subcaliber projectile. The outer surface of the bourrelet would then be machined to size and concentric with the subcaliber projectile.

ARMOR PIERCING SABOT PROJECTILE FOR THE 75-MM GUN

Request for the Development

About the end of 1942 it became quite evident that the work at the University of New Mexico had reached the stage at which it should be directed toward the development of a specific projectile for a specific gun. The Office of the Chief of Ordnance, which was consulted by Division 1, NDRC, indicated that the gun in which the sabot projectile would be the most useful was the 75-mm. Division 1, NDRC advised the University of New Mexico to direct their work toward the development of an AP round for the 75-mm[19]. However, no 75-mm gun was available at the University of New Mexico, and without it very little could be done in this direction.

19/ There were three 75-mm guns concerned. All had the same chamber and rifling and consequently fired the same ammunition. All were on automotive mounts.

Gun	Shot Travel in.*	MV ft/sec	Mounting
75-mm M1897A4	88.99	2000	being mounted in Gun Motor Carrige M3
75-mm M2	71.04	1920	mounted in medium tank M3
75-mm M3	97.66	2030	mounted in medium tank M4 and M3

* With projectile APC M61, weighing 14.92 lb.

The twist of these guns is 1 turn in 25.58 calibers.

Division 1, NDRC had an estimate prepared of the performance to be expected from a tungsten carbide projectile fired from the 75-mm gun M3 by means of a sabot, and had graphs prepared that, by comparing the calculated performance of this projectile with that of the standard APC M61 projectile, showed the advantage to be gained by means of the tungsten carbide sabot projectile, at ranges up to 2400 yds, in (1) penetration of armor at 20° incidence[20], (2) lead needed when firing at a moving tank, (3) error that could be made in estimating the range to a tank without resulting in a miss.

The calculated improvement in performance was impressive, and, although (1) the muzzle velocity used was admittedly optimistic, and (2) it was apparent from what was known about the behavior of tungsten carbide against plate that considerable work would likely be needed to develop a satisfactory tungsten carbide projectile, it was evident that there was a good prospect of great improvement from the use of tungsten carbide in the sabot projectiles for this and other guns.

20/ This estimate was based on the data that were then available to Division 1, NDRC from firing trials of tungsten carbide cored projectiles against plate. These were: the results of a British trial of a captured German 28mm/20mm tapered bore gun and projectiles (Proc. O. B. 14227), and two ballistic limits obtained by the Ordnance Dept. in trials of 0.600" diameter cores, 2" homo/20°/2270 ft/sec and 4" homo/20°/3600ft/sec. The first of these was supplied by the Ballistics Section, the second was from Inclosure 2 of "Second Report on the 37/28mm and 37 mm High Velocity Armor Piercing Projectiles, and Twenty-Second Report on O. P. 5364."

The MV used in the estimate, 3550 ft/sec, was calculated for a 5.4 lb projectile using the maximum possible charge of M2 powder with an ideal web. A somewhat lower MV for a projectile of this weight would have to be accepted in any service use to provide the necessary leeway in charge necessitated by variations in different lots of powder. Also the assumed ratio of mass of tungsten carbide core to total mass of projectile, 3.6/5.4, was higher than has been realized in practice with a core of this size in a gun of this caliber.

At this time, however, the Office of the Chief of Ordnance was very skeptical about the value of tungsten carbide against tanks. In their experience tungsten carbide cores had pulverized on emerging from plate, and they considered that the particles so formed were too small to do much damage inside a tank.

Finally, at a conference on February 9, 1943, the Office of the Chief of Ordnance requested that Division 1, NDRC develop a sabot for firing the projectile 57-mm APC M86 21/ from the 75-mm gun M3, and undertook to arrange for the supply of a gun to the University of New Mexico.

An analysis prepared for Division 1, NDRC showed (1) that by means of a sabot this shot could probably be fired from the 75-mm gun M3 with a slightly higher MV than that given to it by the 57-mm gun M1, and (2) that compared with the standard APC M61 projectile, assuming equal accuracy, the sabot projectile, at battle ranges, should give a better chance of hitting, because it would have a shorter time of flight and a flatter trajectory, and (3) that it should penetrate a greater thickness of armor than the APC M61 provided the quality of the projectile

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21/ This was a newly designed projectile for the 57-mm gun M1 (antitank) and the British 6-pounder, 7 cwt. (tank and antitank). It was expected that it would soon be in production. It was a steel armor piercing projectile, fitted with a steel armor piercing cap and a ballistic cap or windshield. It contained a cavity in the base, for a small bursting charge of HE, and was to be fitted with a base detonating fuze designed to burst the projectile inside a vehicle, i.e., after it had passed through the armor. The fuze was to contain a tracer to be ignited by the propellant. This was to be in a heavy tracer pocket that projected to the rear in the form of a truncated cone. The MV from the 57-mm gun M1 was to be 2700 ft/sec.

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was such that it did not deform on impact[22/]. The stability factor of the APC M86 fired from the 57-mm gun M1 was not known, but the Office of the Chief of Ordnance believed that its stability in the 75-mm gun would be adequate.

However, much greater improvements in respect to time of flight, flatness of trajectory, and thickness of armor penetrated were to be expected from the use of tungsten carbide than from the use of steel subcaliber projectiles in this gun.

All the reasons for the choice of projectile by the Office of the Chief of Ordnance are not known, but the following appeared at the time to be the principal ones. British and U.S. armor piercing projectiles for use against tanks had, in the past, consisted almost entirely of solid steel shot, with or without an armor piercing cap. The Germans, on the other hand, had used armor piercing shell, containing a small cavity in the base, filled with a bursting charge of HE. These shells were fitted with armor piercing caps and ballistic caps or windshields. They were beautifully made and were supplied even in quite small sizes. Experience in Libya had shown that British AFV's (armored fighting vehicles, e.g., tanks) were more prone to catch fire when German projectiles went through their armor [redacted] than were German AFV's after similar hits by British shot. Ordnance

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22/ With the sabot projectile developed for the 75-mm gun M3 the expected penetration of the 57-mm APC M86 is about 25 percent greater at be muzzle and about 20 percent greater at 2000 yards than that of the APC M61 fired from the same gun. The estimate is based on the curves of penetration prepared by the Ballistics Section, Technical Division, OCO. The achievement of the increase in penetration at the higher striking velocities, i.e., shorter ranges, requires projectiles of excellent quality.

Department observers who had studied the derelict AFV's in Libya were convinced that this was because the Germans were using projectiles containing a bursting charge, and that solid shot were much less effective in starting fires. There had been repeated demands from the British Middle East Command to the authorities in U. K. for armor piercing shell. This could be taken to indicate a similar conclusion on the part of that Command[23]. This was probably the major reason why this projectile, the APC M86, was chosen instead of the corresponding solid shot, the AP M70. There was the additional reason that the very blunt armor piercing nose of the AP M70 resulted in high retardation while the long tapered ballistic cap or windshield of the APC M86 resulted in much lower retardation, and consequently, in the retention of a greater proportion of the energy for armor penetration at a distance from the muzzle. Of course the fitting of a windshield would overcome this defect.

The objections arising from the absence of a bursting charge applied also against tungsten carbide cored projectiles. Moreover, as already stated, because of the results of firing tests against plate, the Office of the Chief of Ordnance was at that time very skeptical about the value of tungsten carbide against tanks.

23/ The case for the shell was not quite as clear as may appear from the above. The bursting charge can be useful only if the shell remains in condition to burst after it has gone through the armor. Solid shot will go through a greater thickness of plate than will corresponding shell. Moreover, there were reasons to believe that it was easier for flying fragments to ignite the propellant charges in British AFV's than those in German AFV's, and this was believed by authorities in U.K. to be a contributing factor to the greater proneness of the British AFV's to take fire when hit.

Development and Production by University of New Mexico

The request of the Office of the Chief of Ordnance to have a sabot developed for firing the 57-mm APC M86 projectile from the 75-mm gun M3 was made on February 9, 1943. A gun and mount, together with the necessary ammunition components, were to be supplied. Some delay occurred, however, before this was done, so that it was not until April that the gun and mount were received. In the meantime the ammunition components had been received, with the exception of the APC M86 projectiles which were not yet ready. The gun supplied was mounted in the mount used in the turret of the medium tank; the combination mount M 34 A1. When it had been received, it was mounted on a concrete pedestal at the University of New Mexico Proving Ground. The first round was fired from it on April 13th.

While waiting for the 75-mm gun, preliminary work had been carried on using the 6-pdr. Mk VII, and when the 75-mm gun arrived the work progressed rapidly. The first sabot projectile, design No. 1-75, was fired from the 75-mm gun on April 19. The first small shipment of APC M86 projectiles was received on May 7, and on May 26 a successful dispersion shoot of 18 rounds of the final design was carried out. The results of this and other dispersion firings are collected in Table VIII.

The sabot projectile design developed by the University of New Mexico to fire the 57-mm APC M86 projectile from the 75-mm is designated 28-75 D, dated 5-27-43. Drawings of the design are shown in Figures 1 and 2.

The work done in developing this projectile and in manufacturing the lot to be supplied to the Ordnance Department is detailed in the

Monthly Progress Reports, and summarized in Final Report Contract OEMsr-668, Supplements 1, 2, and 3, dated March 10, 1944. A discussion of the mechanics of this sabot projectile, together with a stress analysis and the results of firings, will be found in NDRC Armor and Ordnance Report A-234 (OSRD No. 3010).

This is a simple design of sabot, and quite easy to manufacture. It involves but a slight modification of the standard projectile used with it. A steel ring, partially segmented from the front, is threaded over the rear end of the subcaliber projectile. After this ring is in place the rotating band is seated in the groove, or band seat, on the ring, by being forced through compression dies. This not only seats the band, but also closes the forward ends of the segments of the ring tightly on the subcaliber projectile, thus eliminating some of the play between these parts. A steel skirt, to fit inside the mouth of the cartridge case, projects from the rear of the threaded steel ring and is integral with it[24/]. In front of the threaded steel ring a plastic sleeve, partially segmented from the inside, surrounds the subcaliber projectile and acts as the bourrelet.

It will be noted on Plate II that the rear outer surface of the projectile 57-mm APC M86 is to be threaded for 0.750" forward from the

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24/ In this design the crimping groove is immediately behind the band so the mouth of the case has to be formed into the groove. Current practice is to have the crimping groove behind the mouth of the case. This gives a stronger construction. However, the sabot projectile is lighter than the standard projectile so that this design may provide adequate strength. Before adopting this design, the Ammunition Development Branch, Technical Division, OCO, was consulted about the practicability of crimping in this way. They reported that it could be done by a slight modification of the crimping machine

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base. It should be mentioned that the projectiles used by the University of New Mexico were not standard projectiles. They were from a small lot, specially processed for this work, from the first production of this projectile. The modifications of the projectiles consisted in (1) leaving off the rotating band and omitting the groove in which it seats, (2) omitting the hardening process 25/. Forward of the 0.750" of threads to the ogive the projectile was therefore cylindrical. The center of the groove in the projectile into which the cartridge case is normally crimped is approximately 0.5" forward of the base. The groove is therefore within the threaded section, which could probably be decreased slightly in length if this crimping groove were omitted.

It should be noted here that although the drawing of the threaded steel sabot ring on Plate II shows the band seat smoothly grooved this was not its condition when the bands were applied. A series of cold chisel cuts were first made across the grooves to prevent any tendency of the band to rotate in the grooves.

Attention is drawn to the fact that the base of the sabot, i.e., the threaded steel ring, and the subcaliber projectile are securely fastened together and presumably will remain so as the projectile passes up the bore. Exactly how important this may be is not definitely known.

25/ The projectiles supplied were otherwise as shown on Ordnance Department drawings

75-2-320	Metal Parts and Assembly	January 27, 1943, and
75-2-323	Details	January 27, 1943,

Extensive reversion of the dimension and tolerances were later introduced, and new drawings were prepared under the same numbers.

However, it was found, when firing sabot projectiles with a base plate in the British 17-pounder[26/] against plate at Aberdeen, that, unless the subcaliber projectiles were properly seated against the base when firing occurred, large yaws were experienced. In the firings at Aberdeen, of sabot projectiles made by the Remington Arms Co., described later in these notes, failures occurred within the bore when the base and the subcaliber projectile were not adequately fastened together. This occurred in guns but little worn. When there is considerable free run, the likelihood of separation and consequent trouble is much greater. How well the threaded steel ring design will work in a gun with considerable free run is not yet known.

On emerging from the muzzle the sabot parts break off under centrifugal force with no apparent disturbance of the subcaliber projectile. A muzzle velocity of 2800 ft/sec is readily obtained from the 75-mm M3 gun.

The projectile was given a considerable amount of testing at the University of New Mexico by firing through yaw cards and for dispersion against a vertical target at 1000 yards. The results of the dispersion tests are given in Table IX. It was expected that if it were given extended tests some modifications would prove necessary, but it did appear to be in a suitable stage of development for submission to the Ordnance Department for firing tests at Aberdeen Proving Ground.

A lot of 70 of these projectiles was made up and supplied to the Ordnance Department for test at Aberdeen Proving Ground. They were shipped by express on June 19, 1943.

26/ These projectiles were designed and supplied by the Geophysical Laboratory for armor penetration experiments with steel projectiles at high velocities.

Many of the AP caps and windshields were loose on the APC M86 projectiles when they were received at the University of New Mexico.27/ The AP caps and windshields were brazed to 60 of this lot of 70 projectiles during assembly of the sabots. The remaining 10 projectiles were left as received in this respect. The APC M86 projectiles in this lot of 70 were not fitted with fuzes or tracers. The cavities were filled with sand and shot to bring the weight to 7 lbs and were plugged. The complete sabot projectile weighed 8 lb, 6 oz ± 1/2 oz.

Tests at Aberdeen Proving Ground

The tests at Aberdeen Proving Ground, and the results, are described in detail in APG Firing Records M24862, 12, 13, 14, 15, 16, 20, 21 July 1943, and M25496, August 10, 1943.

The stability factor of the projectile 57-mm APC M86 had not yet been determined. Therefore, although it was expected that the projectile would be found to be sufficiently stable,28/ it was important to obtain a value for the stability factor. Accordingly, although these projectiles were not fuzed but only plugged, and would therefore have

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27/ At the time these projectiles were made, the method of attaching the AP cap to the body and the ballistic cap to the AP cap by crimping or rolling had not been perfected. The fact that the hardening process had been omitted in manufacture may have added to the number of loose caps.

28/ This projectile, the APC M86, had closely the same proportions as the 3" APC M62 that had been designed for the new 3" gun, the 76-mm which had a twist of 1 turn in 40 calibers. The twist of this projectile fired from the 75-mm gun was considerably greater, 1 turn in 33.7 calibers.

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a slightly different stability factor than the fuzed projectile (probably higher) efforts were made to determine their stability factor. Although these efforts did not result in an entirely satisfactory determination of the stability factor, they did show that when the projectiles were fired from a moderately worn gun the projectiles did not always receive full spin, in all probability because of failure of the rotating band 29/. These firings for stability are covered in the APG Firing Records cited above.

The first firing for stability took place on July 14 from a 75-mm Gun M3 that had previously fired 1905 rounds and was consequently but little worn. Eleven rounds were fired at an MV of 2800 ft/sec. Only one of these had enough yaw to permit a determination. The maximum yaw in this case was 8°. A second attempt was made on July 20. The gun used was a 75-mm M1897 that had previously fired 9215 rounds and was badly worn. Three sabot projectiles and one 75-mm APC M61 projectiles were fired. All tumbled because of the excessive wear of the gun. In two cases the spin imparted to the sabot was so low that the sabot parts did not separate. A third attempt to obtain a stability factor was made on August 10, using a 75-mm gun M1897A4 that had previously fired 4694 rounds. Five sabot projectiles and one 75-mm APC M61 projectiles were fired. The standard projectile had small yaw (0°). Two of the sabot projectiles had small yaws (3.5° and 3.7°). The stability factor was calculated for one of

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29/ This gun has the same chamber and rifling as the old French 75. The rotating band used is very narrow in comparison with that on most present day projectiles. The gilding metal band on the standard projectiles had given trouble from slipping.

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these rounds. One sabot projectile had large yaw (up to 24°), and, from the rate of precession of the yaw, had definitely not received full spin. Two other sabot projectiles had large yaws but lost their windshields when they struck the cards. Presumably they did not receive full spin.

From these results it appears probable that a stronger rotating band may be needed for a sabot for these guns. As the width of the band cannot be increased this means a band made of stronger material, e.g., soft iron.

The stability factors determined for the plugged projectiles, calculated to the muzzle and standard atmospheric conditions, but without taking into account the retardation from the yaw cards, were: July 14 — 1.23; August 10 — 1.33[30/]. These values were obtained informally by Division 1, NDRC, September 9, 1943. They appear in the Firing Records cited.

On July 10, ten rounds were fired for accuracy at a vertical target at 800 yards, and ten standard 75-mm APC M61's were fired in comparison with them. The gun used was the one that had been used on July 14 for the stability firings. The dispersion found was about the same as had been found at the University of New Mexico; horizontal 1.10 minutes, vertical 0.69 minutes. The corresponding dispersion of the APC M61 was horizontal 0.71 minutes, vertical 0.76 minutes (see Table VIII). A photograph of the target is included in the APG Firing Record.

30/ Although at this time a stability factor as low as 1.25 was considered acceptable, it was subsequently decided that a considerably higher value was needed. A value of 1.5 was later chosen for the sub-caliber projectile used in the armor piercing sabot projectile developed for the 105-mm Howitzer M3.

During the tests at Aberdeen a number of rounds were fired at night to obtain stereoscopic micro-flash photographs of the projectile a few feet in front of the muzzle. These photographs were taken by personnel of the Geophysical Laboratory using equipment that they brought with them. In order that the muzzle flash should not prevent taking these pictures a flashless powder was used. Each of the photographs shows the M86 projectile free in flight together with the annular zone of the discarded sabot parts.

In order to obtain some idea of the spread of the parts of the sabot in flight a screen was erected at 75 ft from the muzzle. After eleven rounds had been fired, this was photographed. The extreme spread of the parts was about 27 feet. The personnel working at the University of New Mexico Proving Ground had already tried to obtain a figure for the maximum range of the parts. The greatest distance from the gun at which any parts were found there was 600 yards.

The results of the tests at Aberdeen, as known on July 21, appeared quite satisfactory[31/], and on July 22 instructions were issued by Division 1, NDRC to the University of New Mexico to proceed immediately with arrangements for the manufacture of 1000 projectiles for extended service tests. The Mueller Company of Decatur, Illinois, who were at that time making the M86 projectile, undertook to manufacture the metal parts. In conversations with their engineers, a

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31/ The information obtained by Aberdeen as a result of their calculations of the stability of the rounds fired on July 14 and July 20 were not known until much later, and, although additional firings, in a worn gun, had been requested by Division 1, NDRC, these had not yet been made. They were made on August 10.

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few slight modifications of the design were suggested to facilitate manufacture. These were incorporated in models made up at the University of New Mexico and tested at the proving ground (See 28-75H, Table IX). However, while this was being done, the instructions to arrange for the manufacture of the 1000 projectiles was canceled for reasons to be stated later.

ARMOR PIERCING AND HIGH EXPLOSION SABOT PROJECTILES FOR THE 105-MM HOWITZER M3

Request for the Development

On July 20, 1943, Division 1, NDRC appointed a Subcommittee of Division members to make a general survey of the development of sub-caliber projectiles by the Division with a view to deciding how best to prosecute the development in the future. In order that this committee could meet with representives of the Army Ground Forces (Infantry, Artillery, and Armored Forces), and obtain from them opinions as to the probable uses of sabot projectiles by the Services that they represented, the Office of the Chief of Ordnance arranged a conference in the Pentagon Building on August 7, 1943. This conference was attended by representatives of the committee mentioned above, and by representatives of the Infantry, Artillery, and Armored Forces, and of the Office of the Chief of Ordnance.

A model of UNM design 28-75D that could be disassembled by hand was examined by the representatives of the Services. The mechanism was explained and the behavior described. Division 1, NDRC had had charts prepared showing graphically against range, the striking velocity, penetration, time of flight, angle of fall, and danger space of the 28-75D sabot projectile for the 75-mm gun M3, and of armor piercing sabot projectiles for the 105-mm Howitzers M2 and M3[32], and corresponding data for the standard projectiles for comparison. Copies were supplied to the persons attending the conference.

After studying the information presented and after some discussion, the representatives of the three using Services stated their opinions.

The Armored Forces were not interested in the sabot projectile for the 75-mm gun. This decision rested mainly on the fact that this gun was to be replaced by the 76-mm gun. As this latter gun had a twist of only 1 turn in 40 calibers, sabots of this type would in all probability be impracticable in it. Nor were they interested in

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32/ The Geophysical Laboratory had prepared armor piercing sabot projectiles for the 105 Howitzer M2 using the 75-mm APC M61 projectile as the subcaliber projectile, and also for the 105-mm Howitzer M3 using the 57-mm APC M86 projectile as the subcaliber projectile. These had been fired at Aberdeen Proving Ground on July 21, 22, and 23 (see APG Firing Record M24905 for description of this projectile and details of the firing). These tests formed the basis for the curves of expected performance presented.

Six of the projectiles using the APC M61, weighing 20 lbs each, had been fired from the M2 Howitzer at a vertical target at 800 yards, and had impacted within a rectangle 11 3/4" wide and 15 1/2" high compared with 19 1/2" and 23 1/2" respectively for the impact area of 9 HE M1 shells fired for comparison. Three of the sabot projectiles with APC M86 subcaliber projectiles, weighing 12 lbs each, had been fired from an M3 Howitzer through yaw cards for a stability determination. The MV was approximately 2500 ft/sec. The maximum yaw obtained was only 5.4°; not enough to permit a satisfactory determination. However, the projectile was stable as fired. On September 9, 1943 Division 1, NDRC obtained informally the uncorrected value of the stability factor computed from the data obtained from this round. It was 1.2. The M86 projectiles were plugged.

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an AP sabot projectile for the 105 Howitzer M2 mounted in the Howitzer Motor Carriage M7. The Ordnance Department had under development a high velocity AP round for this weapon (28 1/2 lb shot) that duplicated the armor penetration to be expected from the sabot round with the 75-mm APC M61 or the 57-mm APC M86 as subcaliber projectile. Moreover, this weapon was used in support of infantry and it was thought that the danger to the infantry from flying fragments of the sabot offset any advantages in time of flight or flatness of trajectory. In addition there was a disadvantage in carrying an extra type of ammunition.

The Artillery were not interested in the sabot for the 105-mm Howitzer M2. The reasons were not stated explicity but were evidently the same as those that had determined the opinion of the representative of the Armored Forces.

The Infantry were interested in the use of the sabot in the 105-mm Howitzer M3[33]. The representative asked that an armor piercing round

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33/ The 105-mm Howitzer M2A1 on wheeled carriage M2A2 is the standard light field Howitzer. This Howitzer, on a different carriage, is also mounted on the Howitzer Motor Carriage M7. This Howitzer has a twist of 1 turn in 20 calibers. The shot travel is 81.67". It fires the 33 lb HE M1 shell at a maximum MV of 1550 ft/sec (5th zone), and the 28.8 lb H.E.A.T. M67 shell at a MV of 1250 ft/sec (The low MV of the H.E.A.T. round is required because high spin causes the jet of hollow charges to fan out and so impairs the penetration.) An AP shot was under development. It was to weigh 28.5 lb, and to be fired at an MV of 1950 ft/sec. This was a solid steel shot with a ballistic cap or windshield and no AP cap or bursting charge.

The 105-mm Howitzer M3 is the M2 Howitzer with 27" left off the muzzle end of the tube. It is mounted on a light wheel carriage M3A1, which is a slightly modified 75-mm Howitzer Carriage M3A2. From this howitzer the maximum MV (5th zone) of the 33 lb HE M1 is 1020 ft/sec. The H.E.A.T. M67 is also fired at a MV of 1020 ft/sec. The upper limit to the MV of the 33-lb shell, in this case, is not determined by the chamber capacity and the pressure that the tube will stand but by the carriage.

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and also an HE round, the latter for use against "spot" targets, be developed for it, and that 100 of each be supplied for test by the Infantry Board. After this number had been tried, it should be possible to decide whether or not to continue with them.

The advantages to be expected from the AP round were clear enough; those from the HE much less so. During the discussion that preceded this request it was pointed out, by a representative of Division 1, that the HE projectile would have to be a small shell weighing less than 15 lbs (the 75-mm or 3" shell), and that the burst of such a shell would be much less effective than that of the standard 33-lb shell. It was said that the shooting of the Howitzer with the standard 33-lb HE M1 shell at full charge (MV 1020-S) was very inaccurate and that the charge had to be reduced to that for the third zone (MV 780 ft/sec) before the accuracy became satisfactory. It was thought that the lighter sabot projectile might prove better for spot targets.

As a result of this conference, the Office of the Chief of Ordnance advised Division 1, NDRC to drop work on the 75-mm/57-mm (APC M86) projectile for the 75-mm gun M3, and to develop the two projectiles requested by the Infantry.

Now the facilities and personnel available for work on sabots at the Geophysical Laboratory were so extremely limited that it appeared impracticable to have this work done there in an adequately short time; moreover, work there was handicapped by the lack of a suitable firing range, so that all experimental firings had to be made at Aberdeen. In both these respects the situation at the University of New Mexico was much better. In addition, it was considered that the design 28-75 D had reached a somewhat more advanced stage of development than the designs to which the Geophysical Laboratory's projectile had been made[34/], and it appeared that it would be a fairly simple matter to adapt this basic design to the two projectiles wanted. When Division 1 decided to undertake the development of these two projectiles, they asked the University of New Mexico to do it. An informal request to do this was received by the University of New Mexico on August 18, 1943 and design work began at once.

Limitations Imposed by Howitzer

The 105-mm Howitzer M3 is the 105-mm Howitzer M2, with the tube shortened 27" at the muzzle end, mounted on a 75-mm Pack Howitzer carriage that has been slightly modified to increase the strength[35/]. At the time the Geophysical Laboratory sabot projectiles had been tried in it, at Aberdeen Proving Ground, in July 1943[36/], it had been known that the maximum velocity attainable with the standard 33-lb

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34/ Although no comparative tests have been conducted in worn guns, it was thought that projectiles with threaded ring bases were more likely to remain securely held together in the bore.

35/ The cylinder and piston of the recoil system had been strengthened and the nitrogen pressure increased, and other slight modifications made.

36/ APG Firing Record M-24905 July 21, 22, 23, 1943. With 12-lb slugs and sabot projectiles a charge of 59 oz of FNH M2 had given an average MV of 2527 ft/sec with an average peak pressure of 24500 p.s.i. (copper) and an average recoil of approximately 31 1/4" (max. 31 5/8", min. 30 3/4") at 0° elevation (approximately).
The letter from OCO requesting the firings had asked that the charge should be that to give the highest velocity possible in this Howitzer with a 12-lb projectile.

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HE M1 projectile (MV with full service charge 1020 ft/sec) was governed, not by the capacity of the chamber or by the strength of the tube, in both of which respects the howitzer was identical with the M2, but by the carriage.

At the conference on August 7, 1943 it had been brought out that the accuracy with the standard HE M1 round was unsatisfactory with full charge, and became satisfactory only when the charge was reduced to that for the third zone. However, neither the cause of the inaccuracy, nor any measure of it had been given.

Thus it appeared that a limit to the muzzle velocity attainable by a sabot round in this howitzer might be set, not only by the strength and dimensions of the tube, as is usually the case, but also by either the strength of the recoil system or by the accuracy.

It seemed probable that, so far as the strength of the carriage was concerned, the total momentum of the round might be used for estimating the velocity attainable with a sabot projectile of a given weight, and that the total momentum could equal that of the standard round at full charge, or of the rounds fired at Aberdeen in July[37].

The Office of the Chief of Ordnance was consulted about the limitation imposed by the strength of the carriage, and it was learned that, when firing at low angles of elevation, no damage would actually be done to any part of the carriage until the recoil reached the point

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37/ At this time no one connected with this work knew of a satisfactory way to compute the total momentum. This is considered in some detail later in the section on the choice of the armor piercing projectile. The total momentum of the rounds fired at Aberdeen is considerably in excess of that of the standard round with full charge, (projectile 33 lb, charge 1.33 lb FNH M1, MV 1020 ft/sec).

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at which metal came against metal. The length of recoil, metal to metal, is 33.4". The maximum rated recoil in 32" (at 0° elevation, 70°F). Because of slight differences in dimensions, which are unavoidable in manufacture, some differences in recoil are to be expected from carriage to carriage, Differences in recoil also occur because of differences in the temperature of the oil.

The reason for the unsatisfactory accuracy was not learned. In fact, it was said that in firings at Aberdeen the accuracy had been good in all zones. The only actual figures obtained for accuracy, with HE M1 at full charge, were for a range of 3725 yards, and in this case the dispersion was small. It was evident that the work would have to proceed without information about the cause of the inaccuracy reported by the Infantry, and with the expectation that the cause might appear from the actual experience with the howitzer, during the course of the development of the two sabot projectiles. If it should be found that it was due to some easily remedied cause it might not actually limit the attainable MV.

There was a premium attached to the highest attainable muzzle velocity, especially in the case of the armor piercing round. It appeared, therefore, that the sabots should be designed so that they would work properly with charges large enough to give recoils approaching 32 inches at 0° elevation in hot weather, and, as this would probably be too great a recoil in view of the difference in temperatures and in carriages, that they should also work properly with considerably lower charges, say those giving normal recoil, and that they might have to work properly with still lower charges as the attainment of good accuracy might require such charges.

It appeared also that charges should be established that would give the highest muzzle velocity attainable with good accuracy and without exceeding the limits set by the recoil system.

Choice of HE Subcaliber Projectile

For the HE subcaliber projectile two shells were available; the 75-mm M48 weighing 14.7 lb when filled and fuzed, and the 3-inch M42A1 weighing 12.87 lb when filled and fuzed. The first of these was a rather long shell with a boat-tail. The stability factor when fired from the 75-mm gun, with a twist of 1 turn in 25.58 calibers, (MV 1980 ft/sec) was 1.32. When fired from the 105-mm Howitzer (twist 1:20) the "twist" of the shell would be 1 turn in 28 calibers. This would reduce the stability factor to 1.1. For this reason this shell could not be used. The M42A1 was a rather short shell with a cylindrical base. It was in regular use in the 3" gun with a twist of 1 turn in 40 calibers. The "twist" in the 105-mm Howitzer would be 1 turn in 27.6 calibers. The stability factor would thus be more than doubled in the howitzer. However, this would be no disadvantage as the projectile would not be used at long ranges. In other respects also this shell appeared suitable. There was plenty of room, behind the seat for the rotating band, for a thread for the sabot ring, if that type of sabot should be used. The acceleration that the shell would have to withstand in the howitzer would probably be greater than that experienced in the 3" gun but the shell walls were thick and short and would not be weakened by a thread for a ring type sabot as the thread would be well behind the rear end of the cylindrical part of the shell cavity. Moreover, the cylindrical base of the shell would be suitable for use with a base plate type of sabot if it should be adopted. The choice of shell could then be made without doing any experimental work, and was made by Division 1 before asking the University of New Mexico to undertake the development of the sabot projectile.

Choice of Armor Piercing Subcaliber Projectile

The choice of the subcaliber projectile for the armor piercing round was not so simple as that for the HE. In the case of most guns, the stated muzzle velocities of standard rounds are about as high as can be obtained from the gun with the projectile and propellant used, when allowance is made for the variation to be expected in the manufacture of different lots of propellant, and for the variation in the temperature at which the round will have to be fired.

A close approximation to the muzzle velocity that will be attainable with a lighter projectile using a charge of the same weight and kind of powder is to be had by assuming that the muzzle energy of the sabot round will be equal to that of the standard round.

The approximate expression for muzzle energy that is usually used is:

$$\text{Muzzle energy} = (M + 1/3\ C)\ V^2 \quad \underline{38}/$$

where $\underline{M}$ is the mass of the projectile, $\underline{C}$ is the mass of the charge, and $\underline{V}$ is the muzzle velocity.

38/ A somewhat better, although less conservative, estimate of the muzzle velocity that can be realized with a sabot can be obtained by using a smaller fraction of the mass of the charge in the expression for muzzle energy.

J. O. Hirschfelder, R. B. Kershner, and C. F. Curtiss go into the motion of the powder gas in some detail in NDRC Report A-142, Interior Ballistics I, pp. 98-105. If the density of the powder gas were uniform throughout the bore the fraction would be 1/3. This is of course

(Concluded on page 58)

If the muzzle energy of the sabot round is equal to that of the standard round, and the muzzle velocity is higher, the muzzle energy of the sabot projectile is less than that of the standard projectile by an amount equal to the increase in the energy of the forward motion of the powder gas, approximately $1/3\ C\ (V^2_{Sabot} - V^2_{Std.})$. Moreover, a portion of the muzzle energy of the sabot projectile is in the sabot itself. With constant muzzle energy, therefore, the muzzle energy of the subcaliber projectile is always less than that of the heavier standard projectile by these two amounts. Nonetheless, it is often practicable to increase the energy per unit of cross sectional area of the subcaliber projectile, over that of the standard projectile, to such an extent that there is a worthwhile increase in armor penetration at all battle ranges.

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38 - Concluded/
never the case, for the gas itself has to be accelerated. Using Kent's special solution for the motion of the powder gas (Kent, R. H., Physics 7, 319, 1936), instead of the assumption of uniform density, results in an increase in the value of in the expression

$$\text{Muzzle Energy} = (M + \frac{1}{\delta} C)\ V^2$$

Figure 11 on page 103 of their paper shows curves for δ against log C/M for three different powder gases, assumed to be ideal, having ratios of specific heats, γ, of 1.17, 1.20, and 1.25 for values of log C/M from about -.7 to +7. For all practical purposes, however, differences of γ need not be considered as the three curves are sensibly one until log $C/M > 1$, i.e., until the mass of the charge is ten times that of the projectile.

Figure 10, again for ideal gas, shows δ against M/C for values of M/C from about 0.05 to 2.

The following table gives values of δ corresponding to different ratios of mass of projectile to mass of charge read from the graphs:

M/C	δ
∞	3.
2	3.16
1	3.26
0.5	3.47
0.25	3.75

Critchfield, in NDRC Report A-233, p. 49, speaking of an analysis covering high velocity guns with ratio M/C ranging from roughly 3/1 to 1/2, says that 0.270 x C would be applicable, i.e., $\delta = 3.7$.

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In the case of the 105-mm Howitzer M3, the prospect for improving armor penetration by using a sabot was better than in the usual case discussed above. In the case of this howitzer, the muzzle velocity of the standard round, (the 33-lb HE M1 with full charge) is limited, not by the pressure that the tube will stand nor by the capacity of the chamber, but by the carriage. It was expected, therefore, that the total momentum imparted to the howitzer by the sabot round could be made equal to, or somewhat greater than, that imparted to it by the standard round and that with the lighter sabot projectile a material increase in muzzle energy could be realized.

Total momentum imparted to the howitzer by the round may conveniently be thought of as imparted in two parts, first, that imparted up to the instant that the projectile leaves the muzzle, second, that imparted by the gas afterward. The first part is essentially equal to the momentum of the projectile and the propellant at shot ejection or approximately $(M + 1/2\ C)V$. For the second part, no one connected with the work knew a satisfactory expression.

An increase in muzzle energy is realized only by increasing the charge. As the charge is increased V increases, and if the total momentum is to remain constant $(M + 1/2\ C)V$ must decrease to compensate for the increase in the momentum added after shot ejection. This decrease is brought about by decreasing M. Corresponding values of M, C, and V can be reliably computed by the use of a system of internal ballistics[39/], but some expression for total momentum has to be assumed

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39/ For example, the Division 1, NDRC System of Ballistics, which appeared in a series of seven reports and has been summarized in NDRC Report A-397 (OSRD Report No. 6468).

before the velocities corresponding to different values of M, at constant total momentum, can be computed. Obviously the way in which penetration at battle ranges is affected by changing the size, shape, and density of the subcaliber projectile keeping the total momentum constant cannot be calculated without a reliable means of calculating the total momentum. In this case, however, for practical reasons the problem was reduced to the much simpler one of deciding with which, of a very few projectiles, the best performance would be obtained at battle ranges. The choice, in the first instance, lay between the 57-mm APC M86 and the 75-mm APC M61, or possibly the 3" APC M62. Even when what appear to be extreme values are assigned to the momentum contributed by the gas after shot exit, it is found that the M86 will give materially greater penetration than the heavier M61, and will have the additional advantage of a shorter time of flight and a flatter trajectory[40, 41].

40/ This is assuming the validity of the curves published by the Ballistic Section, Technical Division, Office of the Chief of Ordnance, showing penetration against striking velocity and striking velocity against range. On these curves the penetration of the M86 is given for striking velocities as high as 2700 ft/sec. High quality M86 projectiles will certainly be required to give the penetrations shown at the higher striking velocities.

