WORLD WAR II BALLISTICS:
Armor and Gunnery

Lorrin Rexford Bird

and

Robert D. Livingston

SECOND EDITION

Overmatch Press

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1. INTRODUCTION

GENERAL NOTES

Recreating WW II tank battles on the war game table, or analyzing battlefield reports, is not a simple task. Each nation used ammunition and armor with different shapes, weights, caps, hardness, toughness characteristics and thickness. While American data is available and comprehensive for WW II ammunition, national differences limit the accuracy of straight-forward extrapolation from American figures.

Based on over 25 years of research on armor and projectile effectiveness, data for British, American, Soviet, Italian and German vehicles and guns has been converted to a single basis allowing direct comparison. Estimated penetration ranges computed from curves and data in this booklet have been compared to battlefield reports and firing tests, are reasonably consistent with reported ranges and address a number of hard-to-explain results that include the following:

1. Variable resistance offered by Panther and Sherman glacis
2. Inability of commonly assumed slope multipliers to predict armor resistance
3. Greater resistance of face-hardened armor when hit by uncapped rounds
4. Variable resistance offered by rounded armor, including mantlets and turrets
5. Increased vulnerability of many vehicles against relatively large diameter rounds (75mm and above versus 50mm and smaller)
6. Greater reported penetration range of Soviet 122mm APBC rounds against Panther glacis, compared to 122mm AP
7. Ability of Panther and Tiger tanks to penetrate the frontal armor of IS-2 and IS-2m tanks.

This book will also address various issues related to hit probability and shot placement.

The intent of the book is to provide the tools needed to analyze and predict penetration ranges against WW II tank targets, and the book presentation ranges from graphs to mathematical equations. The authors realize that many war gamers and researchers will not be interested in every section of this book, and complex subjects may be bypassed.

The book is not set up as a war game reference since the various sections are spread throughout the booklet. This is a reference document that may be used to prepare specially formatted war game materials.

SPECIAL NOTES ON PROCEDURE USE

The standard armor resistance in this booklet is American penetration test plate, which had a Brinell Hardness Number of 220 to 240, was rolled, homogeneous (about the same hardness all the way through) and was good quality. Good quality armor is free of flaws and brittle behavior that can decrease resistance.

Face-hardened armor consists of two different hardnesses in a single plate, where a thin and very hard surface layer (450 to 650 Brinell Hardness) is designed to shatter projectile noses on impact, or before they can penetrate too far. American face-hardened armor was used as the standard.

The procedures also, as a general rule, convert angled hits on armor to vertical equivalent thicknesses for comparison with penetration data against vertical plate at 0° impact. An impact angle of 0° is defined as a hit perpendicular to the armor surface, so horizontal projectile motion against a vertical plate would have an impact angle of 0°.

The simplest and most space efficient way to tabulate penetration data is at one impact angle as a function of range. While penetration against 18 angles from 0° to 85°, at 5° intervals, could be accomplished, the tables would probably double the size of this booklet, be unwieldy to use and leave out angles like 53°.

Penetration data is presented at 0° impact. The procedures in this booklet convert armor to an equivalent thickness at 0°, which allows direct comparison.

Penetration data is presented for 50% success, which is based on firing tests where a given plate thickness is attacked and the highest velocity failure, and the lowest velocity success, are averaged to define the impact velocity where half the hits fully penetrate. An assumed curve for impact velocity versus range is then used to estimate penetration as a function of range from the penetration-velocity data. The U.S. Navy Ballistic Limit is assumed to apply, where a good portion of the projectile passes through the armor.

All of the multipliers that will be discussed and presented, whether from graphs, tables or equations, convert armor to a single thickness of U.S. standard plate. The conversions to good quality, rolled homogeneous armor at 240 Brinell Hardness affect the following armor types:

> flawed armor, which loses resistance as a function of impact angle and T/D ratio (thickness of armor/projectile diameter), and generally has multipliers below 1.00
>
> high hardness armor, which loses resistance when projectile diameter approaches armor thickness
>
> cast armor, which is not as resistant as rolled armor except when very thick
>
> edge effects, spaced armor plates and layered armor (plates in contact) modifiers convert armor resistance to center area hits on a wide and high single plate thickness

When the T/D ratio is calculated, the actual armor thickness is used, except for layered armor, where equivalent resistance may be different than the overall thickness. If the 2" cast armor on the front of a Sherman is hit by a 75mm German projectile, the T/D ratio is 50.8/75, or 0.68 (two decimal places are used here, although variations in penetration and armor resistance really only justify one decimal place).

If the slope multiplier at an unspecified impact angle is 2.40 and the cast modifier equals 0.92 for 75mm hits on 2" cast Sherman armor, the vertical armor equivalent (good quality, rolled homogeneous armor) would equal 50.8 x 2.40 x 0.92, or 112mm at 0°. Two inches of good quality cast armor, hit at a given angle by a 75mm steel projectile that is associated with a 2.40 slope multiplier, would offer the same penetration resistance as a 112mm plate that is attacked at 0° impact angle. We have converted cast armor hits at an angle

to an equivalent thickness of good quality rolled armor hit at 0°, which can then be compared to 0° penetration data.

If the cast armor contained flaws, a flaw multiplier would apply, and the equivalent vertical resistance would be less than 112mm.

If 75mm projectile penetration at range in the preceding example was listed as 116mm, the round would penetrate on more than half the hits, since 50% success occurs when penetration equals armor resistance. The probability of successful penetration is a function of the penetration/armor resistance ratio, and successes will occur when listed penetration is less than armor resistance and failures may be experienced when penetration exceeds resistance.

Allied and Russian steel projectiles with nose hardness below 59 Rockwell C may shatter when penetration exceeds armor resistance by certain ratios, due to back pressures related to rapid acceleration of armor material by the projectile nose. While harder steel is normally assumed to be more vulnerable to shatter after impact, in this case softer projectile noses will absorb more energy and fail while harder noses succeed. Instead of penetrating German tank armor with a fair degree of certainty (high probability), hits on relatively thick armor by softer nose projectiles may fail despite penetration/resistance ratios above 1.00.

Shatter failure on over-penetrating hits was noted by the British in North Africa, where 2 Pounder AP would fail at point blank and short range, but penetrate further out, or would penetrate at close and far range but fail in between, creating a "shatter gap" in the penetration range.

Armor piercing caps were introduced to reduce shatter tendencies, although firing test data against Tiger armor and face-hardened plate revealed that the caps did not eliminate the problem. U.S. Navy tests with 76mm APCBC (armor piercing and ballistic windshield caps) resulted in clear cases of shatter failure above the penetration-equals-armor threshold.

The "shatter gap" phenomena, which occurs when penetration/resistance ratio's fall within a certain ratio, explains many important situations where over-penetration of the armor would predict a high probability of success and battle reports indicate consistent failure.

THE T/D RATIO

Failure mechanisms for armor are a function of the T/D ratio, where T is the armor thickness and D is steel projectile diameter. When T/D is below 1.00, shear forces may be insufficient to resist failure (shear resistance equals maximum shear stress times depth times failure area perimeter), and a solid plug may be ejected from the plate or casting. This would be similar to hitting a thin drywall with a large hammer, when a piece of wall is driven through by the hammer head.

Since primary shear resistance is along a line and limited by armor depth, plug failure tends to be a low energy mode of failure. Slope multipliers, high hardness armor resistance and cast equivalency to rolled armor will be minimum when T/D is well below 1.00.

When armor thickness exceeds steel projectile diameter, shear resistance is sufficient to minimize plug ejection and the projectile must push its way through armor, which requires considerably more energy than shear failure. While plate defeat on angled hits tends to occur by plug failure, as angled armor becomes thicker the

projectile is forced to dig into the plate prior to shear failure, which increases energy requirements and leads to higher slope multipliers. As T/D exceeds 1.00, cast and high hardness armor is brought closer to good quality rolled armor in terms of penetration resistance.

Analysis of DeMarre equation predictions will serve to illustrate the above issues.

In its simplest form, the DeMarre equation for 0° penetration relates projectile energy for penetration as a function of T/D when all variables except for projectile weight W and diameter D, velocity V and plate thickness T are treated as constants:

Kinetic Energy $WV^2/(2g)$ equals K x $(T/D)^{1.4}$, where K is a constant dependent upon the projectile and armor characteristics and "g" is the acceleration of gravity.

If plate thickness is 25mm and projectile diameter is 50mm, kinetic energy for 50% penetration success is equal to 0.38K. Against a 75mm thick plate, the 50mm round would require kinetic energy equal to 1.76K, where tripling the plate thickness (25mm to 75mm) increases energy requirements by a factor of 4.63 (1.76/0.38). Energy requirements increase faster than plate thickness due to a shift in the primary failure mode from plugging to pushing armor out of the way.

ARMOR HISTORY

American Armor Plate and Castings

The United States was blessed with an abundance of high grade iron ore and alloys necessary for armor, notably molybdenum and manganese. Chromium, nickel, and vanadium were available but not plentiful. Alloy content of armor was reduced throughout the war, but as manufacturing and testing techniques improved, ballistic qualities actually improved.

Battlefield photographs of late-war U.S. vehicles which have been penetrated by German armor piercing projectiles tend to show the smooth penetrations which are associated with ductile, tough armor, while welds are usually intact.

The inclusion of appropriate alloys allowed U.S. armor to be heat treated to adequate hardness levels without increasing the carbon content. Elevated levels of carbon increase the hardness level to which steel may be heat treated, but degrades weldability. Thus, American armor plates and castings could be assembled by welding without reliance on costly and time consuming interlocking features.

