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SPACED ARMOR

Paper Presented at Second Tank Conference
Ballistic Research Laboratories
Aberdeen Proving Ground
Maryland

27-29 November 1950

By

A. Hurlich
Metallurgist

20 November 1950

WATERTOWN ARSENAL
WATERTOWN, MASS.

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SPACED ARMOR

The earliest reference that I have found to the modern use of spaced armor is in Brassey's Naval Annual for 1913, where, on page 372, reference is made to a proposal to employ a 1" thick plate in front of and separated by a space from the main armor of naval vessels. The function of this relatively thin plate was to decap the attacking projectile so that it would be shattered and consequently defeated by the heavy face-hardened belt armor of the vessel.

The anti-torpedo blisters that were fastened to ships at and below their waterlines during World War I represented another use of spaced armor to increase the defensive ability of armored vessels. The function of the outer plating of the blisters was to detonate the torpedoes some distance from the hull of the vessel and prevent the full force of the detonation from breaching the vessel.

Spaced armor was first used in World War II by the Germans who, in 1943, fitted some of their tanks, assault vehicles, and motorized artillery mounts with auxiliary armor consisting of thin plates suspended by means of brackets along the sides of the hulls and turrets of the vehicles. Figures 1 and 2 demonstrate this use of spaced armor on an assault vehicle at the Russion front and on a PzKw IV tank in Italy.

"Tactical and Technical Trends" No. 40, 16 December 1943, reported that the 1/8" to 1/4" thick side plating of the type shown above provided protection against hollow charge shells and moderately small caliber tungsten carbide cored ammunition, and may cause high velocity AP shot to deflect and strike the main armor sideways or at an increased angle. It was reported from Russian sources, however, that the skirting armor did not protect against hollow-charge anti-tank ammunition.

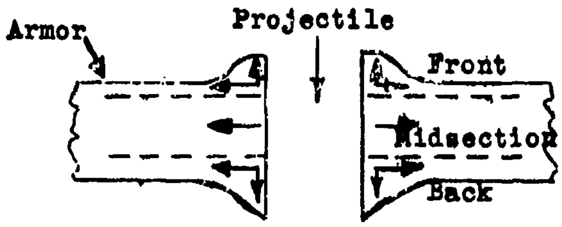
It is the purpose of this discussion to explore the utility of spaced armor in greatly increasing protection with only a slight increase in the weight of armor, to consider the types of attack which may be effectively coped with by spaced armor, and also to describe the limitations of spaced armor. Means of improving the effectiveness of armor-piercing projectiles against spaced armor will also be considered.

It would be well at this point to define what is meant by "spaced armor." As used throughout this discussion, "spaced armor" refers to a structure consisting of a moderately thin plate in front of, and separated by a space from, a considerably thicker armor plate which constitutes the main armor of the vehicle under consideration. The thin front plate, called the "skirting plate," faces the attack, and represents approximately 10% or less of the total weight of the armor. A more complex spaced armor arrangement may comprise a number of skirting plates, but for the sake of simplicity in presenting basic information, spaced armor with only one skirting plate will be considered in the following discussion. The skirting plate may or may not be parallel to the main armor, and the specific effects of such arrangements will be discussed later.

The function of the skirting plate is not to absorb any significant proportion of the kinetic energy of attacking projectiles, but to so affect the projectiles that their performance against the main armor is drastically reduced. The means by which this degradation in performance is effected will also be considered in detail later. The basic approach to the design of spaced armor arrangements is to have the skirting plate of the minimum thickness capable of producing the desired effect upon the projectile. There is a sound reason for this approach. Numerous trials against laminated or spaced armor arrangements consisting of a number of plates of equal or approximately equal thickness have invariably shown that such armor combinations provide considerably less protection than a single solid plate of the same total thickness.

For example, a 3" thick rolled homogeneous armor plate (270 BHN) has a ballistic limit of approximately 2350 ft/sec when attacked by the 90 mm APC M82 projectile at an obliquity of 45°. When two 1-1/2" thick plates of the same hardness as above are placed in contact with each other and are attacked under the same conditions, the ballistic limit falls to about 1980 ft/sec.* When the two 1-1/2" plates are separated by a space of 6" (both plates parallel and at 45° to the line of fire), the ballistic limit decreases still further to a value of approximately 1640 ft/sec.*

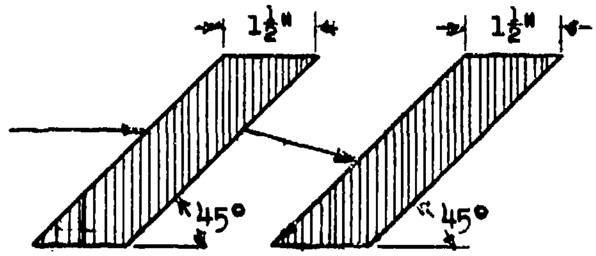
The single 3" thick plate was ballistically superior to the two 1-1/2" thick plates in close contact with each other for the following reason. The front and rear surfaces of armor provide less resistance to the penetration of a projectile than does the midsection of the plate. This is so because the front and rear surfaces of the armor can be deformed not only laterally, but can flow outward to form face and rear bulges and petals. The midsection of the plate flows only laterally, its upward and downward movement being constrained by the surface material. This is illustrated in the following sketch:



* Aberdeen Proving Ground Report AD-843, "Ballistic Test of Spaced Armor Arrangements which can be used for Increasing the Protection of T26E1, M24, and M4 Series of Tanks," 4 January 1945.

The midsection of the plate therefore offers more resistance to penetration than do both the front and rear of the plate. Putting two thin plates together to represent a single thick plate thus increases the amount of less resistant surface material and decreases the amount of more resistant midsection material. Consequently, the composite armor will have a lower ballistic limit than the solid plate of the same total thickness.