41/ Various approximate formulas have been used to express total momentum. $(M + 1/2\ C)\ V$, where M is the mass of the shot, C the mass of the charge, and V the muzzle velocity, is usually employed to express the momentum of shot and gas at the moment of shot ejection. The momentum added later depends on the "effective" velocity with which the gas leaves. If the "effective" velocity is stated as a fraction of the muzzle velocity, e.g., as $\underline{a}$ times V, the expression for the total momentum becomes $(M + \underline{a}C)V$. Values used for $\underline{a}$ have varied from 1.5 to 2.5, and possibly higher values have had to be used in some cases.

Late in November 1943, OB Proceedings, minute 25208, dated October 22, 1943 came to hand. This contained an expression for total momentum that had been taken from a paper by J. Corner. After examining this paper, ARD / Ball/ Report 54/43, June 1943, which had been distributed

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In many respects the 57-mm APC M86 appeared suitable. It contained a bursting charge; and was fitted with a ballistic cap or windshield, and certainly no standard projectile of smaller diameter could be used, because of instability. At this time the minimum value of the stability factor that would be considered acceptable was not known, nor had a satisfactory determination of the stability factor of the M86 been made. The 57-mm APC M86 had very closely the same proportions as the 3" APC M62 projectile, then in use in the 76-mm Gun M1A1, and would, when fired from the 105-mm howitzer, have a higher twist (1:36.84) than the 3" projectile received from the 76-mm Gun M1A1 (1:40). At equal MV's, therefore, it was thought that it would be the more stable. The MV expected was somewhat lower than that of the 76-mm gun, but this

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41 Concluded/
also as AC 4502, and another paper distributed as AC 4509 containing some experimental data, one of the members of the internal ballistics group of the Geophysical Laboratory recommended this expression in the form given below, and with the values of constants noted.

Total momentum imparted to the gun by breech pressure from a round in lb ft/sec

$$= (M + 1/2\ C)V + bC\sqrt{gF}$$

where M = mass of shot in lbs

C = mass of powder in lbs

V = muzzle velocity in ft/sec

g, in ft/sec^2, = 32.17

F = "Force" of propellant in ft lb per lb

nominal value for FNH M1 310,000

nominal value for FNH M2 384,000

b = an empirical constant, about 1.2.

It is evident that, as the mass of the charge increases in proportion to the mass of the shot, uncertainty in the value of b to be used introduces increased uncertainty in the result.

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would reduce the stability only slightly. However, the other information available indicated that the stability factor of this projectile would be low when fired from the 105-mm Howitzer.

Even if the stability factor of the M86 should prove to be too low, there remained the possibility that it might be raised sufficiently by shortening the ballistic cap or windshield. The Ammunition Development Division of the Research and Development Service of the Office of the Chief of Ordnance were consulted about this and they indicated that the substitution of a shorter windshield would not introduce a serious production difficulty.

No other available projectile appeared to be suitable. The 75-mm APC M61 (14.96 lb) or the 3-inch APC M62 (15.44 lb) would have an ample margin of stability, but there would be a considerable reduction in armor penetration as compared with that to be expected from a 57-mm projectile of the weight of the M86 if both sabot rounds had the same momentum. The AP M70 was the only other standard U. S. 57-mm armor piercing projectile. It was a solid shot with no armor piercing cap or ballistic cap. It would, in all probability, be amply stable; but, because of the very short nose (length of nose 2", radius of ogive 3.14"), its retardation would be high. Moreover, it had no bursting charge. It was no longer in production, but large stocks were on hand.

There were three British armor piercing 57-mm projectiles, the AP, the APC and the APC BC shot for the QF 6-pr. 7 cwt. The first of these was identical with the M70. The second was slightly shorter than the M70, and, because of its armor piercing cap, might be considered to be better than the M70; but its retardation would be very high, and it had no bursting charge. Moreover, it was not being made either in the United States or Canada, although in limited production in UK. The APC BC shot would probably be somewhat more stabile than the M86, as the body plus armor piercing cap was about the same length as the corresponding parts of the M86, while the ballistic cap was shorter, so that the overall length was about 9.5" against 10.3" for the M86. It was in production in Canada. However, it had no bursting charge.

It was evident that the APC M86 should be used if possible, but that it was not possible at this time to say whether it could be used or not. Under these circumstances it appeared necessary to have:

(1) A firm decision on the minimum value of the stability factor that would be considered acceptable.

(2) A reliable value of the stability factor of the 57-mm APC M86.

It was Division 1's job to get the first. The University of New Mexico undertook to determine the stability factor, using sabot projectiles. This work was done concurrently with the development of a sabot for firing the 57-mm projectile from the 105-mm Howitzer M3, but, for convenience, it will be described first.

Determination of Stability Factor of 57-mm APC M86 Projectile and Modifications

As this was the first stability factor determination to be made at the University of New Mexico, a good deal of preparatory work had to be done both in building the necessary line of yaw card frames and in becoming familiar with the theory and technique involved. The method used was that currently in use at Aberdeen Proving Ground[42].

In the case of some of the earlier determinations a check on the value of the stability factor computed by the APG method was obtained by using the data to compute a stability factor by the formula of Fowler, Gallop, Locke, and Richmond 43/. The methods employed and the experimental data used in the computation for the first determinations were made the subject matter of a special report 44/.

The University of New Mexico decided to make the first determination on projectiles fired from the 75-mm gun M3. To avoid the labor of making up the sabots for this work, 15 projectiles from the lot of 70 projectiles made to design 28-75 D that had been supplied to Aberdeen were obtained. As supplied to APG the M86 subcaliber projectiles had been filled with sand and shot and plugged. For the stability factor determinations these projectiles, and all other M86 projectiles used, were filled with ammonium alum and fitted with an 0.85 lb dummy fuze made to simulate the base detonating fuze M72.

The results of this and other stability determinations made in the course of developing the AP round for the 105-mm Howitzer M3, are given in Table X. Two values are given. The value in the ninth column, is the value obtained directly by computation from the yaw

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42/ This is described in APG Report X-113, "Resistance and Stability of Projectiles. Experimental Methods and Details of Computation," by H. P. Hitchcock.

43/ The Aerodynamics of Spinning Shell. Phil. Trans. Roy. Soc. Vol. A-221, pp. 296-397.

44/ "Stability of the 57-mm M86 Projectile Saboted in the 75-mm Gun M3 October 26, 1943." University of New Mexico Special Progress Report, Contract OEMsr-668.

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card data, corrected to standard air density. It thus applies at a point, designated a, some distance in front of the muzzle. The value for the stability factor at the muzzle is computed from it by finding the drop in velocity of the projectile in going from the muzzle to the point a, and assuming that no change in spin occurs in going this distance. This value is given in the next column. It is the value with which we are concerned.[45]

Stability factor determinations were also made by firing the projectile from the 105-mm Howitzer M3. The values obtained with the 75-mm gun and with the 105-mm Howitzer showed that the stability factor of the projectile was too low to permit its use in a sabot for the 105-mm Howitzer without modification.

While these determinations were in progress, Division 1 had been looking into what might be expected from shortening the windshield. It was found that the windshield from the 3" APC M86 or from the 75-mm APC M61 projectile, if cut off so as to be 3.3" in length measured along the axis, could be fitted nicely to the armor piercing cap of the M86 by turning down a portion of this cap, in front of the crimping groove for the windshield, to fit the taper of the windshield. Calculations of the stability factor to be expected from the modification were made for Division 1 by the Geophysical Laboratory using an empirical formula due to Hitchcock[46]. The value of the stability factor of the

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45/ The computation of the stability to the muzzle was done for Division 1 by J. McG. Millar ofthe Geophysical Laboratory.

46/ A.P.G. Report X-113, p 31.

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modified projectile arrived at by the calculations was as high as appeared useful.

In the meantime, an experimental determination of the stability factor of the projectile without windshield was made. When this result became known, it appeared that the actual value of the stability factor with a 3.3" windshield would be considerably below the value that had been calculated. However, a considerable reduction could probably be tolerated, the 3.3" windshield was easily made and attached, and a value determined with it would permit drawing a curve of stability factor against length of windshield. Accordingly, the determination was carried out. This was done using steel windshileds 3.3" long cut from windshields for the 75-mm APC M61. The value obtained is shown in Table X. From the curve showing the reactionship of stability factor to length of windshield, it was now possible to select a length of windshield to give any stability factor desired.

Choice of Stability Factor for Subcaliber Projectile

While the stability factor determinations were being made, Division 1, had been trying to obtain a figure for the minimum value of the stability factor that would be considered satisfactory. The Ordnance Department had no set minimum figure. In A.P.G. Report X-113, on page 33, it is stated that "in practice, s (stability factor) should be at least 1.3 to allow for the effect of high air density as well as errors in the computations and estimation of h and C_v." A figure of 1.25 was stated by one authority to be the minimum acceptable value. Another authority said that the stability factor should be at least 1.1 under the conditions of firing. The stability factor varies inversely as the density of the air. If it is to be 1.1 in still air at -40°F and 760-mm Hg, it must be 1.39 under standard conditions. If it is to be 1.1 in still air at 0°F and 760-mm Hg, it must be 1.27 under standard conditions. There was a requirement that ammunition should be serviceable at -40°F. From this it appeared that 1.40 was the minimum value acceptable. Now yaw of an armor piercing projectile at the instant of impact results in decreased penetration, and the higher the stability factor the quicker yaw is damped out. There is therefore, in the case of armor piercing projectiles, an advantage in a stability factor higher than the minimum.

On November 17, the curve of stability factor against length of windshield, obtained as a result of the determinations made by the University of New Mexico, together with drawings showing the M86 with the different windshields, was studied at the Ballistic Section[47]. It was then stated that a factor of 1.5 would be considered acceptable, and that, judging from the data available, it would be better to accept a value of 1.5 than to try to obtain a higher value, as that would increase the retardation, and consequently decrease the penetration at zero yaw except close to the muzzle.

In order to learn whether or not there was in production, or on hand, a windshield that could be used to make a windshield for the APC M86 that would give a stability factor close to 1.5, a search was made through the drawings of all projectiles being made for the Ordnance Department. None was found.

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47/ The Ballistic Section of the Material Branch of the Technical Division of the Office of the Chief of Ordnance.

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On December 2, at a conference in the Ballistic Section attended by representatives of the Ballistic Section, Division 1, NDRC and the University of New Mexico, it was decided to use a windshield 2.9" long which was the length corresponding to a stability factor of 1.5" according to the curve of stability factor vs. length of windshield.

On December 3, the Atlantic Elevator Company of Philadelphia undertook to spin up the windshields from steel following a drawing supplied by the University of New Mexico. The first small lot of windshields was received at the University of New Mexico about the New Year.

On January 10 and 11, firings were made at the University of New Mexico Proving Ground for stability factor of the 57-mm APC M86 projectiles fitted with the new 2.9" windshield. The value found, 1.44 (see Table II), was slightly lower than the expected 1.5, but was considered to be satisfactorily close to it.

Determinations of Trajectories by Tracer Photography

During the discussion of the most suitable stability factor, on November 17, it was quite evident that calculations of the penetration to be expected at different ranges with different lengths of windshield were needed. Before these calculations could be made, however, retardation measurements were required so that striking velocities could be computed. The necessary data were on han[illegible] [illegible]he M86 projectile fitted with the standard windshield but data w[illegible] [illegible]ed for the modified projectiles and it appeared that a [illegible] [illegible]uld probably elapse before measurements could be made at A.P. [illegible], was requested by the Office of the Chief of Ordnance that, if the Uni[illegible]sity of New Mexico could make the required measurements, they be asked to do so.

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The University of New Mexico had developed a technique by which the data needed, i.e., the striking velocities, could be obtained experimentally from each individual round over the full length of the required range. The equipment needed was simple and was on hand. After the problem had been discussed with the University of New Mexico, Division 1, on November 20, 1943 requested that the measurements be made firing on APC M86 with standard windshield, and with no windshield but with the ogive of the armor piercing cap continued forward to a point48/.

The technique used has been described in detail in an NDRC report and therefore will be but briefly outlined here49/. A projectile fitted with a tracer is fired along a previously surveyed line along which reference lights are fixed at known points. A camera is set up to one side of the surveyed line and oriented so that its field embraces the trajectory to be studied. A vibrating vane swings in front of the camera lens and gives a succession of breaks in the image of the tracer, two breaks for each cycle. Comparator measurements are made of the coordinates of the beginning and end of each break, and of the images of the reference lights. Horizontal and vertical coordinates can then be determined for the corresponding points of the trajectory, and related in time through the period of the vane.

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48/ The AP caps of the 57-mm APC M86 projectiles on hand at the University of New Mexico had a flat on the nose; however, the curve of the ogive if continued forward gave a sharp point at the position of the flat.

49/ "Trajectory determination by tracer photography." NDRC Armor and Ordnance Report A-283 (OSRD No. 3890), July 3, 1944, by W. D. Crozier and others, of the University of New Mexico.

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Table V

List of Charts Showing Range Against Time of Flight, and Remaining Velocity Against Time of Flight

Date of Firing	Gun	Length of Windshield Inches	Design No. of Sabot	MV ft/sec	Conditions for which Data Given
10/29/43	75-mm gun M3	Standard, 4.5"	28-75 D	2700*	field
10/29/43	75-mm gun M3	Standard, 4.5"	28-75 D	2700	standard
10/29/43	75-mm gun M3		Standard 75-mm APC M61	2030	standard
11/30/43	105-mm How M3	Standard, 4.5"	9-105 C	2300	field
12/7/43	105-mm How M3	3.3"	9-105 C	2640	fiad
12/7/43	105-mm How M3	1.35" **	9-105 C	2605	field
2/17/44	105-mm How M3	2.9"	2-105 R	2650	field
2/17/44	105-mm How M3	2.9"	2-105 R	2680	field

* This is also the MV of the 57-mm gun M1 firing projectile 57-mm APC M86.
** No windshield - effective length 1.35".

In each case the chart shows the weight of the projectile as fired.

In this way, data were obtained, and charts prepared showing the remaining velocity and range against time of flight for the various modifications of the 57-mm APC M86. The same was done for the standard 75-mm APC M61, plugged, so that comparisons could be made with corresponding data obtained by orthodox methods. These charts are listed in Table V[50]. Copies of the first six charts listed, together with a report on the method used, were delivered to the Office of the Chief of Ordnance by Division 1, NDRC on December 24, 1943.

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[50] Copies of all these charts are included in Final Report, Contract OEMsr-668, Supplements 1, 2, and 3, dated March 10, 1944.

The data for projectiles fitted with 2.9" windshields were obtained by firing projectiles identical with the 110 sabot projectiles 105-mm/57-mm (APC M86 modified) supplied for testing by Aberdeen Proving Ground and by the Infantry Board but filled with ammonum alum and fitted with inert fuze BD M72. The charts prepared from these data were sent to the Ordnance Depratment on March 10, 1944, together with other data about this lot of projectiles.

It has been noted that charts giving data for firings from the 75-mm Gun M3 were inclosed with those sent to the Office of the Chief of Ordnance on December 24, 1943. One of these charts was prepared from data obtained from a standard 75-mm APC M61 round. The Ballistic Section carefully compared the data on this chart with corresponding data that had been obtained by Aberdeen Proving Ground using the orthodox methods. The agreement was excellent.

Development of Sabot Mechanism for, and Production of, Armor Piercing Sabot Projectiles

The informal request by Division 1, NDRC, on August 18, 1943, to have armor piercing and high explosive sabot projectiles for the 105-mm Howitzer M3 developed by the University of New Mexico had stated that the subcaliber projectile for the high explosive projectile should be the [illegible] shell M42A1 and that for the armor piercing projectile should be the 57-mm APC M86, unless experimental work should prove that this was impracticable.

Design work was commenced at once on receipt of the request, and, as a supply of M86 projectiles was on hand, some sabot projectiles were soon made up. The howitzer was received on September 10, and by

October 12 powder, cartridge cases, and primers had been received and experimental firings could begin. The first design of sabot for the 57-mm M86 projectiles, No. 2-105, followed very closely the design 28-75 D to which the 75-mm/57-mm (APC M86) sabot projectiles supplied to the Ordnance Department had been made. Some details of this and succeeding designs are given in table XIA. Because of the advantage in armor penetration to be gained from a light sabot, a good deal of effort was directed toward lightening it. The first modification, resulting in design 2-105A, was to lighten the threaded steel ring by drilling 8 equally spaced holes 1 inch deep from the front face. For the same reason 8 holes were drilled the length of the plastic sleeve or bourrelet. This "ventilation" of the sleeve also took the place of the usual radial slits to insure symmetrical breakup.

The next move was to use dural instead of steel in the threaded ring. Three designs, incorporating this feature, 6-105, 9-105, and 9-105A were tried. The first two of these had solid plastic sleeves with the usual breaking slits. In the third design the sleeve was "ventilated." At this time the only powders available at the University of New Mexico Proving Ground (lots 4254 and 5870) were not too well suited to firing these sabots. Lot 4254 was rather too slow, so that there was some spitting of unburned powder from the muzzle. However, it gave quite satisfactorily uniform pressures and velocities. Lot 5870 gave rather erratic pressures, some of which were quite high. The dural worked fairly well with lot 4254 but would not stand up to the higher pressures frequently given by lot 5870. A design, 9-105C, was tried in which the dural ring of 9-105 was replaced by a steel

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ring with 12 holes drilled from the front to lighten it. The sleeve was again ventilated. This design gave moderately good results with both powders, verifying the conclusion that the failure had been because of the dural. It was concluded that the margin of strength in the dural was insufficient for these designs, and its use was abandoned.

A base ring type of sabot, design 5-105, was tried while the experiments with dural were under way. The base ring, of heat treated steel, had a shallow cup on the front face, into which the base of the M86 projectile fitted. The plastic sleeve was threaded to the steel base ring. This design gave poor flight. This was attributed to the weakness of the bourrelet brought about by the large diameter of the "ventilating" holes. It should also be noted, however, that the base ring and the subcaliber projectile are not held together as securely as the threaded ring and subcaliber projectile of designs like 2-105. All the other designs tried were threaded ring types.

Attention was now centered on modifications of design 2-105. The length of the threaded steel ring was shortened so that it extended forward only just beyond the rotating band, and holes were drilled in it from the rear. Both these changes removed weight. Efforts were still made to lighten the plastic bourrelet by drilling holes lengthwise in it, "ventilating it," or by removing material from the inside of the sleeve except at the ends. However, these efforts were abandoned as large initial yaws persisted, and in the effort to reduce the large initial yaws the plastic sleeve was again made solid except for the breaking slits, and the windage was reduced. The bore diameter of this howitzer is 4.134" + .002". The diameter of the sleeves had been 4.128" - .005". This was increased to 4.131" - .003", but the large initial yaws persisted. Although there had been no direct evidence of asymmetrical release of the parts, and many evidences of symmetrical release, an effort was made to improve the symmetry of release, in the hope of decreasing the yaw, by increasing the number of segments in the threaded ring and in the sleeve, and by dividing the plastic sleeve into three rings. However, the large initial yaws still persisted. No significant engraving of the plastic was being experienced but it seemed possible that the high compressibility of the plastic material permitted considerable decentering of the projectile. Large initial yaws had not been experienced with either the 75-mm/57-mm (APC M86) projectile or the 105-mm/3" (HE M42A1) projectiles. However, not only had these projectiles been longer in proportion to their diameter, but the thickness of the plastic in the sleeve had been less[51/]. The forward part of the plastic was next replaced by a ring of dural and the increased diameter was maintained. This change resulted in decreased yaws, and was adopted for the final design, 2-105R, to which the lot prepared for the Army was made. This design is shown in Figures 4 to 7 . It should be noted that the

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51/ In the work done earlier at the Geophysical Laboratory, after adopting the plastic bourrelet introduced by the University of New Mexico, it was found that yaws remained large and dispersion unsatisfactory until a means was found of simultaneously decreasing the windage and offsetting the high compressibility of the plastic. An internally coned sleeve of plastic was fitted over a corresponding cone on the forward end of the large plastic sleeve. On setback, this sleeve moved to the rear over the coned surface on the large sleeve until stopped by a shoulder on the large sleeve. As it moved back the sleeve was expanded, filling the bore. This idea was incorporated in projectiles for the 20-mm gun* and later in projectiles for the Br.17-pounder (3")** and for the 105-mm Howitzer M3***.

* NDRC Report A-233 (OSRD No. 2067) "Development of subcaliber projectiles for the Hispano-Suiza Gun," by C. L. Critchfield and J. McG. Millar.

** Projectile Test Report AD-P99 Ordnance Research Center, A.P.G. Report on test of 3"/57-mm Sabot type projectile August to November 1943.

*** A.P.G. Firing Record, M24905 July, 1943.

three outside shops. The assembly of the parts was carried out at the University of New Mexico. On March 9, 1944, 110 of these projectiles were shipped to Picatinny Arsenal where the projectiles were to be filled and fuzed and made up into complete rounds preparatory to testing, first by the Ordnance Department at Aberdeen Proving Ground, and then by the Infantry Board at Ft. Benning, Georgia.

A dispersion test of design 2-105R was made on March 10, 1943. The data are listed in Table IX. A dispersion test of design 9-105A in comparison with the standard HE M1 fired with full charge had been fired in November. Only 4 rounds of each type were fired. The data are also listed in Table IX.

The following data will amplify those given on the drawings:

Subcaliber projectile	57-mm APC M86 made up without band seat or rotating band, in condition as machined i.e., not heat treated, fitted with special short windshield 2.9" axial length.
	Weight 6.09 lb, empty, without fuze.
	Weight 7.00 lb, inert loaded with fuze, BD M72.
Sabot	Threaded ring type of cold rolled steel, with bourrelet of paper-laminated phenol-formaldehyde plastic tubing (Textolite) ASTM type XX with dural ring in front, Bourrelet diameter 4.130" - 0.003".
	Weight 4.13 lb.
Total weight	Empty, no fuze, 10.22 lb.
	Inert filled, with fuze BD M72, 11.13 lb.

diameter of the bourrelet in this lot was 4.130"--0.003" i.e., 0.001" less than the maximum diameter tried.

Portions of these dural rings that were recovered at the University of New Mexico Proving Ground showed that only superficial engraving was occurring. It will be recalled that the howitzer in use by the University of New Mexico was new. How these dural rings would have behaved in a more worn howitzer, therefore remains a question. Experience elsewhere with dural has shown that it has very little resistance to deep engraving, and, for this reason, is frequently unsatisfactory as a bourrelet material. Deep engraving tends to occur especially in worn guns. A steel band over the dural, to provide a bearing against the bore, has been used successfully on British and U. S. service projectiles, and was later adopted in the University of New Mexico designs.

About the middle of February, the plastic for the bourrelets was given an immersion test. The piece tested was several inches long. The inside diameter was 2.9", the outside diameter 4.153" initially. It was boiled in water for three hours, then let dry and cool at room temperature for one and one-half hours. The outside diameter was then 4.156". It was then left submerged in water at room temperature for 21 hours and let dry at room temperature for two hours. The outside diameter was then 4.155". It will be recalled that the bourrelet diameter adopted in design 2-105R permitted only 0.003" expansion in the diameter of the plastic.

As soon as the design 2-105R had been found to give good results with small yaws, production of the projectiles to be supplied to the Army was begun. Because of the load of work in the shop of the Department of Physics, arrangements were made to have parts produced by

Development of Sabot Mechanism for, and Production of HE Sabot Projectiles

No difficulty was experienced in developing the sabot for the high explosive shell. The final design 3-105B is shown in Figures This design was developed in three steps from the basic design 28-75D. No difficulty from large yaws was experienced, so the bourrelet diameter was left the same as in the first design tried, i.e., 4.128" - 0.005". In the first design tried, 3-105, the threaded steel ring extended 3/4" in front of the rotating band. The plastic bourrelet was held in place between the threaded steel ring and a small shoulder formed on the bourrelet of the shell M42A1 by turning the shell down to 2.90", from the base forward 5.32". In design 3-105A the threaded steel ring was lightened by removing the steel in front of the rotating band. In 3-105B the lightened ring was retained and the height of the shoulder on the M42A1 was decreased by increasing to 2.965" the diameter to which the shell behind it was turned. In assembly the plastic sleeve was placed on the shell from the rear, then the steel ring, which had already been banded, was screwed on.

3-105A was tested for release at reduced charge. Operation was satisfactory at 11/16 charge MV 1460 ft/sec, but release did not take place at 5/8 charge MV 1330 ft/sec.

A dispersion test of design 3-105A was made on November 25, 1943 and another dispersion test of 3-105B on February 16, 1944. The latter test was made on projectiles chosen at random from the lot made up for test by the Ordnance Department and the Infantry Board. The results of these tests are stated in Table IX.

Although the final design 3-105B is almost exactly the same as 3-105A, the second design tried, other designs were experimented with. The designs tried may be divided into three types according to the type of base by which the thrust and torque are imparted; threaded ring, base plate, and groove and ring. All three have plastic sleeves or bourrelets. Some details of these designs are given in Table XIB.

The only other threaded ring design tried was 10-105B. The threaded steel ring was only the length of the rotating band and was partially segmented by slits running from the inside out. A plastic sealing ring was fitted behind it. The slits were filled with metal sheet to prevent distortion upon transmission of torque. The total weight was 3 lb. Three rounds only were fired. Operation was satisfactory at 2000 ft/sec and at 1755 ft/sec but it did not release at 1535 ft/sec.

Three base plate designs were tried. 4-105 had a solid base plate of cold rolled steel with a shallow cup on the face into which the base of the M42A1 shell fitted. The plastic sleeve was held to the base plate by 4 screws threaded into the plastic. The M42A1 was held in place by set screws passing through the plastic and fitting into the crimping groove of the M42A1. Total weights of the sabots of the two examples tried were 4.25 and 3.93 lb. Operation was satisfactory in both cases. 11-105 was similar to 4-105 but the base plate had a hole in the center, and was made of SAE 4130 steel, heat treated. The total weight of the sabot was 3.4 lb in one model with solid plastic sleeve with 4 breaking slits, and only 2.5 lb in the other model tried, which had holes drilled lengthwise in the bourrelet to lighten it. Both models failed in the gun. 11-105A was the same at 11-105 except that the area of the hole in the base plate was decreased, and, in both of

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the two models fired, the bourrelet was solid except for the breaking slits. Both models fired tumbled in flight. Recovery of parts indicated that separation of the base plate and the subcaliber projectile had occurred in the bore. It should be noted that these designs do not secure the subcaliber projectile to the base plate as strongly as the subcaliber projectile is held to the threaded ring of designs like 3-105, and in this respect are not as satisfactory as the threaded ring type[52].

Design 7-105 made use of the groove of the band seat of the M42A1 slightly deepened (diameter 2.645"), to apply thrust and torque through a steel ring, of 4 tightly fitting segments, that fitted into the groove, and was held together by the rotating band. A plastic sealing ring, partially segmented, was fitted behind the segmented steel ring. The total weight, with solid plastic bourrelet, was 3.75 lb. Two examples were fired. Both performed satisfactorily. Design 7-105A was made slightly lighter by cutting a deep groove in the rear face of the segmented steel ring. Total weight of the sabot was 2.75 lb. Two projectiles were fired, one at full, one at 3/4 charge. Both were satisfactory. Two more projectiles were made to this design but with the

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52/ The drawings of 4-105, base plate design for the 105-mm/3" sabot show the plastic sleeve secured to the steel base plate by screws threaded into the plastic from the rear, and the subcaliber projectile held in place by set screws through the plastic sleeve. In 11-105 the plastic sleeve was held to the base plate by 0.3" of threads 3.27" diameter. The way in which the subcaliber projectile is held in place is not shown on the drawings. Design 5-105, for the 105-mm/57-mm sabot, is like 11-105. The threaded portion of the plastic sleeve is 0.35" long and 3.2" diameter. The way in which the subcaliber projectile is secured in place is not shown.

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segmented steel ring fitted loosely into the groove on the M42A1 with .020" clearance in front of the ring. These were fired, one at full charge, one at 11/16 charge, to see if failure would occur under these circumstances. Separation and flight were satisfactory although there was some initial yaw at full charge.

As soon as the design 3-105B had been selected, during the first week of December 1943, the preparation of 100 projectiles for transmittal to the Army for test was begun in the shop of the Physics Department of the University of New Mexico. However, a great deal of other work was being done there, both on other phases of the sabot development, and on other unrelated work, so that it was not until February 16, 1944, that the 100 projectiles were shipped to Picatinny.

The following data apply to the projectiles of that shipment, UNM Design No. 3-105B.

Subcaliber Projectiles	3" HE shell M42A1 empty. Outside diameter reduced to 2.965" from the base forward for 5.32". Weight empty, 9.53 lb - when filled inert and fitted with inert fuze PD M48 and dummy booster M20, weight 12.50 lb.
Sabot	Threaded ring of cold rolled steel with integral skirt to fit into cartridge case, ring screwed to HE shell M42A1 after having been banded and after plastic sleeve has been put on M42A1. Bourrelet sleeve of paper-laminated phenol-formaldehyde plastic tubing (Textolite) ASTM type XX. Bourellet diameter 4.128" - 0.005".

Total weight of sabot 3.12 lb.

Total weight Empty, 12.65 lb.

Filled inert, with inert fuze PD M48 and dummy booster M20, 15.62 lb.

Propellant Charges for the Sabot Projectiles

Some of the difficulty experienced in developing the sabot for the armor piercing round was connected with the powder. For this reason the following notes about the powders are included.

In July 1943, Aberdeen Proving Ground had fired 12-lb slugs in the 105-mm Howitzer M3 to establish a charge for the 105-mm/57-mm (M86) sabot projectiles supplied by the Geophysical Laboratory. As a result of trying five different lots of powder, a charge was established for FNH M2 lot 4254. The weight of charge was 59 oz, average pressure 24370 p.s.i., average MV 2526 ft/sec maximum recoil 31 5/8 inches. This powder was the best available at APG but was rather too slow as there was considerable spitting of unburned powder. A quantity of this powder was on hand at the University of New Mexico Proving Ground. It was believed that, although a faster powder was desirable, where the maximum uniformity of ballistics was required, this powder would do for the first of the experimental firings of the armor piercing sabot projectiles.

As soon as the approximate weight of the HE sabot projectile, 15 - 17 lb, was known, it was communicated to the Geophysical Laboratory, where calculations were carried out to get the relationship between web, charge weight, pressure, and muzzle velocity, over the range within which the maximum muzzle velocity might be expected to lie from what was known about the limitation to muzzle velocity in this howitzer. At the same time, similar calculations were also made for the lighter armor piercing projectile. Powders to meet the web specifications of the Geophysical Laboratory were selected by the Office of the Chief of Ordnance, and a supply was shipped by express to the University of New Mexico, where it arrived on October 4, 1943. The powders selected were FNH M1 lot 5870 web SP 0.016 and FNH M1 lot X-6099 web SP 0.023.

The slower of these two powders proved quite satisfactory for the HE projectile and was used throughout the experimental work.

The faster of the two, lot 5870, proved rather unsatisfactory for the armor piercing projectile. The pressures were rather erratic and occasionally excessive. However, as lot 4254, which had been on hand, gave satisfactorily low and uniform pressures with satisfactorily uniform muzzle velocities, most of the experimental firings of the armor piercing projectiles were done with it until about the begining of January 1944. About this time it had become evident that the initial yaws of the sabot projectiles were higher than they should be, and efforts were being made to locate the cause. Lot 4254 gave excessive muzzle blast. It was expected that the muzzle pressure with it was high, and there was a suspicion that this might contribute to the yaw. It therefore became most desirable to have some satisfactory powder faster than lot 4254. More attention was paid to lot 5870. Although no slugs had been fired with this powder, it was suspected that the erratic pressures might be caused by differences in starting pressures from round to round, and the sabots were redesigned to test this.

The steel skirt that projects to the rear inside the cartridge case is expanded against the case, and this in turn against the bore, when the pressure inside the cartridge case rises. This introduces a drag. This skirt was omitted in Designs 2-105N and 13-105. In 13-105 the diameter of the rotating band was also decreased. These changes designed to reduce the starting pressure did not remove the difficulty.

By this time there was a moderate body of data on firings with this powder. While the pressure data were erratic, and there were sporadic high pressures which suggested faulty ignition, the pressures were generally high and indicated that a slower powder would be better. Calculations were made at the Geophysical Laboratory for more suitable webs of M1 and M2 powders, both SP and MP and the Office of the Chief of Ordnance chose three powders, FNH M1 lot 3527-30 SP .018, FNH M2 lot Rad-3004 MP .0324 and FNH M2 lot Rad-3005 MP .0370, and had supplies of these shipped by express to the University of New Mexico. Shortly before this, the Office of the Chief of Ordnance had found that sporadic high pressures in the 76-mm gun were eliminated by using a long primer vented at the forward end, i.e., by igniting the charge at the forward end. It was suggested that similar primers might overcome the difficulty being experienced, and arrangements were made for two types of long primers, the M22 and the M31, differing only in the amount of black powder load, to be sent to the University of New Mexico. In the meantime, weights of charges for the three new powders were computed at the Geophysical Laboratory. When the new powders arrived, it was found that both lot 3004 and lot 3005 worked well with the standard primers used in the cartridge cases for this howitzer, giving uniform and satisfactorily low pressures. All subsequent firings were made using these powders. Lot 3527-30 was used only once, an excessive pressure resulted.

When the sabot projectiles were shipped to Picatinny Arsenal for filling, Division 1, NDRC passed to the Office of the Chief of Ordnance the data that had been obtained from the firings with respect to propellant charge. These follow:

Sabot projectile to designs 2-105R.

Total weight, inert loaded, with fuze 11.13 lb

Total weight, empty, without fuze 10.23.16

Powder FNH M2, lot Rad-3004, web .0324 MP

Charge wt. 3.55 lb (1610 grams)

Pressure 26000 p.s.i. (copper) (See Appendix II)

MV 2660 ft/sec

Recoil 31.75 in. (at 52°F).

Alternate charge to give approximately the same results 3.9 lb (1770 grams) FNH M2, lot Rad-3005, web .0370 MP.

Sabot projectile to design 3-105B.

Total weight, inert loaded, with fuze and booster 15.62 lb

Total weight, empty, no fuze or booster 12.65 lb

Powder FNH M1, lot No. X-6099, web .022 SP

Charge WT 3.0 lb (1362 grams)

Pressure 1900 p.s.i. (copper) (See Appendix II)

MV 2000 ft/sec

Recoil 31 in. (at 32°F)

Hop about 3 1/4 in.

These charges, as shown by the recoil, were the maximum that could be used. The projectiles were designed so that they had a good margin of safety with these charges and would operate satisfactorily at much lower MV's than given by these charges.

Difficulty with Sights of Howitzer

It will be recalled that at the conference on August 7, 1943, when the Infantry representative had asked for the development of the sabot projectiles for the 105-mm Howitzer M3, it had been said that the accuracy of this howitzer was unsatisfactory with full charge, and became satisfactory only when the charge was reduced to that for the third zone, and that inquiries made by Division 1, had failed to uncover the cause of the inaccuracy.

As the firing with the howitzer at the University of New Mexico proceeded, the main difficulty encountered with it was from the sights. It was found that so much play developed in the sights that accurate shooting was not possible with them. As this was probably brought about by the jarring caused by firing, it was expectable that less trouble from this cause would be encountered when using the charge for the third zone than when firing with full charge.

When this was brought to the attention of the Ordnance Department, it was learned that the sights had given a good deal of trouble, but

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that it was believed that this difficulty had been overcome, without any radical change in design, by increasing the strength in a few places, and by tightening up on specifications and inspection, and that the sights being issued currently would not develop more than about 1 mil play[53/]. It was also believed that the Infantry Board, who were quite familiar with this difficulty, had thoroughly satisfactory sights on the howitzers they were using.

The howitzer carriage has a firing base which is lowered under the carriage to provide a firm support for firing. Even when using this firing base, however, the howitzer has considerable hop with full charge at low angles of elevation.

At the University of New Mexico all firings were done from the firing base. After trouble was experienced with the sights, their use was abandoned. The howitzer was then laid for line by bore sighting, and for elevation by means of a gunner's quadrant. At first, bore sighting was done by means of a peephole and string; later, by means of a telescope held axially in the bore.

53/ The handwheel for traversing this howitzer is located on the left-hand side of the carriage, that for elevating it, on the right. The man who is laying for line looks at the target or at the aiming point through an elbow telescope (M62) which is mounted on a telescope adapter (M9). The adapter provides a motion about a vertical axis and is fitted with an azimuth scale, which for direct fire is set at zero. The telescope adaptor is mounted on telescope mount M16.

Elevation for range is put on by means of a handwheel on the right side, using a range quadrant M8 mounted on the right side of the carriage, or, in case of direct fire, by sighting at the target through an elbow telescope (M61) which is mounted on he range quadrant. This telescope is fitted with a reticule of horizontal lines corresponding to ranges, and laying for range is accomplished by turning the elevating handwheel until the appropriate line is on the target.

Filling Projectiles at Picatinny Arsenal

At Picatinny Arsenal both lots of sabot projectiles were made up into semi-fixed rounds, preparatory to being sent to Aberdeen Proving Ground for tests there by the Ordnance Department. The data on charge, pressure, muzzle velocity, recoil, and hop that had been obtained by the University of New Mexico and passed by Division 1, NDRC to the Office of the Chief of Ordnance were checked over by Aberdeen Proving Ground, and it was decided that it would be unnecessary to make firings to determine a charge, and Picatinny Arsenal was instructed to fill the full charge to which the UNM data applied. In each case this was about the maximum charge that could be used with the projectile as judged by the length of recoil. If, when the projectiles were fired at A.P.G., experts on the 105-mm Howitzer M3 decided that the charges should be reduced, this could be done.