High production rates and inexperienced steel makers characterized American production in the early war years. U.S. rolled armor was often ridden with stringers and laminations through the middle of 1943, at which time specifications were amended to include tests for soundness. These defects may decrease resistance to penetration on the battlefield but do not decrease the measured hardness of a plate. Cracking and spalling on penetration or near-penetration also characterizes unsound armor.

Specification for the acceptance of armor included ballistic testing of sample pieces. Resistance to penetration at normal and obliquity, as well as resistance to shock-inducing projectiles was required. A Pass Through Plate test was required, in which a shot was fired to penetrate without cracking or throwing of broken armor pieces.

In early 1943, radiographic examination of armor castings was commenced in order to detect, and reject, pieces with otherwise invisible interior hot tears and shrinkage cracks.

In October, 1943, cast armor specifications were amended to include the Fiber Fracture Test, which would eliminate cast armor prone to brittle failure from the production stream. This was a cheap, practical test requiring no special equipment, in which sample pieces were broken and the texture of the fractured surface compared visually to a set of standard samples. Armor which failed this test was not passed on for ballistic testing. The Fiber Fracture Test had been developed and validated through a program of ballistic testing.

U.S. cast armor was required to be no less than 5% thinner than specified thickness, or 1/16" if that were a larger dimension. Although there was no maximum over-thickness specified, a single cast piece could not weigh more than 5% over the specified weight. An example of variation is that two Sherman 76mm gun mantlets were measured through the coaxial sight holes and both were found to be 98mm thick, disregarding the reinforcing ring on the exterior surface. Specification for this mantlet (M62) called for 89mm thickness.

In the years 1940-1941 the average hardness of cast armor was 255 BHN for 2" thickness, and 392 BHN for 1" thickness. The latter was reduced to an average 320 BHN during 1942. With requirements for increased shock resistance, and thicker sections, hardness dropped again, so that the following ranges applied to cast armor produced from 1942 through 1945, with hardness in BHN:

U.S. Cast Armor Thickness:	U.S. Cast Armor Hardness:
32mm or less	302-325
32-64mm	235-269
76mm	235-260
102-152mm	220-250
over 152mm	200

Homogeneous rolled plate produced for use in armored vehicles tended to be of the BHN ranges in the center column, while ballistic testing of projectiles was conducted against plate of the BHN in the right column:

U.S. Rolled Armor Thickness:	U.S. Vehicle Plate Hardness:	U.S. Test Plate Hardness:
6-13mm	320-390	330-370
25mm	310-350	240-350
38mm	280-310	240
51mm	260-290	240
63mm	240-275	240
76-127mm	240-260	220-240
over 127mm	220	220

While the mainstay of American production was homogeneous armor, face hardened rolled armor was employed on early production, thinly armored vehicles including the M3 Light Tank through the M3A1 variant. The last M3A1s were accepted in January 1943. Evidence is that M3 Medium Tanks were all homogeneous. As face hardened armor is merely homogeneous armor with extra heat treating on one surface, it is expected that the same quality control problems experienced with homogeneous armor would apply to face hardened armor.

British Armor Plate and Castings

British armor tended to be of insignificantly higher resistance to penetration than U.S. armor, although quality was more variable. For most of the war years, plate was evaluated through ballistic testing, with no evaluation of plate toughness or soundness beyond inspection of the quality of plate failure when penetrated. Surface finish of British armor was observed to be poor by German evaluators examining a captured Infantry Tank Mk. I. A Churchill III at the Aberdeen Proving grounds was found to have a turret side wall with a texture like corduroy. A rough surface can form stress concentration during shot impact, and result in a reduction of resistance to penetration.

British plate as used in production tanks showed incomplete hardening in the center sections of plates greater than approximately 64mm thick. Hardenability problems were resolved by late 1944, with an increase in nickel content and the introduction of fracture tests to monitor toughness.

The following hardness ranges in BHN for British homogeneous armor were evident, for both vehicle and test plates:

British Rolled Armor Thickness:	1940:	1941:	1942-1945:
3-15mm	440-495	320-475	340-388
16-30mm	unknown	300-475	262-321
30-80mm	unknown	300-331	262-321
85-120mm	none	none	255-302
125-160mm	none	none	241-285
Cast, below 80mm	293-332	293-332	293-332
Cast, above 80mm	none	none	293-332

Plates used for vehicle floor armor were of 187-235 BHN in order to be sufficiently ductile to withstand mine detonation.

German Armor Plate and Castings

German armor plate retained a high level of ballistic resistance in the face of declining alloy content. Shortages of nickel and molybdenum resulted in steel alloyed only with vanadium and chromium, produced in thickness up to 120mm. Nickel was added for thicker armor used on the heaviest tanks. Carbon content of most German plate exceeded Allied plate, making welding extremely difficult, but adding to strain hardening properties which resulted in higher resistance to penetration.

Battlefield photographs of penetrated German plate show a mixture of failure modes from clean penetration to catastrophic cracking clear across the plate. This latter form of failure has been observed in 80mm plates in one Panzer IV/70 *Zwischenloesung*, as well as a number of Panthers tested by the Allies. Russian photographs from their proving grounds show a Tiger II with its heaviest armor disintegrated by multiple hits from 85 and 122mm projectiles. Yet, for the most part, German armor stood up well to hits by enemy projectiles in combat, relying more on thickness and obliquity than metallurgical quality.

Improvisations by the German armor industry in the face of declining alloy content included multiple time-quenching of plates in order to provide control over heat treatment, a process which must be conducted with care and precision to be successful. Times for immersing and removing steel from quench baths was specified

to the second. Given the size and weight of plates such as the Panther glacis, inconsistency from one part of a plate to another would be a natural consequence. As alloy content dwindled, the margin for error in armor heat treatment narrowed.

Shortages of plant and raw materials resulted in the substitution of unhardened steel for proper armor. Heinz Guderian and von Senger u. Etterlin both mention unhardened steel used for self propelled guns beginning in mid-1943. The latter author indicates 30mm frontal and 20mm side hull armor of the Nashorn was of such material.

The following shows the relationship between thickness, hardness, and year of production of German homogeneous armor:

German Rolled Armor

Thickness:	1940-41	1942	1943-44	1945
5-15mm	415-475	415-475	415-475	415-475
16-30mm	330-338	309-354	309-354	309-354
35-50mm	320-360	309-354	278-324	278-324
55-80mm	285-331	285-331	266-309	252-295
85-120mm	266-311	266-311	220-266	220-266
125-160mm	none	266-302	220-266	220-266
165-200mm	none	none	220-266	220-266

Beginning in 1944, 16-30mm tank floor plates were specified at 197-224 BHN, in order to be sufficiently ductile to withstand high explosive mine detonation. Prior to that, floor plates were specified to the next lowest hardness category.

Measurement of German vehicles captured by the Allied forces sometimes resulted in hardness significantly lower than official specification:

Jagdpanther 80mm (nominal) glacis	210 BHN
Hetzer 60mm glacis	240 BHN
Hetzer 20mm sides	195 BHN

Production tolerance of +5% thickness was allowed by acceptance criteria, for plates nominally 30mm or more in thickness. However, actual thickness sometimes exceeded permissible limits. Captured vehicles were measured as follow:

	Nominal:	Actual:
Panther Glacis	80mm	85mm (more than five tanks)
Panther lower bow	50-60mm	65, 67, 75mm (at least five tanks)
PzKpfw IV/H upper, lower front	80mm	85mm
StuH Ausf. G welded mantlet	50mm	65mm
Ferdinand or Elefant	100mm	110mm
Ferdinand or Elefant	80mm	86mm

Specification of armor was by angle-immunity curves, in which a given thickness of armor was inclined to a specified angle and fired upon with a specified gun and projectile, usually at 100 meters, with the requirement of shot defeat. For plates of 85-160mm nominal thickness, standard PzGr 39 APCBC was fired from a PAK

40, with the restriction that muzzle velocity must not fall below 700m/s (which constitutes a 13% drop). Use of a worn gun could allow substandard plate to pass. Plates over 20mm thickness were not tested with severely overmatching projectiles, which tended to mask plate weakness. Although 5% thickness overage was allowed, ballistic tests were conducted as if the plate were the exact nominal thickness; thus, a plate 5% weaker than expectation could compensate by its 5% greater thickness. If a plate was immune to penetration at the specified angle, the plate was then tilted toward vertical until the test projectile penetrated, and plate back damage was inspected for evidence of cracking or flaking. If those types of failures exceeded certain limits, the plate was failed.

Metallurgical analysis of a Panther glacis by American technicians turned up a layer of brittle steel in the center of the plate, due to insufficient quenching and incorrect tempering during heat treatment. Although the plate was in the specified range of hardness (262-269 BHN), this flaw could have the effect of premature, spalling failure of the plate when hit hard enough or repeatedly by lesser impacts. Thickness was 83mm.

Although there was no official specification calling for armored vehicle plates to be evaluated by notched bar impact tests for toughness, Krupp performed such tests routinely as an internal quality control measure.

German rolled armor used for ballistic testing of projectiles was of the following thickness and BHN:

Ballistic Test Plate Thickness:	Hardness:
5-15mm	435-465
16-30mm	338-382
31-50mm	326-368
51-80mm	309-338
81-120mm	279-309
121-150mm	235-265
151-275mm	206-235

Not only was ballistic test armor of higher hardness than tank armor, it was also evaluated with notched bar impact tests to monitor toughness.

According to translations of documents appearing in several of Jentz' compilations, German penetration criteria for the proof of projectiles required two-thirds of projectiles tested to perforate plate of given thickness. It is assumed that the perforation was to be complete, with most or all of the projectile passing through the plate. However, Krupp documents captured by the British (dated December, 1944) indicated that *massenfertig* (mass produced) projectiles from 7.5cm through 15cm were only expected to penetrate 8 to 10% thinner plate than first-quality projectiles.