The reason for the still further decrease in ballistic resistance when the two 1-1/2" plates were separated by a distance of 6" from each other is that the projectile, upon emerging from the first plate was turned in such fashion that it impacted the second plate at an obliquity of less than 45°, thus reducing its ballistic resistance yet further. The path of the projectile is illustrated in the following sketch:



We now come to the consideration of the function of the thin skirting plate in reducing the effectiveness of projectiles which perforate it. The skirting plate may affect projectiles in any or all of the following ways:

a. The armor-piercing cap may be removed, see Figure 3, thus causing the shot to be shattered against the heavy main armor.

b. The shot may be turned or yawed, see Figure 4, so that it impacts the main armor at an increased angle.

c. The shot may be fractured upon passage through the skirting armor, see Figures 5 and 6. The loss of the point and the dispersal of the fragments result in a marked decrease in the penetration performance.

A number of years ago, a demonstration firing of the 90 mm HVAP M304 shot was arranged at Aberdeen Proving Ground. The target was to be a 10" thick cast armor plate which can be quite easily penetrated by this carbide cored projectile at 0° obliquity. Because no 10" thick plate was available, a 4" thick and a 6" thick cast plate were placed together and were shot. Much to everyone's chagrin and surprise, the shot failed to perforate the target. Upon subsequent examination, it was found that because the plates were slightly bowed, the two plates were separated from each other about 2" at the point of impact. The shot emerged from the first plate in a fractured condition and the very short distance of 2" was sufficient to destroy the effectiveness of the shot fragments against the second plate.

Although tungsten carbide has other characteristics which make it excellent for projectiles, the material is unfortunately very brittle. It is very rare that a carbide core is recovered intact after perforating armor, even when the impacts are at 0° obliquity. As part of a program aimed at improving the performance of carbide cored projectiles, the Watertown Arsenal arranged, some years ago, trials of the standard 90 mm HVAP M304 shot against a number of spaced armor targets. The main armor consisted of 6" thick wrought homogeneous armor at 30° obliquity. The skirting plate was placed 12" in front of and parallel to the main armor, and the variable was the thickness of the skirting plate. The results of the tests are shown in Figure 7.

Placing a 1/2" thick plate in front of the 6" thick armor reduced the range at which the target could be defeated from 2900 yards to 350 yards! The addition of the 1/2" thick plate more than doubled the energy required to defeat the target which was heavier by only 8-1/3%. The 6-1/2" spaced armor target provides the same protection against the 90 mm HVAP M304 shot as a single solid plate 11-1/2" in thickness. The utilization of spaced armor effects a weight savings of 43.5% in this case.

It will be noted that the spaced armor was, in general, increasingly effective as the thickness of the skirting armor increased. This resulted from the fact that the core was more severely broken up by the heavier skirting plates.

During the past year, the Armor Branch of Aberdeen Proving Ground has been firing 57 mm and 90 mm AP, APC, and HVAP shot against a variety of spaced armor targets to determine the influence of skirting armor upon the above projectiles and to accumulate fundamental information on the interaction of kinetic energy projectiles and spaced armor combinations. The details of the ballistic testing program were laid out jointly by personnel of Watertown Arsenal and Aberdeen Proving Ground.

The first phase of the program consisted of firing projectiles through thin plates at various obliquities and photographing the projectiles in flight at various distances behind the plates. Photographs of this type are shown in Figures 3 through 6. Spaced armor targets were then ballistically tested in the following order:

a. Test of main armor without skirting plates.

b. Test of spaced armor with skirting plate parallel to main armor and 16" away (Plate Arrangement A).

c. Test of spaced armor with skirting plate at same obliquity as main armor but tilted in opposite direction from line of fire. Plates 16" apart along line of fire (Plate Arrangement B).

In all cases, the skirting armor consisted of a number of 1/4" thick plates of unheat-treated steel armor sandwiched together to form skirting of the desired thickness. This procedure was followed because of the unavailability of 1/2" and 3/4" thick plates.

The preliminary firing of 57 mm and 90 mm AP and APC projectiles through skirting armor yielded some surprising results. A total of twenty-six rounds of 57 mm AP M70 and fourteen rounds of 57 mm APC M86 projectiles were fired through 1/2" thick skirting armor at obliquities ranging from 30° through 60°, and in each case the projectile emerged intact. The caps were removed from the APC shot and both the AP and APC shot bodies were yawed, but none were fractured. However, 26 of 28 rounds of 90 mm AP T33 (M318) which were fired through 1/2" thick skirting plate were fractured upon emerging behind the plate, see Figures 5 and 6. The 90 mm APC T50 projectile behaved in a different manner - only 30 rounds of 145 fired were fractured. It required 1" skirting plate at 60° obliquity to consistently fracture the APC shot.

Why the 57 mm AP shot remained intact and the 90 mm AP shot broke up going thru the same target (1/2" plate) is not yet clear. Off-hand, it should be expected that the reverse would happen, since the 57 mm shot are relatively long and thin and were not heat treated according to the best metallurgical practices, while the 90 mm shot are relatively short and stubby and were excellently heat treated. It is believed that longitudinal wave phenomena played a part in this behavior, and this aspect is currently under study at the Watertown Arsenal.

The more interesting data accumulated to date on this project are tabulated in Figure 8. In the case of both the 57 mm AP and APC projectiles, spaced armor with parallel plate arrangements was less efficient than the main armor alone. This resulted from the fact that the unfractured shot were turned or yawed by the skirting armor so that they impacted the main armor at a lesser angle of obliquity than the original, thus resulting in a lower ballistic limit for these spaced armor arrangements. Actually, the decrease in the ballistic limits (approx. 200 ft/sec in both cases) corresponds to a decrease of 5° to 7° in obliquity (from 40° to 33° to 35°). Actual photographic measurements of the yawing of the 57 mm AP and APC projectiles behind the skirting plate were of this same magnitude.

When the skirting plate and the main armor were sloped towards each other (Plate Arrangement B) the ballistic efficiency of the spaced armor against 57 mm AP and APC projectiles was very high. The 2-1/2" spaced armor arrangement is equivalent ballistically to a 3" thick solid plate, thus resulting in a weight savings of 17% in this case.