The projectiles were made up into 4 lots[54]. The propellant charges loaded were the same as those used at the University of New Mexico. The rounds were filled as follows:

105-mm/3" (HE M42A1)

All propellant charges 3 lb, FNH M1, lot X-6099

50 projectiles, lot PAE-61174-2919, filled cast TNT, fuze PD M48A2

50 projectiles, lot PAE-61174-2920, filled inert, live fuze PD M48A2, live boosters M20A1.

105-mm/57-mm (APC M86 modified)

All propellant charges 3.55 lb FNH M2 lot Rad-3004, filled in seven small bags.

54/ Details are given on Ammunition Data Cards #'s 6659(HE inert), 6660 (HE filled TNT), 35515 AP (exp D.), 35516 AP (inert)

--projectiles lot PA-115-1 filled explosive D, fuze BD M72

--projectiles lot PA-116-1 filled inert, live fuze BD M72

The projectiles were then shipped to Aberdeen Proving Ground.

Acceptance Tests at Aberdeen Proving Ground

Firing tests were made at Aberdeen Proving Ground on June 7 and 8, 1944[55]. Observations were made on the functioning of the howitzer with the rounds, and recoil and jump were recorded. Hop was observed, but the estimates are not a part of the record. The pressure, the retardation, and the muzzle velocity were obtained. Tests were also made of the functioning of the fuze and of the HE filling.

The 105-mm/3" (M42A1) rounds proved quite satisfactory. However, the light was so poor that bore sighting was very difficult, and consequently the measurements of jump are only an approximation. Recoil varied from 28 1/2 to 31 in. Pressure averaged 26680 p.s.i., max. 29700, min. 24300. MV averaged 1986 ft/sec, max. 2009, min. 1971. The form factor relative to Projectile Type 6, calculated from the retardation, was 0.96 at 1943 ft/sec.

The 105-mm/57-mm (M86 modified) projectiles were fired on the second night, and, as the light was then much better, the measurements of jump were more reliable. The first round fired developed a pressure of 35,000 p.s.i. and the recoil was 32 1/8". The velocity through

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55/ A.P.G. Firing Record)-31518. This firing record includes copies of the ammunition data cards, and photographs of the projectiles showing the construction. Details of the firings and the results are given.

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the first pair of coils was 2700 ft/sec, at the muzzle 2766 ft/sec. The charge was then reduced to 3.44 lb by removing one of the small sacks, which weighed 0.106 lb (zone II charge). The pressure and recoil resulting were considered acceptable. The recoil varied from 31 5/8 to 31 7/8 in. The pressure and MV were quite uniform. Pressure averaged 28600 p.s.i., the maximum being 29500 p.s.i., and the minimum 27300 p.s.i. MV averaged 2655 ft/sec, max. 2667 ft/sec, min. 2649 ft/sec. The form factor relative to Projectile Type 6, calculated from the retardation, was 1.37 at 2590 ft/sec.

The fuzes and fillings functioned satisfactorily.

Aberdeen Proving Ground recommended that the propellant charge of the 105-mm/57-mm (APC M86 modified) rounds be reduced by at least 0.106 lb, and instructions were issued by the Office of the Chief of Ordnance to reduce them by this amount before shipping the rounds to the Infantry Board at Ft. Benning, Georgia.

Trials by Infantry Board

These projectiles were tested by the Infantry Board at Ft. Benning, Georgia on July 27 and 28, 1944. No official report of these tests has been received by Division 1, NDRC. The following notes are compiled from the report of the Division 1, NDRC observer at the trials - -

105-mm/57-mm (AP M86, shortened windshield)

The tests began on Thursday afternoon, July 27. "During the course of the firing on that afternoon, Col. Ingomar M. Oseth, President of the Infantry Board, stated that the Infantry Board was primarily interested in the possibility of replacing the 57-mm gun with the 105-mm Howitzer M3, firing this sabot projectile. If the Howitzer, when firing this round, should prove to be nearly as satisfactory an anti-tank weapon as the 57-mm gun, they would be willing to accept the small decrease in armor penetration involved. By making the substitution, more fire power could be gained. There are at present eighteen 57-mm AT guns to the Regiment. These are essentially single-purpose weapons, of very little use except against tanks. The Howitzer, on the other hand, is a general purpose, support weapon, firing as it does a 33 lb. HE shell and 29 lb. H.E.A.T. (hollow charge) shell. The possibility of the addition of a satisfactory high velocity AP round was, therefore, of great interest to the Infantry Board.

"The carriage of the 57-mm gun (essentially the British 6 pr.) has been designed especially for direct fire at moving targets. The layer (on the left side) has complete control of the gun. The traverse covers a total arc of 90°. On some models this motion is geared, on others, free, the layer controlling the traverse with his right shoulder. Sighting is direct by open sight or by simple telescope. The sights are mounted directly on the telescope mount which is bolted to the cradle. Range is put on by adjusting the vertical angle between the telescope and the cradle. The pivot by which this is done is the only moving joint between the cradle and the sights. The sights do not traverse except with the gun. Lead is put on by means of graduations in the telescope. The layer also fires. The gun is supported on steel firing segments not on pneumatic tires when firing. With this carriage, especially with the modification having free traverse, it is very easy to follow a rapidly moving target.

"The Howitzer carriage was not designed for direct fire at moving targets. The total traverse is 45°. For direct fire, azimuth is put on by a gunner on the left side of the Howitzer, who operates the traversing gear, using an elbow telescope. Elevation is put on by another gunner on the right side of the Howitzer using another elbow telescope with a range scale on the reticule (For indirect fire, a range drum and bubble are used.) Neither gunner faces the target at which he is shooting but faces in a direction 90° from the target. A very high degree of cooperation between the two gunners is required. There are three moving joints between each telescope and the gun cradle.

"The Infantry Board have modified some of their 105-mm Howitzers for one-man laying. A hand-wheel has been added to the left side, coupled with the elevating gear on the right. A telescope mount, carrying a range drum, is then used on the left side and the telescope with a range scale on the reticule is mounted on it, so that the layer on that side can lay for azimuth and elevation. The telescope is still an elbow telescope so that the layer looks in a direction 90° from the target. The sights are very much less convenient than those fitted to the 57-mm gun and are much more likely to develop play.

"The firings showed up a number of defects. The sights would not remain in adjustment during firing. In conversations with the officers doing the firing, I learned that the sights have, in their experience, retained their adjustment moderately well when firing the standard HE round, using Charge 3, but have never been entirely satisfactory in this respect with Charge 5. With this sabot round, however, they were much worse than with the 33 lb. HE shell and Charge 5. This is undoubtedly connected with the amount and violence of the movement of the carriage on firing. As will appear below, this movement of the carriage was much worse with the sabot round than with the standard HE round, using full charge.

"For the most part, the Howitzer was fired from its wheels. The hop with this round was then excessive. The amount of hop depends on a number of factors and was different in each of the three positions occupied during the tests. In one of these three positions, the hop was compared with that when firing HE M1 with full charge. The standard round gave a hop of not over 6" but the sabot round gave a hop of 10", that is, on firing, the wheels were lifted 10" from the ground. When the gun drops to the ground again, it bounces up and down several times on its pneumatic tires. This usually resulted in the Howitzer rolling ahead about 10" to 12", so that the spades were no longer engaged. On firing again, the whole carriage would run back this distance, then the spades would engage, and the gun would hop up about 10". If, in putting the gun in position, the wheels were dug in so that they would not roll forward, this trouble would be lessened," but hop is bound to be serious when firing from pneumatic tires.

"This violent reaction of the Howitzer when fired from the wheels makes it impossible for the gunners to remain in the laying position, and for this reason, and because the gun does not return to its original position, it is impossible to relay quickly.

"This Howitzer is provided with a firing base so that it need not be fired from the wheels. At my request, the Howitzer was fired from the base, The hop was then very much reduced and the forward motion of the Howitzer, after firing, was eliminated. However, another difficulty appeared. When the Howitzer is on its firing base, it is lower than when on the whells. In this position, the bottom surfaces of the trials are not far from horizontal and thus bear on the surface of the ground over a considerable part of the length of the trials. There is very little tendency for the spades to dig in and what tendency there is is resisted by the trails in contact with the ground. After a few rounds, the earth behind one or other of the spades gives way and the whole Howitzer is thrown to one side. This occurred on sod at Benning. It had also occurred in sand and gravel during test firing at Aberdeen. A larger and especially a deeper spade would help, so would digging the earth out from under the trails when putting the gun into position."56/

However the hop of this weapon is so much, even when fired from the firing base, that the layer or layers can not keep their eyes to the telescope while the Howitzer is fired, (The exit pupils are quite close to the eye pieces so that the eye must be close to the eye piece) consequently really rapid fire against a moving target is not possible.

"Whether, because the spades do not hold well when the Howitzer is on its firing base, because of the slight additional time required to put the weapon into action, of for some other reason, it was evident that the users preferred to fire the Howitzer from the wheels.

"Merely reducing the quantity of propellant will not correct the trouble, for the muzzle velocity becomes unacceptably low before the hop is decreased to an acceptable amount. In this connection it is worth noting that the recoil with reduced charge becomes much less than with the standard round before the hop is reduced to that with the standard round.

"The difficulties were not confined to the Howitzer. When the sabot projectiles were tried in the Howitzer, it was found that the plastic sleeves had swollen so that the projectile could only be loaded by hammering it into place. This was done. However, after a few rounds had been fired, it was found that the sights did not remain in adjustment, and so could not be depended on. Bore sighting for line and laying with quadrant for elevation were then tried but the need for hammering the projectile in after bore sighting made this unsatisfactory. Actually, sighting for line was for the most part done by sighting over a bolt head on the breech block, lining this up with a steel strap held vertically against the muzzle.

"On the evening of the first day, the plastic of a few of the inert rounds was turned down so that they would

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56/ The Ordnance Department have provided an attachable spade plate of considerably greater width than the standard.

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load easily. It was our hope that these rounds would be used for a bore-sighted dispersion shoot during the course of the next day's firing. Although this was not done, everyone seemed satisfied from what they saw that the dispersion of this ammunition was satisfactory and about the same as that of the standard ammunition."

Even if the hop would be adequately reduced and if at the same time the MV of the sabot round could be raised to that of the 57-mm gun M1 (2700 ft/sec) it appears that this Howitzer would not be as effective an anti-tank weapon as the 57-mm gun, for the sighting equipment is unsuitable for direct fire at moving targets, and the elevating gear is designed for operation from the right hand side, i.e., one man cannot lay for line and for range, moreover the traverse is limited to 22 1/2° each side of center. When the carriage is modified, as some were, so that the Howitzer can be elevated by the man on the left, the elevation that can be put on the Howitzer appears to be limited by the shaft of the elevating gear. This limitation does not affect the use of the Howitzer against tanks but probably does limit its use in the normal role.

"From the comments I heard, I believe that a carriage reaction exceeding that of the H.E.A.T. round or of the HE M1 round with full charge will not be acceptable. In this connection it is worth remembering that the carriage on which this Howitzer is mounted was designed for the 75-mm Pack Howitzer, a much smaller weapon. The length and attitude of the trials and the size of the spade were designed for the smaller weapon. Some slight modifications of the recoil mechanism to strengthen it were made when the 105-mm Howitzer was put on the carriage.

"When there was no further interest in fring from the 105-mm Howitzer M3, some rounds were fired from the larger 105-mm Howitzer M2. The ammunition worked much better in the larger Howitzer but even here there was a very material hop.

"105-mm/3" (HE M42)

"A much smaller number of rounds of this sabot then of the AP sabot were fired. The same difficulties were encountered, but to a lesser extent. The hop with this round was about 6" as compared with 10" for the AP.

"The Infantry Board showed very little interest in this round. Col. Oseth said that although the AP round would be splendid if the hop could be reduced, he did not see an application for the HE round. With this round the hop was less than with the AP round but it was greater than with the standard H.E.A.T. round.

"Conclusion:

"It does not appear to me that there will be a demand for either of these rounds in the 105-mm Howitzer M3 even if metal is substituted for the plastic.

"There is still some interest in the AP round for the 105-mm Howitzer M2."

Although the armor piercing sabot projectile could not convert the 105-mm Howitzer M3 into as effective an anti-tank weapon as the 57-mm gun M1 it would provide this howitzer with an emergency round of good anti-tank performance. However, as the projectile had failed in this demonstration before a large assembly of interested officers of high rank, and as the hop was a serious difficulty, there was little reason to expect that it would receive further consideration.

For the attack of concrete with HE shell there is an advantage in increased striking velocity up to the point at which the shell will no longer stand up. The performance of the sabot round with the 3" HE M42 shell fitted with fuze, nose, CP, T 105 should be assessed.

Some time after these tests at the request of Division 1, NDRC, the remaining 105-mm sabot rounds were shipped from Ft. Benning to Picatinny Arsenal where they were to be stored until the Remington Arms Co. were ready to replace the plastic parts with metal.

There was every reason to suppose that the substitution of metal for the plastic would give little difficulty and would remove the cause of the difficult loading experienced at Ft. Benning. Moreover, the work done in developing the 105-mm/57-mm (M86) projectile had given reason to believe that metal would support the projectile central in the bore better than plastic, and would consequently result in smaller yaw and better accuracy.

ARMOR PIERCING SABOT PROJECTILES FOR THE 75-MM PACK HOWITZER

Request for Projectiles

On October 11, 1943, following an inquiry from the Armored Forces, the Office of the Chief of Ordnance asked Division 1, NDRC to estimate what performance could be expected by firing the 57-mm APC M86 projectile by means of a sabot from the 75-mm Pack Howitzer[57].

Calculations were made at the Geophysical Laboratory and led to the estimate given in the footnote[58]. Because of the high twist of the howitzer the projectile would be amply stable, and better penetration would be achieved with this than with a larger projectile. Calculations made at the University of New Mexico indicated that the sabot design 28-75D when fired from the 75-mm gun M3 should release satisfactorily at 2000 ft/sec but probably not at much lower velocity. Firings were made from that gun at MV's of 2250, 2070, and 1950 ft/sec. In each case the sabot separated properly. The spins, at these velocities,

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57/ The 75-mm Pack Howitzers M1A1, M2, and M3 are ballistically identical. The M1A1 is mounted on three different wheeled carriages: the old Pack Carriage M1 with wooden wheels and a box trial, designed for easy disassembly into small units, the Carriage M8 which is similar to the M1 but is equipped with pneumatic tires and a towing lunette, the carriages M3A2 and M3A3, which have a split trail and a firing base. The Pack Howitzer M1A1 in mount T-10 is used on the self-propelled 75-mm Howitzer Carriage T-30. The 75-mm Howitzers M2 and M3 are used in Mount M7 on the 75-mm Howitzer Motor Carriage M8.

These howitzers fire the same projectiles as the 75-mm guns M1897, M2, and M3, but have a smaller chamber, a shorter shot travel, 39.29", deeper rifling, and a higher twist of rifling, 1 turn in 20 calibers.

The MV with the fixed H.E.A.T. round, projectile H.E.A.T. M66, 13.27 lb, is 1000 ft/sec. The MV, with the semi-fixed HE round at full charge, projectile HE M48 14.7 lb, is 1250 ft/sec.

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correspond to those at MV's of 1720, 1620, and 1525 ft/sec, respectively, from the howitzer with its higher twist. As an MV of 1950 ft/sec could be obtained from the howitzer, it appeared certain that the 75-mm/57-mm (M86) sabot projectiles made to design 28-75D that had been supplied to A.P.G. in the early summer, 18 of which were still at A.P.G. would work properly in the Pack Howitzer.

58/ Estimate of Performance of 57-mm APC M86 Fired from 75-mm Pack Howitzer by Means of Sabot, University of New Mexico Design 28-75D

Weights--Estimate of weight of subcaliber projectile filled and fuzed 7.2 lb.
" " " " sabot 1.4 lb.

Estimate of charge and maximum MV obtainable

	Weight lb	Web SP inches	Web MP inches	MV ft/sec
FNH M1	1.77	0.026	0.021	1977
FNH M2	1.66	0.045	0.036	2017

Estimate of penetration, MV taken as 1950 ft/sec

Range	SV ft/sec	Penetration - - (Navy Ballistic Limit) 0°	30°
0	1950	68-mm	57-mm
500	1780	60-mm	50-mm
1000	1620	53-mm	44-mm
1500	1480	47-mm	39-mm

The estimate of penetration was prepared by extrapolation of experimental data at 0° and 30°, using the following DeMarre formula:

$$e^{1.43} = \frac{CMV^2 \cos^2\theta}{d^{1.57}}$$

where e = the penetration
M = the mass of the projectile
d = the diameter of the projectile
V = the striking velocity
~~θ = the angle of obliquity~~
C = constant determined from the known data
θ = angle between trajectory at the plate and the normal to the plate.

On October 22, Division 1 supplied the Office of the Chief of Ordnance with the estimate of performance and stated that the projectiles then at A.P.G. should work properly in the Pack Howitzer.

On October 23, the Office of the Chief of Ordnance requested A.P.G. at the earliest possible date, to establish a charge to give the highest practicable MV with these projectiles, within the allowable pressure in the Pack Howitzer, and then to fire 10 of the sabot projectiles to determine dispersion at 800 yards, and at the same time to get the angle of dispersion of the discarded sabot fragments.

On December 23, A.P.G. made the test requested[59/]. The target was at 800 yards. Ten rounds each of the sabot projectile, and of H.E.A.T. M66 were fired at it. The sabot projectiles hit within a rectange 56" wide and 60" high, the H.E.A.T. within one 60" wide and 25 1/2" high. The mean dispersions determined from measurements made on a photograph of the target were: Sabot, horizontal 15 1/2", (1.9 min.) vertical 12" (1.5 min.), H.E.A.T. M66 horizontal 14" (1.75 min.) vertical 6" (.75 min). These results are included in Table IX.

After the report on the firing at A.P.G. had been received, on February 24, 1944, the Office of the Chief of Ordnance requested Division 1, NDRC to supply 120 sabot projectile similar to those that had been fired at A.P.G.

On February 24, Division 1, NDRC asked the University of New Mexico if they could arrange for the manufacture of these projectiles.

On February 25, the University of New Mexico undertook to do so.

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59/ A.P.G. Firing Record, M 28827, December 23, 1943.

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Work at the University of New Mexico

The APC M86 projectiles used to date in sabots for the 75-mm gun and for the 105-mm Howitzer M3, had been part of a special lot made up without rotating band or band seat. The supply of these projectiles had been exhausted, and a long delay was anticipated if another special lot had to be obtained. It was decided, however, that standard projectiles could be used. It was planned to have the threaded steel rings and the plastic bourrelets made up in outside shops, and to thread the base of the M86, assemble the threaded ring to it, band the projectile, and put on the bourrelet in the shop at the University of New Mexico. This appeared practicable because a lull in the work for the night shift was expected in about ten days, and it should be possible to get the projectiles delivered in that time.

The M86 projectiles were requested on February 29. They were delivered on March 16. After they had been delivered, it was found that the projectiles supplied had been made by a manufacturer whose projectiles had been among the worst M86's made. In threading them it was found that the hardness was extremely erratic. When the manufacturer's name was known the Office of the Chief of Ordnance, anticipating that some trials against armor might be made with the sabot projectiles, arranged for 25 projectiles from a good lot, then at A.P.G., to be sent at once to the University of New Mexico, so that the lot of 120 would include twenty-five of satisfactory and known armor penetrating quality.

The 120 projectiles were shipped by the University of New Mexico to Picatinny Arsenal on April 12.

This lot of sabot projectiles was made to design 28-75D, revised March 2, 1944. The modifications of design 28-75D were quite slight.

The dimensions of the APC M86 had been changed slightly since the first lot had been made; corresponding changes were required in the sabot. The original design had had 8 breaking slits in the bourrelet and in the threaded steel ring. The new design had only 4 in each. In the new design the bourrelet was held to the M86 by two set screws. The length of the threaded steel ring and the length of the threads were very slightly increased. The crimping groove was eliminated, and the low limit to the diameter of the skirt was now made 2.900-.005. The plastic used was laminated cotton fabric base phenolic, Textolite C. The threaded ring was made from mild, free threading, steel B-1112 (because it was on hand). The projectiles containing the good M86's were marked with a white painted band to distinguish them from the others. The subcaliber projectiles weighed 6.25 lb, empty as shipped, and when filled and fuzed would weigh about 7.13 lb. The sabots weighed 1.37 lb.

On April 17, a dispersion test was made at the University of New Mexico Proving Ground firing 10 projectiles selected at random from the lot prepared for the Army. The 75-mm gun M3 was used. The target was at 1000 yards. The MV was 2820 ft/sec. The true mean dispersion was: horizontal 3.1" (0.29 minutes), vertical 4.5" (0.42 minutes). All rounds hit within a rectangle 14.7" wide and 21.2 " high. This was the best result that had been obtained to date (see Table IX).

Subsequent History

At Picatinny these projectiles were made up into two lots of semi-fixed complete rounds. Both lots had the same propellant charge. This was the charge that had been used at A.P.G. for firing from the Pack

Howitzer in December 1943. The cartridge cases used were M5A1, Type I. It will be recalled that the projectiles fired in December were slightly lighter than those of these lots, because they were plugged, whereas these were fitted with fuze BD M72. Lot PA-E-434 consisted of the 25 sabot projectiles with the good subcaliber projectiles, and 35 sabot projectiles with the poor ones. This lot was filled explosive D and fuzed BD M72. The other lot, PA-E-435, was filled inert and fitted with live fuze BD M72 60/. When filled, the projectiles were shipped to Aberdeen Proving Ground for acceptance test.

The two lots were tested at Aberdeen Proving Ground on July 4, 5, 6, and 7 to check functioning and to obtain provisional range-elevation data. The firings were from a 75-mm Pack Howitzer on Carriage M3A3. The sabot projectiles, fuzes, bursting charges, and tracers all functioned satisfactorily. It was found that the pressure developed by the propellant charge that had been loaded was too high, so the charge was reduced from 27.07 oz to 25.87 oz. The projectiles were rather too loose in the cartridge cases supplied, and were therefore tried in case M5A1 type II, which is used for the fixed H.E.A.T. round and has a slightly smaller mouth than Type I. In this they were a better fit. Instructions were issued that the propellant charges, of all the rounds remaining, were to be reduced to 25.87 oz and to be transferred to type II cases.

It was concluded that with these changes the ammunition would be acceptable. When the changes had been made the ammunition was to be shipped to the President of the Armored Board at Ft. Knox, Kentucky.

60/ Ammunition Data Cards 36061 and 36062.

At Ft. Knox, the Armored Board was to conduct a preliminary service test of these projectiles in comparison with standard ammunition. A range elevation table was to be supplied by O.C.O. (Pt. 75-BA-0).

After the 105-mm sabot projectiles had been tested at Ft. Benning, Georgia and it had been learned that the plastic had swollen, this ammunition was still at A.P.G. Arrangements were made to have the bourrelets of a number of rounds gauged to learn whether or not they were swelling to an important extent in the humid atmosphere. Ten from each lot were gauged on August 9. The bourrelets of 3 projectiles from the inert lot and of 7 from the HE loaded lot were found to be over 2.950" in diameter. The maximum diameter found was 2.953". The original diameter shown on the drawing was 2.945"-.005". The bore diameter of the howitzer is 2.950" + .002". The bourrelets of the HE rounds had been painted and this presumably accounted for the difference in the diameters of the two lots.

On receipt of this information, the Office of the Chief of Ordnance inquired into the practicability of turning down the oversize projectiles at A.P.G. It was considered quite safe to do so, but the ammunition had been shipped to Ft. Knox, on August 12.

Dr. C. E. Hablutzel, who was at that time in Washington acting as a special advisor to Division 1, NDRC, drew up a design of a light metal bourrelet that could be substituted for the plastic sleeves on this lot of 75/57 mm projectiles. This design 28-75D revised, Plate IV, 8-30-44, shows a spool-shaped sleeve or bourrelet of dural (17S-T) or of Dowmetal (O-1 or J-1) with 4 breaking slits cut from the inside out. The slits extend completely through the sleeve except at the front and rear. A steel band threads over the light metal sleeve at the forward end and forms the bearing against the bore.

About the middle of September, Dr. Hablutzel visited Ft. Knox and reported that most of the inert rounds would load but that a large number of the HE filled rounds would not. The officers with whom he talked at Ft. Knox were of the opinion that the tests would not be made for some weeks, and recommended that in the mean time the plastic be replaced with metal. Later, on September 26, the O.C.O. was informed by the Armored Board that the ammunition had been tried in a howitzer and that tests were impracticable with it. On September 29, Division 1 informed O.C.O. that they would arrange to have metal substituted for the plastic. This was to be done by the Remington Arms Company then working on sabots under contract OEMsr-1368. See note at the end of the text, page 138.

SUBSTITUTION OF LIGHT METAL FOR PLASTIC IN THE BOURRELETS

On April 14, 1944, a conference attended by representatives of Division 1, NDRC, the Engineering and Transition Office, OSRD, and the University of New Mexico was held at the University of New Mexico to consider future work on sabot projectiles for the 105-mm howitzer and the 75-mm gun and howitzer. At this time, three separate lots of sabot projectiles 105-mm/3" (HE M42) design 3-105, 105-mm/57-mm (APC M86 modified) design 2-105R, 75-mm/57-mm (APC M86) design 28-75D revised, had been supplied to the Army and were awaiting test. It was agreed that if the Army should want more of any of these projectiles some modification of the design would be called for (1) to improve the projectile for service use (2) to facilitate production.

B. 110

A number of modifications were considered. The more important of these were (1) change from plastic to metal bourrelet (2) on 3-105B and on 2-105R the addition of some steel immediately in front of the band seat to prevent the band from being blown forward if it should happen not to be properly seated. This would also help to prevent asymmetry of engraving.

It was agreed that if the Army had further interest in these sabot projectiles:

1. Designs would be prepared embodying the improvements that had been already recognized, or that might be recognized as a result of the coming trials or as a result of study by ordnance personnel or others. These designs would be prepared by the University of New Mexico and also by the Engineering and Transition Office. They would then be discussed and a design or designs for trial drawn up.
2. The procurement of the models for test would be the responsibility of the Engineering and Transition Office.
3. Firing tests of these models would be made by the University of New Mexico, but no machine work would be required of them.
4. Acceptance tests of production lots by firing would also be made by the University of New Mexico if desired.

On April 21, at a conference attended by representatives of the Army Ground Forces, the Office of the Chief of Ordnance, Division 1, NDRC, and the Engineering and Transition Office, OSRD, the Office of the Chief of Ordnance asked that Division 1 proceed at once with the necessary modifications of the designs of the 105-mm and 75-mm sabots to eliminate the plastic without awaiting the results of the pending tests. Division 1 undertook to do so.

The Engineering and Transition Office, OSRD undertook to have designs drawn up for discussion and Division 1 asked the University of New Mexico to do the same.

On May 6, drawings of the modifications proposed by the University of New Mexico were sent to Division 1, NDRC. On receipt of the drawings, Division 1 transmitted copies to the Engineering and Transition Office, OSRD, and to the Ammunition Development Branch of the Technical Division of the Office of the Chief of Ordnance.

The designations of the new drawings and the modifications shown on them are as follows:

28-75D revised, Plate III 5-6-44 shows a sleeve type bourrelet of dural or Dowmetal in 4 segments. The segments are held together at the forward end by a threaded steel band, which acts also as a bearing against the bore. At the rear end the segments bear against the front face of the threaded steel base ring, and are prevented from moving outward by the outer edge of the steel base ring which projects forward over the rear ends of the segments. The sleeves were designed to be segmented after machining, so 4 metal strips were provided to fill the saw cuts. Later the University of New Mexico devised a technique for machining the sleeves after cutting them into four pieces. This made it possible to have the segments close fitting and so eliminated the strips. The information was passed on to Division 1, on May 12, 1944.

2-105R Plate IV, dated 5-6-44. The bourrelet, which is of dural, is similar to that described above. The threaded steel base ring is brought forward 0.1" in front of the rotating band, and a recess for the rear ends of the segments of the bourrelet is provided on the front face.

3-105B, Plate III, dated 5-6-44. The description above under 2-105R, Plate IV applies here also.

The changes in weight of the sleeve or bourrelet are as follows:

28-75D	Dural sleeve is 2.1 oz heavier than plastic
	Dowmetal sleeve is 1.4 oz lighter than plastic
2-105R	Dural sleeve is 8.0 oz lighter than plastic
3-105B	Dural sleeve is 0.5 oz lighter than plastic

ARMOR PIERCING SABOT PROJECTILES WITH TUNGSTEN CARBIDE CORES FOR THE 76-MM GUN M1A2

Request for the Development

On October 21, 1943, the Office of the Chief of Ordnance asked Division 1, NDRC to estimate what could be done against armor, with steel and with tungsten carbide cored subcaliber projectiles, fired by means of a sabot from the 76-mm and the 90-mm guns. The 76-mm gun then in use was the M1A1 with a twist of 1 turn in 40 calibers. Because of the low twist, this gun was particularly unfavorable for the use of sabots. However, it was to be replaced by the M1A2 with a twist of 1 turn in 32 calibers, the same as in the 90-mm. The new gun was then being tried out at Aberdeen Proving Ground, and it was expected that it would soon be in production. The British had been experimenting with tungsten carbide cored projectiles, and were developing several for anti-tank use. The U. S. Military Attache in London was obtaining detailed information about the designs of the projectiles and their performance against plate. When this information came to hand it could form the basis of an estimate of the performance to be expected using tungsten carbide. In the meantime an estimate of the performance to be expected with steel subcaliber projectiles was prepared for Division 1 by the Geophysical Laboratory. This was submitted to the Office of the Chief of Ordnance on November 27, 1943.

There is no need to give a detailed statement of the estimate here. It was found that the use of sabots with standard steel APC projectiles as subcaliber projectiles, the 57-mm APC M86 in the 76-mm gun, and the 3" APC M62 in the 90-mm gun, would result in no significant improvement in performance, although there would be material increases in MV.

The 57-mm APC M86 projectile could only be made adequately stable in the 76-mm gun M1A2 (twist 1:32) by substituting an extremely short windshield. The retardation would then be so high that the striking velocity of the modified M86 would probably become less than that of the standard projectile (3" APC M62) for the gun at ranges over 1800 yards, and the penetration of the modified M86 (at 0° angle of attack) would actually be less than that of the standard at ranges over 500 yards. Even at the shorter ranges the actual penetration would also be less because of the deformation of the M86 at the high striking velocities involved[61/]. The highest obtainable muzzle velocity was estimated to be

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61/ At this time a program to test the performance of standard 57-mm APC M86 projectiles against plate at very high striking velocities was under way at Aberdeen Proving Ground. However, the results were not available for this estimate. In this program the 57-mm projectiles were fired from the British 17-pounder using sabots provided by the Geophysical Laboratory. Muzzle velocities in excess of 4000 ft/sec were obtained in this way. See Aberdeen Proving Ground, Projectile Test Report AD-P99, Dates of tests August 29 to November 18, 1943.

3650 ft/sec which would drop to 2850 ft/sec at 1000 yards.

The 3" APC M62 fired from the 90-mm gun would have a stability factor of about 1.23[62/]. The calculated improvement in penetration even if no shattering or serious deformation occurred was insignificant, of the order of 2 per cent, and it seemed likely that, even with excellent projectiles, the penetration at ranges under about 1500 yards would actually be less than that of the standard because of breakup of the projectile. The maximum MV obtainable was estimated to be 3310 ft/sec which would drop to 2860 ft/sec at 1500 yards.

The stability factor 1.23 was rather low. It could readily be increased by using a shorter windshield. This would of course decrease the striking velocity and penetration except at the muzzle.

It was known before the detailed estimate of performance was made that very little if anything could be gained by using standard steel projectiles in sabots in either of these guns, and that the only way the performance could be greatly improved was to use tungsten carbide. On November 17, 1943, the Office of the Chief of Ordnance requested Division 1, NDRC to develop a sabot projectile using a tungsten carbide core for one of these two guns, the 76-mm Gun M1A2 or the 90-mm Gun M1, M2, and M3. It was believed that it would be easier to do the experimental work in the smaller gun, and quite a simple matter to scale up a satisfactory design for the larger gun, and the Office of the Chief of Ordnance believed that a 76-mm Gun M1A2 for the experimental work could soon be made available. Therefore this gun was preferred.

62/ The stability factor of the 3" APC M62 fired from the 76-mm Gun M1A1 was said to be 1.10. Multiplying by the ratio of the square of the twists in the two cases gives 1.23. As the MV of the sabot projectile would be considerable higher than the MV of the M62 projectile in the 76-mm gun, the actual value would probably be slightly greater.

The Geophysical Laboratory prepared an estimate of the comparative performance of a tungsten carbide cored sabot projectile and the 3" APC M62 projectile fired from the 76-mm Gun M1A2. This estimate, based on information about the penetration of British tungsten carbide cored projectiles, is given in Table VI.

At a conference on December 4, 1943 between representatives of the Office of the Chief of Ordnance, Division 1, NDRC and the University of New Mexico, it was decided (1) that it would be best to begin work with the smaller gun, i.e., the 76-mm M1A2 (twist of rifling 1 turn in 32 calibers[63/]), (2) that the subcaliber projectile should be one using a core based directly on the British design of core as used in the 2-pr. Littlejohn Mk II shot, the 6-pr. discarding sabot shot and the 6-pr. C.R. shot[64/].

At that time it appeared that an all-metal sabot following in a general way the basic design 28-75D that had been used for the 75-mm/57-mm (APC M86) sabot would be quite satisfactory, and that it could probably be developed in a short time after a 76-mm gun M1A2 had been delivered

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63/ The 76-mm gun in use at that time was the M1A1 which was rifled with a twist of 1 turn in 40 calibers. In order to improve the stability of the standard armor piercing projectile used in this gun, the 3" APC M62, the twist was to be increased to 1 turn in 32 calibers. In other respects the new gun was to be identical ballistically with the M1A1. The M1A1 was in use in the medium tank M4 where it had replaced the 75-mm Gun M3, and on the gun motor carriage T-70. The new gun was also to be mounted on a wheeled anti-tank carriage. The gun produced for the automotive mounts was termed the M1A2, that for the anti-tank carriage the T3. The tubes were identical, the difference being in the breech mechanism. These so called 76-mm guns are 3" guns. They fire the 15.44 lb 3" APC M62 projectile with an MV of 2600 ft/sec or the 12.87 lb. 3" HE shell M42A1 with an MV of 2700 ft/sec.

64/ Shot, Armour Piercing, Q.F., 2-Pr., S.V. Mk II B.T./L
Shot, Armour Piercing, D.S., Q.F., 6-Pr., 7 cwt., Mk I B.T./L
Shot, Armour Piercing, Q.F., 6-Pr., 7 cwt., C.R. Mk I A.T./L

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Table VI

Estimated Performance of Tungsten Carbide Cored Sabot Projectile
Compared with that of Standard 3" APC M62 Projectile, Fired
From the 76-mm Gun M1A2.

Striking Velocity and Penetration Against Range

	Muzzle Energy Equal to That of APC M62 Round				MV Maximum Obtainable using M2 Powder			
	Striking Velocity		Penetration 30° Homogeneous Armor		Striking Velocity		Penetration 30° Homogeneous Armor	
Range	M62	Sabot	M62	Sabot	M62	Sabot	M62	Sabot
Yards	ft/sec	ft/sec	inches	inches	ft/sec	ft/sec	inches	inches
0	2600	3450	4.4	6.5	2820	3745	4.9	7.3
500	2450	3240	4.0	6.0	2670	3535	4.5	6.8
1000	2300	3040	3.7	5.5	2520	3335	4.2	6.2
1500	2150	2850	3.4	5.0	2370	3135	3.9	5.7
2000	2000	2650	3.0	4.5	2220	2935	3.6	5.2

Weights   Sabot Projectiles
WC core 3.89 lb
Total 8.15 lb
Std. Projectile APC M62 15.4 lb

Striking velocity and penetration of 3" APC M62 taken from curves prepared by the Ballistic Section, Technical Division, OCO.

Striking velocity of sabot subcaliber projectile computed using ballistic coefficient 1.275 and British tables for cylindrical based projectiles (1940 Law).

Penetration of subcaliber projectile based on data from table prepared by D. G. of A. A2(b)A, S,/7/43.(British)

Muzzle energy = (mass of projectile + 1/3 mass of charge) x square of the muzzle velocity.

to the University of New Mexico. However, on December 7, Division 1 learned that both the 76-mm and the 90-mm guns in tanks and on anti-tank mountings would be fitted with muzzle brakes. The brakes to be used consisted essentially of two, spaced, baffle plates, with central holes for the passage of the projectile, supported some inches in front of the muzzle. The diameters of these holes allowed only a very small clearance between the baffle and a projectile with no yaw (0.05" all around in the case of the rear baffle of the brake for the 76-mm gun M1A2). The parts of a sabot like 28-75D separate as they leave the muzzle, and travel essentially in the direction in which they were moving in the bore at the muzzle, i.e., their paths approach the direction of the lands at the muzzle. It was quite evident, therefore, that a sabot of this type could not be used with the muzzle brake unless the openings in the baffles of the brake were very considerably enlarged so as to clear the diverging pieces of the sabot[65]. Further, it was quite evident that there would be many barriers to an increase in the diameter of these openings, and that the sabot would therefore have to be designed to pass through them. This was the problem that the University of New Mexico was asked to solve.