German cast armor was of generally good quality, and was limited to cupolas, gun mantlets, small covers, drive housings, and sprockets. Thickness and hardness was as below:

German Cast Armor Thickness:	Hardness:
45-70mm	250-294 (Feb.-June 1943)
Over 70mm	235-280 (Feb.-June 1943)
50-120mm	220-265 (after June 1943)
120-250mm	192-235 (date unknown, presumed 1944-'45)

Welding of armor was difficult due to the elevated carbon content of German steel, resulting in weak, brittle welds which tended to fail under ballistic attack. Load-bearing interlocks were cut on plate edges, with the desired effect on ballistic resistance, but at the cost of increased production time, material, and human resources. A Tiger I captured in Tunisia and examined by American technicians was found to have severe cracks in welds joining hull to hull roof., and turret side wall to turret roof. Cracks were not due to enemy fire, but had occurred as the weld cooled, according to metallurgical analysis. Weld material could be broken up with hammer blows.

The Germans continued to use face hardened armor longer than their adversaries, even though such armor requires extra time and resources to manufacture. The extra benefit it bestowed was negated by the Western Allies' shift to capped projectiles in 1942, but it continued to be beneficial when confronting the uncapped, soft projectiles fired by Russian guns throughout the war. Given the relative number of armored vehicles deployed on the Eastern opposed to Western fronts, the decision appears justified.

Italian Armor Plate

Italian armor was described in a British analysis of sample plates taken from vehicles captured in North Africa. The plates originated in an M 11/39, an M13/40 and a Semovente 40. Hardness ranged from 210 BHN on the turret of the M13/40, to 323 BHN on the side of the M/11/39, with most measurements in the mid-200's. Despite its softness the armor was described as brittle and flaky, as well as possessing poor resistance to bullet penetration. Sulfur and phosphorus content was high, and alloy content was low. The report states: *"Taken in conjunction with the reports that this armour flakes so badly that the whole crew is usually killed when the armour is pierced and a photograph showing a plate cracked extremely badly by a 2 pr. shot, it can only be concluded that the armor is of extremely poor quality."* A veteran of the 4th Tank Regiment who participated in the Italian fighting against the Germans in Rome, September 8-10, 1943, reported that when he attempted to use the front of an M13 tank as an anvil to straighten a large nail, the nail left a scar on the armor plate.

After the first reports of substandard plate in 1941, Italian industry began a program of tightened standards, resulting in improved quality. Plates showed smooth edges at penetration holes, as evidence of better ductility. Although details are lacking, it appears that for the rest of the war Italian armor continued to be at a relatively low level of quality, although improved over that described by the British in North Africa.

Russian Armor Plate and Castings

Russian armor is described in American and British reports. Detailed metallurgical analyses were undertaken of two T-34 model 42's, two KV 1 model 42's, and a number of T34-85 and IS-2 tanks recovered from Berlin in 1945. A handful of additional T34-85's and SU's were analyzed after the war. As of this writing, official information concerning armor is slowly coming to light from Russia, following the dissolution of the Soviet Union.

There is some evidence that the American Disston company exported a considerable tonnage of rolled armor plate to the Soviet Union beginning in the late 1930's, with shipments continuing through 1941. It is reported that 1941 model T34's were armored with this plate. As this armor was to have been made to U.S. Army specification, it may be assumed that it was of the same hardness and quality as plate described in the American section of this chapter. T34's with American armor plate may have offered increased resistance, compared to standard Russian armor, which may account for reported variations in effective ranges of

German ammunition (limited to within 1000m in some German combat reports, and 1200m to 1600m in other cases, based on reports presented in Jentz' books) .

T34 and IS tanks analyzed in the West were remarkable for high-hardness homogeneous armor in the 350-495 BHN range. High silicon content contributed to poor ductility. Although the Western combatants found that thicker armor worked best when tempered to 250 BHN or less, IS-2 hull front and side sections of 102-127mm were 435-443 BHN. However, KV-1 model 42's analyzed in Britain and the United States had cast turret armor in the 250-293 BHN range, and 75-77mm rolled hull armor of 239-290 BHN.

The following is an approximate guide to average Russian armor BHN, based on a small number of samples:

Armor Type:	Year:	Under 60mm:	61 to 80mm:	Over 80mm:
Rolled	1942-45	450	340	300
Cast	1942-43	480	300	300
Cast	1944-45	420	420	420

Bow castings of T34 Model 42 and T34-85's examined in America were only 200-248 BHN, the earlier pieces ridden with large interior voids. Contrary to western practice, sponson floors and turret rings of T-34-85 and IS tanks were reportedly not heat treated at all.

Design plate hardness and quality could vary greatly, even in the same tank. The lower hull side plate of an IS-2 was 300 BHN, in contrast to other plates of much higher hardness in the same vehicle. The lower bow plate of a T-34 was sound and adequately cross-rolled, while the glacis of the same tank had been rolled in only one direction, and contained stringers of nonmetallic material.

Thickness of Russian armor is found to vary from official figures, as shown by the following comparison of measurements taken from actual vehicles:

	Nominal:	Actual:
IS-2 bow	100mm	95mm
SU-100 glacis	75mm	68, 72mm (two vehicles)
SU-100 bow	45mm	60mm
SU-100 superstructure side	45mm	42, 50mm (two vehicles)

T34-85 driver's hatches were a 75mm thick casting on an early-production tank evaluated in Germany, and another at the Aberdeen Proving Grounds, although glacis thickness was 45-47mm.

Russian welding practice was erratic, characterized by voids, undercuts, incomplete fusion, and partial penetration through the joint, reflecting an emergency workforce. Although plates were interlocked, fit was often poor.

Ballistic testing of Russian projectiles was carried out against rolled homogeneous plate in the hardness range of 250-350 BHN. Russian penetration criteria consisted of two success criteria, where thicknesses would be determined for 20% and 80% probability of success, and the 50% success thickness would be the average of the two. Of those that succeeded, all or most of the projectile body was required to pass through the plate.

2. HOMOGENEOUS ARMOR SLOPE EFFECTS

SLOPE EFFECT VERSUS T/D RATIO

Analysis of WW II data indicates that many armor resistance factors are related to the T/D ratio, armor thickness divided by the projectile diameter. These factors include slope effect, flaws, cast armor resistance multiplier and high hardness reductions in penetration resistance.

U.S. Army Technical Manual TM9-1907 provides penetration data as a function of impact velocity and armor slope, and the following data for the 57mm M86 APCBC round illustrates how T/D influences slope effect:

IMPACT VELOCITY	0° PEN.	60° PEN.	SLOPE EFFECT	60° THICKNESS T/D RATIO
2610 fps	4.2"	1.5"	2.80	0.67
1870 fps	2.5"	1.0"	2.50	0.45

NOTE: Slope effect is defined as the multiplier that converts an angled impact penetration to an equivalent resistance at 0°, where slope is measured from a vertical line.

Soviet T34 and T34/85 has frontal hull armor of 45mm thickness at 60° from vertical, and interpolating between the above two points for 60° slope effect at 0.6 T/D ratio yields a slope multiplier of 2.70. Applying the 60° slope multiplier to 45mm results in 122mm effective thickness at 0° versus 75mm APCBC hits. Equivalent vertical resistance (0° impact from vertical) is now presented for Sherman, T34 and Panther front hull armor against a variety of projectile sizes:

			APCBC/APC				APBC			AP		
TANK	AREA	ARMOR	75	76	88	128	100	122	152	100	122	152
Panther	Glacis	85 @ 55°		221			161	144	127	180	176	171
Panther	Nose	65 @ 55°		159			106	95	84	133	130	126
Panther	Glacis	80 @ 55°		205			146	131	116	168	164	159
Panther	Nose	60 @ 55°		144			93	83	74	121	118	115
T34	Front Hull	45 @ 60°	122		118	107						
Sherman	Glacis	51 @ 56°	123		118	108						
Sherman	Glacis	64 @ 47°	118		115	107						
Sherman	Nose	51 @ 56°	123		118	108						
M4A1	Glacis	51 @ 52°	107		103	95						
M4A1	Glacis	51 @ 53°	110		106	98						
M4A1	Glacis	51 @ 55°	118		113	103						
M4A1	Glacis	64 @ 52°	139		135	124						
M4A1	Hood	64 @ 35°	87		85	82						
M4A1	Hood	64 @ 47°	118		115	107						

Data in the above table assumes that armor resists penetration like good quality rolled homogeneous armor, without flaws or cast deficiency. In addition, Panther armor thickness is based on figures that exceed the standard "80mm glacis, 60mm nose" listing, since American, British and Russian sources often use 85mm and

65mm thickness. American measurements of Panther nose thickness during tests at Isigny resulted in 67mm, which is consistent with figures used in above table.

The graphs following this page present predicted slope effect results as a function of T/D ratio, determined by mathematical models for a variety of projectile types. Sloped armor resistance to HEAT rounds and tungsten ammunition does not appear to be influenced by T/D considerations.

Where graphs indicate slope multipliers below 1.00, the results represent mathematical extrapolation and may not be realistic. It is suggested that slope effects below 1.00 be treated as 1.00.

Ammunition types are defined as:

AP:
Armor piercing rounds without ballistic or armor piercing caps, may include an HE burster. Used by all nations. British AP rounds, from 40mm 2 pounder through 87.6mm 25 pounder, appear to have similar slope effects for a given T/D ratio (see drawing next page).