Both the parallel and non-parallel spaced armor arrangements were approximately equally effective in degrading the performance of the 90 mm HVAP M304 shot. Since this projectile is affected by core breakage rather than by yawing, the angle between the skirting plate and the main armor is not critical. The 4-1/2" thick spaced armor arrangement at 30° obliquity is ballistically equivalent at the same obliquity to a single solid plate 7" in thickness, representing a weight savings of approximately 33%. The 4-1/2" thick spaced armor arrangement at 45° is ballistically equal to 8" of solid armor; a weight savings of almost 44%.

Since, however, the 90 mm APC shot is not always fractured by skirting armor, the behavior of this projectile against spaced armor targets was sometimes inconsistent. The addition of 1/2" thick skirting armor to 4" thick armor at 30° obliquity resulted in a 50% decrease in the maximum range at which the target could be defeated by the 90 mm APC T50 shot, while 3/4" thick skirting plate added to 3" armor at 40° obliquity actually made the armor more vulnerable, increasing the range at which it could be defeated from 4800 to 5250 yards.

It has been observed that spaced armor is most efficient when the attacking projectile is broken up by the skirting plate. When this happens, spaced armor arrangements can effect weight savings in the range of 30% to 50% over solid armor with no sacrifice in protection performance. When, however, projectiles are not broken, but only decapped or yawed, weight savings of 10% to 20% can be effected if the projectiles are yawed to impact the main armor at an increased obliquity. If the projectiles are yawed to impact the main armor at a reduced obliquity, spaced armor becomes considerably less efficient than the same weight of solid armor; becoming, in fact, even less efficient than the main armor alone.

We now come to the consideration of what might be done to kinetic-energy projectiles to minimize their degradation by spaced armor. Dr. Clarence Zener and his group at the Watertown Arsenal worked on this problem during the last war and they came up with some interesting results. They found that a one-twelfth caliber thick plate was sufficient to strip the caps from standard APC projectiles at service velocities.[1] Upon removal of their caps, the shot would shatter against targets which they could otherwise penetrate, thus resulting in a lowering of their ballistic performance.[2] Efforts were made to discover means for preventing the decapping of APC shot by skirting plates. Analysis of the fracture of caps by skirting plates showed that biaxial tensile stresses were set up in the cap forward of the nose of the shot which resulted in brittle fracture of the cap. The mechanism of biaxial stress formation is illustrated in Figure 9.

The function of caps on APC shot is to reduce the peak inertial pressures on the nose of the shot in the early stages of penetration of armor and thus prevent the shatter of the ogive section of the shot.

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[1] C. Zener and J. F. Sullivan, "Principles of Armor Protection, 4th Partial Report," Report No. WAL 710/607-3.

[2] C. Zener and J. F. Sullivan, "Principles of Projectile Design for Penetration, 2nd Partial Report," Report No. WAL 762/231-2.

Therefore, putting a cap on the AP cap should do the same for the AP cap. This was found to work.[1] Figure 10 shows some designs of copper buffer caps which were fitted on APC caps and which prevented the caps from being stripped off by skirting armor. Figure 11 shows some 37 mm APC projectiles which were fitted with these copper buffer caps. There is no reason to prevent this procedure from being applied to larger caliber APC shot.

With respect to the present standard HVAP rounds, the cores of these shot are completely unprotected against fracture during the penetration of skirting plates. The sub-projectiles of British and Canadian APDS rounds contain tungsten carbide cores which are capped with aluminum or tungsten nose pads and are encased in rather sturdy steel sheaths which completely surround the tungsten carbide cores. Tests have demonstrated that these rounds are very much less degraded by spaced armor than our standard HVAP rounds. The nose pads and the steel sheaths reduce the tendency toward break-up of the core upon perforation of thin plates. The performance of the best APDS shot are, however, degraded by spaced armor combinations but to a lesser extent than HVAP shot.

There are other types of armor-defeating ammunition which do not depend upon their kinetic energy for the defeat of armor. Among these types are the "squash-head" or high-explosive plastic charge shell and the shaped charge shell. The former achieves defeat of armor by setting up shock waves which result in tensile fracture of the armor in a plane parallel to the plate surfaces and the subsequent dislodging of a circular spall from the rear surface of the armor at a velocity of some hundreds of feet/second. The second type of ammunition achieves penetration of armor by the formation of a very high velocity jet of small particles which perforates armor as if it were a fluid medium. In the latter case, wide variations in the mechanical properties of the armor material produce little or no change in its resistance to penetration by shaped-charge shell.

The British have done a fairly considerable amount of firing of the "squash-head" shell against spaced armor structures and have found that this ammunition can be rendered ineffective by skirting armor which prevents the shock wave from reaching and being transmitted thru the main armor plate.[2] Spaced armor combinations are undoubtedly the most effective means of coping with "squash-head" shell, since this type of ammunition can spall considerable thicknesses of solid armor. Spaced armor consisting of a layer of sponge rubber between the skirting plate and the main armor have been found effective in preventing spalling by "squash-head" shell. In designing spaced armor structures to defeat "squash-head" shell attack, it is important to prevent contact between the skirting plate and the main armor during detonation of the shell, for otherwise the shock waves would be transmitted to the main armor.

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1 B. C. Ward, "Principles of Projectile Design for Penetration, 7th Partial Report," Report No. WAL 762/231-7.

2 Proc. No. Q5,476, "Attack of Armor," Ordnance Board Investigation No. 1901.

There are conflicting data on the performance of spaced armor arrangements against shaped-charge shell. Tests during World War II showed that the 105 mm HEAT M67 shell could be defeated by spaced armor consisting of two 1-1/2" thick homogeneous armor plates spaced 12" apart.[1] NDRC reported[2] that spaced armor is superior to solid steel on a weight basis for protection against shaped-charge shell. This advantage was attributed largely to the effect of the increased standoff caused by the spaced armor arrangements. The British report[3] that "Hollow charge shell likewise exhibit a similar degradation of performance against such combination targets (Procs. Nos. 26,523 and 29,486). The efficiency of the jet deteriorates markedly with space distance (Procs. Nos. 28,486 and 29,574)."

More recent information on newly designed shaped-charge shell[4] indicate that they are not degraded by spaced armor combinations unless the skirting plates are placed at distances from the main armor which are impossible from a practical engineering viewpoint to use in actual vehicle designs.