Research and Development Work at The University of New Mexico

At this time the Department of Physics of the University of New Mexico was heavily engaged in other projects of high priority, in addition

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65/ In developing sabot projectiles first for the 6-pr., later for the 17-pr., the British opened up the baffles of the muzzle brakes until the centrifugally released parts of the sabot cleared the brake.

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to the work on sabots, and both the technical staff and shop facilities were overtaxed. Dr. Workman, who was at that time head of the Department of Physics and under whose direction the work was being done was very loath to undertake this additional commitment and recommended against it. However, Division 1, was unable to have the work done promptly elsewhere, and the University of New Mexico finally, late in February 1944, agreed to undertake it. Some work had indeed been done on this project shortly after the request to have it undertaken had been made, but, at that time, the work on the 105-mm sabots was being done and it was not until late in February that the work really got under way.

The first part of the work was the development of a design that would pass through the brake. At the outset of the work a 75-mm gun M3, but no 76-mm gun, was available at the University of New Mexico. Accordingly, a number of the designs were made up to fit the 75-mm gun and tested in it; later, when the 76-mm gun with muzzle brake was supplied, the work continued with it. Much of this early work was done using steel subcaliber projectiles to avoid the expense of heavy alloy cores.

In all, some twenty different designs were tried[66]. These may be grouped into three types according to the mechanism by which the sabot parts are released fom the subcaliber projectile.

(1) Axial release -- The sabot is cuplike and is removed from the subcaliber projectile in flight by the drag of the air. The relative motion of the two is in the direction of the axis of the projectile. Some of these sabots were designed to

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66/ For details see, Final Report, Contract OEMsr-668, Supplement 4, August 1, 1944, in which the work is summarized. Drawings are included.

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remain in one piece, others to separate into two. The essential feature is that they do not break up centrifugally, and for this reason they pass through the brake without interference if the yaw is small enough.

(2) Bourrelet released centrifugally — A number of designs were tried in which the "bourrelet" broke up by centrifugal force into segments, but did not do so until the rear ends of the segments were released by the base. Two types of release by the base were tried.

(a) The base is a threaded ring, similar to that used in 28-75D, that breaks up under centrifugal force and releases the rear ends of the bourrelet segments. The action following this release is the same as that described under (b) below. The design aimed at such strength in this ring that it would not "explode" at the muzzle but would yield slowly enough to pass through the brake before significant expansion had occurred. The material used in the ring was cold rolled steel of good elongation. This release is designated as "delayed centrifugal."

(b) A base plate, of heat treated alloy steel, is used. When the forward pressure of the propellant gases against the base of the projectile ceases, well in front of the brake, this plate is moved to the rear by air drag, thus releasing the rear ends of the bourrelet segments which then move outward. These segments, which are of light alloy, are held together near the forward end by a bourrelet band of steel. This band is strong enough to hold the segments against centrifugal force until the rear ends are released but not strong enough to hold them after that. When the rear ends of the segments are released they move outward. The segments pivot about their forward edge and, using the subcaliber projectile as fulcrum, expand and burst the bourrelet band. The release is termed "axial and delayed centrifugal."

Although the different mechanisms just described were tried out, about two-thirds of the experimental firings, made during the development, were of models of the last-described type. The first such design, 42-75, was tried out in the 75-mm gun using a solid steel subcaliber projectile. It was quite successful and design 3-76 for the 76-mm gun was based on it. Quite a number of slight modifications of this basic design, each designated by a letter following the number, were tried. The final design is designated 3-76EH. This design consists of 3-76E, revised to 7/1/44, but with the base plate or sabot shown on 3-76H, 6/27/44, substituted for the corresponding part shown on Plate I of 3-76E. Drawings of this design have not been reproduced here, but the design is very like 3-76J drawings of which are reproduced as figures 12 - 15.

If Plate I of 3-76J is examined, it will be seen that a tracer pocket on the base of the subcaliber projectile projects through the steel base plate or sabot, and a sabot retaining ring is threaded to it behind the base plate, thus holding the parts together. The first model of 42-75 tried had a dural sabot retaining ring. It was expected that this ring would disintegrate under the action of the powder gas. When the model was fired from the 75-mm Gun M3, release did not occur. Retaining rings of red fiber and of Dowmetal were then tried, and release appeared to be satisfactory. Dowmetal was chosen for this ring. As will appear later, however, in the description of the tests at Aberdeen Proving Ground, Dowmetal rings did not prove to be completely reliable, and were subsequently replaced by split steel rings designed to be thrown by centrifugal force.

The real test of a sabot projectile presumably is its behavior when fired from a worn gun. It was not possible to test it in this way at the University of New Mexico Proving Ground. Therefore, in order to simulate such a test, some 75-mm models were made up with all surfaces that bear against the bore 0.03" under size. In addition, one of these undersize models was fitted to a cartridge case that had been shortened 0.5", to give 0.5" free run. Dowmetal retaining rings were used on these models. They were fired from the 75-mm Gun M3. In all cases the mechanism worked properly, yaws were too small to measure, and flight was good.

When a 76-mm gun became available for firing, models made to design 3-76 and modifications of this design were tested. By this time the choice of this type of design had pretty well been made. Of 38 models fired from the 76-mm gun during the development all but eleven were made to design 3-76 and modifications of it. The early models had dural bourrelet segments, but, when Dowmetal was tried out, and found to work satisfactorily, it replaced the heavier dural. One model of 3-76 EH with a core of Elkonite 5W3 was machined with the outer diameter of parts bearing against the bore 0.020" under size. When fired from the 76-mm Gun M1A2 with muzzle brake, it behaved normally. The yaw was too small to be observed. (Report of December 1, 1944, p. 4)

Besides the design of a sabot to pass through the muzzle brake, the work also involved the design of a subcaliber projectile. For some time, active development of high velocity tungsten carbide cored armor piercing projectiles had been under way in the United Kingdom. A satisfactory core and carrier had first been developed for the 2-pr. (40-mm) Littlejohn Mk II shot[67]. Then this core had been scaled up in the ratio of the bore diameters and used in projectiles for the 6-pr., 7-cwt. (57-mm), and 17-pr. (3"). This type of core was used in the Littlejohn (tapered bore) projectiles, Composite Rigid (light weight full caliber), and Sabot projectiles. Very satisfactory penetration had been obtained with it. It appeared that a subcaliber projectile following closely the British design of subcaliber projectile for the 6-pr. sabot (57-mm), and using a tungsten carbide core of the size used in 17-pr. projectiles[68] could be constructed that would have sufficient stability when fired from the 76-mm Gun M1A2. It was accordingly agreed, at the Conference on December 4, to base the design of the subcaliber projectile on this British projectile. This resulted in the design of subcaliber projectile shown on Plate III of design 3-76E.

A determination of the stability factor of this projectile was made at the University of New Mexico Proving Ground. The projectiles were made to design 3-76E, but modified in two respects: (1) The base plate had no skirt and was divided into four segments held together by the rotating band so that it would break up centrifugally at the muzzle and could not destroy the record made by the subcaliber projectile on the yaw cards as it might if it remained intact and followed the subcaliber

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67/ Shot, Armour Piercing, Q.F., 2-Pr., S.V. Mk II B.T./L.

68/ The 17-pr. sabot design was based on the 6-pr. sabot but drawings were not available until later.

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projectile through the cards, (2) The cores were of Elkonite 5W3 instead of tungsten carbide. The gun used was an M1A1 (twist of rifling 1:40) that had been sent to the University of New Mexico by mistake instead of an M1A2.

The stability factor found, at the cards, under field conditions was 1.15. Computed to a twist of 1:32, to standard atmospheric conditions, and back to the muzzle, this gave a stability factor of 1.39. (Report of August 1, 1944, pp. 16-19). The MV to which this stability factor applies is not stated, but on p. 14 a velocity of 3440 ft/sec at the coils is given for one of the two rounds used. The value therefore applies at an MV of about 3450 ft/sec 69/.

Determinations by tracer photography of velocity vs. time of flight and of range vs. time of flight were also made on two 3-76E projectiles. The results are presented in Final Report, Contract OEMsr-668, Supplement 4, August 1, 1944.

As the subcaliber projectile follows very closely the design of the subcaliber projectile in the British 6-pr. and 17-pr. sabots, British armor penetration data are directly applicable to these projectiles 70/.

The muzzle velocities obtained at the University of New Mexico Proving Ground were lower than could be realized with a suitable powder.

69/ Final Report, Contract OEMsr-668, Supplement 4, August 1, 1944, p. 16.

70/ As the British 17-pr. (3") is a much more powerful gun than the 76-mm, the striking velocity, and therefore the penetration, at a given range is greater for the 17-pr. sabot fired from it than for the University of New Mexico sabot fired from the 76-mm gun. However, when the data are expressed in terms of striking velocity they are directly applicable. The penetration of this sabot projectile can also readily be computed from data for the 6-pr., 7- cwt., (57-mm), Sabot and Composite Rigid shot by use of the De Marre formula.

The most suitable powder available there was FNH M2 lot Rad-3006. This was rather too fast a powder and a charge of 1410 grams (49.7 oz) was all that could be used without exceeding the rated pressure of the gun. Therefore it was to be expected that using a larger charge of slower powder would give higher MV's than could be had with this powder. At Aberdeen Proving Ground using FNH M2 Lot Rad-3008, a slower powder, MV's of 3642 and 3655 ft/sec were obtained (A.P.G. F.R. P32198). In subsequent firings at Aberdeen, to get a desired MV of 3600 ft/sec, a charge of 64 oz of FNH M2 lot 18830 was used.

Projectiles were being made up for a dispersion test when Division 1 informed the University of New Mexico that the Office of the Chief of Ordnance was very anxious to have an opportunity to test some of these projectiles against plate, and had asked for 20 at the earliest possible date, and undertaken to test any projectiles supplied, immediately upon receipt. The Division asked if the design was thought to be sufficiently advanced for such a test and suggested that, if so, the request be met. Although only a limited number of projectiles had yet been fired through a muzzle brake, and although no dispersion test had yet been made, the design did appear to be satisfactory. It appeared, moreover, that there were some advantages to be gained by supplying projectiles to the Ordnance Department for test under these circumstances. It was decided to meet the request and to supply the projectiles then being made up for a dispersion test, and to defer that test until after the projectiles asked for had been delivered.

Actually 25 projectiles to design 3-76EH were made up and supplied to the Ordnance Department for test at Aberdeen Proving Ground. The cores in these were of Carboloy grade 55A which is cemented tungsten carbide with 13% cobalt. These were delivered to A.P.G. in small groups as they were made up, 8 on July 23, 8 on August 1, and 9 on August 13, 1944. They were fired there promptly. The results of these firings are given later.

On August 12, eight projectiles to design 3-76EH but with cores of Elkonite 5W3 were fired, at the University of New Mexico Proving Ground for accuracy, from a new 76-mm Gun M1A2 fitted with a muzzle brake, against a vertical target at 1000 yards. All rounds hit the target. Round one was used for ranging and the elevation was adjusted after firing it. One round did not function properly, as cutouts of the base plate and the subcaliber projectile were partly superposed on the target. The other 6 rounds gave a mean dispersion of 14" or 1.3 minutes of arc, and fell within a rectangle 39" high and 71" wide. These results are included in Table VIII.

Tests at Aberdeen Proving Ground, Design 3-76EH[71/]

Most of the projectiles supplied to Aberdeen Proving Ground were fired against plate to obtain penetration data. The penetration was as expected from British data and was of course greatly superior to that obtainable with steel projectiles from the same gun. The following data, taken from the Aberdeen Proving Ground Firing Records indicated, summarize the results:

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71/ "First Report on the Projectile, H.V.A.P., (Sabot), 76-mm 3-76EH (University of New Mexico), T23 and T23E1, and Second Report on Ordnance Program No. 5962," issued by Ordnance Research and Development Center Aberdeen Proving Ground, October 1945, covers the testing at Aberdeen of these subsequent 76-mm sabot projectiles.

A.P.G. Firing Records Nos. P32198, P32743, and P33112, which form a part of the above report, cover these firings.

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Table VII
Armor Penetration, 3-76 EH, at A.P.G.

Homogeneous Plate		Striking Velocity ft/sec		See F.R. No.
Thickness Inches	Angle Degrees	Projectile Completely Through Plate	Partial Penetration	
6 1/16	20	2756	2656	P-32198
5	30	2986	2833	P-32198, P-33112
3 15/16	30	2276	2184	P-33112
3	55	3621		
4	30	at 2100 yards completely through plate		P-32743

Yaw cards just in front of the plates showed that there was very little yaw.

No satisfactory dispersion test was made, although on two occasions some rounds were fired against 4" homogeneous armor plate at 30° at 2100 yards. On the first occasion, August 5, three rounds were fired.72/ All missed the plate. No NDRC representative was present. On August 13, five more rounds were fired against 4" homogeneous plate at 30° at 2100 yards. A large screen had been erected in front of the plate. A new gun with brake mounted in a tank was used for the firing. The first round was short. The next two struck the target about 2 feet apart. The fourth was defective. It struck short and far to the right. It is not certain that it separated properly. The brake was then replaced with

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72/ Firing Record No. P-33112. The charge is given as 64 oz of M2 powder and the MV is estimated as 2800 ft/sec. This charge should give MV of about 3600 ft/sec. Either the estimate of the MV or the statement of the charge is in error. Almost certainly the charge was as stated.

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a lighter one. The next round hit higher and this the gunner attributed the the lighter brake. All these rounds were fired at about 3600 ft/sec muzzle velocity. The firing showed that the shot would "completely penetrate 4" of homogeneous plate at 30° obliquity at 2100 yards range. The velocity after plate penetration was sufficient to completely penetrate a 12" x 12" oaken support." (A.P.G. firing record No. P-32743).

Information about the way the sabot parts separated from the subcaliber projectile was obtained during the firings described above, and in addition from three rounds fired on August 13 especially to study the separation by the use of photography. On the latter occasion two good x-ray photographs were taken. One showed the projectile in the brake, the other showed it just after it had emerged from the brake. No relative displacement of the parts of the projectile appeared in these x-ray photographs. An attempt was also made to obtain micro flash photographs of each of the three projectiles at 7, 22, 37, and 52 feet from the muzzle. However, the technique was faulty, and photographs were obtained only at 52 feet. One of these shows the subcaliber projectile completely free in flight with the base a few inches behind it. All that could be said from the other two was that the bourrelet parts had been thrown.

For the firing against plate at 2100 yards on August 13, plywood screens had been erected on each side of the trajectory at 52 ft from the muzzle. Bourrelet parts from three of the five rounds hit these screens. No parts of the other two projectiles hit these screens but one of them definitely separated in flight.

All of the firings against plate except those at 2100 yds were made at close range, controlling the muzzle velocity to obtain the striking velocity desired. Under these circumstances, when the muzzle velocity was lowered, the bourrelet bands had to be weakened, hence the information obtained about separation does not apply directly to the projectile fired without alteration at full muzzle velocity.

In these firings the projectiles had behaved as expected. It appeared that (1) the projectile passed through the muzzle brake without interference, (2) the projectile separated in flight, (3) the subcaliber projectile had very little yaw, (4) a muzzle velocity greater than 3600 ft/sec was obtainable, (5) armor penetration was very satisfactory and in agreement with British data.

It was thought that the Dowmetal retaining ring that held the subcaliber projectile to the base plate was scarcely strong enough even to withstand rough handling (no test was made). Moreover there was a suspicion that it had not always released the subcaliber projectile from the base uniformly in the firings at full muzzle velocity. It was thought that a stronger, and more positively acting, ring should be substituted for it. Apart from this, the mechanism appeared to function satisfactorily. However, the guns used for the firings had in no case been badly worn. One gun had previously fired 602 rounds. Another had fired 217. The others had fired fewer

Preparation of Second Lot of Projectiles, Design 3-76J

The 25 projectiles made to design 3-76EH had worked well at A.P.G. but several outstanding questions awaited an answer. It appeared, therefore, that more of these projectiles should be supplied for tests at the earliest possible date. The Office of the Chief of Ordnance requested Division 1, NDRC, to supply 25. The S.T.B. committee of Division 1 recommended that the Division supply 50. Research ad development work under contract OEMsr-668 had been terminated on July 31, 1944 at the request of the University of New Mexico, so the projectiles had to be made elsewhere. Dr. C. E. Hablutzel, who had been in charge of the development of the projectile at the University of New Mexico under Dr. Workman, was in Washington acting as a special consultant to Division 1. He prepared a new set of drawings, 3-76J. The Remington Arms Company Inc., who had a contract for research and development of sabot projectiles, was asked to make up the projectiles. However, it soon became clear that a long time would elapse before they could supply these projectiles. It was then decided by Division 1 to have 25 projectiles made up, under Dr. Hablutzel's supervision, by some other machine shop, and to have the Geophysical Laboratory meet the cost of manufacture through their contract. It was a fortunate circumstance that the order was placed with the Turbo Machine Company of Lansdale, Pennsylvania. They turned out an excellent job most expeditiously. Mr. H. A. Matthews of that company received the order orally on Saturday, August 26. The projectiles were delivered to A.P.G. on September 13.

These 25 projectiles were made to design 3-76J, Plates I, II, and III revised 8/30/44, and Plate IV dated 8/28/24 (see figs. 12-15). This design differs only slightly from 2-76EH. The following list shows the modifications of design 3-76EH that resulted in 3-76J. Plates I, II and III of 3-76E and 3-76J show corresponding parts. The base plates or sabots are shown on 3-76H and Plate I of 3-76J.

3-76E, Plate I. Weights changed slightly. The total weight of the projectile with tracer was 7.7 lb (see p. 157).

3-76E, Plate II. Contour of Dowmetal bourrelet modified for ease of machining. The segments were now completely separate. Steel bourrelet band thinner and narrower.

3-76E, Plate III. The tungsten carbide cores, which were made by Kenametal and supplied by the Ordnance Department, were made to conform

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to the standard British design of 17-pr. core. This core was slightly shorter than those used in the earlier projectiles. The base of the core is recessed slightly. The recess insures that, on setback, the thrust is applied on the outer portion of the base and not on the central portion; thus the torque of the frictional forces, through which spin is imparted to the core, is increased.

The sheath was modified as required by the new core and a conical nose was substituted for the ogival one of 3-76E.

The aluminum pad, and the recess for it in the sheath, were modified for increased ease in machining.

The tracer pocket was changed to accept the tracer used in fuze BD M66 instead of that of fuze BD M72, and tracers were fitted. The outer contour was modified as required by changes in the base plate.

A steel ring, 3-76J, Plate IV, was substituted for the Dowmetal retaining ring. This ring threaded onto the outside of the tracer pocket when the projectile had been assembled and held the base plate to the subcaliber projectile. It was designed to open under the centrifugal force of spin and so to release the base plate.

Plate I of 3-76J.

3-76H. The base plate was lightened by coning the rear face,/ This resulted in a shorter length of bearing between the base plate and the tracer pocket of the subcaliber projectile. A shorter travel of the base plate relative to the subcaliber projectile was thus required for separation of the two.

Materials. The steels and the magnesium alloy used in construction were different. The choice was dictated by the availability. See table XIIB for a statement of these materials.

Tests at Aberdeen Proving Ground, Design 3-76J

A.P.G. firing record P-33805, September 15, 18, 21, covers the firing of these 25 projectiles.

On September 14 and 15, five rounds were fired for stability determination from a gun without a muzzle brake that had previously fired 618 rounds. The charge was 64 oz. Four rounds gave records that were considered satisfactory for stability determination. The maximum yaw found was 9°. All projectiles had separated, apparently uniformly, before reaching the first card at 70 ft from the muzzle. No report on the determination has yet been received73/.

On the same day, 8 rounds were fired from a new gun fitted with a muzzle brake for retardation determination. This gun had previously fired only 4 rounds. The charge was 64 oz. Again all separated apparently uniformly before reaching the first card, which was at 150' from the muzzle. Yaws were very slight. A form factor of 1.31 relative to projectile type 8 was arrived at .

Although, judging from the relationship of the cutouts due to the base and to the subcaliber projectile on the first card, all the projectiles fired for retardation and for stability had separated uniformly, a circular cutout made by a steel sabot retaining ring was found after one round, showing that this ring had opened enough to release the projectile, but had not broken.

Twelve projectiles were left. They were to be fired for dispersion from a worn gun fitted with a brake. As no worn gun at A.P.G. was

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73/ It is understood that A.P.G. is preparing a report on this determination.

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threaded to accept a brake, arrangements were made for A.P.G. to thread one. Unfortunately, the projectiles were fired by A.P.G. before this gun was ready and without a representative of either Division 1, or the Office of the Chief of Ordnance being present, contrary to an understanding between Division 1, NDRC and the Office of the Chief of Ordnance. The following information is taken from A.P.G. Firing Record, P-33805. Six projectiles from a gun that had previously fired 627 rounds, and six from a gun that had previously fired seven rounds, were fired against a vertical target at 1700 yards. The charge was 64 oz. The first three rounds from the worn gun missed the target. The next three, said to have been fired at the same elevation and deflection, struck the target within a rectangel 53" wide, and 17.5" high. The first two rounds from the new gun, fired at the elevation given for the worn gun firings, missed the target. The elevation was increased and the last four shots hit the target within a rectangle 68" wide and 49" high. These tests are unsatisfactory in each case because of the small number of rounds fired after getting onto the target. The data are included in Table IX.

DESIGNS FOR 76-MM AND 90-MM GUNS PREPARED BY UNIVERSITY OF NEW MEXICO FOR CONSTRUCTION BY REMINGTON ARMS COMPANY, INC.

Because of limited facilities and the large amount of other work, the University of New Mexico had found it difficult to press the development of the sabot as they would have liked and had, therefore, arranged with Division 1, NDRC for research and development under contract OEMsr-668 to terminate on July 31, 1944.

In order to have the work continued, Division 1, had arranged for a contract, OEMsr-1368, with the Remington Arms Company, Inc. for research and development of sabot projectiles.

Following a conference in April 1944, between representive of the Office of the Chief of Ordnance, the Army Ground Forces, and Division 1, NDRC, Division 1 had undertaken to develop a sabot projectile for the 90-mm gun. When the 76-mm projectiles, made to design 3-76EH, had been fired at A.P.G. the Office of the Chief of Ordnance immediately requested scaled up projectiles for the 90-mm. Division 1 asked the Remington Arms Company to make up a number of these projectiles, and arranged with the University of New Mexico to supply a design and also to supply the services of Dr. C. E. Hablutzel for the period August 15 to September 15 in order that he might supervise their construction, and see them through tests at Aberdeen, and also supervise the construction and test of additional 76-mm projectiles, which it was anticipated would be needed.

The University of New Mexico prepared a design for the 90-mm gun based on the 76-mm design 3-76EH. This is University of New Mexico design 1-90 dated 7-26-44. The drawings, together with the calculations, were supplied to Remington Arms Company, Inc., and Dr. Hablutzel visited the Remington Arms Company at Ilion, N. Y. and discussed the design in detail with representatives of that company. Following this visit Remington drew up a design that departed from University of New Mexico design 1-90 in some minor details and made up a lot of ten projectiles. These were delivered to Aberdeen Proving Ground where some were fired September 26 against plate. Before this, however, Dr. Hablutzel had returned to the University of New Mexico as previously arranged.

The design University of New Mexico 1-90 followed closely design 3-76EH. The tungsten carbide core was one that was being made for the Ordnance Department. The design of this core followed closely that of the British cores. (Essentially this design would result from scaling up the core shown on Plate III of design 3-76J to a diameter of 1.75".) Drawings of this projectile including its core are included in Final Report, Contract OEMsr-668, Supplement 5, dated December 1, 1944.

The University of New Mexico also supplied a design of 76-mm sabot projectile to the Remington Arms Company. When the 25 projectiles made to design 3-76EH had been fired at A.P.G. the S.T.B. committee of Division 1 recommended that the Division supply 50 more to the Ordnance Depaartment and that the Remington Arms Company be requested to make them. The latter was done. After consultation with representatives of the Remington Arms Company, Dr. Hablutzel drew up design 3-76J, Plates I, II, and III dated 8-22-44. This design differs but very slightly from design 3-76J, Plates I, II, and III, revised 8-30-44, that was later used for the construction of the projectiles made by the Turbo Machine Company, and has been described already. Later, when the modification introduced by Plate IV of the latter design, the substitution of a split threaded steel ring for the Dowmetal sabot retaining ring, proved successful, it was suggested to Division 1 that the projectile being made by Remington should be modified in the same way.

FURTHER DEVELOPMENT OF UNIVERSITY OF NEW MEXICO BASIC DESIGN FOR 76-MM AND 90-MM GUNS BY REMINGTON ARMS COMPANY, INC.

Although the University of New Mexico exercised no actual supervision over the manufacture of the projectiles made by the Remington Arms Company and had no connection with their manufacture or test beyond that already noted, it is appropriate to record here briefly the further development of this design by the Remington Arms Company and the results of firing tests. This is done in the following section. The information is drawn from Aberdeen Proving Ground Firing Records, from the final report of the Remington Arms Company[74] and from reports of Remington representatives at A.P.G. trials dated October 5, December 13, and December 16, 1944. These records are not complete enough or consistent enough to permit the development of a complete picture of the course of the work. However, they do appear to be adequate for the use made of them here.

The first lot of these projectiles made by the Remington Arms Company, Inc. were for the 90-mm gun. They were fired at Aberdeen Proving Ground on September 26, 1944. The Firing Record P33526 states that they were made to Remington design 1-90-R2. The Ordnance Department's designation is projectile H.V.A.P., (Sabot) 90-mm, T32E10. This design followed closely the University of New Mexico's design 1-90

74/ Sabot Projectiles developed under OSRD contract OEMsr-1368 by Remington Arms Company, Inc., Technical Department, Ilion, New York, October 15, 1945.

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and incorporated the Dowmetal retaining ring, which, it will be recalled, had been replaced by a steel ring in the projectiles made to design 3-76J. The gun used had previously fired 2435 rounds[75].

The first round was fired with a charge of 80 oz and at a M.V. of about 2300 ft/sec. The projectile did not separate because the Dowmetal ring was not thrown. These rings were then removed from all the remaining projectiles. Two more rounds were fired with similar charges. These apparently functioned properly. The charge was then increased to 115 ounces which should give an MV of over 3800 ft/sec. The round was wild. The charge was reduced slightly and two more rounds were fired. Only one of these struck the plate. Firing was stopped.

In the discussion that followed it developed that the Ordnance Department had already fired some 90-mm projectiles made to a similar design of their own, and that they had been unsatisfactory. From the deep engraving on recovered pieces and its distribution, it had been concluded that the projectile had been passing down the bore in a cocked position. It had also been found that the subcaliber projectile had punched through the base plate of the sabot. Moreover, some projectiles had broken up in the bore. The design had then been modified to offer greater resistance to cocking in the bore, and to increase the strength of the base plate. Some of these new projectiles, T32E11, were on hand and it was decided to fire them next.

75/ The advance of rifling is not stated but presumably was several inches. In a similar gun, used for a subsequent firing, the rifling had advanced 5.3" after firing 1842 rounds.

The second T32E11 fired broke up in the bore, damaging the tube. Firing was stopped.

Some parts of the Remington projectiles were recovered and examined. The rear edge of a Dowmetal bourrelet segment had been severely eroded or gas washed on fractured surfaces. As this must have occurred in the bore it appeared that the bourrelet was being broken up in the bore. This led to the supposition that the leakage of gas past the rotating band was a major source of the trouble. Whether this leakage was because of cocking in the bore or was independent of it could not be determined. However, it was thought that if gas leaked past the rotating band the bourrelet might be stripped from the subcaliber projectile.

Attention was now focused on trying to prevent this. Several successive 90-mm models were tried in which changes were incorporated that were designed: (1) to prevent gas passing the rotating band, by the use of an obturating cup of copper or rubber; (2) to prevent cocking in the bore, by increasing the resistance to deep engraving at the rear bearing and at the bourrelet; (3) to prevent the bourrelet parts being forced ahead with respect to the subcaliber projectile.

The first lot of these modified projectiles, Ordnance Department designation T-38, was made to Remington design 1-90-R5, Assembly drawing B-365. To improve the sealing against the escape of gas past the rotating band an obturating cup was fitted, which lined the concave rear surface of the base plate or sabot and at the periphery extended a short distance behind it to provide a seal against the bore. Cups of both copper and rubber were provided. The steel base was lengthened in front of the rotating band, thus providing a steel bearing surface to prevent eccentric engraving. This added metal extended forward past the base of the subcaliber projectile so that the latter was now seated in a shallow cup on the front face of the base plate. The subcaliber projectile was held in place in the base plate by a piano wire snap ring of circular section that engaged in a groove cut in the inner wall of the shallow cup and a corresponding groove cut in the sheath of the subcaliber projectile. The snap ring was designed to open into the groove in the base plate under centrifugal force. Judging from the assembly drawing in the Remington final report, a small forward thrust applied to the subcaliber projectile would open this ring, releasing the subcaliber projectile. It appears by no means certain that the projectile would not separate if the round were loaded by being thrown into the chamber. The number and size of the set screws holding the bourrelet to the sheath of the subcaliber projectile were increased, thus providing increased resistance to the stripping of these parts from the subcaliber projectile by gas escaping past the rotating band.

These projectiles were fired on October 26, 1944 at Aberdeen Proving Ground from a gun that had previously fired 440 rounds, resulting in 0.4" advance of rifling (A.P.G. Firing Record P34048). The first round, assembled with a copper obturating cup, was fired with a charge of 105 oz. It broke up in the bore. Three rounds were then fired for recovery, using the same charge, one without an obturating cup, one with a copper cup, one with a rubber cup. The first of these broke up in the bore. The other two, and two additional rounds fired at plate with a charge of 113 oz, functioned without breakup.

On October 31, and November 1, 1944, four more projectiles were fired to obtain x-ray photographs at the muzzle. Two of these were assembled with rubber obturating cup and without set screws. One was assembled with a copper cup and with set screws, one without cup and with set screws. These were fired with a charge of 113 oz, from a gun that had previously fired 1854 rounds and showed an advance of rifling of 5.3". The two x-ray photographs obtained showed no indication of separation at the muzzle. Yaw cards at 100' from the muzzle showed that the sabots had separated properly (A.P.G. Firing Record P34094). According to the firing record, these projectiles were like those fired on October 26. This firing added no information about the cause of the breakups.

In parallel with the work on the 90-mm projectiles a lot of 76-mm sabot projectiles was prepared, Ordnance Department's designation T-23. These were made at Remington design 3-76-R2. This design is essentially the same as the University of New Mexico's design 3-76J except for the means employed to retain the subcaliber projectile in the sabot. Instead of the steel ring threaded to the tracer pocket, a garter spring consisting of a loop of closely coiled wire which fitted into a groove on the outside of the tracer pocket was used. Ten of these projectiles were fired for accuracy at Aberdeen on November 12, 1944, at a 12' x 12' vertical target at 1700 yds. The gun used had previously fired 270 rounds. The charge used was 64 oz. Pressure measurements were not taken. The results were quite unsatisfactory. Five of the projectiles, including the first four fired, struck the target. Five missed it. Of this five, three broke up in the bore. A number of sabot parts were recovered. All were broken (A.P.G. Firing Record P34104). These were the only 76-mm sabot projectiles of this type made by the Remington Arms Company that were fired.

The behavior of these projectiles contrasts strongly with that of the 50 similar 76-mm projectiles (3-76EH and 3-76J) that had been fired at A.P.G. in July, August, and September, 1944. A large proportion of those projectiles had been fired with full (64 oz) charge from guns that have previously fired various numbers of rounds up to 633. No mishap had occurred in those firings. The only important design change that appears to have been introduced by the Remington Arms Company was in the substitution of the garter spring for the threaded ring to secure the subcaliber projectile to the sabot.

Attention was now directed to strengthening the forward support of the 90-mm projectiles, as it was thought that failure there might be the cause of the bore failures. This resulted in design 1-90-R8 Ordnance Department designation T38E1. The steel bourrelet band, which bears against the bore, was thickened greatly so that engraving could not cut through it to the less resistant Dowmetal. This band was cut partly through from the outside so that it would be broken when the bourrelet segments expanded. The length of the Dowmetal bourrelet that is made the full diameter of the projectile was increased, both behind the bourrelet band, and at the rear in front of the steel base plate. The bourrelet was secured to the subcaliber projectile by a lock ring of rectangular section that engaged corresponding grooves in the bourrelet and in the subcaliber projectile. The subcaliber projectile was held in the base plate by a snap ring exactly as in design 1-90-R5. Two of these projectiles were fired on December 6 for recovery, using a gun that had previously fired 1861 rounds. The charge was 115 oz (A.P.G. Firing Record P-32190). The first round appeared to work satisfactorily. Recovered pieces of the second showed that failure had occurred in the bore. The subcaliber projectile had punched through the base plate or sabot. The latter was deeply engraved, presumably from having been expanded when the subcaliber projectile punched through it. The bourrelet was badly eroded by powder gas, and one segment showed that the bourrelet ring had moved back approximately 1/4" when the material behind it had been eroded away. The core did not break up.

Some sabot projectiles of a radically different type had been made up and taken to Aberdeen for firing at the same time as those made to design 1-90-R8. These were of the deep cup type and were made to design 90-56-R1, Ordnance Department's designation T38E2. The cup was of steel. The subcaliber projectile was supported axially in it. At the rear end it bore directly against the metal of the cup and at the front end against a Dowmetal ring which was supported by the rim of the cup. As in the earlier projectiles, a tracer pocket projected through the base of the sabot. The subcaliber projectile was retained in place in the sabot by a garter spring engaging in a groove on the outside of the tracer pocket, i.e., in the same manner as in the 76-mm projectiles made to design 3-76-R2. With this construction, powder gas escaping past the rotating band could not blow away the bourrelet or remove it by erosion.

The first one of these projectiles fired (charge 100 oz) broke up in the bore. Recovered pieces showed that the subcaliber projectile had punched through the bottom of the cup, and that considerable erosion of the Dowmetal ring had occurred. The firing of these two projectiles T38E1 (1-90-R8) and T38E2 (90-56-R1) in both of which the subcaliber projectile had punched through the base plate led to recognition of the possibility that the means that had been employed to hold the subcaliber projectile in the sabot, snap rings and garter springs, were inadequate, and that separation might be occurring in the first part of travel. If this occurred, the sabot might subsequently be driven forward against the subcaliber projectile with sufficient force to punch through the sabot. Powder gas would also have direct access to the Dowmetal parts. In fact, all the failures that had occurred could be accounted for in this way. To prevent this, a heavy steel locking-ring in two parts, that engaged in a groove in the tracer pocket and was held in place by three snap springs, was designed. A number of projectiles of the deep cup type incorporating this feature were made up. The cups were like those of design 90-56-R1, but the ring used to center the forward end of the subcaliber projectile in the cups was changed in some of the projectiles, (Ordnance Department designations T38E3, T38E4, and T38E5).

These projectiles were fired at Aberdeen, December 8 and 9, 1944 (A.P.G. Firing Record P-32190). The tube used was the one that had been used on December 6. The charges were from 116 to 119.5 oz. Eight rounds in all were fired. No breakup occurred. It was concluded, by the Remington representative at the firings, that the use of the heavy locking ring had eliminated the bore failures hitherto experienced, and that Dowmetal appeared to be satisfactory so long as premature separation did not occur.

Although the projectiles made to the University of New Mexico designs 3-76EH and 3-76J had shown up very well in the firings at the University of New Mexico Proving Ground and at Aberdeen, and although it was now concluded that the difficulties that the Remington Arms Company had subsequently experienced with their modifications of the

University of New Mexico designs had been occasioned by the absence of an adequate means of holding the subcaliber projectile to the sabot, and although they had not fired a single projectile of this type incorporated such adequate means, this adequate means was not now applied to these projectiles, but instead all further efforts were devoted to cup type sabots. No further bore failures were experienced in the Remington work on sabots.

The following is taken from their Final Report p-9.

> Under the heading "The Short Sabot Type (1-90 Series Designs)" it is said that this is the University of New Mexico design with "an altered locking device and with other minor alterations to facilitate mass production."
>
> "The failure of this type within the gun tube and the erratic accuracy were felt to be caused by inadequate support afforded by the bourrelet surfaces within the tube. Failure in the firings of later deep cup types showed that the bore failures resulted from separation at the origin of rifling and the subsequent set back of the subcaliber projectile against the Sabot seating surface.
>
> "However, to effectively retain the bourrelet segments thru the muzzle brake by hoop tension of the bourrelet ring afforded many design problems and machining to tolerances not compatible with good production practices. Unless complete obturation was effected, the dowmetal gaswashed badly in contact with the powder gases and offered an unpredictable source of failure for the shot. The light weight of the dowmetal segments offered a weak lever arm to break the bourrelet ring and to accommodate this light force the ring was very thin in section. Thus the thin section was very susceptible to any eccentric engraving and offered another source of bore failure.
>
> "The deep cup Sabot sought to reduce the variables in the short Sabot type by eliminating, or reducing the function of, the doubtful parts.
>
> B. <u>The Deep Cup Type</u> (90-56-R1 To R9 Designs)
>
> "The first design of the deep cup type did not have an adequate locking device, as all previous bore failures had been attributed to the bourrelet failures. Test firings of 90-56-R4 resulted in bore failure and a locking device was designed to release at 200 r.p.s. This prevented separation and resultant bore failures at the origin of rifling." (90-56-R4 is apparently an error. It should be 90-56-R1).