APC:
Armor piercing with armor piercing cap (AP + APC, abbreviated APC instead of APAPC), where cap is designed to reduce shatter tendencies against face-hardened armor and increase ensuing penetration. These caps were also promoted to reduce shatter against rolled homogeneous armor (homogeneous armor has same thickness throughout, face-hardened has thin extremely hard layer). APC is usually solid shot, used by British and Americans. Projectile caps reduce homogeneous armor penetration due to energy absorbed during impact (see drawing next page).

APCBC:
Armor piercing cap (APC) to reduce shatter and ballistic cap (BC) to reduce wind resistance and increase penetration at range. Used by British, Americans and Germans, and may include HE burster (see drawing next page).

American 37mm APCBC has significantly different slope effects than larger diameter APCBC.

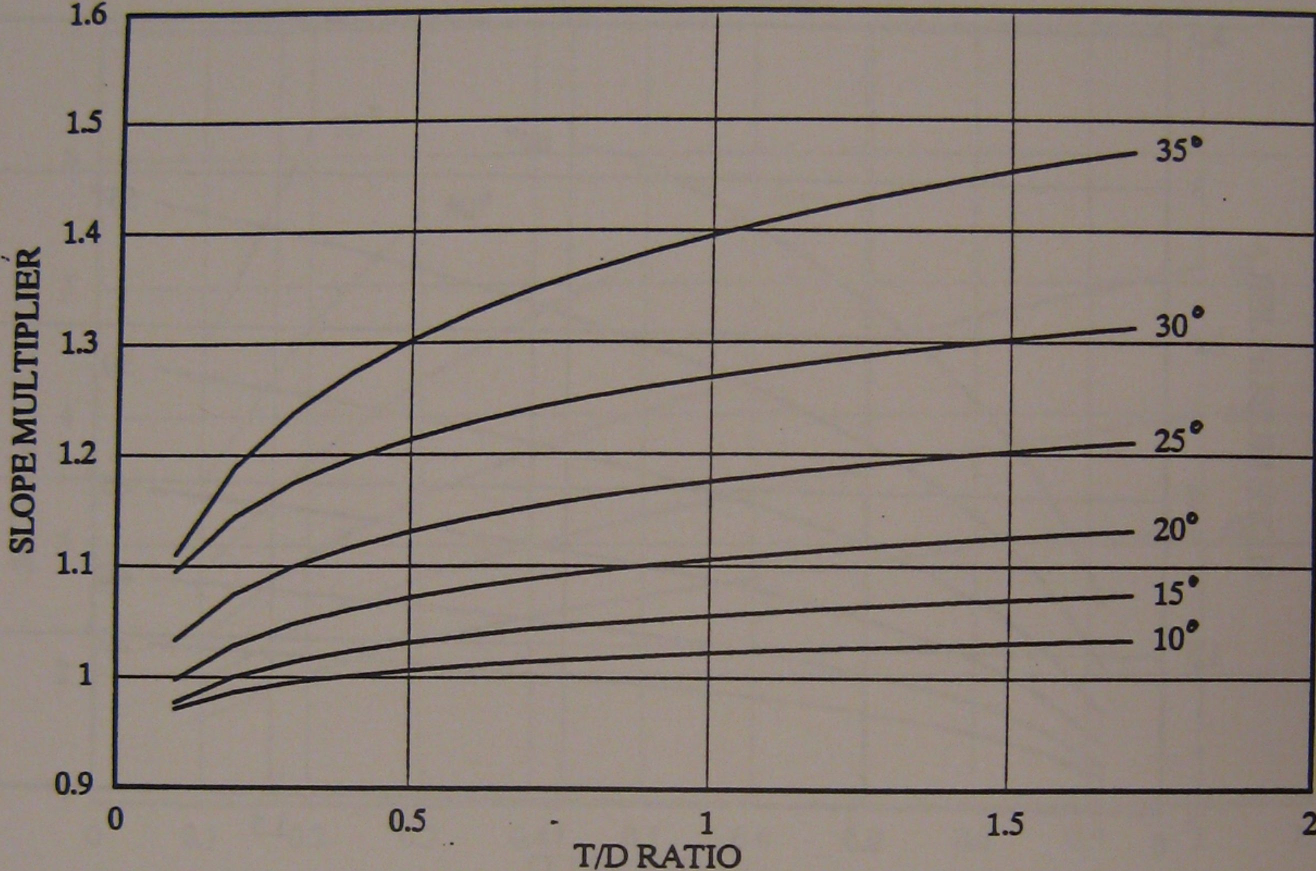
APBC:
Italian APBC and American 90mm T33 APBC is a traditional armor piercing round with a ballistic cap, which use the AP slope effects and equations.

Flat-nosed APBC armor piercing round used by Soviets and patterned after naval ammunition, especially effective against sloped armor (see drawing next page). Solid shot or HE burster. Has ballistic cap to counter poor aerodynamic shape of flat nose. Uses APBC slope effect graph and equations.

The interesting aspect of Russian APBC was the use of a ballistic cap, which may alternatively be referred to as a windscreen or windshield, to reduce air resistance and promote greater velocity (and penetration) at medium and long range. 85mm BR-365 was produced during 1939 with a ballistic cap and photos of Russian tanks during the Spanish Civil War appear to show 45mm APBC rounds being loaded. Russian use of ballistic caps on tank and field gun rounds may represent the first use of windscreens on tank related armor piercing ammunition. The initial American and British ammunition during WW II was solid shot AP, which lost velocity relatively quickly.