More information on the performance and design of spaced armor combinations against "squash-head" and shaped-charge shell is vitally needed. It is understood that the Ballistic Research Laboratories will obtain such information as part of its general study on the Tank Vulnerability and Effectiveness Program.

I would like to conclude with the presentation of a tentative proposal for armoring vehicles with spaced armor arrangements to provide a well-balanced degree of protection against a considerable number of the different types of available attack. Last March, in the paper on "Terminal Ballistics of Armor and Armor-Piercing Shot,"[5] data were presented to show the disposition of armor to provide defense against specific attacks with the minimum weight of armor. It was shown that optimum defense against carbide cored and APC shot was provided by highly sloping armor at approximately 60°-65° obliquity, whereas best protection against AP shot was provided by armor sloped at approximately 30° obliquity.

It is believed possible to design a spaced armor structure which will be equally effective against all types of kinetic-energy projectiles, which will defeat "squash-head" shell and which may provide a real measure of defense against shaped-charge shell. Such arrangements will have the main

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1 Aberdeen Proving Ground Report No. AD-843, "Ballistic Test of Spaced Armor Arrangements Which Can Be Used for Increasing the Protection of T26E1, M24, and M4 Series of Tanks," 4 January 1945.

2 NDRC Report No. A-346, "Symposium on Shaped Charges," 9 May 1945.

3 Proc. No. Q5-476, "Attack of Armor," 30 January 1948.

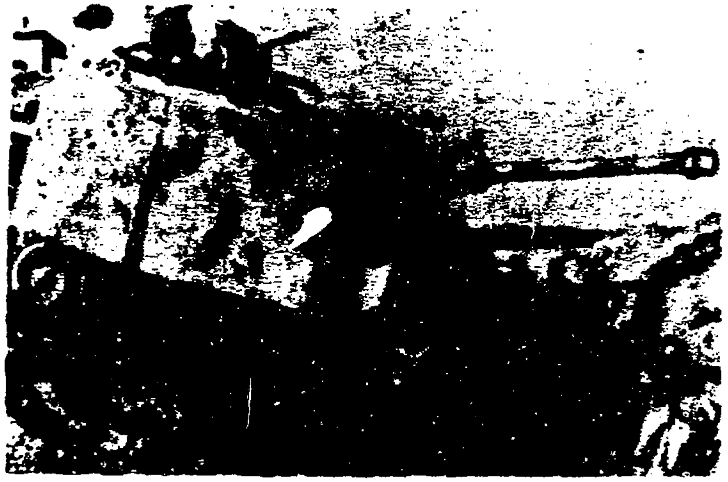
4 Private communication to the author from personnel of Aberdeen Proving Ground.

5 A. Hurlich, "Terminal Ballistics of Armor and Armor-Piercing Shot," Report No. WAL 710/930, 17 March 1950.

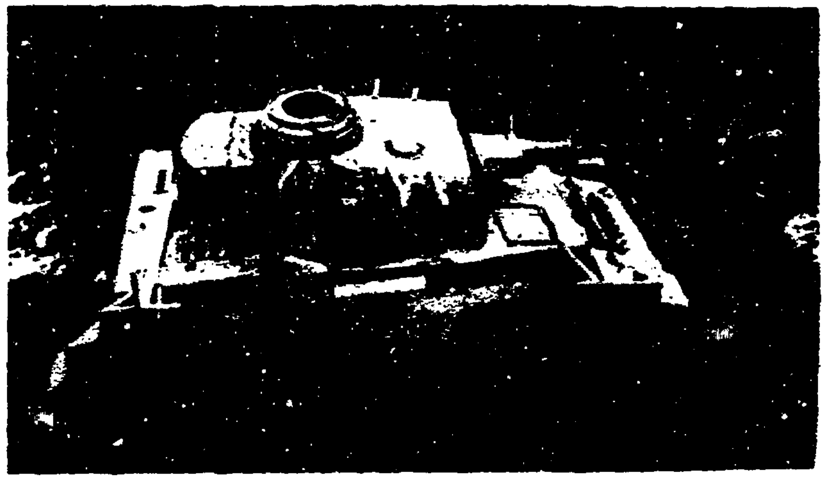
armor sloped at about 30° obliquity, with the skirting plate tilted in the opposite direction, either as a single plate or as a series of plates arranged in a Venetian-window blind arrangement. Capped AP shot would be decapped and yawed so as to strike the armor at an angle between 30° and 40° obliquity, in which range monobloc shot are least efficient against heavy targets. Carbide cored projectiles will be fractured and rendered ineffective, and both monobloc and capped steel shot may be fractured, but even if they are not fractured, they will impact the main armor under the least efficient conditions. "Squash-head" shell will be defeated by this structure, but a considerable amount of development is needed to design spaced armor structures which will not be destroyed by the detonation of the first round and made susceptible to defeat by the second round.

As a matter of fact, the Watertown Arsenal was requested, just prior to V-J Day, to develop armor which could be added as a field modification to the M4 tank to protect it from point-blank attack by the Japanese 47 mm APC shot. Some of our tanks on the Pacific islands were being ambushed by the Japanese, who would hide 47 mm anti-tank guns along jungle roads and wait for days, if need be, before the right target would present itself. Samples of the Japanese 47 mm APC shot were made available for the necessary tests. It was found that a one-tenth caliber thick plate would remove the caps from these shot. The shot were poorly made from a metallurgical viewpoint, being essentially skin-hardened only, and once they were decapped, they shattered against and failed to penetrate armor corresponding in thickness to the side armor of the M4 tank. It was accordingly recommended that a Venetian-blind arrangement of 0.2" thick mild steel plates be attached to the tanks in the Pacific theatre, but the war ended before this could be done.

A few months ago, Watertown Arsenal was asked to determine the nature of the armor-piercing projectile which perforated the sponson plate of one of our M4 tanks in Korea. We were sent the sample of armor which had the hole through it, and we were asked to describe the projectile which caused the hole. It was found that this tank was knocked out by a 47 or 50 mm carbide core armor-piercing projectile of the arrowhead type used by both the Germans and Russians during World War II. Had that tank been fitted with spaced armor, it may not have been knocked out.