The paragraph beginning "However" may be taken to give the reasons for stopping work on this projectile.

Now it is well known that both aluminum and magnesium alloys are rapidly eroded when powder gases stream over them at high temperature, pressure, and velocity. However, experience in the United States and in Great Britain has shown clearly that aluminum alloys can be used in projectiles in front of the ordinary rotating band. Less is known about the use of magnesium alloys in this position. No difficulties with its use was experienced in firing the 76-mm sabot projectiles made to design 3-76EH or 3-76J at the University of New Mexico or at Aberdeen Proving Ground. It is possible that difficulty might have been encountered if firings had been made from badly worn guns. However, that may be, it is quite clear that the Remington experimental firings outlined above give no information on this question.

It is quite true that the steel bourrelet band on the original University of New Mexico design was thin, and that engraving was likely to occur, and would change its strength. Although it worked satisfactorily in the firings of projectiles made to designs 3-76EH and 3-76J and although recovered bands showed only shallow engraving, it is possible that if those projectiles had been fired from a badly worn gun, engraving might have been so deep that the engraved band would have permitted the bourrelet segments to separate at the muzzle. Had this difficulty been encountered it might have been met by thickening the band and cutting it partly through from the outside so that the engraving would not change its strength. This scheme was actually used in the Remington design 1-90-RS. The thickness necessary with any given width and hardness of hand depends on the depth of engraving that may occur. This can only be determined by recovery firing of properly assembled projectiles in a well worn gun, and cannot possibly be arrived at from the Remington experiments. It does not appear, therefore, to have been shown by the experimental work that the tolerances needed are not compatible with good production practices, nor are any calculations in support of this statement given in the report.

When the firing of the second lot of twenty-five 76-mm sabot projectiles (made to design 3-76J) had been completed on September 21, 1944, the projectile appeared to have functioned satisfactorily in the tests to which it had been subjected. However, much remained to be learned about its behavior, especially when fired from well worn guns, and it was to be expected that modifications would be necessary to produce a completely satisfactory design. The Remington Arms Company's work emphasized the importance of securing the subcaliber projectile to the sabot, but it does not appear to have otherwise contributed needed information. Thus the situation when they stopped work on this type of projectile remained essentially what it had been after the firing of the projectiles to design 3-76J.

After this compilation had been completed and typed it was learned that the Remington Arms Co. had prepared Dowmetal parts to replace the plastic sleeves on some of the 75-mm/57-mm (APC M86) sabot projectiles for the 75-mm pack howitzer that had been made to U.N.M. design 28-75D Revised, and supplied for test by the Armored Board at Fort Knox, and that some of the projectiles so modified had been fired at Aberdeen Proving Ground on November 23, 1944, A.P.G. F.R. P-34113.

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Table VIII

List of Reports by University of New Mexico

Progress Reports and Final Reports

Date	Title
November 1942	First Progress Report, Contract OEMsr-668, covers work done to end of October 1942.
December 1942	Second Progress Report, Contract OEMsr-668, covers work done November 1 to November 28, 1942.
December 1942	Special Report, Contract OEMsr-668, summary statement of the position arrived at in the investigation.
April 21, 1943	Fourth Progress Report, Contract OEMsr-668, with Progress Report on Supplement 1 as Appendix X. This report summarizes the work done to date. In later reports the first part of this report is sometimes referred to as the final report on the original contract.
June 5, 1943	Report for the month of May. This is in the form of a letter to Dr. L. H. Adams, Chairman, Division 1, NDRC.
July 8, 1943	A letter to Dr. L. H. Adams, Chairman, Division 1, NDRC covering the month of June.
September 7, 1943	A letter to Dr. L. H. Adams, Chairman, Division 1, NDRC covering the months of July and August.
October 1, 1943	A letter to Dr. L. H. Adams. Chairman, Division 1, NDRC covering the month of September.
November 3, 1943	Progress Report for October 1943, Contract OEMsr-668, Supplement 2.

Table VIII (Contd.)

Date	Title
December 10, 1943	Progress Report for November 1943, Contract OEMsr-668, Supplement 2.
January 3, 1944	Progress Report for December 1943, Contract OEMsr-668, Supplement 2.
February 2, 1944	Progress Report for January, 1944, Contract OEMsr-668, Supplement 2.
March 10, 1944	Final Report, Contract OEMsr-668, Supplements 1, 2, and 3. The report summarizes the work done under the contract and supplements. This includes all the work done in the development of sabot projectiles for the 75-mm Gun and Howitzer and for the 105-mm Howitzer.
April 8, 1944	Letter to Dr. L. H. Adams, Chairman, Division 1, NDRC covering work done in March 1944.
May 3, 1944	Progress Report for April, 1944, Contract OEMsr-668, Supplement 4.
June 2, 1944	Progress Report for May 1944, Contract OEMsr-668, Supplement 4.
July 1, 1944	Progress Report for June 1944, Contract OEMsr-668, Supplement 4.
August 1, 1944	Final Report, Contract OEMsr-668, Supplement 4, covers the work done on the development of a sabot projectile for the 76-mm Gun M1A2.
December 1, 1944	Final Report, Contract OEMsr-668, Supplement 5, covers work done after July 31, 1944.

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Table VIII (Contd.)

Date	Title
Special Reports	
June 1, 1944 (approx.)	"Application of sabot principle to large caliber guns," Lincoln LaPaz and Henry F. Dunlap.
July 24, 1943	"Sabot Cannon Projectiles," by W. D. Crozier, H. F. Dunlap, C. E. Hablutzel, D. T. MacRoberts. This report contains sketches of designs 48-57A, 25-75A, and 28-75D, together with statements of the results obtained in experimental frings of projectiles made to these designs. However, this report is not primarily a report on experimental work done at the University of New Mexico but rather a treatise on selected phases of the subject of sabot projectiles. Three of its chapters are devoted to considerations entering into the mechanical design of sabots of the types experimented with. These chapters cover stress analysis, centrifugal release, and stability in flight.
October 26, 1943	"Stability of the 57-mm M86 projectile saboted in the 75-mm Gun M3," by Lincoln LaPaz, W. D. Crozier, C. E. Hablutzel, D. T. MacRoberts.
NDRC Reports	
December 1, 1943	NDRC Report No. A-234 (OSRD No. 3010) Sabot projectiles for cannon by W. D. Crozier, H. F. Dunlap, C. E. Hablutzel, Lincoln LaPaz, D. T. MacRoberts. This is a revised edition of the report of July 24.

Table VIII (Concluded)

Date	Title
July 10, 1944	NDRC Report No. A-283 (OSRD No. 3890) "Trajectory determination by tracer photography," by W. D. Crozier.

Table IX

Dispersion Firings

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Ref. No.	Design No.	Date Fired	No. of Rounds	M.V. ft/sec	True Mean Dispersion Horizontal in.	Horizontal min arc	Vertical in.	Vertical min. arc	Rectangle Hor. in.	Rectangle Vert. in.	Reference
28-75D and modifications fired at Univ. of New Mexico Proving Ground, 75-mm Gun M3, Range 1000 yds.											
1	28-75D	26-5-43	18	2820	11.4	1.08	9.2	.90	68	45	A-234, 10-3-44
2	28-75D	31-5-43	10	2820	10.6	1.00	12.5	1.18	32	27	Report 10-3-44
3	28-75D	17-6-43	10	2820		1.00		0.60			Letter to JWG 23-6-43
4	28-75D modified	14-7-43	10	2820	3.6	0.34	10.2	0.96	16	35	7-9-43, 10-3-44
5	28-75D	29-7-43	5	2820	10.9	1.03	2.8	0.26	24	9	7-9-43, 10-3-44
6	28-75E	22-6-43	10	2820	13.5	1.27	15.1	1.42	41	82	Letter to JWG 23-6-43, 10-3-44
7	28-75F	3-7-43	9	2820	5.8	0.57	7.8	0.75	28	35	7-9-43, 10-3-44
8	28-75H	18-9-43	6	2820	6.3	0.59	10.6	1.00	15	27	1-10-43, 10-3-44
9	28-75D revised	17-4-44	10	2820	3.1	0.29	4.5	0.42	13	19	3-5-44, 1-8-44
28-75D fired at Aberdeen Proving Ground from 75-mm Gun M3, target at 800 yards											
10	28-75D	15-7-43	10	2800	9.2	1.10	5.8	0.69	47	31.5	A.P.G. F.R. M24862, A-234
28-75D fired at Aberdeen Proving Ground from 75-mm Pack Howitzer, target at 800 yards											
11	28-75D	23-12-43	10	2048	15.5	1.9	12.	1.5	56	60	A.P.G. F.R. M28827
75-mm A.P.C. M61 fired at Univ. of New Mexico from 75-mm Gun M3 in comparison with 28-75D, target at 1000 yards											
12	APC.M61	4-6-43	10	2050	7.4	0.70	5.1	0.50	25	15	10-3-44
75-mm A.P.C. M61 fired at Aberdeen Proving Ground from 75-mm Gun M3 in comparison with 28-75D, target at 800 yards											
13	A.P.C.M61	15-7-43	10	2050	5.9	0.71	6.4	0.76	23¼	23¾	A.P.G. F.R. M24862, A-234
HEAT M66 fired at Aberdeen Proving Ground from 75-mm Pack Howitzer in comparison with 28-75D											
14	HEAT M66	23-12-43	10	998	14.	1.75	6.	0.75	60	25½	A.P.G. F.R. M28827
Sabot projectiles fired at Univ. of New Mexico Proving Ground, 105-mm Howitzer M3, Range 1000 yards											
15	9-105A	1 to 6/11/43	4	2400	15.5	1.55	10.8	1.02	40	31	Letter to JWG 6-11-43, 10-12-43, 10-3-44
16	2-105B	10/3/44	10	2660	10.8	1.02	11.1	1.05	45	46	10-3-44
17	3-105A	25/11/43	9	2000	13.8	1.30	11.9	1.12	51	44	10-12-43, 10-3-44
18	3-105B	16/2/44	10	2000	13.7	1.29	11.2	1.06	46	57	10-3-44
19	7-105A	15/12/43	6	2000	7.7	0.73	8.0	0.76	31	27	10-3-44, 3-1-44
Standard H.E. M1 fired at Univ. of New Mexico Proving Ground from 105-mm Howitzer M3 in comparison with 9-105A											
20	HE M1		4	1020	21.3	2.01	13.7	1.29	57	57	10-12-43, 10-3-44
3-76 E.H. fired at Univ. of New Mexico Proving Ground, 76-mm Gun M1A2 with muzzle brake target at 1000 yards											
21	3-76 EH	12/8/44	6	3500	14.0	1.32	10.6	1.00	69	37	1-12-44
3-76 J fired at Aberdeen Proving Ground from 76-mm Gun M1A2, that had previously fired 7 rounds, target at 1700 yards.											
22	3-76 J	21/9/44	4	3600	16.75	.94	21.0	1.18	68	49	A.P.G. F.R. P-33805
3-76 J fired at Aberdeen Proving Ground from 76-mm Gun M1A2, that had previously fired 627 rounds											
23	3-76 J	21/9/44	3	3600	13.75	.75	5.25	.30	53	17.5	A.P.G. F.R. P-33805
28-75A fired at University of New Mexico Proving Ground, 75-mm Gun M3, Range 1000 yards											
24	28-75A	3/6/43	10	2820	15.9	1.50	8.6	0.82	57.5	27.0	A-234.

Notes for Table IX

Dates are given day, month, year.

Rectangle - the rectangle containing the centers of all impacts.

References, a date standing by itself refers to a University of New Mexico report to Division 1 of that date. A list of all University of New Mexico reports is given in Table VIII. A-234 = NDRC report A-234.

Note that the range used was 1000 yards at the University of New Mexico Proving Ground but 800 yards or 1700 yards at Aberdeen Proving Ground. The dispersions have been given in minutes of arc so that they can be compared directly.

A-234 = Sabot Projectiles for Cannon by W. D. Crozier, H. E. Dunlap, C. E. Hablutzel, Lincoln LaPaz, and D. T. MacRoberts.

Report 10 March 1944 is the Final Report, Contract OEMsr-668, Supplements 1, 2, and 3.

1. A. P. caps and ballistic caps brazed on APC-M86 projectiles at University of New Mexico. These projectiles were from the first production of the APC M86, and were without groove for band-seat and without being hardened. At that time the method of attaching the AP caps and windshields by crimping or rolling had not been perfected, and considerable trouble was being experienced with loose caps on the standard projectile. Because a good many were loose when received, and more might become so in firing, they were brazed on to avoid any trouble from this source. The distribution of the brazing metal was never quite symmetrical. Subcaliber projectile empty, and plugged.

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Notes for Table IX (Contd.)

2. AP caps and ballistic caps left as received. Subcaliber projectiles plugged, not filled.

3. Sabot projectiles selected at random from the lot prepared for test at Aberdeen Proving Ground. AP caps and windshields brazed on. Subcaliber projectiles filled sand and shot and plugged. Weight of subcaliber projectiles 7.0 lb. Complete sabot projectiles weighed 8 lb 6 oz ± 1/2 oz.

4. This design is the same as those of reference 1, 2, 3 except that the threaded steel ring of the sabot has 4 instead of 8 breaking slits, and the plastic, which in this case was macerated phenolic fabric (Celeron) with two zones of weakness diametrically opposite each other, had no breaking slits,

5. The subcaliber projectiles were fitted with mock-ups of fuze BD M72. Weight of APC M86 with mock-up of fuze BD M72 7.3 lb. The sabots were identical with those of references 1, 2, and 3.

6. The threaded steel base ring and the plastic sleeve of the sabot have only 2 breaking slits instead of the 8 slits in 28-75D.

7. The plastic sleeves were the same as in the projectiles of reference 4. The threaded steel ring appears to have had 8 slits.

8. This design resulted from modifying 28-75D along lines suggested by engineers of the Mueller Co. to facilitate mass production. Drawing is included in Final Report Contract OEMsr-668, Supplements 1, 2 and 3, March 10, 1944.

9. These projectiles were selected at random from the lot prepared for test in the 75-mm Pack Howitzer by the Armored Board. Subcaliber projectiles probably filled ammonium alum and fuzed BD M72 inert. Drawings

Notes for Table IX (Contd.)

are included in the Final Report Contract OEMsr-668, Supplement 4, August 1, 1944.

10. These projectiles were from the same lot as those of reference 3.

11. These projectiles were from the same lot as those of reference 3.

15. Subcaliber projectile 57-mm APC M86 from same lot as those of reference 1, filled with ammonium alum and fuzed BD M72 inert. Sabot is same as 9-105 except that plastic bourrelet is lightened by drilling holes length-wise in it. Report of 10 March 1944 contains drawing of 9-105.

16. These projectiles were the same as those supplied for test by the Infantry Board, except that the 57-mm APC M86's were filled ammonium alum and fuzed BD M72 inert. Windshields 2.9" long.

17. The subcaliber projectile was the HE shell M42A1, slightly modified, filled ammonium alum and fuzed PD M48 inert. This design differs from 3-105B only in that the diameter of the M42A1, behind the shoulder retaining the plastic sleeve or bourrelet, is slightly less than in 3-105B.

18. These projectiles were picked at random from the lot prepared for test by the Infantry Board. Eleven rounds were fired. One projectile went over the target. The data are for the other ten.

19. Seven rounds were fired. One tumbled. Data are for other six. Drawings included in Report for November 1943 and Report of March 10, 1944.

Notes for Table IX (Concld.)

20. The standard HE round for the 105-mm Howitzer M3, fired with full service charge.

21. These projectiles were identical with the 25 projectiles, made to design 3-76 EH, supplied to Aberdeen Proving Ground, except that the cores were of copper Elkonite 5W3 instead of cemented tungsten carbide. The density of the Elkonite is almost identical with that of the tungsten carbide.

Eight rounds were fired. The first was used as a ranger. It hit the target but the elevation was changed after it hit. Round 5 hit the outside the rectangle stated, but at about average height. "The cut out on the target consisted of a hole the size of the base plate and a partially superimposed hole the size of the subcaliber projectile." The data stated in the table are for the other six.

These projectiles were fitted with Dowmetal sabot retaining rings which were replaced in design 3-76J by split threaded steel rings, to be thrown by centrifugal force.

The MV stated is a rough approximation. No MV is given in the report. Page 14 of the Report of August 1, 1944 gives velocity data for two rounds identical with these. Velocities at the coils were 3480 ft/sec and 3530 ft/sec.

24. This entry should follow 11, but was inadvertently dropped from the table. It has been put in here to avoid rearranging the table.

28-75A is a base plate type sabot with plastic sleeve bourrelet. Fig. 22, p. 91 of NDRC Report A-234 shows an assembly drawing. Results of firing tests are given on p. 96 of that report. Windshields and AP caps of the APC M86 subcaliber projectiles were brazed on.

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Table X

Determinations of Stability Factors of Modifications of Projectile 57-mm APC M86[1] m
of New Mexico Proving Ground

Date of Firing	Windshield[2] Length inches	Round No.	Gun Used	Observer[3]	Muzzle Velocity ft/sec	Retardation ft/sec/ft	Velocity[4] at point a, ft/sec	Sta at
11/10/43	Standard 4.5	1	75-mm	1	2820	.116	2763	
11/10/43	Standard 4.5	1	75-mm	2	2820	.116	2763	
11/10/43	Standard 4.5	1	75-mm	1	2820	.116	2805	
11/10/43	Standard 4.5	1	75-mm	2	2820	.116	2805	
12/10/43	Standard 4.5	1	75-mm	1	2800 est.	.116	2747	
12/10/43	Standard 4.5	1	75-mm	2	2800	.116	2747	
12/10/43	Standard 4.5	1	75-mm	1	2800	.116	2785	
12/10/43	Standard 4.5	1	75-mm	2	2800	.116	2785	
13/10/43	Standard 4.5	1	75-mm	1	2870	.116	2814	
13/10/43	Standard 4.5	1	75-mm	2	2870	.116	2814	
13/10/43	Standard 4.5	1	75-mm	1	2870	.116	2854	
13/10/43	Standard 4.5	1	75-mm	2	2870	.116	2854	
26/10/43	Standard 4.5	1	105-mm	1	2640	.116	2584	
26/10/43	Standard 4.5	1	105-mm	2	2640	.116	2589	
27/10/43	Standard 4.5	1	105-mm	1	2350	.116	2291	1
27/10/43	Standard 4.5	1	105-mm	2	2350	.116	2297	1
27/10/43	Standard 4.5	3	105-mm	2	2440	.116	2377	1
21/10/43	No Windshield	1	75-mm		2800 est.	.32	2752	2
21/10/43	No Windshield	1	75-mm		2800 est.	.32	2640	3
28/10/43	No Windshield	1	105-mm	3	2340	.274	2196	2
28/10/43	No Windshield	2	105-mm	3	2570	.291	2423	2
29/10/43	No Windshield	1	105-mm	2	2300	.246	2180	2.
10/11/43	3.3	2	105-mm	2	2300	.146	2230	1.
10/11/43	3.3	2	105-mm	3	2300	.146	2230	1.
10/11/43	3.3	3	105-mm	2	2300	.146	2230	1.
10/11/43	3.3	3	105-mm	3	2300	.146	2230	1.
10/11/43	3.3	4	105-mm	2	2300	.146	2230	1.
10/11/43	3.3	4	105-mm	3	2300	.146	2230	1.
10/1/44	2.9	1	105-mm	3	2380	.16	2300	1.
10/1/44	2.9	2	105-mm	4	2620	.16	2540	1.
10/1/44	2.9	2	105-mm	3	2620	.16	2540	1.
10/1/44	2.9	2	105-mm	2	2620	.16	2540	1.
11/1/44	2.9	1	105-mm	1	2600 est.	.16	2520	1.

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Table X

ions of Projectile 57-mm APC M86[1] made at University
co Proving Ground

y	Retardation ft/sec/ft	Velocity[4] at point a, ft/sec	Stability Factor Standard Atmospheric Conditions at point a	at the muzzle[5]	Method Used to Compute S_a	Average Stability Factor if fired from 105 How M3[6]
	.116	2763	1.324	1.27	A.P.G.	
	.116	2763	1.331	1.28	A.P.G.	
	.116	2805	1.304	1.29	Fowler	
	.116	2805	1.333	1.32	Fowler	
st.	.116	2747	1.345	1.30	A.P.G.	
	.116	2747	1.314	1.27	A.P.G.	A.P.G. 1.05 Fowler 1.05
	.116	2785	1.230	1.22	Fowler	
	.116	2785	1.269	1.26	Fowler	
	.116	2814	1.250	1.21	A.P.G.	
	.116	2814	1.279	1.23	A.P.G.	
	.116	2854	1.227	1.21	Fowler	
	.116	2854	1.276	1.26	Fowler	
	.116	2584	1.09	1.05	A.P.G.	
	.116	2589	1.00	.96	A.P.G.	
	.116	2291	1.04	.99	A.P.G.	1.00
	.116	2297	1.04	1.00	A.P.G.	
	.116	2377	1.06	1.00	A.P.G.	
t.	.32	2752	2.97	2.86	A.P.G.	2.42
t.	.32	2640	3.30	2.93	A.P.G.	
	.274	2196	2.71	2.38	A.P.G.	
	.291	2423	2.61	2.32	A.P.G.	2.37
	.246	2180	2.68	2.40	A.P.G.	
	.146	2230	1.45	1.36	A.P.G.	
	.146	2230	1.42	1.33	A.P.G.	
	.146	2230	1.36	1.28	A.P.G.	1.31
	.146	2230	1.36	1.28	A.P.G.	
	.146	2230	1.36	1.28	A.P.G.	
	.146	2230	1.37	1.29	A.P.G.	
	.16	2300	1.46	1.36	A.P.G.	
	.16	2540	1.58	1.48	A.P.G.	
	.16	2540	1.57	1.47	A.P.G.	1.44
	.16	2540	1.59	1.49	A.P.G.	
.	.16	2520	1.57	1.47	A.P.G.	

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Notes for Table X

Dates are given day, month, year.

(1) The 57-mm APC M86 projectiles were all from the special lot described on page 43. They were without rotating band and without the groove or seat for the band. All were filled with ammonium alum and were fitted with dummy fuzes made to simulate fuze BD M72. The mass distribution in the projectiles with standard windshields used in the 2875-D Sabots was as follows:

APC M86 with standard windshield, windshield and AP Cap brazed on, base threaded for sabot ring,

empty	6 lb. 4.25 oz
Mock-up of fuze BD M72	13.5 oz
Ammonium alum filling	1.0 oz
Total assembled weights	7 lb 2.75 oz
A (longitudinal moment of inertia)	0.0299 lb ft^2
B(transverse moment of inertia)	0.2328 lb ft^2
Ratio A/B	0.1284 ± 0.1%

(2) The length of the windshield is the length measured along the axis. The standard windshield is 4.50" long. When no windshield is used the equivalent length is 1.35".

(3) Designates the person who obtained the data from the yaw cards.

(4) Computed using the value in the preceding column.

(5) This value is obtained from the value in the preceding column by use of the formula:

$$\frac{S_{op}}{S_{ap}} = \left(\frac{V_a}{V_o}\right)^2 \qquad \text{see R. Kent, A.P.G. Report No. 65, page 13.}$$

Notes for Table X (Concld.)

where $S_{\underline{a}p}$ is the determined value of the stability factor down the range, i.e., the stability factor at the point a corrected to standard air density.

S_{op} is the stability factor at the muzzle at standard air density.

$V_{\underline{a}}$ is the velocity at point a.

V_o is the velocity at the muzzle.

$S_{\underline{a}p}$ is equivalent to the symbol S as used in the special report by the University of New Mexico on the stability of the M86 in the 75-mm gun, referred to in the text.

Standard Atmospheric Conditions are:

Pressure 750-mm Hg (29.53 in. Hg), Temperature 15°C. (59°F), Humidity 78% saturation, Density 1.2034 kg/m^3 (525.9 gr/ft^3). (APG Report X-113, p. 40)

(6) This is the value that the stability factor, at the muzzle, would have, if the projectile were fired from the 105-mm Howitzer M3 at the MV of the determination. It is computed from the average of the values in the preceding column. This is done by multiplying that average by the square of the ratio of the distance traveled in the Howitzer in making one turn to the distance traveled in the 75-mm guns in making one turn, i.e., by $\left(\frac{105 \times 20}{75 \times 25.58}\right)^2$. It applies at the MV stated in the 5th column.

(7) A.P.G. The method in current use at Aberdeen Proving Ground. See A.P.G. Report X-113. "Resistance and Stability of Projectiles," by H. P. Hitchcock. Fowler - The method described by Fowler, Gallop, Locke, and Richmond in "The Aerodynamics of a Spinning Shell," Phil Trans. Royal Society Vol. A-221, 296 - 397.

The figures in this table are taken from a table prepared by J. McG. Millar, of the Geophysical Laboratory, who made the computations to reduce the stability factors to the muzzle, from the University of New Mexico data.

Table XIIA

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Summary of Features of Designs of 105-mm/57-mm (APC M86 mod.) Sabots

Design No.	Base			Plastic Sleeve					Sabot total weight
	Type	Material	Remarks	Remarks	Holes No.	Holes Diameter	Extends in front of band to	Diameter	
						inches	inches	inches	lb.
2-105	T.R.	C.R.S.	Extends .4" in front of band.		None	None	3.4	4.128 -.005	4.9
2-105A	T.R.	C.R.S.	As 2-105, but 8 holes .565" dia. drilled 1" deep from front.		8	.875	3.4	4.128 -.005	3.8
2-105B	T.R.	C.R.S.	As 2-105, but all but .05" in front of band removed, 12 holes drilled from front.		8	.875	3.4	4.128 -.005	3.0
2-105C	T.R.	C.R.S.	As 2-105, but no holes drilled.		8	.875	3.4	4.128 -.005	3.5
2-105D	T.R.	C.R.S.	As 2-105B, but holes drilled from rear after banding.		8	.875	3.4	4.128 -.005	3.1
2-105E	T.R.	C.R.S.	As 2-105B, but 8 holes .5" dia. drilled from rear after banding		8	.75	3.3	4.128 -.005	3.2
2-105F	T.R.	C.R.S.	As 2-105E	Holes drilled from rear 3" deep 8 breaking slits full length.	8	.75	3.5	4.128 -.005	3.25
2-105G	T.R.	C.R.S.	As 2-105E	Hollow shell with solid section at each end.	None	None		4.128 -.005	3.2
2-105H	T.R.	C.R.S.	As 2-105E.	Solid except for breaking slits	None	None	3.5	4.131 -.003	3.8
2-105J	T.R.	C.R.S.	As 2-105E, but skirt omitted	Solid except for breaking slits	None	None	3.5	4.131 -.003	3.1
2-105K	T.R.	C.R.S.	As 2-105E, but 8 segments	Solid except for breaking slits	None	None	3.5	?	3.7
2-105L	T.R.	C.R.S.	As 2-105E.	Plastic in three rings	None	None	3.5	?	3.7
2-105N	T.R.	C.R.S.	As 2-105E, but skirt shortened	Solid except for breaking slits .8" dural ring in front of plastic	None	None	3.3	4.131 -.003	4.2
2-105P	T.R.	C.R.S.	As 2-105E	.6" dural ring in front of plastic	None	None		?	3.9
2-105Q	T.R.	C.R.S.	As 2-105E	.8" dural ring in front of plastic	None	None	3.3	?	3.3
2-105R	T.R.	C.R.S.	As 2-105E	.8" dural ring in front of plastic, set screws in dural	None	None	3.3	4.130(1) -.003	4.1
5-105	B.R.	Steel yield >100,000 p.s.i.		Solid except for breaking slits	8	15/16	4.35	4.128 -.005	3.7
6-105	T.R.	Dural & C.R.S.	Dural ring forms band seat and extends .44" in front of band, skirted steel disc behind dural	Solid except for breaking slits	None	None	3.74	4.128 -.005	3.00
9-105	T.R.	Dural & Plastic	Dural ring forms band seat, plastic ring behind dural. Both rings slit from inside leaving outer surface intact.	Solid except for breaking slits	None	None	2.90	4.128 -.005	3.1
9-105A	T.R.	Dural & Plastic	Same as 9-105		None	None	2.90	4.128 -.005	2.2
9-105C	T.R.	C.R.S. & Plastic	Like 9-105 but dural replaced by C.R.S. 12 9/16" holes drilled from front in steel ring				2.90	4.128 -.005	3.1
13-105	T.R.	C.R.S.	As 2-105E but crimping skirt shortened and band diameter decreased	.6" dural in front of plastic, plastic hollowed out in center				?	3.5

T.R. Threaded base ring. Ring surrounds the rear end of the subcaliber projectile and is threaded to it.

B.R. Base ring. This is a base with a central hole. Thrust and torque are applied by it to the base of the subcaliber projectile.

C.R.S. Cold rolled steel.

(1) There are two drawings of Plate I, Design 2-105R, dated 1/31/44. The first, bound into the report of February 2, 1944, shows the diameter of the sleeve as 4.131" -.003". The second, [redacted] shows it as 4.130" -.003". The lot of projectiles supplied to the Army were made to the latter drawing.

Table XIB

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Summary of Features of Design of 105-mm/3" (HE M42A1) Sabots

Design No.	Base			Plastic Sleeve		Diameter M42A1 under band	Total weight of sabot
	Type	Material	Remarks	Remarks	Extends in front of band to		
					inches	inches	lb.
3-105	T.R.	C.R.S.	Sabot is patterned on 28-75D. Threaded steel ring lightened by cutting a deep wide groove in front of rotating band.	Solid except for breaking slits	4.57	2.900	3.91
3-105A	T.R.	C.R.S.	Like 3-105 but steel in front of rotating band eliminated.	Solid except for breaking slits	4.48	2.900	3.25
3-105B	T.R.	C.R.S.	Like 3-105A	Solid except for breaking slits	4.48	2.965	3.2
4-105	B.P.	C.R.S.	Rear face of plate coned. Front face of plate has shallow cup tocenter the M42A1. No center hole in plate.	Solid except for breaking slits	5.30	2.980	4.2
7-105	G.R.	Steel Plastic	The groove for the band seat of the M42A1 was deepened, dia 2.645", and a steel ring in 4 segments fitted in it. The ring was held together by the rotating band. A plastic sealing ring was fitted behing the steel ring.	Solid except for breaking slits	3.29	2.965	3.75
7-105A	G.R.	C.R.S. Plastic	The segmented steel ring was lightened by cutting a deep groove in it from the rear face	Solid except for breaking slits	3.10	2.965	2.75
7-105A	G.R.	C.R.S. Plastic	Same as 7-105A but with .20" play between steel ring and ends of groove in M42A1	Solid except for breaking slits	3.10	2.965	2.75
10-105B	T.R.	C.R.S.	The threaded steel ring is the length of the rotating band only, partially segmented by 4 radial slits. Plastic sealing ring behind steel ring.	Solid except for breaking slits	4.48	2.965	3.25
11-105	B.R.	Steel S.A.E. 4130 H. T.	Ring coned on rear face, shallow depression for M42A1 on front face. Threaded to hold plastic sleeve. Opening in ring 2.47" dia	Sleeve lightened by drilling 16 holes 9/16" dia lengthwise.	5.30	2.970	
11-105A	B.R.	Steel S.A.E. 4130 H. T.	Diameter of central hole decreased	Sleeve solid except for breaking slits	5.30	2.970	2.5

T.R. Threaded base ring. Ring surrounds the rear end of the subcaliber projectile and is threaded to it.

B.P. Base "plate". This is a solid base, without a central hole. Thrust and torque are applied by it to the base of the subcaliber projectile.

B.R. Base ring. Like the base "plate" but with central hole.

G.R. Groove and ring. See remarks under 7-105.

H.T. Heat treated.

C.R.S. Cold rolled steel

The outside diameter of the bourrelet was the same in all designs, 4.128" -.005".

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Table XIIA

Materials Used in 105-mm and 75-mm Sabot Projectiles Supplied to the U. S. Army

Design	28-75D	28-75D (Revised) for Pack Howitzer	2-105R	3-105B
Threaded base ring	Cold rolled steel	Mild free threading steel B-1112	Cold rolled steel	Cold rolled steel
Bourrelet sleeve	Plastic	Cotton fabric laminated phenolic tubing type C, Textolite C	Paper laminated phenolic tubing type XX, Textolite XX	Paper laminated phenolic tubing type XX, Textolite XX
Subcaliber projectile	APC M86 from special lot, see text	APC M86, with band machined flush, rear end threaded.	APC M86, from special lot, fitted with 2.9" windshield	Shell, HE, M42A1 body reduced to 2.965" from base forward 5.3 ins.
Weight of Sabot	1.37 lb	1.37 lb	4.13 lb	3.12 lb
Weight of subcaliber projectile as supplied to Army	7.0 lb filled and plugged	6.25 empty	6.09 empty	9.53 lb empty

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Table XIIB

Materials Used in Sabot Projectiles for the 76-mm Gun M1A2

	Projectiles made by Univ. of New Mexico to design 3-76 EH	Projectiles made by Turbo Machine Co. to design 3-76J revised to 30/8/44 and plate IV dated 28/8/44.
Base or Sabot	steel, heat treated	8744 N.E. H.R. steel. Machined before heat treating. 363 - 365 brinell, 156,750 p.s.i. yield, 170,250 p.s.i. tensile.
Sabot retaining ring	Dowmetal type 0-1	X1020 steel, used as received from mill
Bourrelet sleeve	Dowmetal type 0-1	Cast Dowmetal H, heat treated and aged (aging time was rather short)(1)
Bourrelet band	Cold rolled steel	Cold drawn seamless tubing, used as received from mill
Sheath rear portion	Steel, heat treated	Same as used for base
Sheath front portion	Cold rolled steel	Cold finish X1020 steel, used as received from mill
Pad	Aluminum alloy 17S-T	Aluminum alloy 17S-T
Core	Tungsten carbide, 13 percent cobalt, carboloy 55A.	Tungsten carbide, 13 percent cobalt, made by Kenametal
Total weight	7.97 lb	7.7 lb
Weight of WC core	3.96 lb	Slightly less than of core used in 3-76 EH.

(1) Dowmetal type 0-1 was preferred but type H was available, and was used. The makers data show that aging increases the strength of this cast alloy but decreases the elongation.

University of New Mexico Drawings

The following University of New Mexico design drawings have been selected for inclusion in this report; and reproductions of them follow:

28-75D, plates I and II dated 27 May 1943

28-75D, revised, plate III dated 6 May 1944

2-105R, plates I and II dated 31 January 1944, plate III dated 6 March 1944, drawing of windshield, plate IV dated 6 May 1944.

3-105B, plates I and II dated 26 November 1943, plate III dated 6 May 1944

3-76J, plates I, II and III revised 30 August 1944, plate IV dated 28 August 1944.

This list does not include all the drawings to which sabot projectiles that were supplied to the U.S. Army for test were made, but with the notes in the text it is sufficient to give a fairly detailed description of all these projectiles. For greater detail the drawings contained in the University of [redacted] reports to Division 1 may be consulted. Drawings of [redacted] were supplied to the Office of the Chief of Ordnance at [redacted] the projectiles were delivered.

The following notes will serve to identify the drawings pertaining to the different lots of sabot projectiles supplied to the U.S. Army for test.

28-75D. Plates I and II show the design to which the 75-mm/57-mm (APC M86) sabot projectiles for the 75-mm Gun M3 that were tested at A.P.G. in 1943 were made. For some details see pages 42 and 43.

28-75H, (not reproduced here) was 28-75D with the steel base ring slightly modified to facilitate production - see pages 48 and 49. Plate II forms a part of the U.N.M. Report of March 10, 1943.

28-75D Revised. Plates I and II dated March 2, 1944 (not reproduced here), show the design to which the 75-mm/57-mm (APC M86) sabot projectiles for the 75-mm Pack Howitzer that were supplied in 1944 were made. For a description of this design see pages 98 and 99. These plates form a part of U.N.M. Report of August 1, 1944. Plate III dated May 6, 1944 shows the U.N.M. proposal for substituting light metal for the plastic in this design, see page 104. This plate also forms a part of the U.N.M. Report of August 1, 1944. Plate IV dated August 30, 1944 (not reproduced here) shows the design of light metal sleeve proposed by the University of New Mexico for replacing the plastic sleeves on the projectiles already made and furnished to the U.S. Army, see page 101.

2-105R. Plates I, II and III together with the drawing of the windshield show the design to which the 105-mm/57-mm (APC M86 modified) sabot projectiles for the 105-mm Howitzer M3 were made, see page 76 for some details. Plate IV, dated May 6, 1944 shows the University of New Mexico's proposal for substituting light metal for the plastic in this design, see page 104.

3-105B. Plates I and II show the design to which the 105-mm/3" (HE M42A1) sabot projectiles for the 105-mm Howitzer M3 were made, see page 80 for some details. Plate III shows the University of New Mexico's proposal for substituting light metal for the plastic in this design, see page 105.