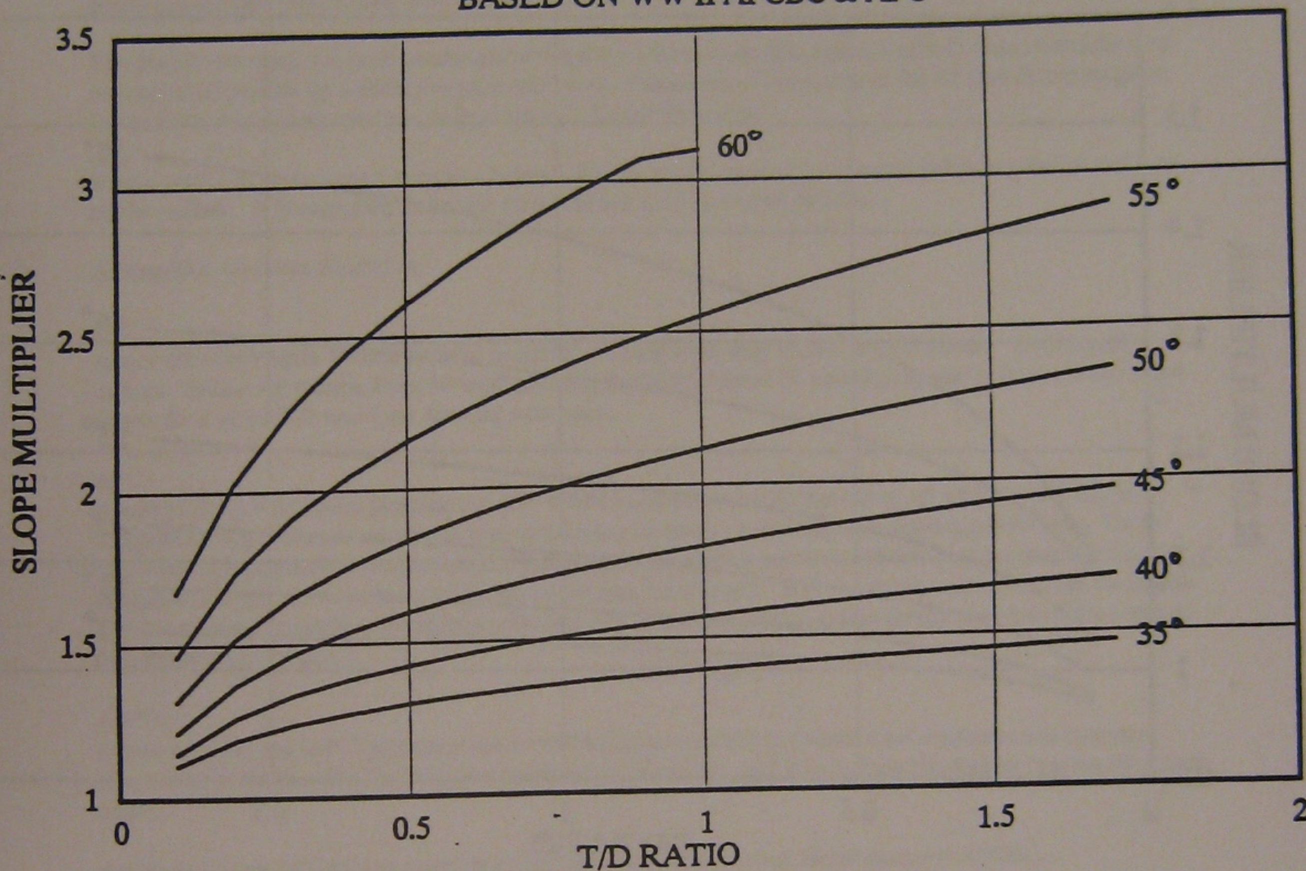
SLOPE MULTIPLIERS VERSUS T/D RATIO

BASED ON WW II APCBC & APC



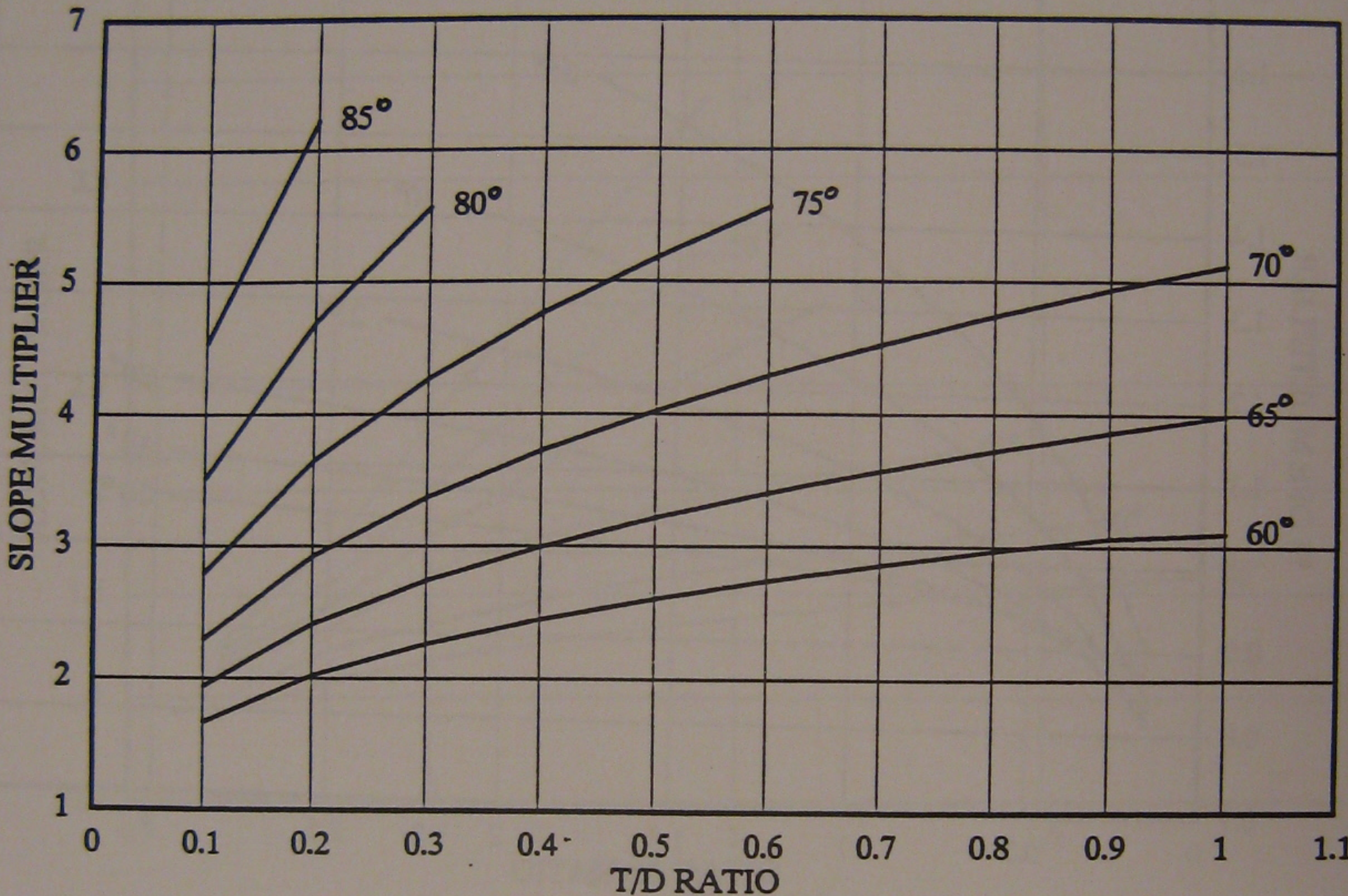
SLOPE MULTIPLIERS VERSUS T/D RATIO

BASED ON WW II APCBC & APC

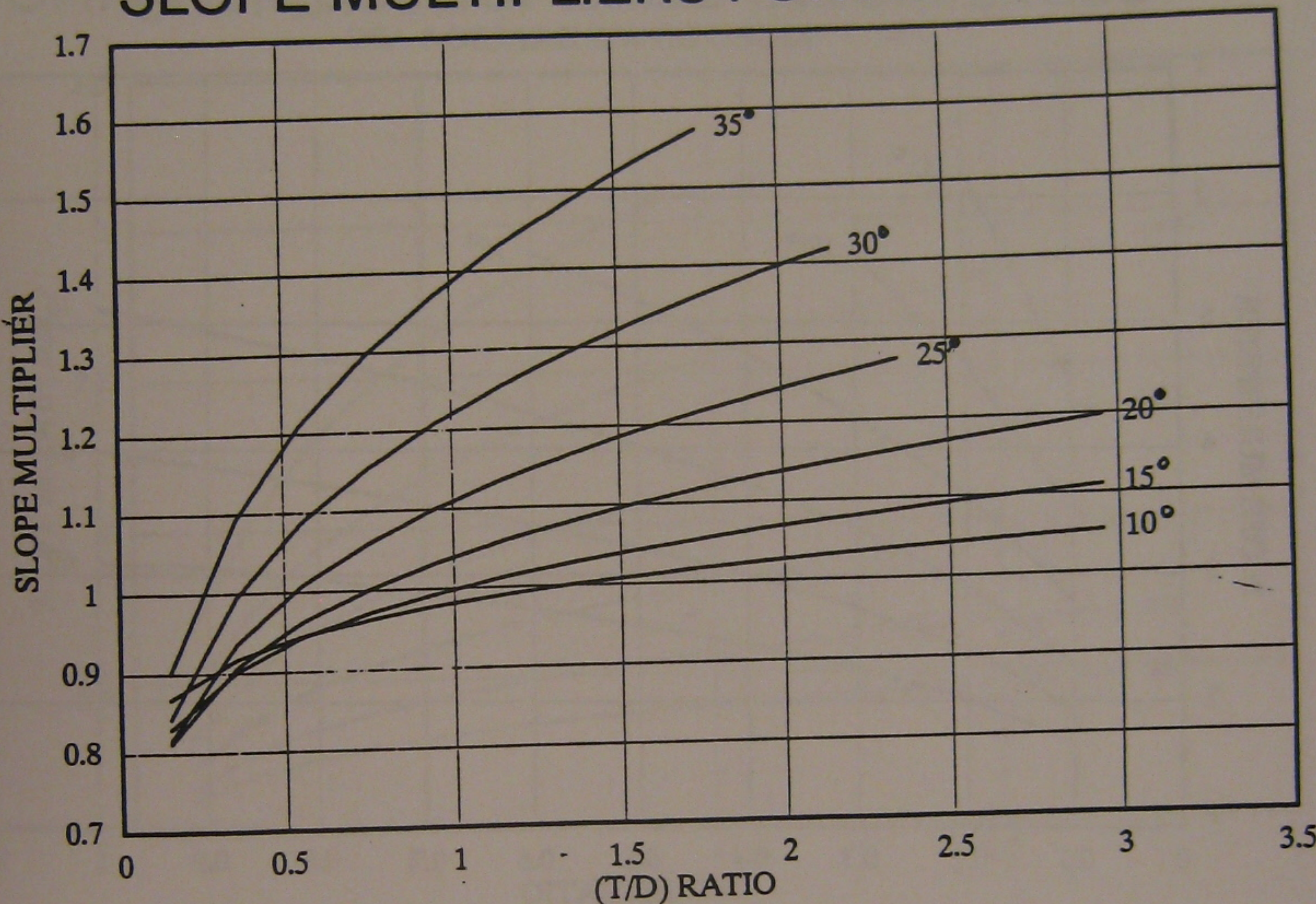


SLOPE MULTIPLIERS VERSUS T/D RATIO

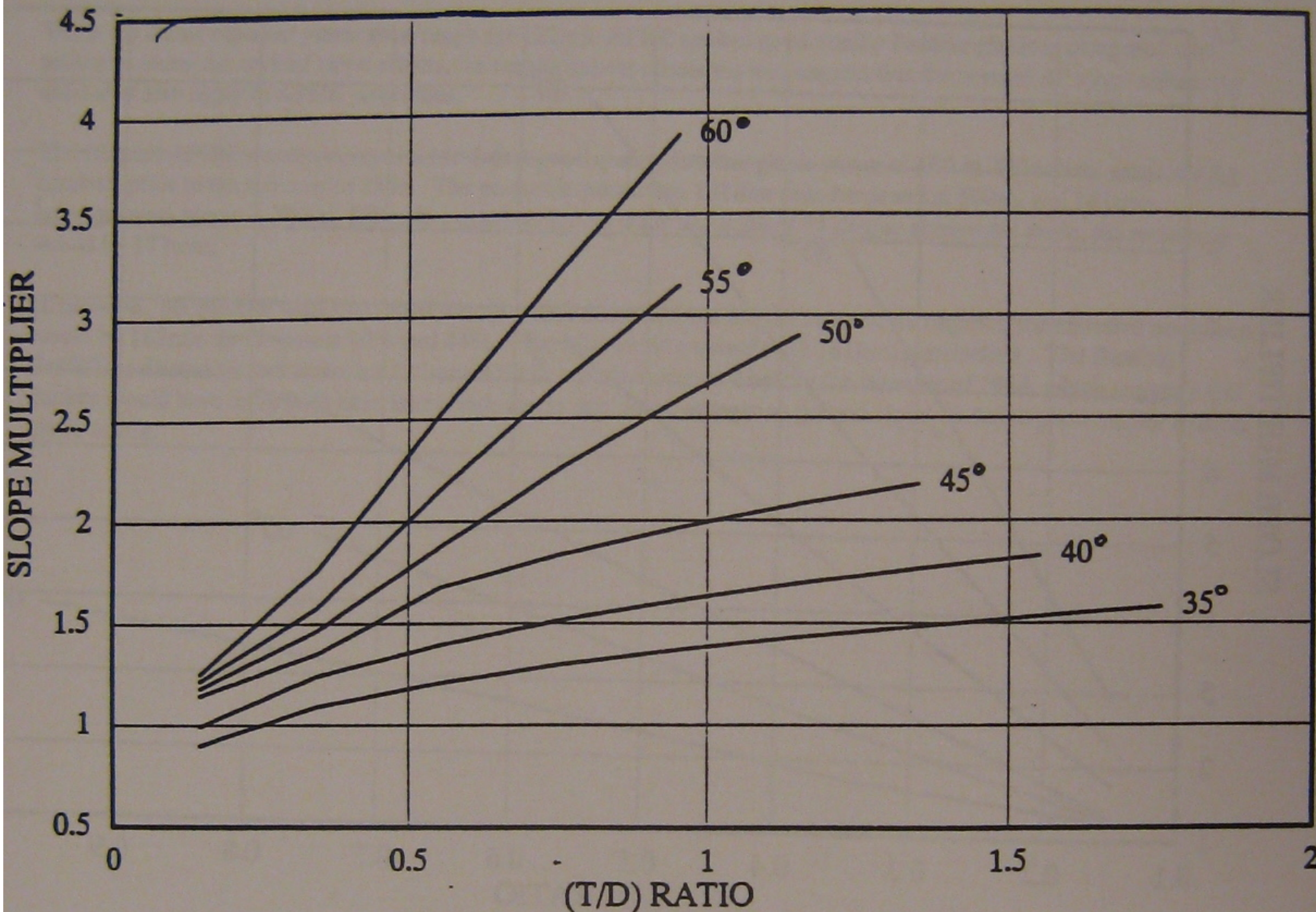
BASED ON WW II APCBC & APC



SLOPE MULTIPLIERS FOR AP



SLOPE MULTIPLIERS FOR AP



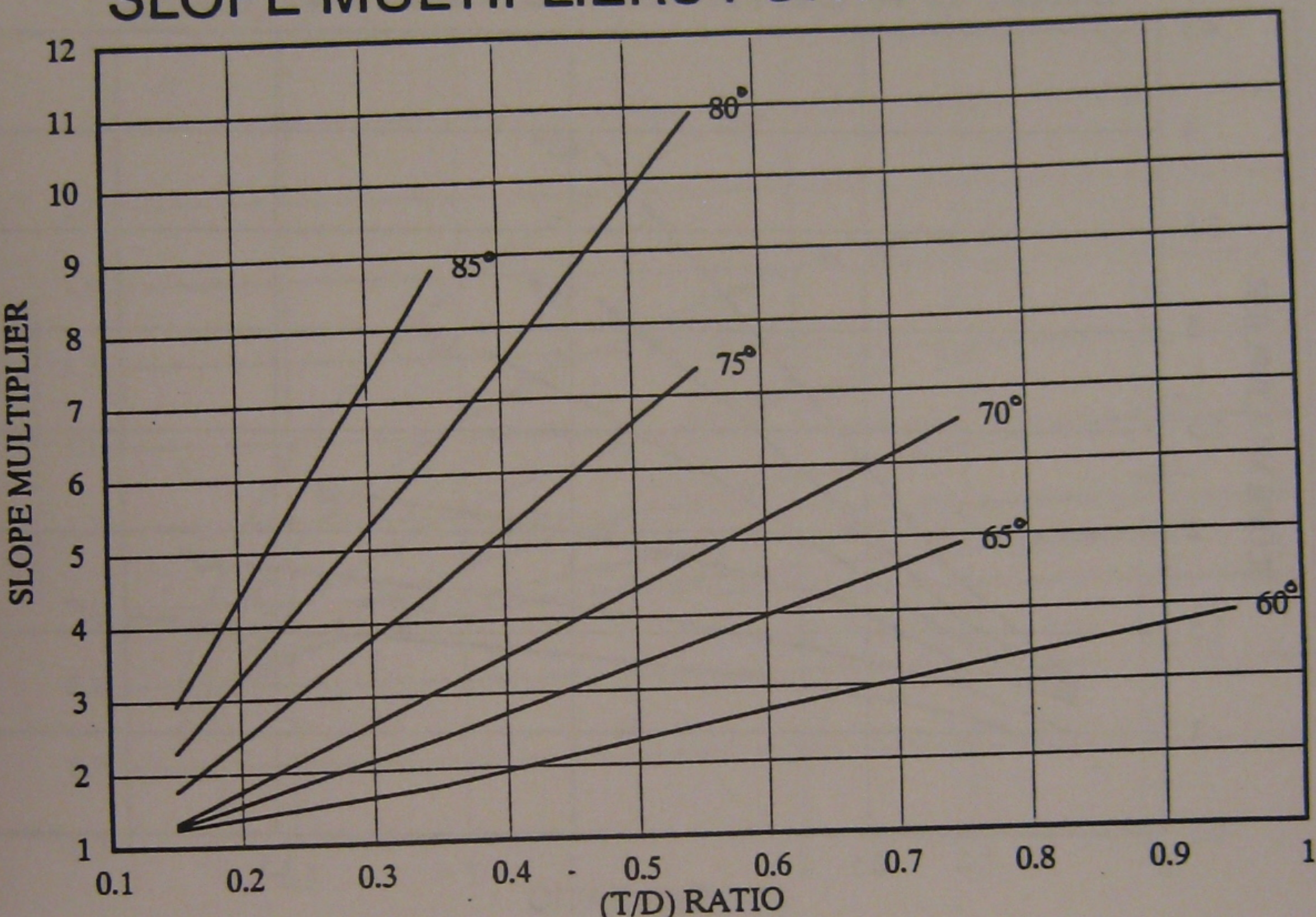
45 TO 60 DEGREE CURVES

SUPERCEDED BY SECTION ON

"SLOPE EFFECTS FOR AP ROUNDS"

WHICH IMMEDIATELY FOLLOWS

SLOPE MULTIPLIERS FOR AP