AT OREL Nazis hung slabs of armored skirting on gun chassis to shield hull and suspension system. Periscope and 7.9-mm. AA gun are on top.



Nazi PzKw Mark IV has appeared in Italy and on the Eastern Front with spaced armor bracketed to the turret wall and to the sides of the hull. The broadened turret silhouette looks much like that of the Tiger.

EXAMPLES OF GERMAN USE OF AUXILIARY ARMOR

FIGURE 1

WTN.639-10,633

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Figure 1

Prominent armored skirting on Mark IV conceals and protects hul and suspension system. Turret looks larger in diameter with added ar mor. Prominent cupola is German feature, as is muzzle brake on gun

Interesting view of the German Mark IV shows how the armored side skirting, attached to brackets, hangs away from the hull. Notice how extra turret armor stands away from turret, curves toward mantlet.

EXAMPLES OF GERMAN USE OF AUXILIARY ARMOR

WTN.639-10,636

FIGURE 2

(FROM RECOGNITION JOURNAL, NOS. 10-11)

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Figure 2

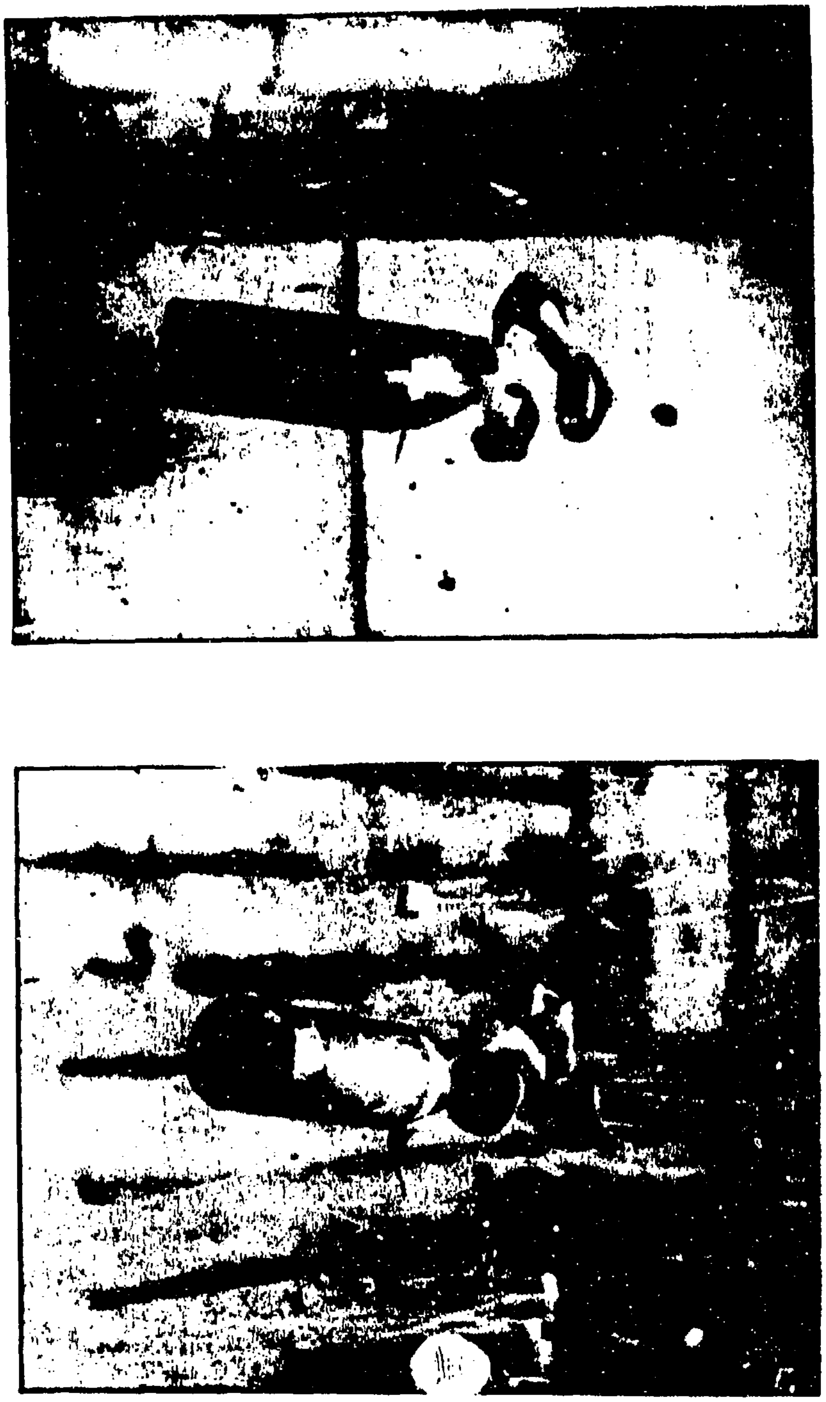
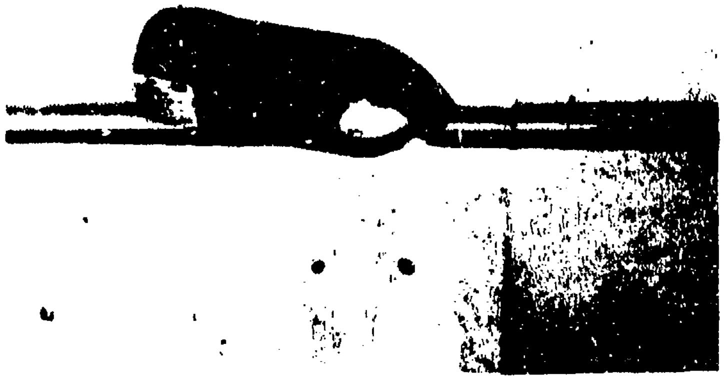


FIG. 49.
Arditron flash photographs of 6-pr.
Two simultaneous views from different aspects showing breakage of piercing cap.