3-76EH (not reproduced here). The first lot of twenty-five tungsten carbide cored AP sabot projectiles for the 76-mm Gun M1A2 made by the

University of New Mexico and supplied to A.P.G. on July 23, August 1, and August 13, 1944 were made to this design. The drawings 3-76E, plates I, II and III revised to July 1, 1944 and 3-76H dated June 27, 1944 form a part of U.N.M. Report of August 1, 1944. The design consists of design 3-76E as shown on the three plates mentioned, but with the base or sabot shown on 3-76H substituted for that shown on 3-76E. The design is very similar to design 3-76J the drawings of which are reproduced here. The main differences between these two designs are given on pages 122 and 123.

3-76J. Plates I, II and III revised August 30, 1944 and Plate IV dated August 28, 1944 show the design to which the second twenty-five sabot projectiles for the 76-mm Gun M1A2 were constructed, see pages 122 and 123. The weights of parts are as follows:

core	3.87 lb	(4 weighed)
sabot banded	1.53 lb	(1 weighed)
bourrelet + band	.521 lb	(1 weighed)
base of sheath with tracer	.500 lb	(1 weighed)
front of sheath	1.125 lb	(1 weighed)
pad	.031 lb	(1 weighed)
assembled projectile	7.66 lb	(1 weighed)

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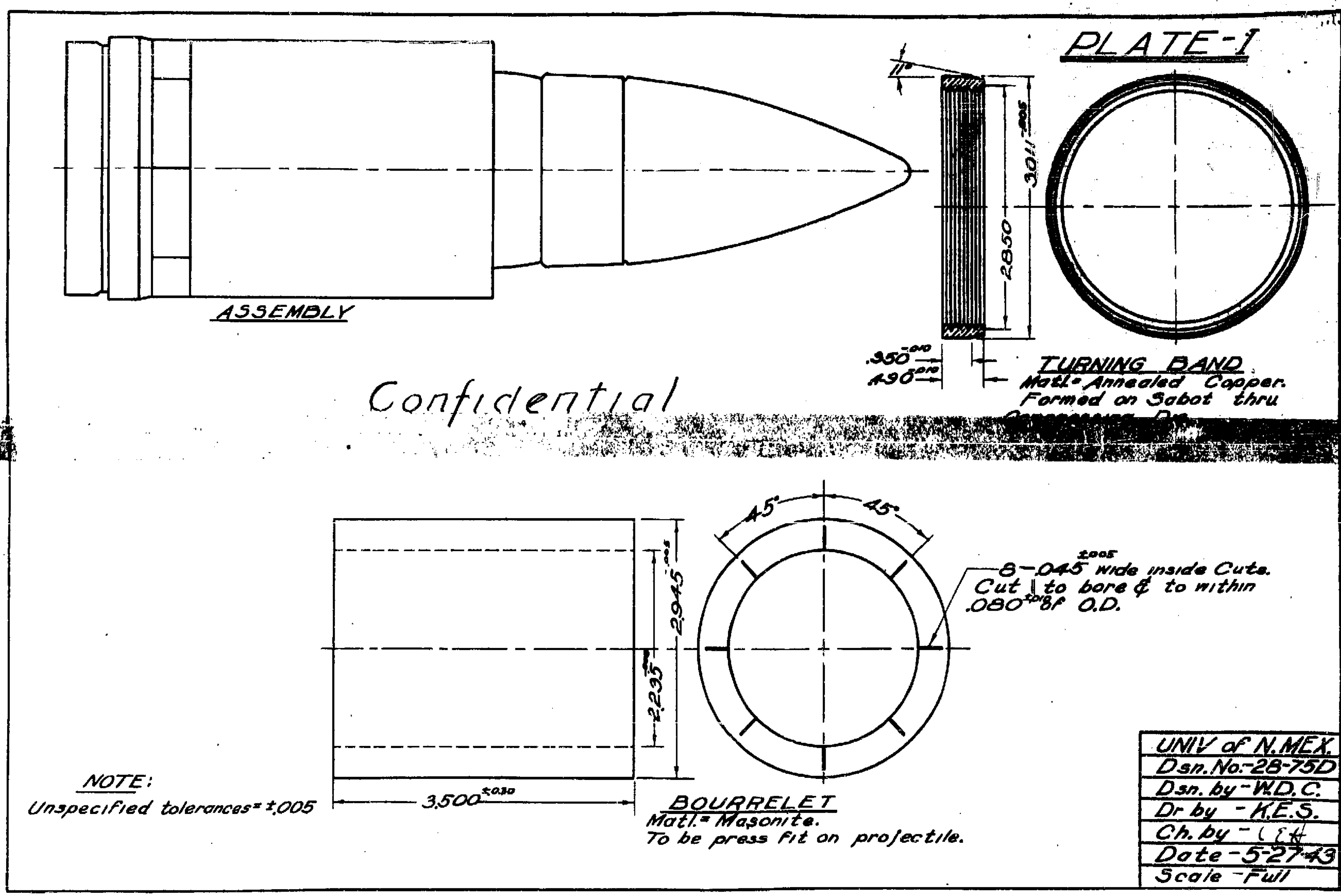
PLATE-I
ASSEMBLY
3.011 -.005
2.850
11°
.350 -.010
.490 -.010
TURNING BAND
Matl.= Annealed Copper.
Formed on Sabot thru
Confidential
45°
45°
8-.045 ±.005 wide inside Cuts.
Cut ⊥ to bore ℄ to within
.080 ±.010 of O.D.
2.945 -.005
2.235
3.500 ±.030
NOTE:
Unspecified tolerances = ±.005
BOURRELET
Matl.= Masonite.
To be press fit on projectile.
UNIV of N.MEX.
Dsn.No.-28-75D
Dsn. by - W.D.C.
Dr by - K.E.S.
Ch. by - C.E.H.
Date - 5-27-43
Scale - Full

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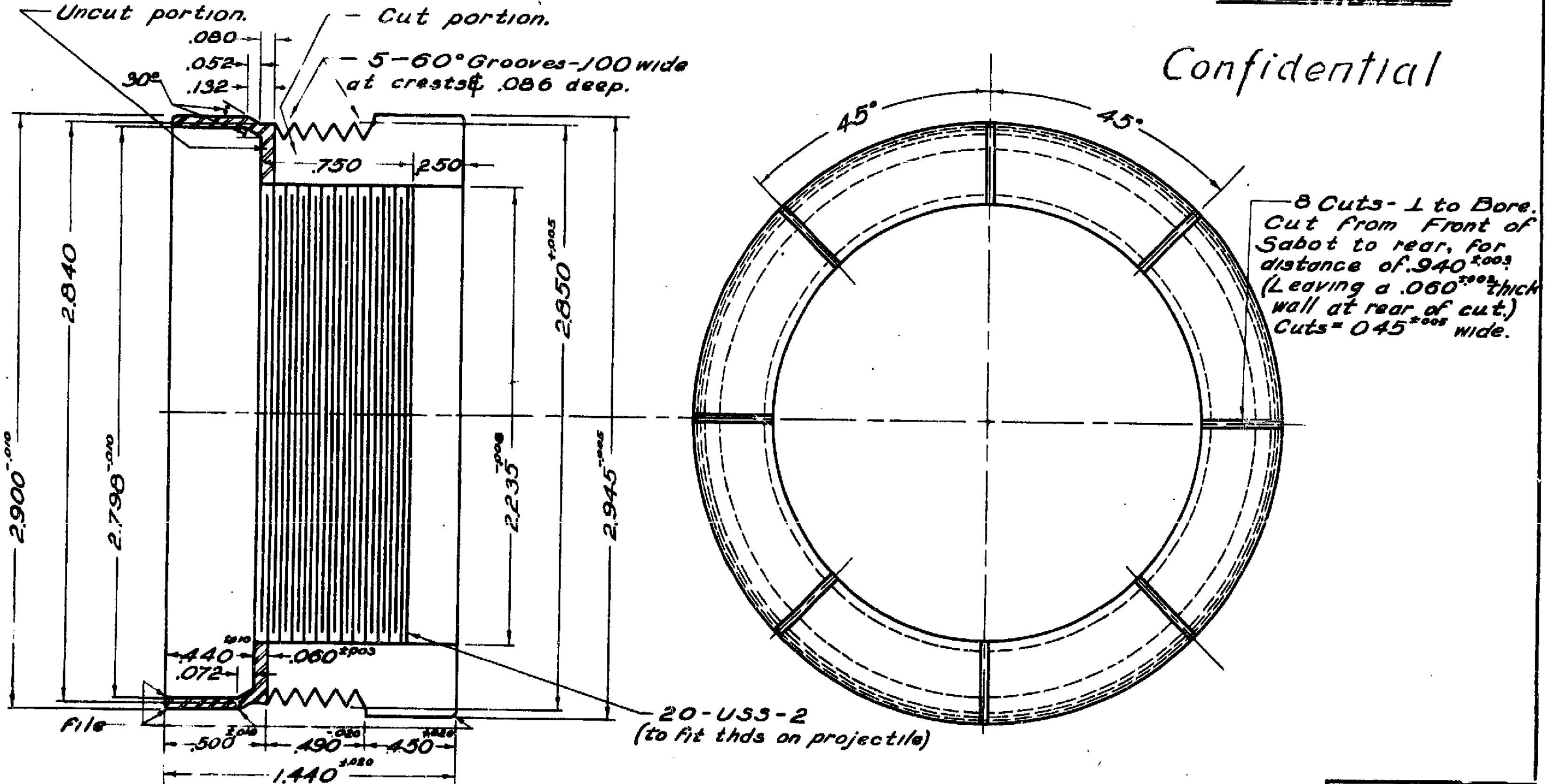
PLATE-II

Confidential

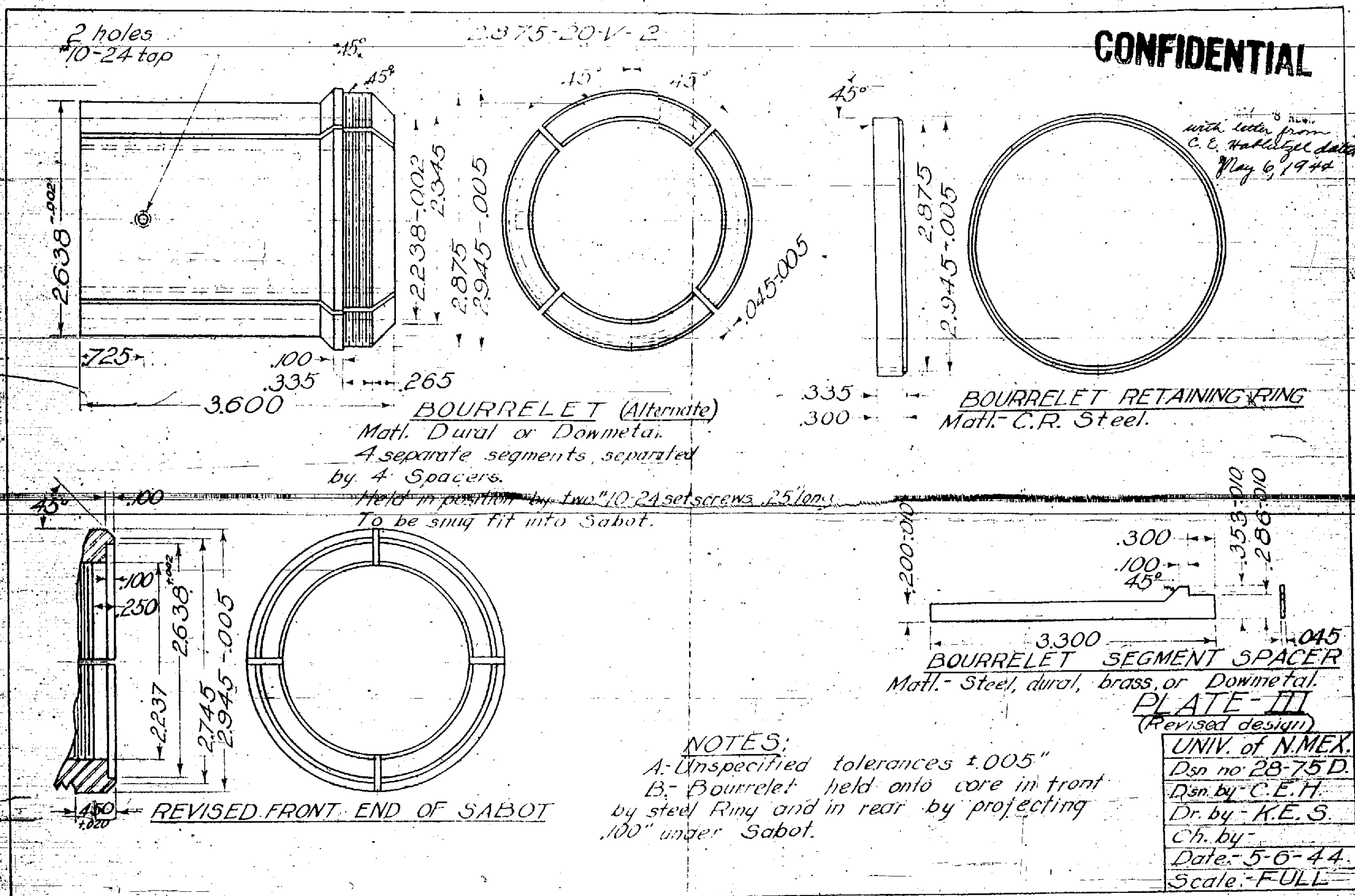


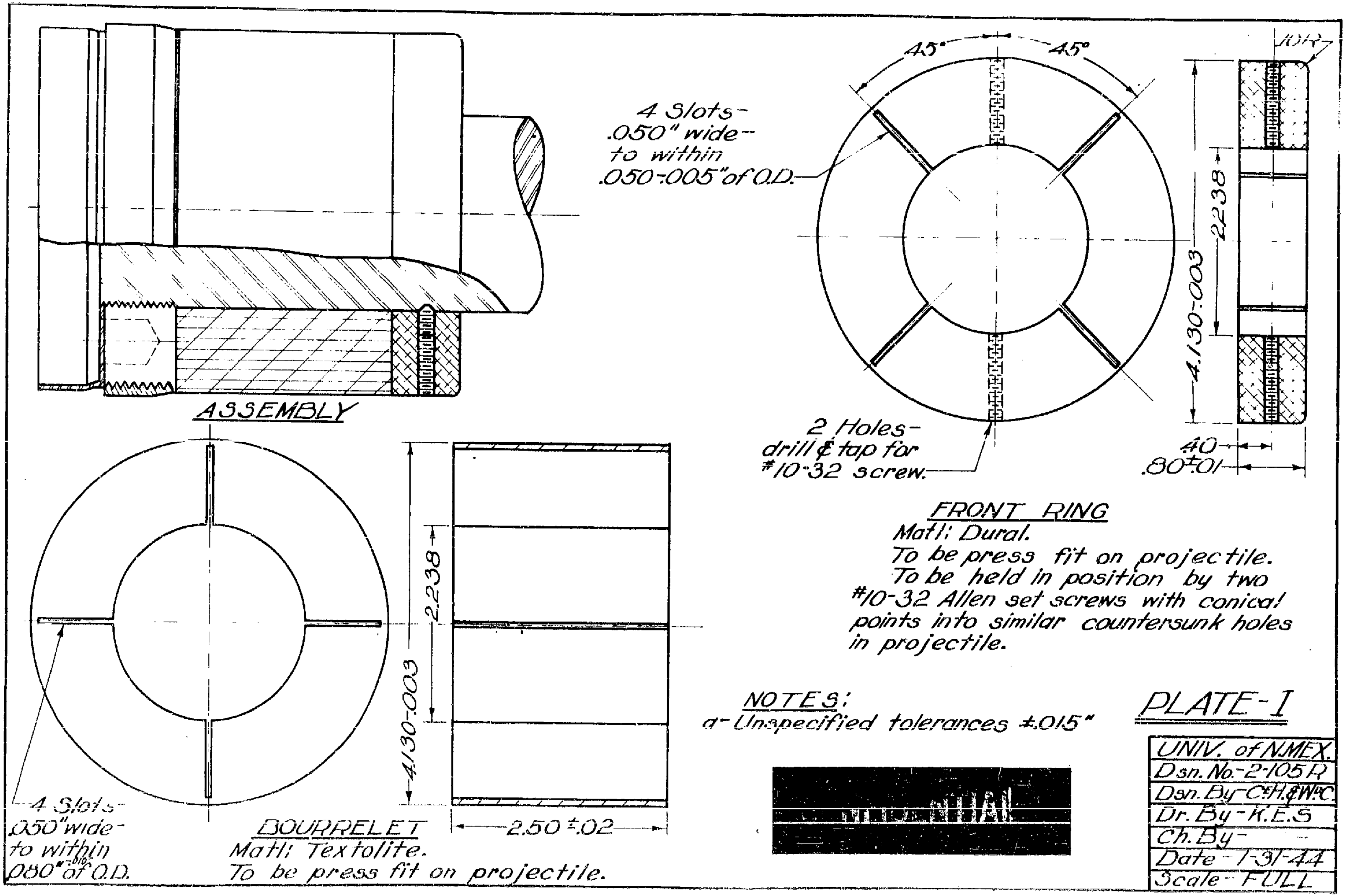
SABOT
Matl. = C.R.S.

NOTES:

a: Unspecified tolerances = ±.005
b: Projectile = Standard M 86, threaded for .750" forward from base with 20-USS-2.

UNIV. of N.MEX.
Dsn. No-2875D
Dsn. By-W.D.C.
Dr. By-K.E.S.
Ch. By-C.C.4
Date-5-27-43
Scale-2"=1"


CONFIDENTIAL
with letter from C. E. Hablitzel dated May 6, 1944
2 holes #10-24 tap
2.375-20-V-2
2.638
3.600
.725
.100
.335
.265
2.238-.002
2.345
2.875
2.945-.005
.045-.005
BOURRELET (Alternate)
Matl. Dural or Dowmetal.
4 separate segments, separated by 4 Spacers.
Held in position by two "10-24 setscrews .25" long
To be snug fit into Sabot.
.335
.300
2.875
2.945-.005
BOURRELET RETAINING RING
Matl.- C.R. Steel.
.100
.250
2.638
2.237
2.745
2.945-.005
.450
REVISED FRONT END OF SABOT
.200-.010
.300
.100
.353-.010
.286-.010
.045
3.300
BOURRELET SEGMENT SPACER
Matl.- Steel, dural, brass, or Dowmetal.
PLATE-III
(Revised design)
NOTES:
A.- Unspecified tolerances ±.005"
B.- Bourrelet held onto core in front by steel Ring and in rear by projecting .100" under Sabot.
UNIV. of N.MEX.
Dsn no 28-75 D.
Dsn. by- C.E.H.
Dr. by- K.E.S.
Ch. by-
Date.- 5-6-44
Scale.- FULL


ASSEMBLY
4 Slots-
.050" wide-
to within
.050-.005" of O.D.
45°
45°
.10R
2.238
4.130-.003
.40
.80±.01
2 Holes-
drill & tap for
#10-32 screw.
FRONT RING
Mat'l: Dural.
To be press fit on projectile.
To be held in position by two
#10-32 Allen set screws with conical
points into similar countersunk holes
in projectile.
2.238
4.130-.003
2.50±.02
4 Slots-
.050" wide-
to within
.080" -.010 of O.D.
BOURRELET
Mat'l: Textolite.
To be press fit on projectile.
NOTES:
a- Unspecified tolerances ±.015"
PLATE-I
[redacted]
UNIV. of N.MEX.
Dsn. No.-2-105 R
Dsn. By-C.H. & W.C.
Dr. By-K.E.S.
Ch. By-
Date-1-31-44
Scale-FULL

CONFIDENTIAL

NOTES:

a- Unspecified tolerances ±.015"

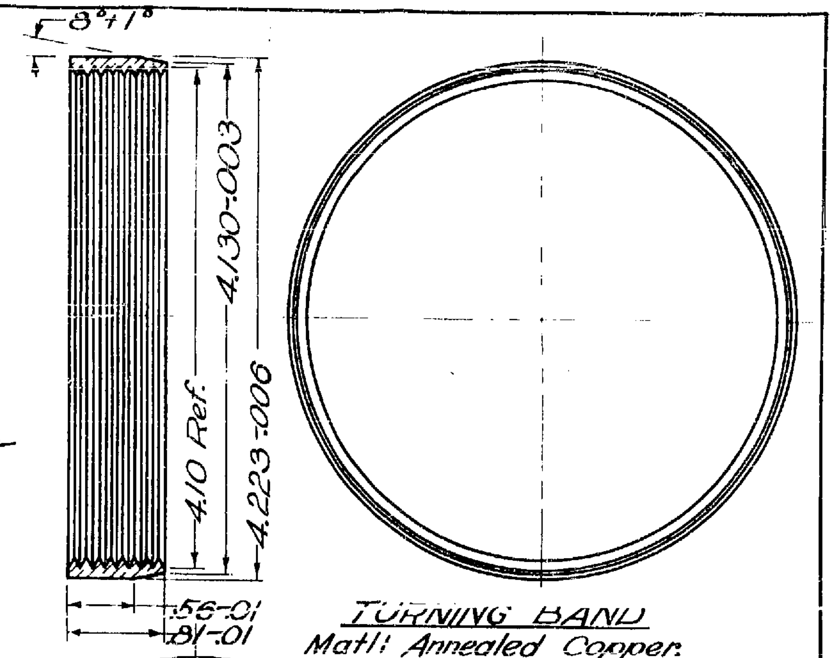
b- Turning Band mounted on Sabot thru Compressing Die.

c- Sabot to be screwed on Projectile before banding.

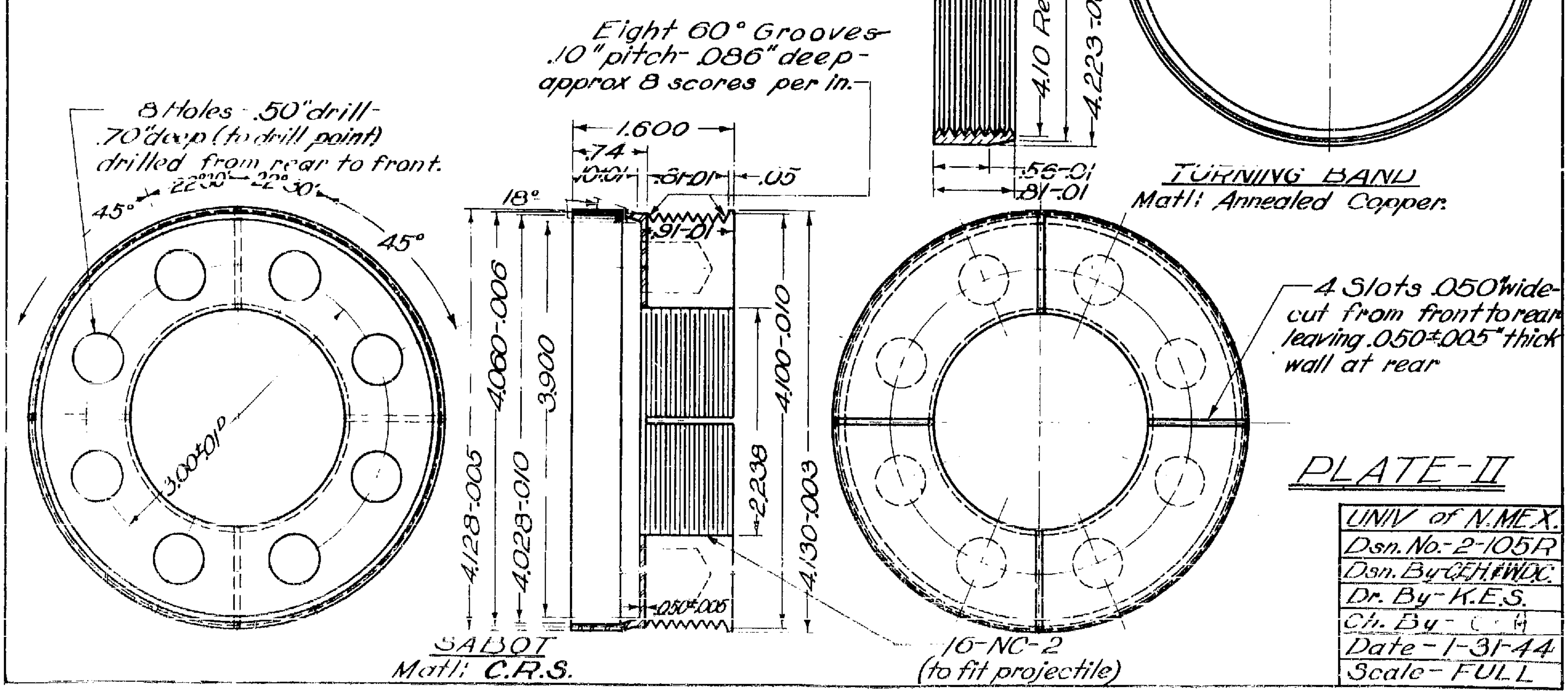
d- Sabot to be banded before holes are drilled.

e- Projectile: M86 with special windshield of 2.90" axial length.

f- Projectile base to be threaded for .910" forward from rear with 16-NC-2.



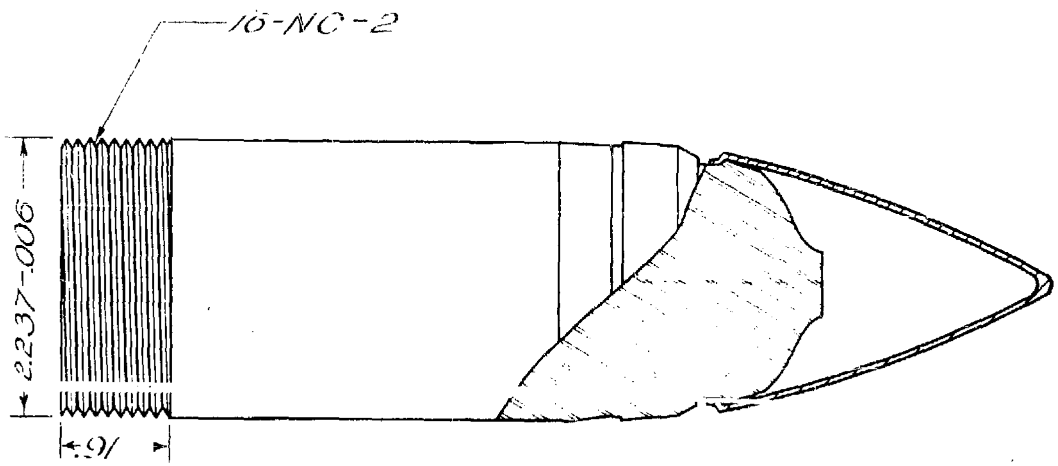
TURNING BAND
Mat'l: Annealed Copper.



SABOT
Mat'l: C.R.S.

PLATE-II

UNIV of N.MEX.
Dsn. No.-2-105R
Dsn. By-C.E.H. & W.D.C.
Dr. By-K.E.S.
Ch. By- C. H.
Date-1-31-44
Scale-FULL



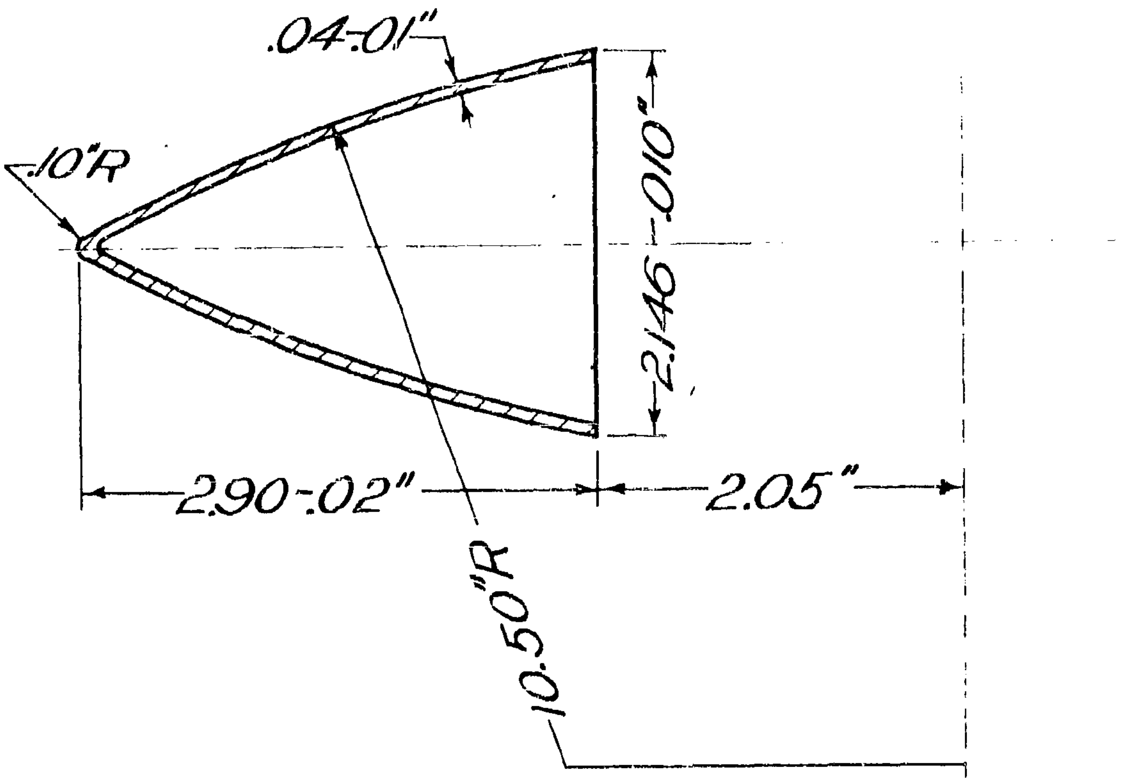
PROJECTILE: M86 with no Turning Band or Turning Band groove. Special windshield of 2.90" axial length (before crimping)

Confidential

PLATE-III

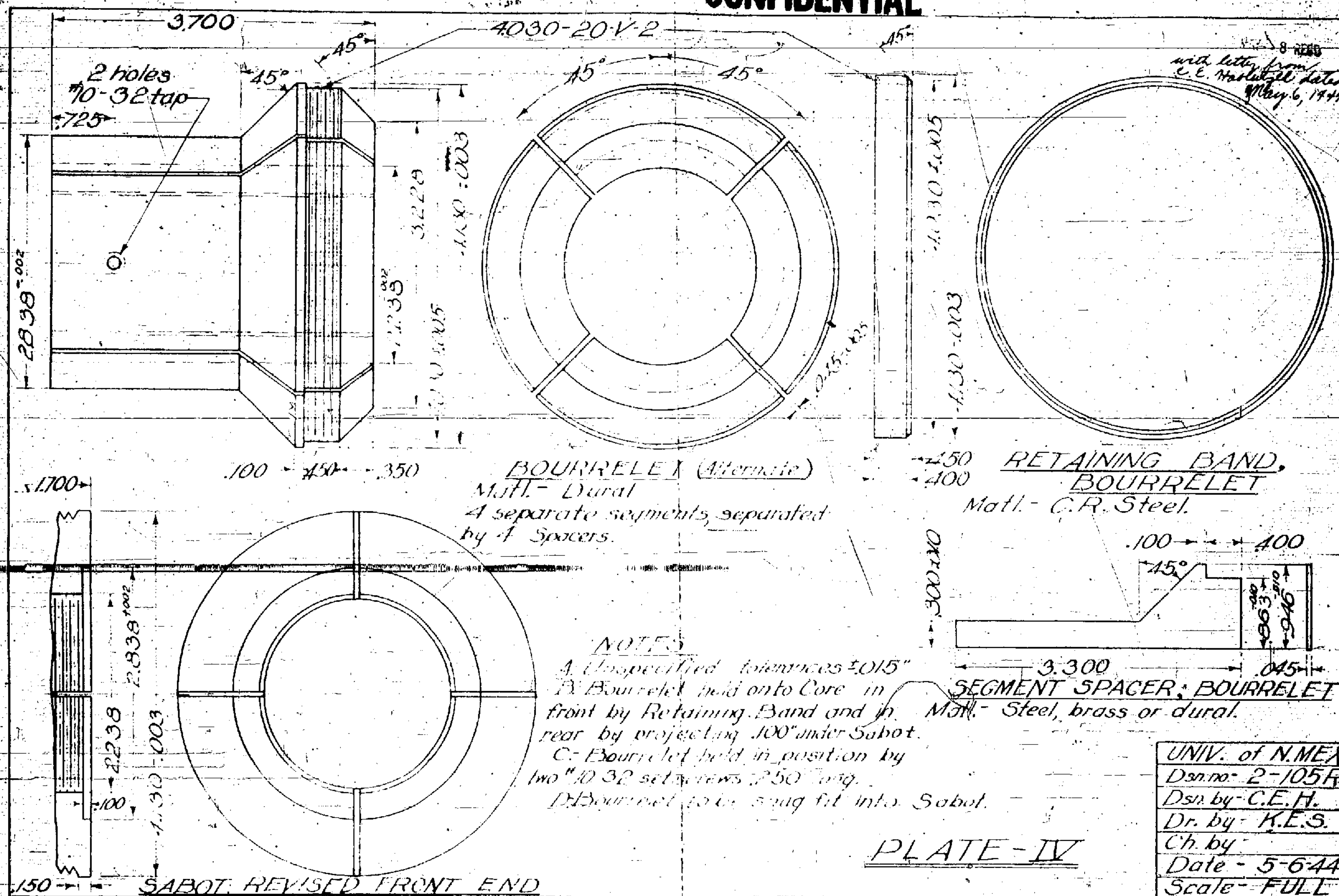
UNIV. of N.MEX.
Dsn. No: 2-105R
Dsn. By: C.E.H. & W.D.C.
Dr. By: K.E.S.
Ch. By:
Date: 3-6-44
Scale: FULL

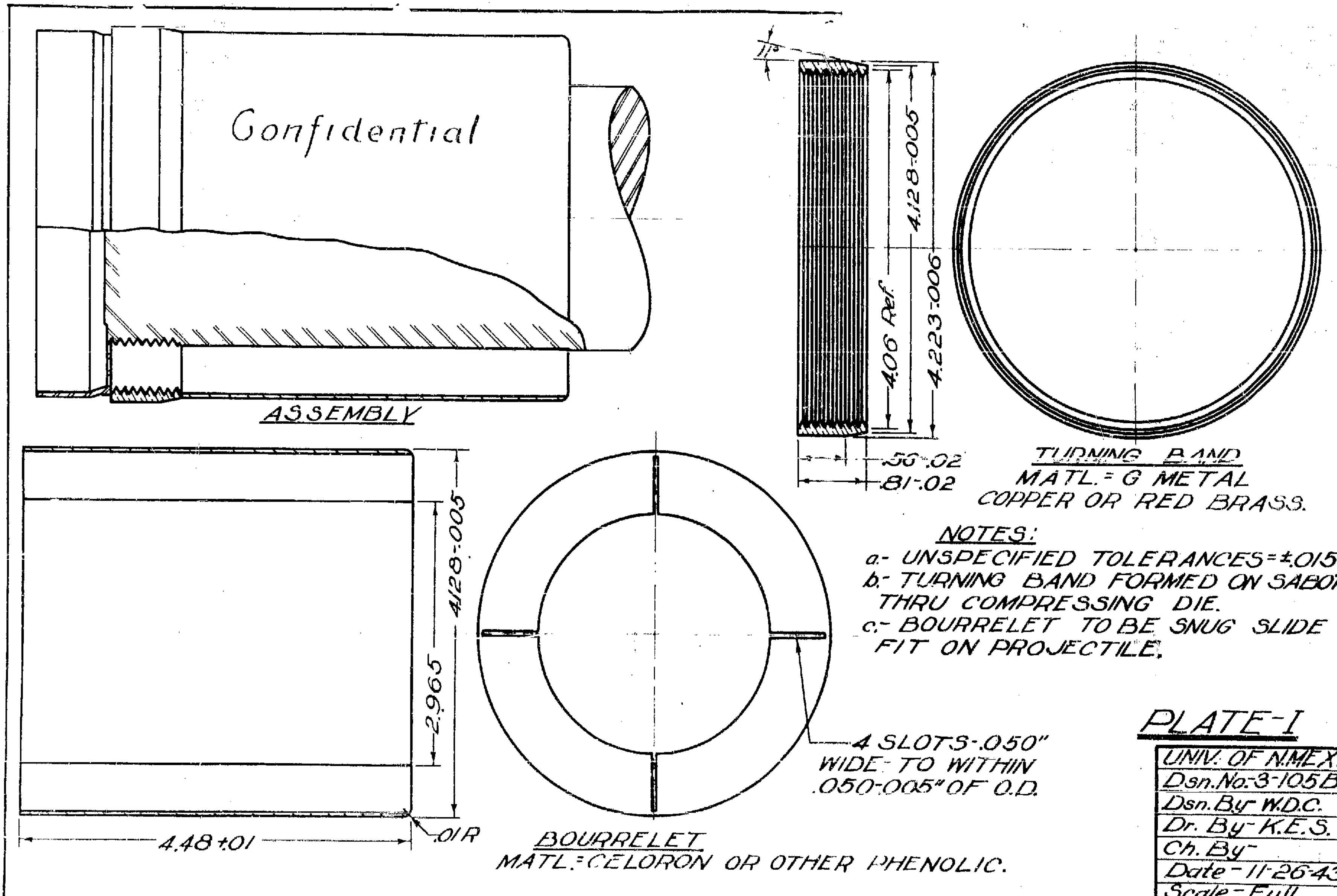
Confidential



SPECIAL WINDSHIELD
FOR M86 SHELL

CONFIDENTIAL





NOTES:

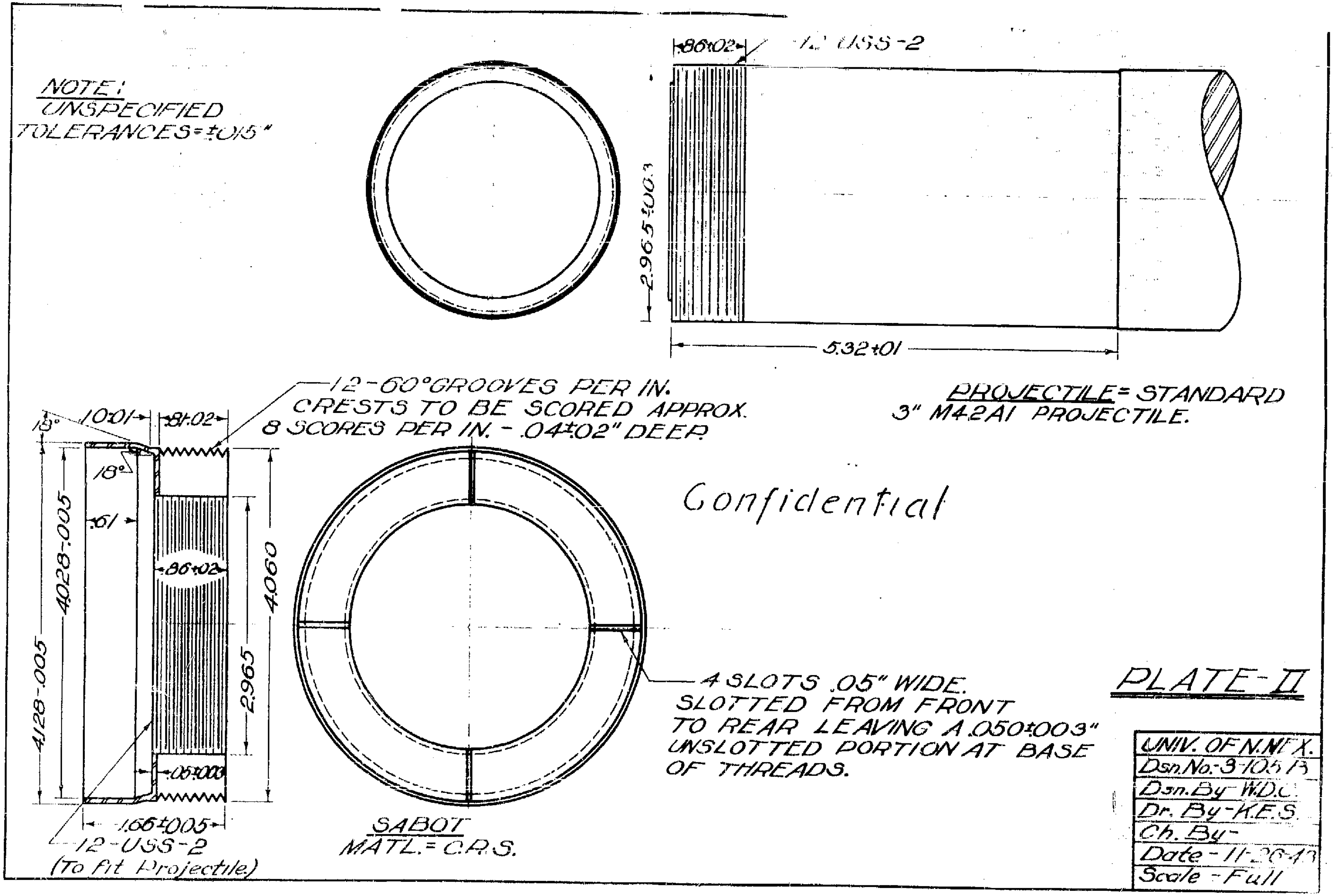
a.- UNSPECIFIED TOLERANCES=±.015"

b.- TURNING BAND FORMED ON SABOT THRU COMPRESSING DIE.