SUPERCEDED BY SECTION ON

"SLOPE EFFECTS FOR AP ROUNDS"

WHICH IMMEDIATELY FOLLOWS

SLOPE EFFECTS FOR AP ROUNDS (SOLID SHOT, NO ARMOR PIERCING CAP)

Analysis of sloped armor penetration data for 6 and 17 pounder AP, and 90mm T33 APBC and M77 AP, result in lowered slope effects than previously assumed. All of the rounds used in the AP analysis are solid shot.

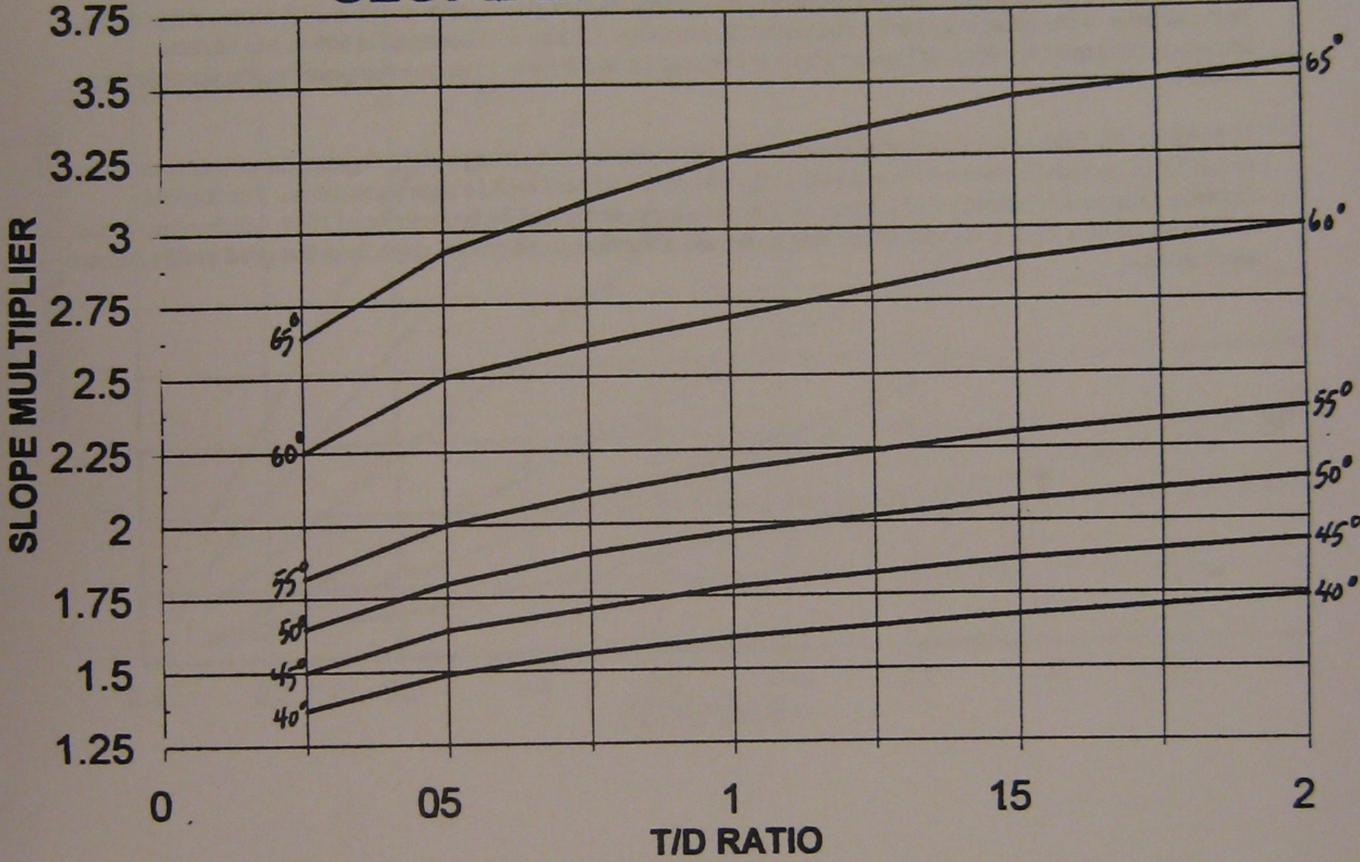
The following graph and table present the results of analyzing new data, which suggests that AP without armor piercing caps will have lower slope multipliers than APCBC rounds for same T/D ratio.