Figure 3

Side View



Top View

Round [illegible]

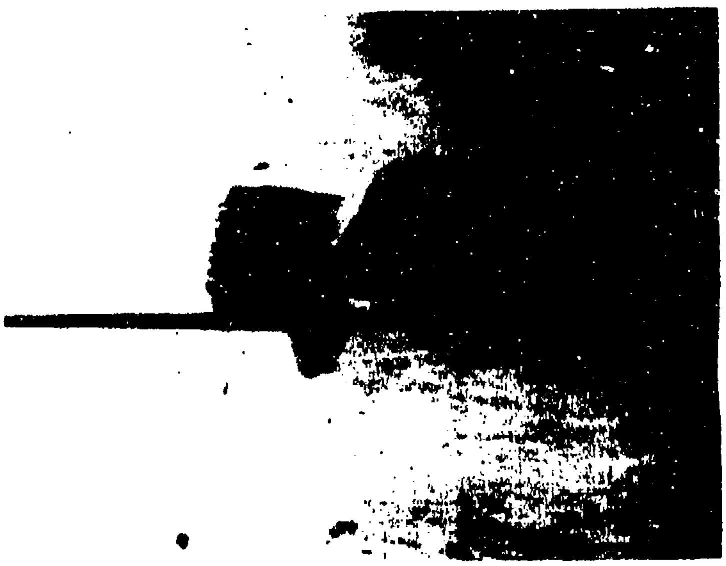
WTN.639-11,126

A62744 RESTRICTED ABERDEEN PROVING GROUND 14 August 1950

Project No. TB3-1224B. 90mm, AP, T33 Projectile After Passing Through Skirting Plate, Consisting of Four Pieces of 1/4" Armor in Contact With Each Other and Inclined at 60° Obliquity so that it's Top Edge is Nearest to Gun Muzzle. Projectile Velocity 2070 fps.

Figure 4

Side View



Top View

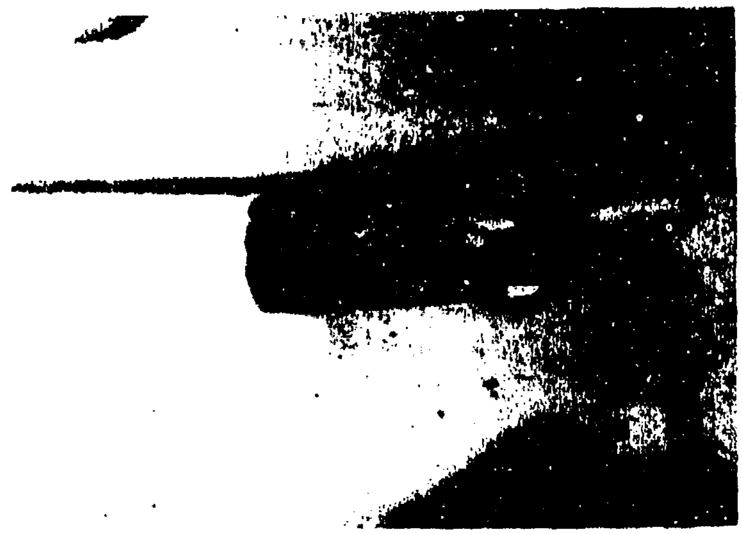
Round [illegible]

WTN.639-11,128

A62736 RESTRICTED ABERDEEN PROVING GROUND 14 August 1950

Project No. TB3-1224B. 90mm, AP, T33 Projectile After Passing Through Skirting Plate, Consisting of Four Pieces of 1/4" Armor in Contact with Each Other and Inclined at 60° Obliquity so That it's Top Edge is Nearest to Gun Muzzle. Projectile Velocity 2424 fps.

Figure 5



Side View

Top View

Round [illegible]

WTN.639-11,127

A62745 RESTRICTED ABERDEEN PROVING GROUND 14 August 1950

Project No. TB3-1224B. 90mm, AP, T33 Projectile After Passing Through Skirting Plate, Consisting of Two Pieces of 1/4" Armor in Contact with Each other and Inclined at 60° Obliquity so that it's Top Edge is Nearest to Gun Muzzle. Projectile Velocity 2025 fps

Figure 6

TABLE # I

PERFORMANCE OF TUNGSTEN CARBIDE CORE ARMOR-PIERCING AMMUNITION

(90 mm HVAP M304) AGAINST SPACED ARMOR COMBINATIONS

Thickness Main Armor	Thickness Skirting Armor	Protection Ballistic Limit f/s	Maximum Range for Penetration - yds
6" R.H.	None	2590	2900
6" R.H.	1/4"	3379	1050
6" R.H.	3/8"	3263	1300
6" R.H.	1/2"	3689	350
6" R.H.	1"	Partial Penetrations at 3735, 3742 f/s	Less than 200

NOTE:
Main Armor at 30° obliquity, with skirting armor 12" in front of main armor and parallel to it.