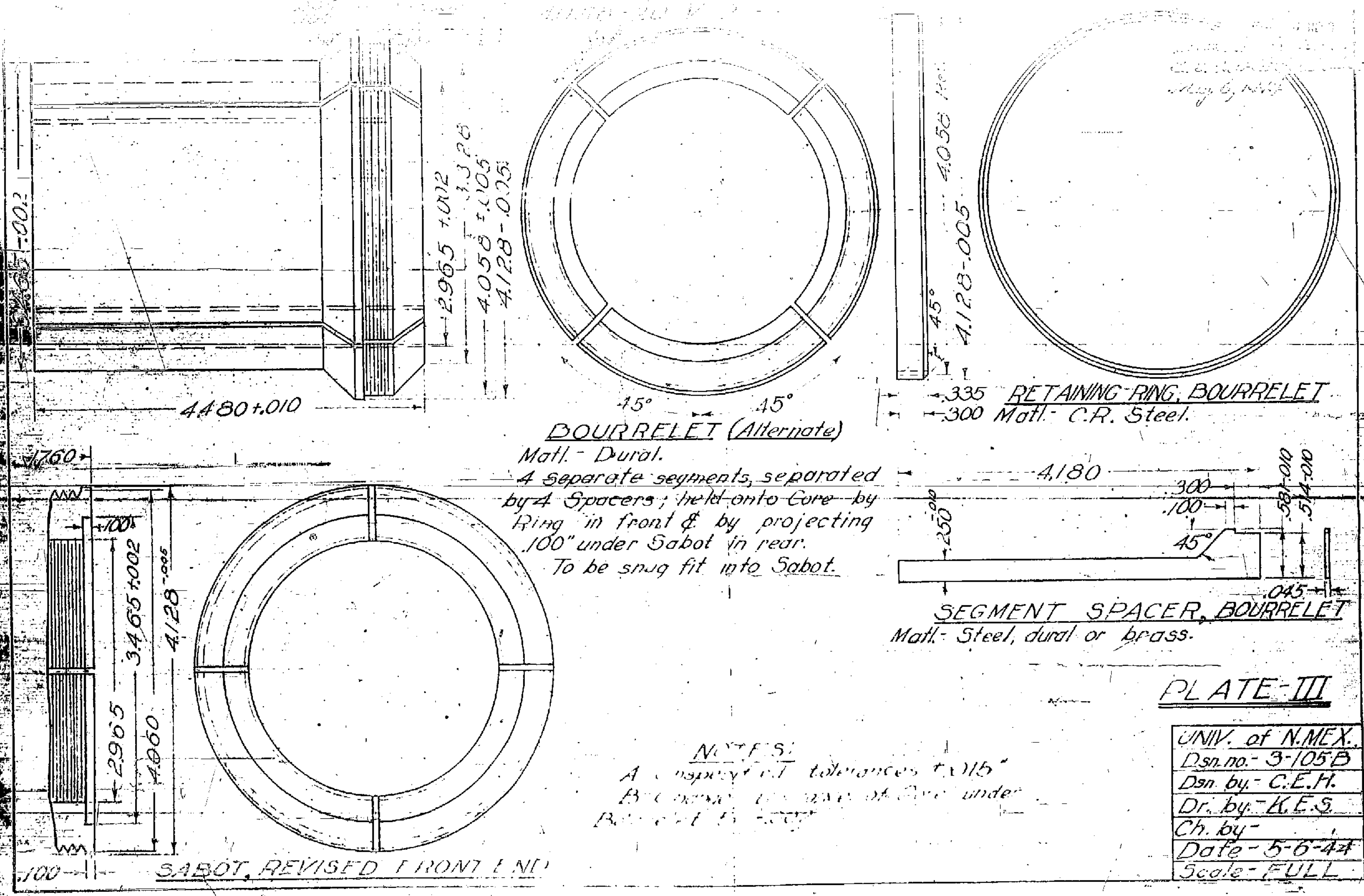
c.- BOURRELET TO BE SNUG SLIDE FIT ON PROJECTILE.

PLATE-I

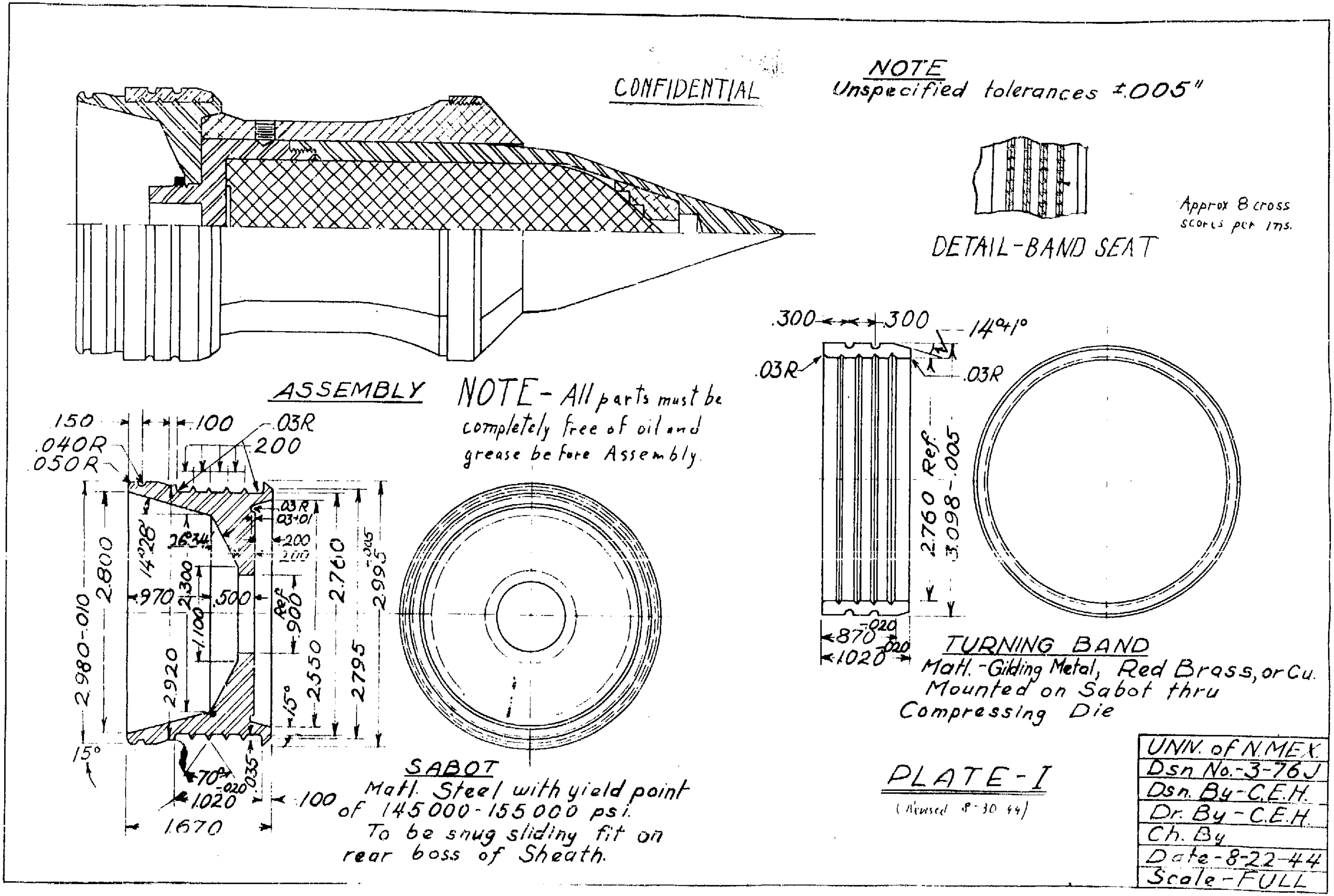
UNIV. OF N.MEX.
Dsn. No.-3-105B
Dsn. By- W.D.C.
Dr. By- K.E.S.
Ch. By-
Date-11-26-43
Scale-Full


NOTE:
UNSPECIFIED
TOLERANCES=±.015"
.86±.02
12 USS-2
2.965±.003
5.32±.01
PROJECTILE= STANDARD
3" M42A1 PROJECTILE.
12-60°GROOVES PER IN.
CRESTS TO BE SCORED APPROX.
8 SCORES PER IN. - .04±.02" DEEP
18°
.10±.01
.81±.02
18°
.61
4.028-.005
4.128-.005
.86±.02
2.965
4.060
.05±.003
1.66±.005
12-USS-2
(To fit Projectile)
Confidential
4 SLOTS .05" WIDE.
SLOTTED FROM FRONT
TO REAR LEAVING A .050±.003"
UNSLOTTED PORTION AT BASE
OF THREADS.
SABOT
MATL.= C.R.S.
PLATE-II
UNIV. OF N.MEX.
Dsn.No.-3-105 B
Dsn.By-W.D.C.
Dr. By-K.E.S.
Ch. By-
Date-11-26-43
Scale - Full

B-175



4480+.010
2965+.002
3.328
4.058±.005
4.128-.005
45°
45°
BOURRELET (Alternate)
Matl. - Dural.
4 separate segments, separated by 4 Spacers; held onto Core by Ring in front & by projecting .100" under Sabot in rear.
To be snug fit into Sabot.
.335
.300
RETAINING RING, BOURRELET
Matl.- C.R. Steel.
4.058 Ref.
4.128-.005
4.180
.300
.100
.581-.010
.514-.010
.250-.010
.045
SEGMENT SPACER, BOURRELET
Matl.- Steel, dural or brass.
.1760
.100
3.465+.002
4.128-.005
2.965
4.060
.100
SABOT, REVISED FRONT END
PLATE-III
UNIV. of N.MEX.
Dsn.no.- 3-105B
Dsn. by.- C.E.H.
Dr. by.- K.E.S.
Ch. by-
Date- 5-6-44
Scale- FULL


CONFIDENTIAL
NOTE
Unspecified tolerances ±.005"
DETAIL-BAND SEAT
Approx 8 cross scores per ins.
ASSEMBLY
NOTE- All parts must be completely free of oil and grease before Assembly.
.150
.100
.040R
.050R
.03R
.200
.03R
.03+.01
.200
2.634
14°28'
2.300
.970
.500
.900 Ref.
1.100
2.980-.010
2.800
2.920
2.550
2.760
2.795
2.995 -.005
15°
15°
70°
.035
1.020 -.020
.100
1.670
SABOT
Matl. Steel with yield point of 145000-155000 psi.
To be snug sliding fit on rear boss of Sheath.
.300
.300
14°41°
.03R
.03R
2.760 Ref.
3.098-.005
.870 -.020
1.020 -.020
TURNING BAND
Matl.-Gilding Metal, Red Brass, or Cu.
Mounted on Sabot thru Compressing Die
PLATE-I
(Revised 8-30-44)
UNIV. of N.MEX.
Dsn No.-3-76J
Dsn. By-C.E.H.
Dr. By-C.E.H.
Ch. By
Date-8-22-44
Scale-FULL

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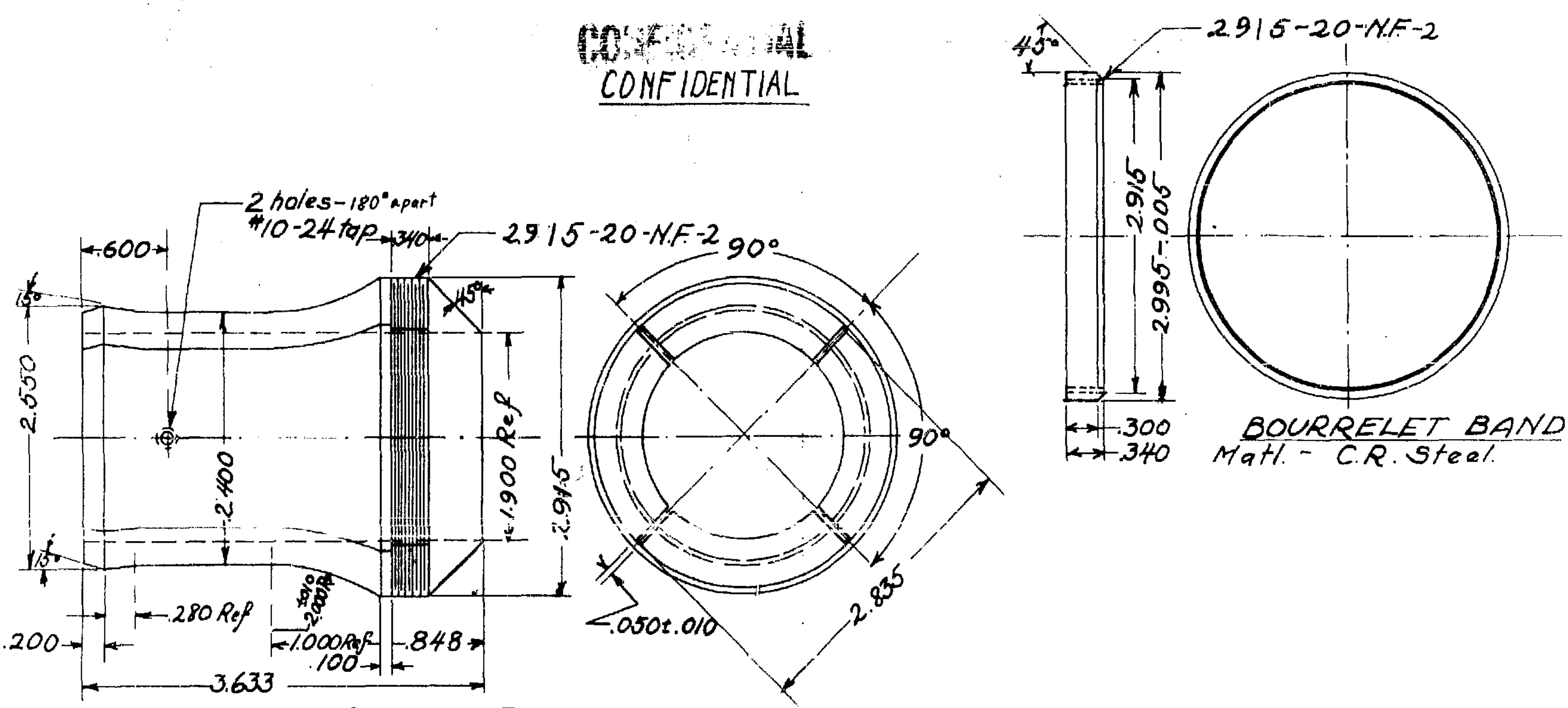


BOURRELET

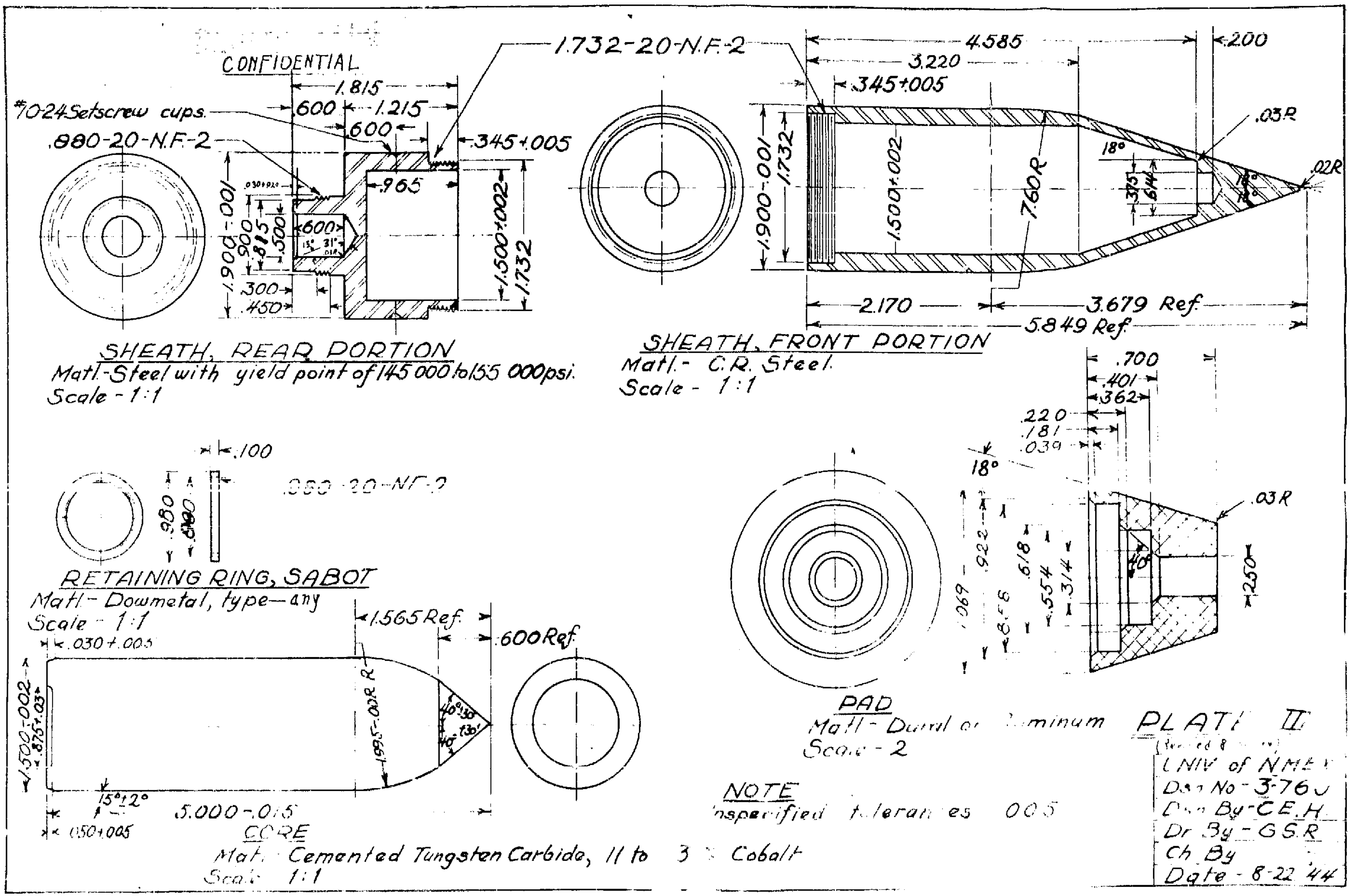
Matl. - Dowmetal types O-1 or J-1 extruded rod, or H-HTA[Cast]
4 slots 90° apart, .050±.010 wide, cut from inside out, leaving uncut portion at front end with I.D. of 2.835 and O.D. of 2.915
Held in position on Sheath by two #10-24 setscrews .250" long
To be force fit on Sheath

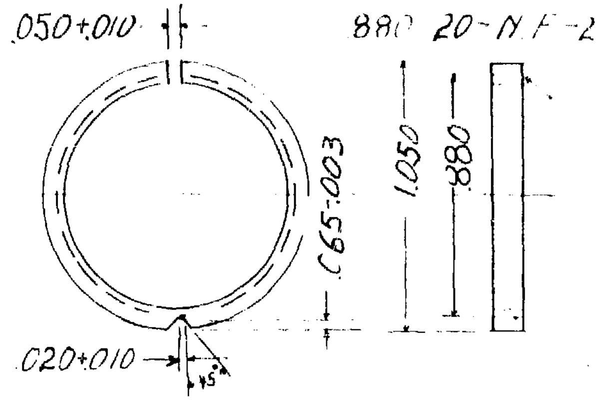
NOTES

1. Unspecified tolerances ±.005"
2. Alternate I. Bourrelet may be completely divided into 4 segments, either close fitting or separated by not more than .060", held together by band at front and subot at rear. In this case inside diameter of Bourrelet Band must be changed from 2.915" to 2.895"

PLATE - II
(Revised 8-30-44)

UNIV. of N. MEX.
Dsn. No. 3-76-J
Dsn. By - C.E.H.
Dr. By - G.S.R.
Ch. By -
Date - 8-22-44
Scale - FULL


CONFIDENTIAL
#10-24 Setscrew cups.
.880-20-N.F.-2
1.732-20-N.F.-2
SHEATH, REAR PORTION
Matl.-Steel with yield point of 145 000 to 155 000 psi.
Scale - 1:1
SHEATH, FRONT PORTION
Matl.- C.R. Steel.
Scale - 1:1
RETAINING RING, SABOT
Matl.- Dowmetal, type—any
Scale - 1:1
PAD
Matl.- Dural or Aluminum
Scale - 2
CORE
Matl. Cemented Tungsten Carbide, 11 to 13 % Cobalt
Scale 1:1
NOTE
Unspecified tolerances .005
PLATE II
UNIV of N.MEX.
Dwg No - 3-76
Dr By - C.E.H.
Dr By - G.S.R.
Ch By
Date - 8-22-44
B-119



ALTERNATE I

RETAINING RING, SABOT

Matl - C.R. Steel

To be staked in place after assembly

NOTE

Unspecified Tolerances ±.005

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PLATE IV

UNIV. of N. MEX.
Dsn No-3-76J
Dsn. By-C.E.H.
Dr. By-C.E.H.
Ch. By- CEH
Date- 8-28-44
Scale - 2:1

Chart giving striking velocity and penetration of U.N.M. sabot projectiles for the 76-mm Gun M1A2.

This chart, the original of which was prepared by the Ballistic Branch, Research and Materials Division, Research and Development Service, Office of the Chief of Ordnance, is based on data obtained at Aberdeen Proving Ground using several different projectiles. The form factor used in computing the striking velocity VS range relationship was obtained by firings of U.N.M. 3-76J. The penetration data was obtained from firings of U.N.M. 3-76EH, British 17-pr sabots, and other projectiles having a 4 lb core of cemented tungsten carbide. The subcaliber projectiles of the two U.N.M. designs are so like that of the British 17-pr sabot projectile that the penetrations of all three should be identical at any given striking velocity (assuming no yaw at the plate in all cases). The construction of the other projectiles was radically different but the cores were the same as those in the sabot projectiles.

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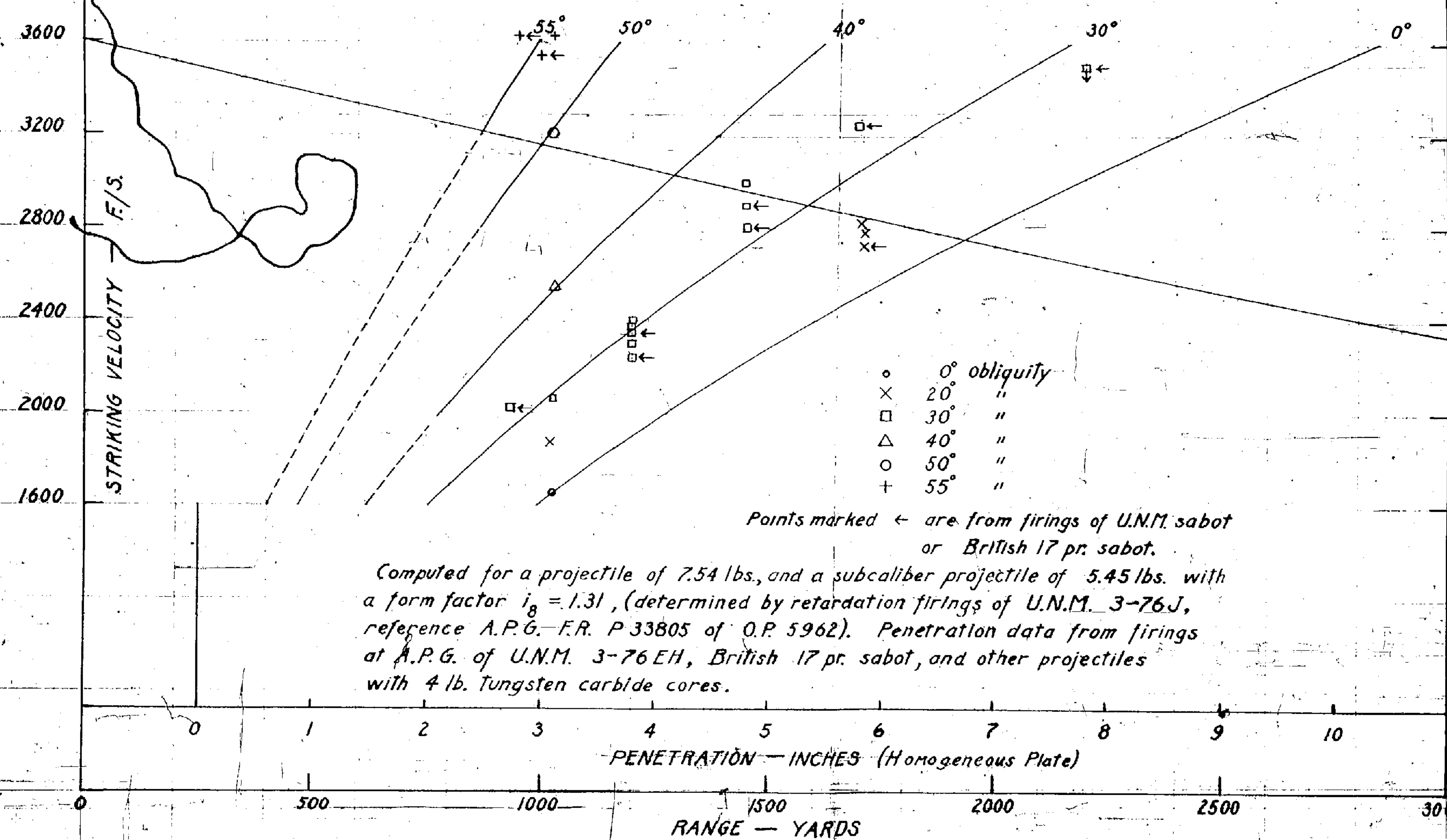
STRIKING VELOCITY vs. PENETRATION & RANGE

U.N.M. SABOT PROJECTILE FOR 76-MM GUN M1A2
4 lb. TUNGSTEN CARBIDE CORE
M.V. 3600 F/S.



Computed for a projectile of 7.54 lbs., and a subcaliber projectile of 5.45 lbs. with a form factor $i_8 = 1.31$, (determined by retardation firings of U.N.M. 3-76J, reference A.P.G. F.R. P 33805 of O.P. 5962). Penetration data from firings at A.P.G. of U.N.M. 3-76 EH, British 17 pr. sabot, and other projectiles with 4 lb. Tungsten carbide cores.

Copied from chart prepared by Ballistic Branch, Res. & Mat. Div., Res. & Dev. Service, O.C.O.

APPENDIX I

EFFECT OF MOISTURE ON DIMENSIONS OF PLASTIC PARTS

Some information about the changes in dimensions of laminated phenolic plastics has been collected in this Appendix. This includes test data selected from two papers and a short statement of the results of some tests made at the Geophysical Laboratory.

First, however, it is desirable to have in mind what expansion of the diameter of the plastic sleeves of the University of New Mexico designs is tolerable after machining. Table I shows this on the assumption that no paint or other material that will increase the diameter is applied over the plastic. If the limit of tolerable expansion is exceeded, the projectile may not load. If, to increase the amount of expansion that can be tolerated, the design diameter of the sleeve is reduced, this will presumably result in increased yaw and dispersion of projectiles that have been well dried.

Table I

Design No.	Diameter of sleeve inches	Diameter of bore inches	Limit of expansion tolerable inches	Limit of expansion tolerable percent
28 - 75D	2.945 - .005	2.950 + .002	.005	0.17
2 - 105R	4.130 - .003	4.134 + .002	.004	0.097
3 - 105B	4.128 - .005	4.134 + .002	.006	0.145

Data from the Literature

Table II presents selected test data from a paper by Wakeman[1].

[1] Wakeman, Reginald L. "Dimensional Changes in Boiling Water," Modern Plastics, Vol. 18, July 1941, p. 65 et seq.

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Table II

CHANGES IN LAMINATED PHENOLIC PLASTICS*

	Weight Loss after 1 hr 105°C	Immersed in Water at Room Temperature: Increase in length after 6 wks	Immersed in Water at Room Temperature: Increase in length after 2 yrs	Immersed in Water at Room Temperature: Increase in weight 2 yrs	Immersed in Boiling Water: Increase in length after 1 day	4 days	4 mos	1 yr	2 yrs
	%	%	%	%	%	%	%	%	%
1 Fabric base, Grade C	1.02	.42			.16	.08	-.08	-.16	-.27
2 " " " "	.87	.37	.20	5.29	.11	-.08	-.59	-.67	-.84
3 " " " " Graphite filled	.86	.53	.49	5.83	.33	.27	.06	-.02	-.13
4 " " " " Special for marine service	.41	.50			.28	.38	.36	.29	.20
5 " " Grade L	1.07	.50			.20	.14	-.10	-.22	-.28
6 Paper base, Grade XX	.32	.72	.77	7.11	50	.70	.76	.70	.42

Test specimens were 2 3/4" x 1" x 1/8". Before being immersed the specimens were dried by heating them at 105°C for 1 hour. They were then cooled in a desiccator before being weighed and measured.

Fabric base, cotton fabric — "Grade C" is ASTM designation for "mechanical"
"Grade L" is ASTM " " "fine machining"

Paper base, cellulose paper — "Grade XX" is ASTM " " "electrical and mechanical"

* Data selected from Wakeman.

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Columns 3 and 4 give percentage increases in the length of test pieces 2 3/4" x 1" x 1/8" after being immersed in distilled water at room temperature for 6 weeks and for 2 years. How representative these data or those of Table III may be is not known to the writer.

Table III presents some data taken from a paper by Titus[2/]. The tests resulting in the figures given in the table were made on specimens that had been dried by heating at 149°C for 21 hours. The specimens were then placed in glass desiccators containing water, salt solution in equilibrium with solid salt, or desiccant, to give the relative humidities noted in the table. The desiccators were left at room temperature throughout the test. It should be noted that at the beginning of their exposures to the relative humidities noted, the specimens were drier than any machined part made from the same plastic would be when it came off the lathe, and that the expansion of the machined part, if it were the same size as the test specimen, would therefore be less, at 100 percent relative humidity, than that of the test specimen.

The ASTM tentative specifications for laminated thermosetting materials (D 709 - rr T) specify maximum water absorption. However, the specifications are in terms of weight and for short term immersion tests and give no information about the changes of dimensions to be expected.

A recent paper by Burns[3/] gives a good deal of interesting information on dimensional changes of plastics but none of the data pertain directly to the particular plastics with which we are concerned.

2/ A. C. Titus, "Effect of High Relative Humidities in Producing Changes in Dimensions of Plastics," Plastics and Resins Industry, August 1944, p. 12 et seq.

Table III

PERCENTAGE INCREASE IN LENGTH OF LAMINATED PHENOLIC PLASTICS*

	100% R.H. 80 days	27% R.H. 62 days	0% R. H.
Cotton cloth base	0.36	0.15	-0.025
Glass cloth base	0.15	0.075	0
Asbestos base	0.19	0.1	+0.025

The specimens were strips 4" x 0.9" x 0.07". They were dried for 21 hours at 149°C before being exposed to the relative humidities stated. All changes are relative to the lengths after heating and subsequent cooling. The specimens were exposed to the different relative humidities at room temperature.

* Data from Titus

It will be noted from the data of Tables II and III that the glass cloth base laminated phenolic material expands much less than laminated phenolic plastics with an organic fiber base, but that even this material expanded 0.15 percent when exposed to a relative humidity of 100 percent at room temperature. Still greater expansion is to be expected from immersion in water. Now ammunition may be exposed to high relative humidities, 90 percent or more, for long periods of time, and may stand in the rain or be immersed in mud or water, or it may be used in desert country and be exposed to high temperatures and low relative humidities, under 10 percent, over long periods of time. Thus it is not certain that even glass fabric base laminated phenolic material could be used

3/ Robert Burns, "Dimensional Stability of Plastics," ASTM Bulletin, May 1945, p. 27 et seq.

for sleeve bourrelets on projectiles that might be used in any part of the world without allowing greater design windage than is allowed by the University of New Mexico designs, even if the moisture content at the time of machining were controlled.

It may also be noted in passing that plastics are subject to other slight changes in dimensions in addition to those brought about by moisture. The data of the last five columns of Table II reflect this.

The sliding bourrelet of Critchfield[4/] provides one means of overcoming the difficulty. Some of the objections to its use for service projectiles would be removed by putting the sliding collar on the inside instead of on the outside of the sleeve.

Tests made at the Geophysical Laboratory

In January 1944, the Geophysical Laboratory began making a number of tests of a design that had been proposed for a sabot for the 20-mm Hispano. This design utilized a sleeve of plastic surrounding the subcaliber projectile in the way that had been introduced by the University of New Mexico. It was necessary to know how the dimensions of these plastic parts would be affected by the most extreme moisture conditions that they might be exposed to in service. Accordingly, long-term tests in which specimens were immersed in water or exposed to high or to low relative humidity were begun about the middle of January. After a few preliminary tests had been carried out, the series of tests reported on in the following article was begun. These tests were conducted by J. McG. Millar. Portions of his summary of the changes in dimensions that occurred have been appended to these notes, as they are pertinent to any consideration of the use of plastics of these types in ammunition components.