When the actual reported penetration range for 122mm APHE against good quality Panther glacis is compared with estimates using the revised slope effects, the results appear consistent and suggest that the revised AP slope effects for solid shot also apply to APHE projectiles.

The 122mm APHE round was reported to defeat good quality Panther glacis armor at 600 to 700 meters range during combats prior to the summer of 1944. The projectile penetrates 161mm face-hardened at 600m, and 161mm homogeneous armor at 700m. If Panther glacis is 85mm thick and is hit at 55 degree compound angle, the resistance would be 177mm.

If, however, the Panther were on sloped terrain which decreased the impact angle to 52 degrees, the effective resistance would be 162mm and between 40% and 44% of the hits would succeed with 161mm penetration . The Russian Battlefield discussion indicates that 122mm AP hits mostly ricocheted before the summer of 1944, which suggests that the hits would have to hit with little lateral side angle, and an advantageous ground slope, to defeat good quality Panther glacis armor.

SLOPE EFFECTS FOR AP

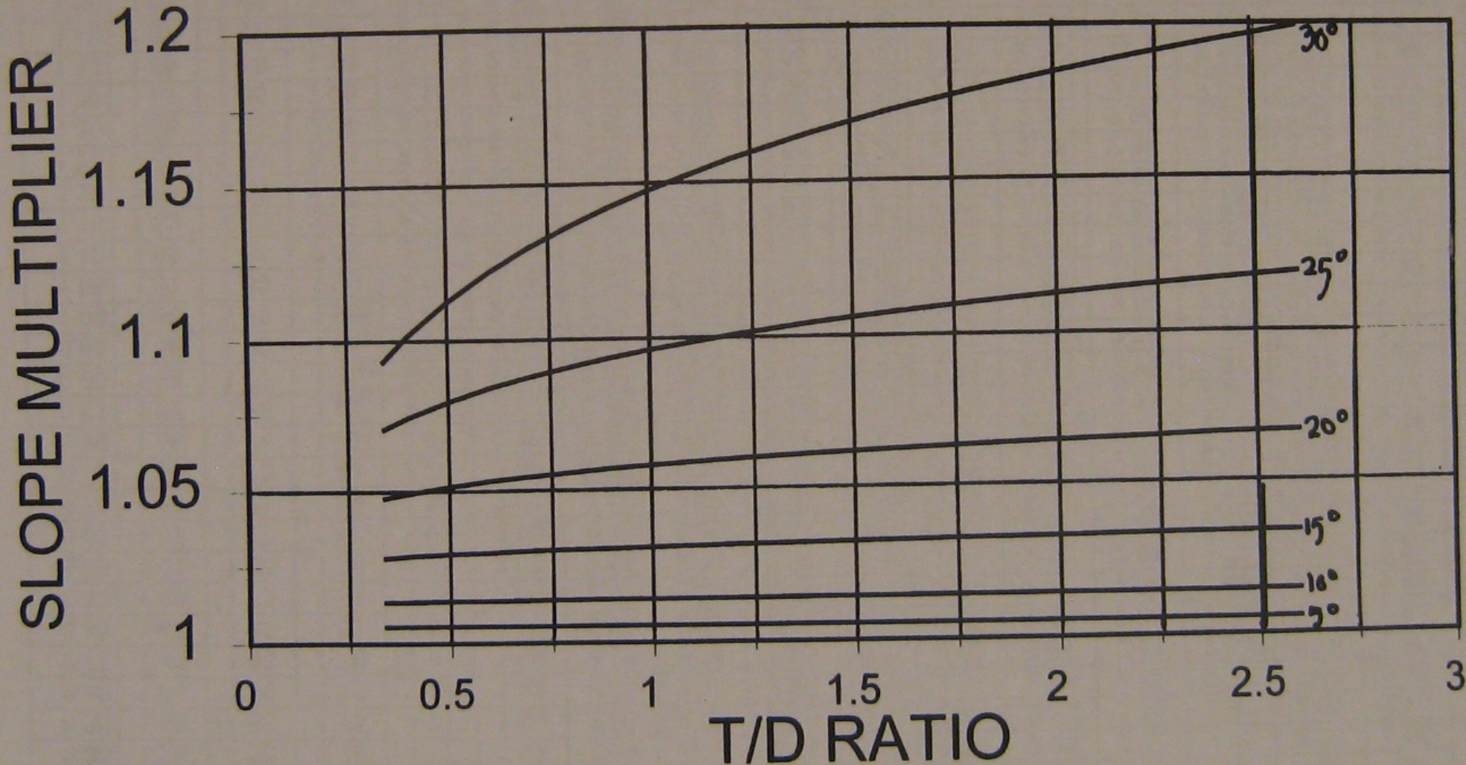


SLOPE MULTIPLIERS FOR AP PROJECTILES

	COMPOUND IMPACT ANGLE																
T/D	40	45	50	52.5	55	56	57	58	T/D	59	60	61	62	63	64	65	T/D
0.30	1.39	1.55	1.70	1.77	1.85	1.95	2.03	2.11	0.30	2.20	2.28	2.37	2.46	2.55	2.65	2.74	0.30
0.35	1.42	1.58	1.73	1.81	1.89	1.99	2.07	2.16	0.35	2.24	2.33	2.42	2.51	2.61	2.70	2.80	0.35
0.40	1.44	1.60	1.76	1.84	1.92	2.03	2.11	2.20	0.40	2.28	2.37	2.47	2.56	2.66	2.76	2.86	0.40
0.45	1.46	1.63	1.79	1.87	1.95	2.06	2.14	2.23	0.45	2.32	2.41	2.51	2.60	2.70	2.80	2.90	0.45
0.50	1.48	1.65	1.81	1.89	1.98	2.09	2.17	2.26	0.50	2.35	2.45	2.54	2.64	2.74	2.84	2.95	0.50
0.55	1.49	1.67	1.83	1.92	2.00	2.11	2.20	2.29	0.55	2.39	2.48	2.58	2.68	2.78	2.88	2.99	0.55
0.60	1.51	1.68	1.85	1.94	2.02	2.14	2.23	2.32	0.60	2.41	2.51	2.61	2.71	2.81	2.92	3.03	0.60
0.65	1.52	1.70	1.87	1.96	2.05	2.16	2.25	2.34	0.65	2.44	2.54	2.64	2.74	2.85	2.95	3.06	0.65
0.70	1.54	1.71	1.89	1.98	2.07	2.18	2.27	2.37	0.70	2.47	2.56	2.67	2.77	2.87	2.98	3.09	0.70
0.75	1.55	1.73	1.91	2.00	2.09	2.20	2.30	2.39	0.75	2.49	2.59	2.69	2.80	2.90	3.01	3.12	0.75
0.80	1.56	1.74	1.92	2.01	2.10	2.22	2.31	2.41	0.80	2.51	2.61	2.72	2.82	2.93	3.04	3.15	0.80
0.85	1.57	1.75	1.94	2.03	2.12	2.24	2.33	2.43	0.85	2.53	2.63	2.74	2.84	2.95	3.07	3.18	0.85
0.90	1.58	1.77	1.95	2.04	2.14	2.26	2.35	2.45	0.90	2.55	2.65	2.76	2.87	2.98	3.09	3.21	0.90
0.95	1.59	1.78	1.97	2.06	2.15	2.27	2.37	2.47	0.95	2.57	2.67	2.78	2.89	3.00	3.11	3.23	0.95
1.00	1.60	1.79	1.98	2.07	2.17	2.29	2.39	2.49	1.00	2.59	2.69	2.80	2.91	3.02	3.14	3.25	1.00
1.05	1.61	1.80	1.99	2.09	2.18	2.30	2.40	2.50	1.05	2.61	2.71	2.82	2.93	3.04	3.16	3.28	1.05
1.10	1.62	1.81	2.00	2.10	2.19	2.32	2.42	2.52	1.10	2.62	2.73	2.84	2.95	3.06	3.18	3.30	1.10
1.15	1.62	1.82	2.01	2.11	2.21	2.33	2.43	2.53	1.15	2.64	2.75	2.86	2.97	3.08	3.20	3.32	1.15
1.20	1.63	1.83	2.02	2.12	2.22	2.34	2.44	2.55	1.20	2.65	2.76	2.87	2.99	3.10	3.22	3.34	1.20
1.25	1.64	1.84	2.03	2.13	2.23	2.36	2.46	2.56	1.25	2.67	2.78	2.89	3.00	3.12	3.24	3.36	1.25
1.30	1.65	1.85	2.04	2.14	2.24	2.37	2.47	2.58	1.30	2.68	2.79	2.90	3.02	3.14	3.26	3.38	1.30
1.35	1.65	1.85	2.05	2.15	2.25	2.38	2.48	2.59	1.35	2.70	2.81	2.92	3.03	3.15	3.27	3.40	1.35
1.40	1.66	1.86	2.06	2.16	2.26	2.39	2.50	2.60	1.40	2.71	2.82	2.93	3.05	3.17	3.29	3.41	1.40
1.45	1.67	1.87	2.07	2.17	2.27	2.40	2.51	2.61	1.45	2.72	2.83	2.95	3.06	3.18	3.31	3.43	1.45
1.50	1.67	1.88	2.08	2.18	2.28	2.41	2.52	2.63	1.50	2.73	2.85	2.96	3.08	3.20	3.32	3.45	1.50
1.55	1.68	1.89	2.09	2.19	2.29	2.42	2.53	2.64	1.55	2.75	2.86	2.98	3.09	3.21	3.34	3.46	1.55
1.60	1.69	1.89	2.10	2.20	2.30	2.43	2.54	2.65	1.60	2.76	2.87	2.99	3.11	3.23	3.35	3.48	1.60
1.65	1.69	1.90	2.11	2.21	2.31	2.44	2.55	2.66	1.65	2.77	2.88	3.00	3.12	3.24	3.37	3.49	1.65
1.70	1.70	1.91	2.11	2.22	2.32	2.45	2.56	2.67	1.70	2.78	2.90	3.01	3.13	3.26	3.38	3.51	1.70
1.75	1.70	1.91	2.12	2.23	2.33	2.46	2.57	2.68	1.75	2.79	2.91	3.03	3.15	3.27	3.40	3.52	1.75
1.80	1.71	1.92	2.13	2.24	2.34	2.47	2.58	2.69	1.80	2.80	2.92	3.04	3.16	3.28	3.41	3.54	1.80
1.85	1.71	1.93	2.14	2.24	2.35	2.48	2.59	2.70	1.85	2.81	2.93	3.05	3.17	3.30	3.42	3.55	1.85
1.90	1.72	1.93	2.14	2.25	2.36	2.49	2.60	2.71	1.90	2.82	2.94	3.06	3.18	3.31	3.44	3.57	1.90
1.95	1.73	1.94	2.15	2.26	2.37	2.50	2.61	2.72	1.95	2.83	2.95	3.07	3.19	3.32	3.45	3.58	1.95
2.00	1.73	1.94	2.16	2.27	2.37	2.51	2.62	2.73	2.00	2.84	2.96	3.08	3.21	3.33	3.46	3.59	2.00