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Figure 7

TABLE II

BALLISTIC PERFORMANCE OF SPACED ARMOR COMBINATIONS

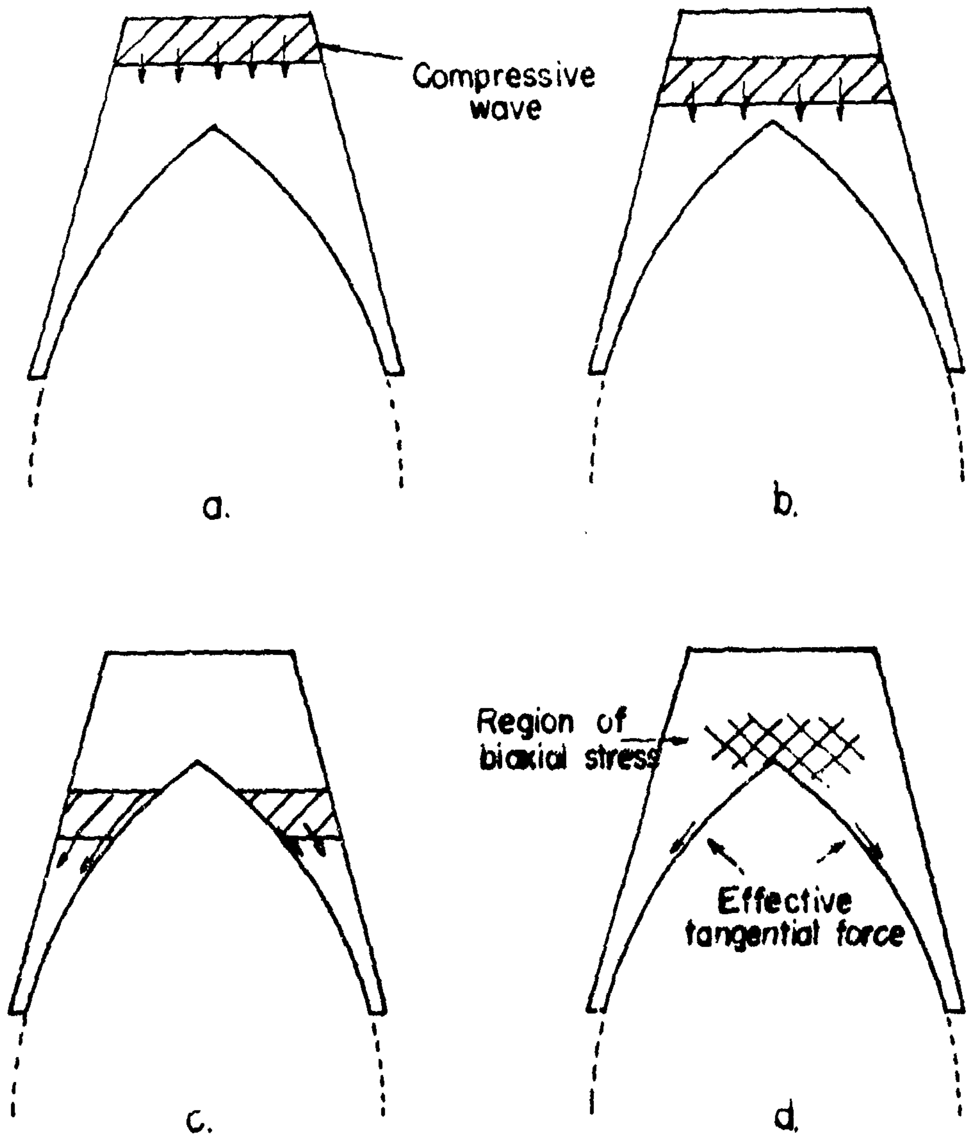
Projectile	Thickness Skirting Plate[1]	Thickness Main Armor[2]	Obliquity of Main Armor	Plate Arrangement[3]	Protection Ballistic Limit f/s	Maximum Range for Penetration - yds
57mm APC	None	2"	40°	-	2149	1500
M86	1/2"	2"	40°	A	1943, 1940	2000
"	1/2"	2"	40°	B	2755	Above m.v.
57mm AP M70	None	2"	40°	-	1997	1850
"	1/2"	2"	40°	A	1772	2500
"	1/2"	2"	40°	B	2620, 2638	175
90mm HVAP	None	4"	30°	-	2226	3750
M304	1/2"	4"	30°	A	2780	2400
"	1/2"	4"	30°	B	2702	2600
90mm HVAP	None	4"	45°	-	3210, 3052	1600
M304	1/2"	4"	45°	A	3774	200
90mm APC	None	4"	30°	-	2171	4200
T50E1	1/2"	4"	30°	A	2681	2000
"	1/2"	4"	30°	B	2657	2100
90mm APC	None	3"	40°	-	2040	4800
T50E1	1/2"	3"	40°	A	2452	3200
"	3/4"	3"	40°	A	2298	3600
"	3/4"	3"	40°	B	1950	5250

- -

1. 1/2" thick skirting plate consisted of two 1/4" thick unheat-treated steel plates sandwiched together.
2. Main armor consisted of rolled homogeneous armor, 2" plate at 300 BHN and 4" plate at 280 BHN.
3. Plate Arrangement: A - Plates parallel to each other and 16" apart.
   B - Plates 16" apart in line of fire and sloped towards each other, each inclined at the same angle but in opposite directions from normal.

Figure 8

DEVELOPMENT OF BIAXIAL TENSION IN CAP THROUGH IMPACT UPON A THIN PLATE



a, b, c: — PROGRESSION OF COMPRESSIVE WAVE DOWN THE CAP, ARROWS GIVE DIRECTION OF MOTION.