4/ See footnote 51, page 74.

- Appendix to Appendix I -

EXPANSION AND CONTRACTION OF PLASTIC SLEEVES EXPOSED TO DIFFERENT DEGREES OF HUMIDITY AND IMMERSED IN WATER

by John McG. Millar

1. Purpose:

The tests described here were intended to show how much the plastic sleeves would expand or contract when exposed to different degrees of humidity, and when immersed in water.

2. Specimens used in tests:

For the most part the specimens were sleeves formed from phenol-formaldehyde plastic with an organic fiber base, and intended for use as bourrelets on 20-mm sabot projectiles. They were essentially short tubes with an outside diameter of 0.784", and an inside diameter of 0.589". They are described in Table I, together with the material from which they were made. The sleeves made from the first two materials listed there were made by molding, the others were machined. The lengths of specimens differed. In part this was due to the necessity of machining a smooth surface of some width on the front end of the sleeve to permit accurate measurements of length to be made.

The Phenolite XX 21 and XX 25 paper base plastics could not be obtained in 0.8" tubing. Therefore 0.5" tubing was used to make test pieces. These were made 0.5" in diameter, 1" long, and had the same wall thickness as standard sleeves. Later, a few scraps of 0.78" tubing of the same kinds, both rolled and molded, were obtained, and tested for immersion only. The results of these tests show that the expansion of the full size tubing is about 90% of that of the 0.5" tubing in the case of immersion. It is probable that the behavior under other humidity conditions is also comparable.

3. Conditions to which exposed:

   a. Immersion in water: The plastics were kept covered with distilled water at room temperature, 68°F to 82°F.

   b. High relative humidity: The sleeves were enclosed in a sealed glass vessel over a saturated solution of cupric chloride in water, and the vessel was kept in a thermostated oven at 102°F to 106°F (38°C - 40°C). The specimens were thus exposed to a relative humidity of 89 - 90%1/ at 102°F and 106°F.

   c. Low relative humidity: The sleeves were kept over potassium hydroxide sticks in a desiccator, and in the same oven, i.e., at a temperature between 102°F and 106°F. They were thus exposed to a relative humidity of less than 1% at these temperatures2/.

4. Method of Measurement:

The outside diameter and the length were measured. Measurements of all dimensions were carried out with a micrometer. Usually the test sleeves were slightly out of round. In this case the maximum and minimum diameters were noted, and the average was considered to be the value of the diameter measured. Maximum and minimum lengths were similarly averaged. The location of the maximum and minimum dimension was marked on the sample on the first measurement. Subsequent measurements were carried out on the same places as the first. The outside diameter of sleeves machined from the molded Phenolite LE 75 plastic and the paper base plastics were circular to within 0.0003", therefore only one diameter was measured.

1/ International Critical Tables, Vol. I, p. 67.

2/ International Critical Tables, Vol. III, p. 385.

Later in the experiment it became apparent that the molding joint has some effect on the expansion: Samples that were round after machining became out of round on expansion. The out-of-roundness is, however, only 0.001" or less. The error in each individual measurement is ± 0.0005".

Measurements were made at 1 and 2 days, and at 1, 2, 3, 4 or sometimes 5, 8, and 13 or 14 weeks after the beginning of the tests. The samples had, of course, to be removed from the containers for measurement but were never left out for more than 90 minutes. The containers were left in the oven while the measurements were being made. The temperature of the oven was checked frequently and was always found to be 38 - 40°C.

5. Results:

The results of the tests are shown in the attached graphs of change in dimensions versus time. It has already been noted that the dimensions of all the specimens were not identical. In plotting the changes in dimensions, therefore, in order to assist direct comparison, all dimensions have been reduced to a common standard by multiplying by the ratio; dimension of standard / original dimension concerned.

"Back Diameters" (see attached graphs) are outside diameters; the micrometer is held so that the rear edge of the sample coincides with the edge of the micrometer flats.

"Front Diameters" (only Bak. 1132 and Durez 1905) are outside diameters; the micrometer is held so that the edges of the micrometer flats are 1/4" from the front edge of the sample.

Lengths were measured parallel to the axis of revolution of the sample. Table II gives a summary of all tests and all final changes in dimensions. This table is represented graphically in graph No. 11.

It will be noted that in the case of the two sets of molded sleeves the changes in the front and back diameters are different, and both are different from the change in length. This may appear strange at first sight. The changes in dimensions are closely related to the organic filler. Both these molded materials have fiber fillers. Examination of fractured surfaces under a Greenough binocular microscope shows that the fibers tend to be arranged with their long dimensions in planes perpendicular to the axis of the sleeve, and that their concentration is greater at the back end than at the front end of the sleeve. This probably accounts for the differences in the changes in dimensions.

An uncertain factor in these tests is the initial condition of the samples with respect to moisture content. We have, for instance, no definite information as to the prevailing humidities at the time the tests were started. (It may be roughly estimated to have been about 50% ± 10%) The influence of the initial condition of the samples may be illustrated by the following. Some preliminary tests were carried out on Bakelite 1132 and Durez 1905. Three and four pieces of each were exposed to the high and low humidity atmospheres under the test conditions already described. The results of these preliminary tests show a larger effect of the desiccation than in the main test and a correspondingly smaller effect of the humidification. However, the total change in dimensions is the same as in the main test. This situation is presumably due to a different initial moisture content of the plastic.

6. Conclusion:

The magnitudes of the expansion and contraction that must be taken into account in using the plastics tested are shown. The magnitude of these effects, together with the difficulty of knowing the moisture content of the plastic at the time of machining, prohibits the use of any of these materials for bourrelets unless some compensating device is used such as a sliding bourrelet.

The effect of ageing of the plastics on the dimensions of parts made for them remains a question.

<u>Note:</u> Four diagrams, graphs 3, 4, 5 and 11, of Mr. Millar's report have been selected for reporduction here. These will be found following the tables.

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TABLE I

DESCRIPTIONS OF TEST SLEEVES

Trade Name	Description	Plastic Furnished by	Sleeves Machined or Molded by	Remarks
Bakelite 1132	Fibre filled molding phenol-formaldehyde plastic	Bakelite Corp.	Molded by Northern Ind. Chem. Co.	The test specimens were molded sleeves. They were chosen at random from lots received from Natl. Pneumatic Co. on Feb. 26, '44. About 1/16" was machined off the front end of the sleeves to permit accurate measurement of their length. Length as used about 1 3/4".
Durez 1905	Fibre filled molding phenol-formaldehyde plastic.	Durez Plastics	Molded by Northern Ind. Chem. Co.	The test sleeves were chosen at random from lots received on Jan. 11, '44 from Natl. Pneumatic Co. About 1/16" was machined off the front end of the sleeves to permit accurate measurement of their length. Length as used about 1 3/4".
Phenolite LE 75	Fine weave cotton fabric base laminated molded phenol-formaldehyde tubing.	Natl. Vulcanized Fibre Co.	Machined by Geophysical Lab. Shop.	The test specimens were in the form of machined sleeves. The taper intended to fit a sliding bourrelet at the front end was cut off to permit accurate measurement of the length. Length as used 1 inch. The available material was used. No sampling was attempted.
Phenolite XX21	Paper Base laminated rolled phenol-formaldehyde tubing.	Natl. Vulcanized Fibre Co.	Machined by Geophysical Lab. Shop a few days before test.	These materials were unobtainable in 0.3" tubing. Therefore 0.5" O.D. pieces of tubing 1" long of the same wall thickness as the other sleeves were used. Rec'd Feb. 28, 1944, from Natl. Vulc. Fibre Co.
Phenolite XX25	Paper Bases laminated molded phenol-formaldehyde tubing.	Natl. Vulcanized Fibre Co.	Machined by Geophysical Lab. shop a few days before test.	

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TABLE II

CHANGES IN DIMENSIONS

Number of Sleeves Measured	Material	Condition to which Exposed	Total Duration of Test	Final Average Expansion % Outside Diameter Front	Final Average Expansion % Outside Diameter Back	Final Average Expansion % Length	Graph No.
10	Bakelite 1132	Low R. H.	93 days	-.29	-.34	-.36	1 and 6
10	" "	High R. H.	" "	.44	.60	.47	
10	" "	Immersion	" "	1.21	1.74	1.48	
10	Durez 1905	Low R. H.	" "	-.19	-.31	-.30	
10	" "	High R. H.	" "	.42	.62	.46	2 and 7
10	" "	Immersion	" "	1.02	1.57	1.25	
10	Phenolite tubing,	Low R. H.	98 days	—	-.24	-.18	
10	fabric base,	High R. H.	" "	—	.21	.30	3 and 8
10	LE 75 (molded)	Immersion	" "	—	.73	.58	
5	Phenolite tubing,	Low R. H.	92 days (0.5" O.D.)	—	-.21	-.25	
5	paper base,	High R. H.	" " "	—	.47	.38	4 and 9
5	XX 25 (molded)	Immersion	" " "	—	1.80	.84	
5	Phenolite tubing,	Low R. H.	" " "	—	-.29	-.32	
5	paper base,	High R. H.	" " "	—	.35	.29	5 and 10
5	XX 21 (rolled)	Immersion	" " "	—	1.12	.71	
3	Phenolite tubing paper base, XX 25 (molded)	Immersion	50 days (0.78" O.D.)	1.52	1.56	—	
4	Phenolite tubing, paper base, XX 21 (rolled)	Immersion	" " "	.89	.89	—	

Conditions to which exposed:

Low R. H.: Low relative humidity; the sleeves were stored in a desiccator over KOH sticks. The desiccator was kept at 38 - 40°C.

High R. H.: High relative humidity; the sleeves were kept in a closed glass vessel over a saturated soln. of $CuCl_2$ in H_2O. Temp. 38 - 40°C R. H. 89-90%.

Immersion: The sleeves were kept in water at room temp., 68° - 82°F.

Accuracy of each individual measurement: ± 0.0005".

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Figures from Mr. Millar's report reproduced here.

1. Percentage change in outside diameter against time of exposure to different moisture conditions for hollow cylinders machined from laminated cotton fabric base phenol-formaldehyde tubing. (Graph 3 of Millar's report)

2. Percentage change in outside diameter against time of exposure to different moisture conditions for hollow cylinders machined from laminated molded paper base phenol-formaldehyde tubing. (Graph 4 of Millar's report)

3. Percentage change in outside diameter against time of exposure to different moisture conditions for hollow cylinders machined from laminated rolled paper base phenol-formaldehyde tubing. (Graph 5 of Millar's report)

4. Percentage change in dimensions of hollow cylinders of various plastics after being exposed for 92-98 days to different moisture conditions. (Graph XI of Millar's report)

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APPENDIX II

PRESSURE MEASUREMENTS AT UNIVERSITY OF NEW MEXICO

All chamber pressure measurements made by the University of New Mexico were made with copper crusher gauges. Prior to June 13, 1944 gauges employing copper balls were used. For measurements on that date, and for all subsequent measurements, standard U.S. Army medium caliber pressure gauges employing copper cylinders were used. The copper ball gauges used had a piston approximately 1/30 square inch in area. The balls used were 5/32" diameter and were supplied to the University of New Mexico ready for use. No drawing of these copper ball gauges is available but the gauges were based on the design introduced by Hickman. 1/

Gauges of this type became widely used in NDRC contracts and many small modifications of the original design were introduced.

The tarage tables for use with the copper ball gauges are based on measurements of the compression of the annealed copper balls produced by different static loads, the measurements being made over the full useful range. The pressure indicated by a gauge, after having been used in the chamber, is therefore the static pressure that, acting over the area of the piston, would produce the compression of the copper ball found. The chamber pressures indicated by copper crusher gauges using either balls or cylinders are always less than the actual peak pressures as indicated by piezo electric gauges.

1/ NDRC Report A-21 "The use of copper balls for measuring pressures in combustion chambers" by C. N. Hickman, Nov. 1941.

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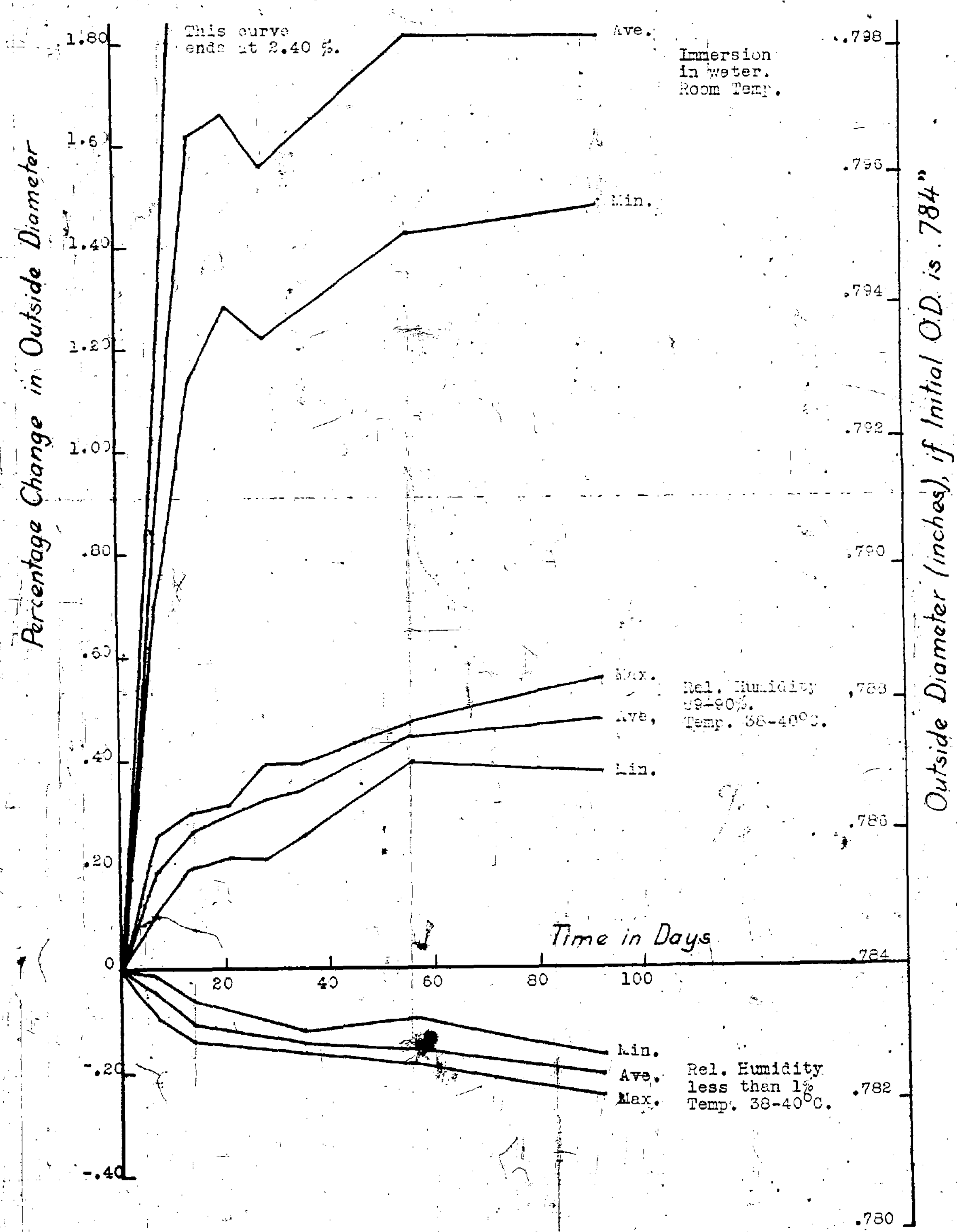
Copper crusher type pressure gauges have long been in use for measuring chamber pressures, and, in spite of the development of piezo electric and strain gauges, they are still used for most measurements of chamber pressures in guns because of their simplicity and convenience. It is current U.S. Army, U.S. Navy, and British practice to state such pressures in terms of the indications of a copper gauge unless otherwise noted[2]. It is desirable therefore to know the relationship between the indications of the copper ball gauges used by the University of New Mexico in their firings, and those of the standard service copper gauge for use in the same guns, in this case the U.S. Army medium caliber pressure gauge using annealed copper cylinders. It is also desirable to know the relationship to the indications of a piezo electric gauge as that gauge presumably gives a close approach to the actual peak pressure.

The University of New Mexico at no time used a piezo electric gauge in their sabot work so no comparison was made of their copper ball gauges with a piezo electric gauge. Nor is there any record of a comparison with the standard U.S. Army medium caliber pressure gauge. Any comparison that can be made now must be a rather indirect one making use of pressure data obtained with each gauge in different firings in which the same powder was used. The records have been searched for such data and what pertinent data have been found have been collected in Table I.

2/ U.S. Army and Navy gauges generally use annealed copper cylinders, while British gauges use copper cylinders that have been annealed and then precompressed. For pressures above 40000 p.s.i. annealed and precompressed copper cylinders are also used by U.S. Army (U.S. Army Specification Nº 52-1-51A August 1944).

Change of the Outside Diameter of Molded Paper Base XX25 Pieces with Time Under Different Moisture Conditions.

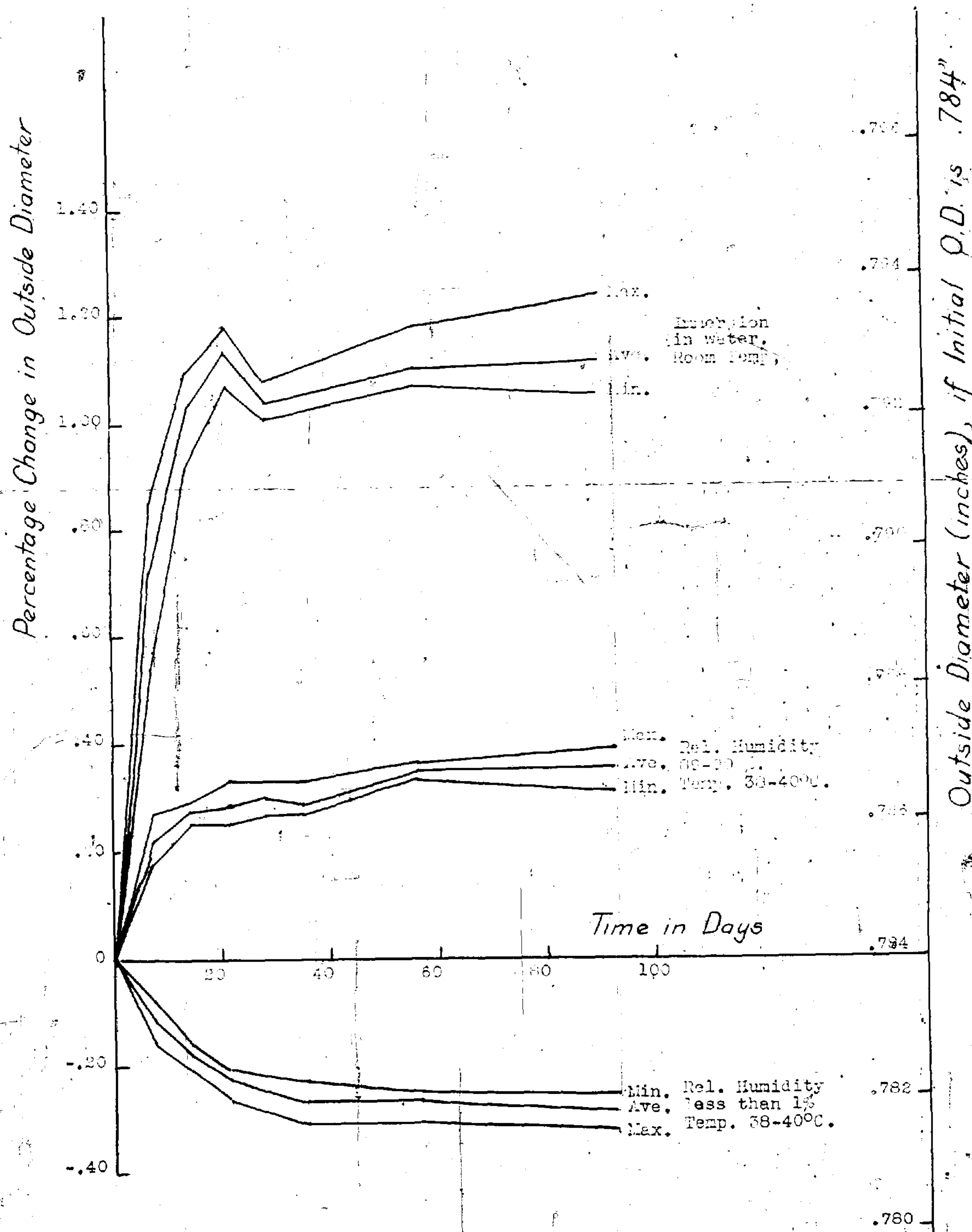
The Averages shown are the arithmetic averages of the change in outside diameter of 5 pieces. The max. and min. change is also shown. The Diameter of the pieces is measured with the micrometer just over the one end of the piece. These Test pieces were initially .5" in diameter. The scale at the right is drawn for an initial diameter of .784".



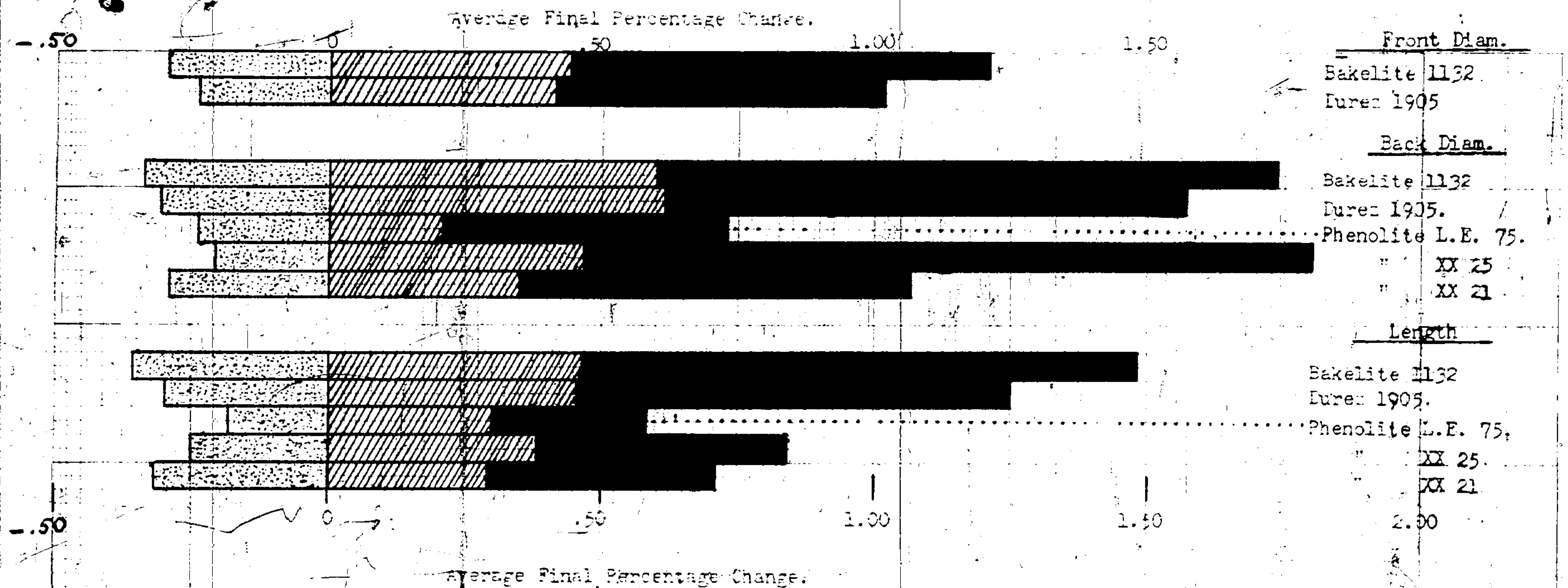
Graph 4

Change of the Outside Diameter of Rolled Paper Base
<u>XX31 Pieces with Time Under Different Moisture Conditions.</u>

The Averages shown are the arithmetic averages of the change in outside diameter of 5 pieces. The Max. and Min. change is also shown. The Diameter of the pieces is measured with the micrometer just over the one end of the piece. These Test pieces were initially .5" in diameter. The scale at the right is drawn for an initial diameter of .784".

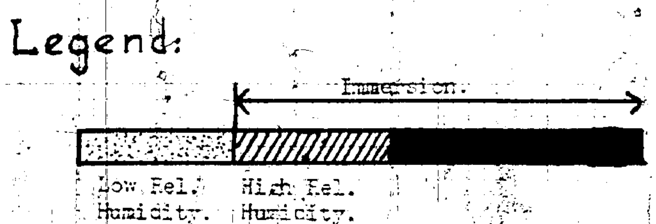


Graph 5



Average Final percentage Change in the Dimensions of plastics

This Graph is a pictorial representation of Table II.
The total duration of the Tests is between 92 and 98 days
for all the samples plotted here.



Graph XI

It may be said at once that no satisfactory comparison is possible from these data.

Part A of Table I presents the available pertinent data from firings using FNH M2 lot 4254 in the 75-mm gun M3. The only adequate number of pressure data obtained with any one design of projectile is that obtained at A.P.G. during the tests of the 75-mm/57-mm (APC M86) sabot projectile in mid summer 1943. To get a significant number of pressure data to compare with these, data from 9 different designs have been assembled. The comparison is unsatisfactory for starting pressures may possibly be affected by the differences in design, and temperature data is lacking. The pressure indications of the copper ball gauges have a rather wide spread but do not average greatly different than those of the medium caliber gauges.

Part B of Table I lists the available pertinent data from firings using FNH M1 lot X-6099 in the 105-mm Howitzer M3. Here again the only adequate number of pressure data obtained with any one design of projectile is that obtained at A.P.G. These data were obtained there during the test of the 105-mm/3" (HE M42) sabot ammunition that had been filled at Picatinny for trials by the Infantry Board. While the data are inadequate for a determination of the relationship between the indications of the copper ball gauges used at the University of New Mexico and of the medium caliber pressure gauge used at Aberdeen, they do show without question that the University of New Mexico gauges read much lower than the A.P.G. gauges.

Part C lists the available pertinent data obtained from firings from the 105-mm Howitzer M3 using FNH M2 lot Rad-3004. Again the data do not permit a determination of the relationship of the indications of the two gauges but do show that the copper ball gauges read much lower than the medium caliber pressure gauges.

Part D of Table I gives pressure data obtained in firings from a nearly new 76-mm Gun M1A2 using charges of FNH M2 lot 4254. On June 2, 1944 a series of 8.0 lb slugs, made from standard HE shell M42A1 were fired. Four copper ball gauges were used in each cartridge case. All the readings obtained (23) have been used in preparing the table. Pressure data obtained with the medium caliber pressure gauge to compare with this is available for only one round. This has been included in the table. It will be seen that there is a large spread in the indications of the copper ball gauges in the same round but that the maximum indication from each round is fairly uniform, indicating that the actual pressures developed were fairly uniform and that many of the gauges did not work well mechanically. As medium caliber gauge readings are available for only one round no valid comparison of the readings of the two gauges is possible. The indication is, however, that the copper ball gauges read lower than the other and this is consistent with the indications from firings in the 105-mm Howitzer M3.

No survey of the relationship between the pressure indication of the U.S. Army copper gauges and a piezo electric gauge will be attempted here. It is appropriate, however, to mention comparisons carried out in the 76-mm gun and reported in B.R.L. Reports 351 and 378. In the work covered by the first mentioned report it was found that at normal temperatures with normal charges in this gun (pressures mostly a little over 40,000 p.s.i. copper) the pressure indicated by the piezo electric gauge was about 1.2 x that indicated by the medium caliber gauge. In the work covered by the second mentioned report in which excess pressures were developed (1) by increasing the charge and (2) by increasing the temperature the relationship was less consistent than in the work at normal pressures, but the results did not demonstrate a change in this relationship.

Table I - Part A

COMPARISON OF PRESSURE INDICATIONS OF U.S. ARMY MEDIUM CALIBER PRESSURE GAUGES, AND COPPER BALL GAUGES USED BY UNIVERSITY OF NEW MEXICO

Data from firings in 75-mm Gun M3 using FNH M2 lot 4254 for 37-mm Gun M3, M5 and M6

Where Fired	Date	Projectile Design	Number Rounds Included	Average Weight lbs	Charge(1) Weight oz	Air Temp. °F	Powder Temp. °F	Indicated Pressure average p.s.i.	Indicated Pressure max p.s.i.	Indicated Pressure min p.s.i.	Previous Rounds from Gun	Reference
A.P.G.		28-75D	11	8.36	32.5		70	33100	34200 (2)	29800	1931	A.P.G. FR M24862
A.P.G.		28-75D	11	8.36	32.5			34900	37400	33300	1905	A.P.G. FR M24862
U.N.M.	19-5-43	28-75D	1	8.5	32.8			34000 (3)			nearly new	NDRC Report NºA-234 p 98
U.N.M.	19-5-43	28-75D	1	8.5	32.8			36000			" "	NDRC Report NºA-234 p 98
U.N.M.	29-7-43	28-75D	1	8.69	32.8			30000			" "	NDRC Report NºA-234 p 98
U.N.M.	14-5-43	32-75 (4)	2	8.28	32.8			28250	31000	25500	" "	Report of Mar 10, 1944 p 18
U.N.M.	8-5-43	34-75	2	8.69	32.8			34500	37000	32000	" "	Report of Mar 10, 1944 p 18
U.N.M.		28-75A (5)	6	8.27	32.8			31600	32500	30000	" "	NDRC Report Nº A-234 p 96
U.N.M.	6-5-43	31-75	2	8.69	32.8			34000	37000	31000	" "	Report of Mar 10, 1944 p 18
U.N.M.	23-4-43	18-75A (6)	2	9.00	31.75			35000	37000	33000	" "	Report of Mar 10, 1944 p 17
U.N.M.	11-5-43 to 17-5-43	18-75D	4	8.58	32.8			35375	37500	34000	" "	Report of Mar 10, 1944 p 17
U.N.M.	14-5-43	4-75A' (7)	2	8.31	32.8			34250	35500	33000	" "	Report of Mar 10, 1944 p 17
U.N.M.	28-4-43	7-75A'	2	8.03	32.8			36000	37000	35000	" "	Report of Mar 10, 1944 p 17

(1) Charge weights are stated by U.N.M. in grams. The two weights involved were 930 and 900 grams. A.P.G. FR M24862 indicates that an increase of 0.3 oz in charge weight raises the pressure about 500 p.s.i.
(2) In A.P.G. firings two gauges were used in each round and the pressure stated was the average of the two readings.
(3) In U.N.M. firings as a rule a single gauge was used in each round.
(4) Designs 32-75 and 34-75 use partially segmented threaded steel ring base similar to that of 28-75D.
(5) Designs 28-75A and 31-75 use a solid base ring that is discarded axially. Thrust is transmitted to the rear face of the subcaliber projectile.
(6) Designs 18-75A and 18-75D use a completely segmented base ring held together on the subcaliber projectile by the rotating band. Thrust is transmitted as in 28-75A.
(7) Designs 4-75A' and 7-75A' use a completely segmented base ring that fits into a groove or grooves on the cylindrical surface of the subcaliber projectile and is held in place by the rotating band.

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Table I – Part B

COMPARISON OF PRESSURE INDICATIONS OF U.S. ARMY MEDIUM CALIBER PRESSURE GAUGES AND COPPER BALL GAUGES USED BY UNIVERSITY OF NEW MEXICO

Data from firings in 105-mm Howitzer M3 using FNH M1 lot X-6099

Where Fired	Date	Projectile Design	Number Rounds Included	Average Weight lbs	Charge Weight oz	Air Temp. °F	Powder Temp. °F	Indicated Pressure average p.s.i.	Indicated Pressure max p.s.i.	Indicated Pressure min p.s.i.	Previous Rounds from Gun	Reference
A.P.G.	7-6-44	3-105B(1)	8	15.6	48	60-68		26700	29700	24300	480	A.P.G. FR P-31518
U.N.M.	22-10-43	3-105	2	15.75	48			18000	18000	18000	nearly new	All U.N.M. data except temperatures are from the Report of March 10, 1944, pp. 27-28. Temperature data are from letters to J.W.G.
U.N.M.	15-11-43	3-105A	2	15.26	48			17500	19500	15500	" "	
U.N.M.	5-11-43	4-105(2)	2	16.61	48	67		18250	19500	17000	" "	
U.N.M.	13-11-43	7-105(3)	2	15.75	48	46		16250	18500	14000	" "	
U.N.M.	28-10-43	10-105B(4)	1	14.94	48	70		22000			" "	

(1) Designs 3-105, 3-105A and 3-105B are so nearly alike that pressures obtained with them under identical conditions should be the same except as they are affected by the weights of the projectiles. The designs are like 28-75D.

(2) Design 4-105 uses solid base plate to which the rotating band is attached.

(3) Design 7-105 uses a segmented steel base ring that fits in a groove on the wall of the subcaliber projectile and is held in place by the rotating band.

(4) Design 10-105B uses a partially segmented steel base ring the length of the rotating band only.

The weight of the charges used at A.P.G. was stated as 3.0 lbs that of those used at U.N.M. as 1362 grams.

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Table I - Part C

COMPARISON OF PRESSURE INDICATIONS OF U.S. ARMY MEDIUM CALIBER PRESSURE GAUGES, AND COPPER BALL GAUGES USED BY UNIVERSITY OF NEW MEXICO

Data from firings in the 105-mm Howitzer M3 using FNH M2 lot Rad-3004

Where Fired	Date	Projectile Design	Number Rounds Included	Average Weight lbs	Charge Weight oz	Air Temp. °F	Powder Temp. °F	Indicated Pressure average p.s.i.	Indicated Pressure max p.s.i.	Indicated Pressure min p.s.i.	Previous Rounds from Gun	Reference
A.P.G.	8-6-44	2-105R	9	11.1	55.1	61-69		28600	29500	27300	491	A.P.G. FR No 31518
A.P.G.	8-6-44	2-105R	1	11.1	56.8	69		34900				
U.N.M	17-2-44	2-105R	1	11.00	56.8	30		22000			nearly new	Report of March 10, 1944, p. 27 and letters to J.W.G. dated Feb 14, 1944 and Feb 19, 1944.
U.N.M.	week of 7-2-44	slug(1)	1	11.13	56.8	45		22000			" "	
U.N.M.	week of 14-2-44	slug	3	10.98	56.8	49-50		24666	27000	21000	" "	

(1) Slugs were made by cutting down standard 105mm HE shells to correct weight.

The weights of the charges used at A.P.G. were stated as 3.444 and 3.550 lbs, that of those used at U.N.M. was 1610 grams.

B-3-1

Table I - Part D

COMPARISON OF PRESSURE INDICATIONS OF U.S. ARMY MEDIUM CALIBER PRESSURE GAUGES, AND COPPER BALL GAUGES USED BY UNIVERSITY OF NEW MEXICO

Data from firings in new 76-mm gun M1A2 using FNH M2 lot 4254

Where Fired	Date	Projectile Design	Number Rounds Included	Average Weight lbs	Charge Weight oz	Air Temp. °F	Powder Temp. °F	Gauge Readings(1) average p.s.i.	max p.s.i.	min p.s.i.	Number of Gauge Readings	Reference
U.N.M.	2-6-44	slug	1	8.0	40	78	65	39375	47000	35000	4	Letter to J.W.G. 2-6-44
U.N.M.	2-6-44	slug	1	8.0	40	79	65	43250	45500	41000	2	
U.N.M.	2-6-44	slug	1	8.0	40	80	65	40000	43000	36000	3	
U.N.M.	2-6-44	slug	1	8.0	40	81	65	39333	45500	30500	3	
U.N.M.	2-6-44	slug	1	8.0	40	82	68	40000	45500	32000	4	
U.N.M.	2-6-44	slug	1	8.0	40	83	68	43166	45500	42000	3	
U.N.M.	2-6-44	slug	1	8.0	40	83	68	40000	43000	37500	4	
					Average of 23 readings			40500				
					Average of 7 maximum readings				45000			
U.N.M.	13-6-44	slug	1	8.0	40	84	70	49700	50200	49200	2	Letter to J.W.G. 14-6-44

(1) In the firings on 2-6-44 four copper ball gauges were used in each round. In the firing on 13-6-44 two medium caliber pressure gauges were used.

The weight of the charges was stated as 1410 grams.

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ABSTRACT:

The work conducted on sabot projectiles by the University of New Mexico from 1942 to 1944 is summarized. Following a discussion of sabot mechanisms and materials of construction, several projectiles are described. These include armor-piercing sabot projectile for the 75-mm gun, armor-piercing and high-explosive sabot projectiles for the 105-mm Howitzer M3, armor-piercing sabot projectiles for the 75-mm pack Howitzer, armor-piercing sabot projectiles with tungsten-carbide cores for the 76-mm gun M1A2, designs for the 76-mm and 90-mm guns for construction by Remington Arms Co., Inc., and further developments in these designs.

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