d: — EFFECTIVE TANGENTIAL FORCES, AND BIAXIAL STRESS PRODUCED THEREBY

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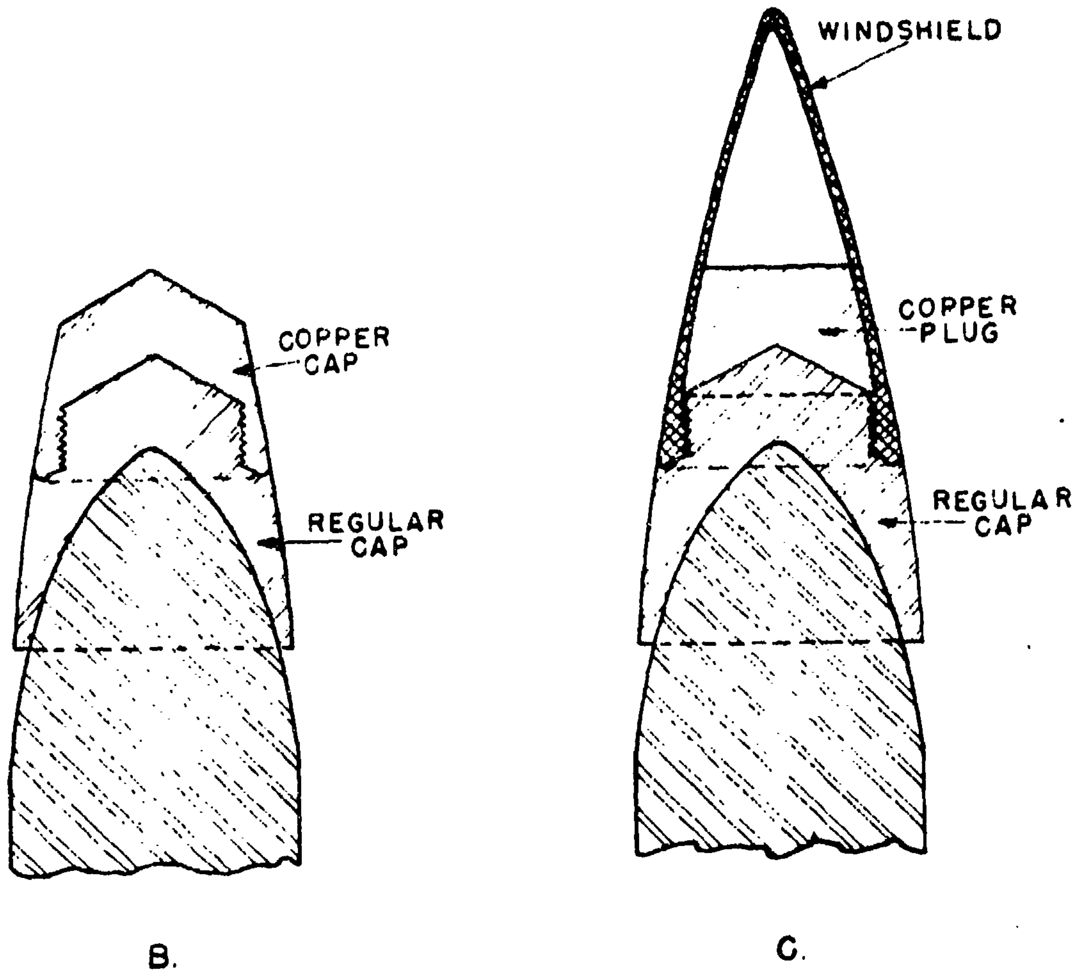
Figure 9



37 MM. M51 A.P.C. PROJECTILES

DIAGRAMS SHOWING PLACEMENT OF
EXPERIMENTAL BUFFER CAPS

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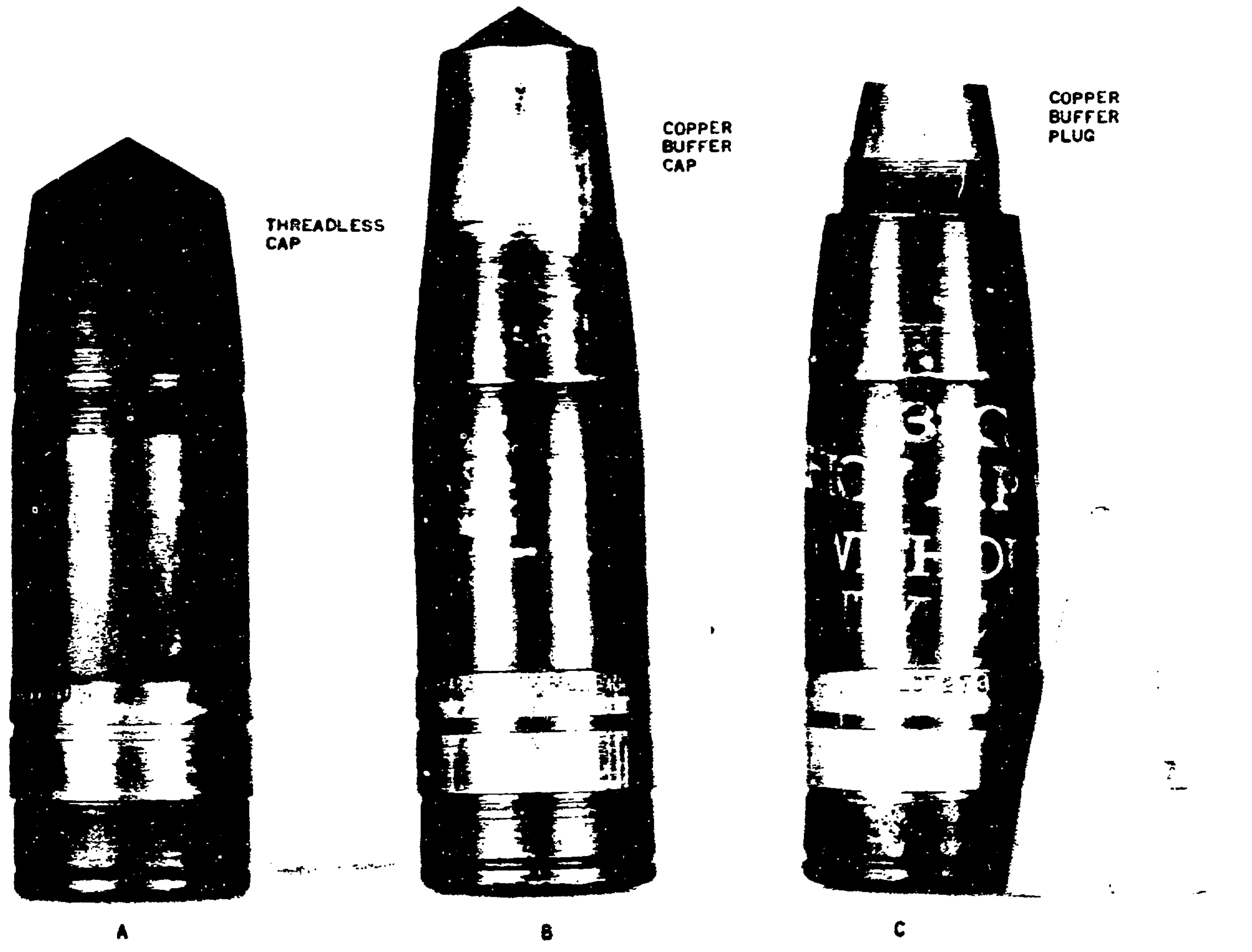
Figure 10

Figure 11



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EXPERIMENTAL PROJECTILES

WTN.751-1421

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Figure 11