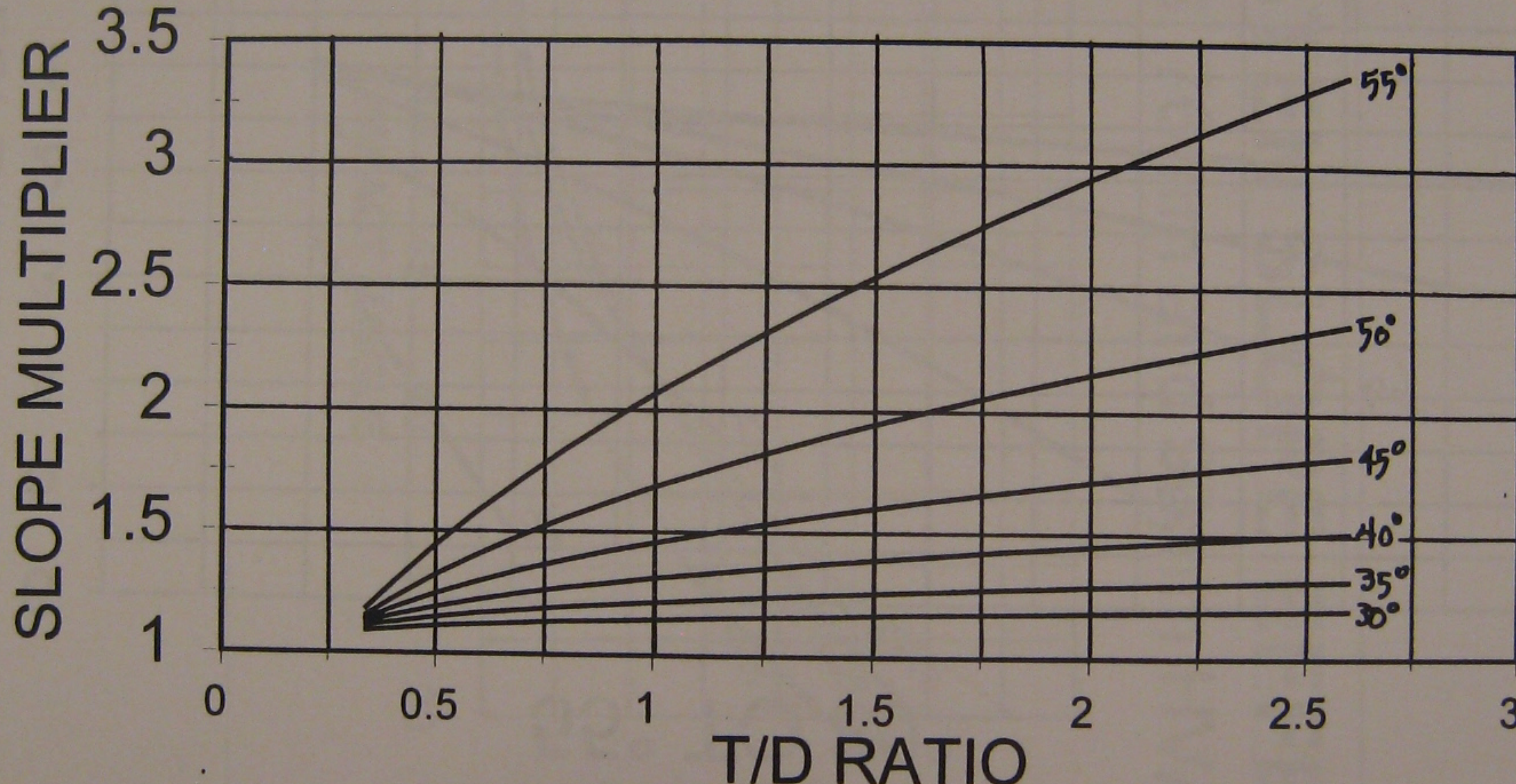
APBC SLOPE MULTIPLIERS

5 TO 30 DEGREES



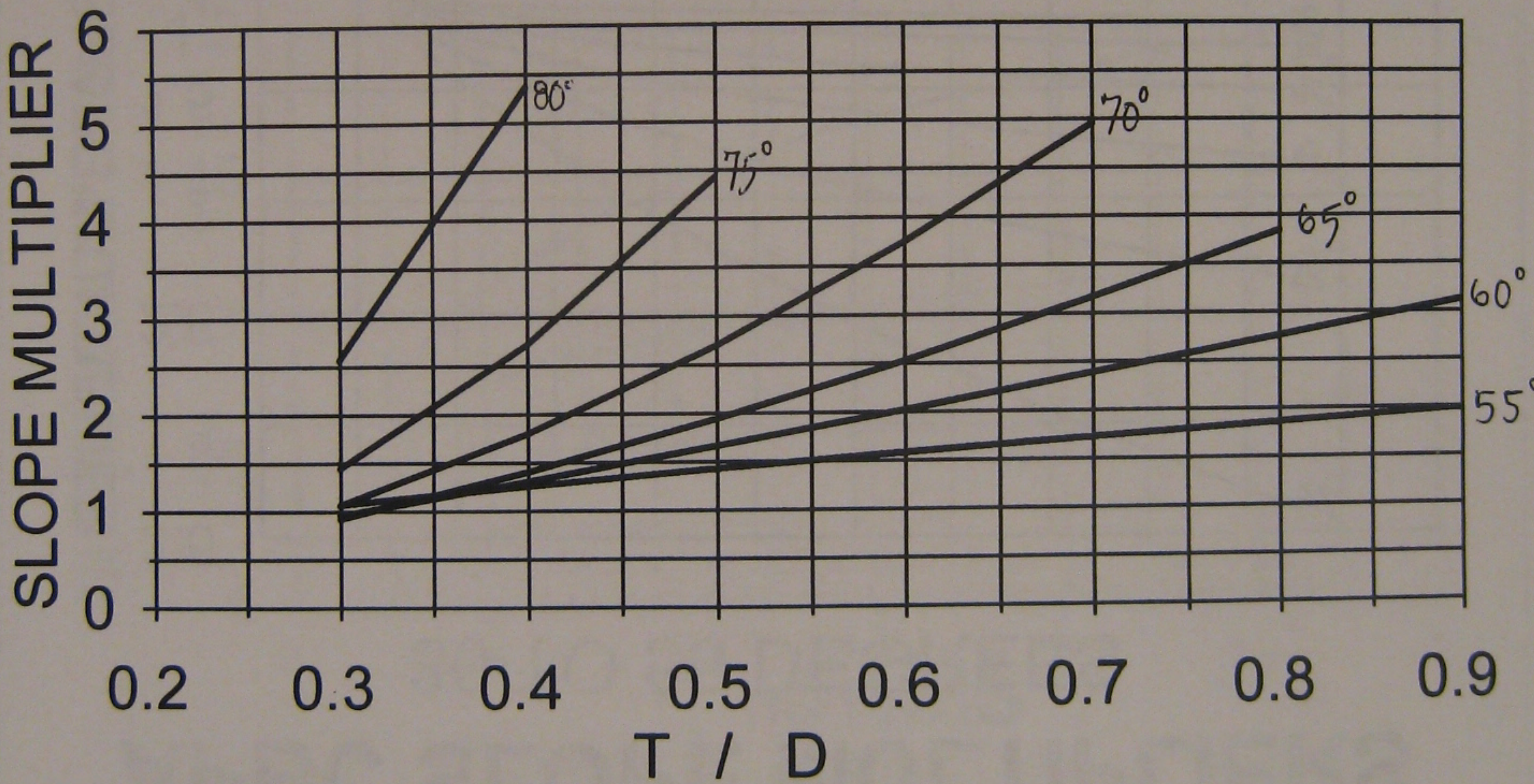
APBC SLOPE MULTIPLIERS

30 TO 55 DEGREES



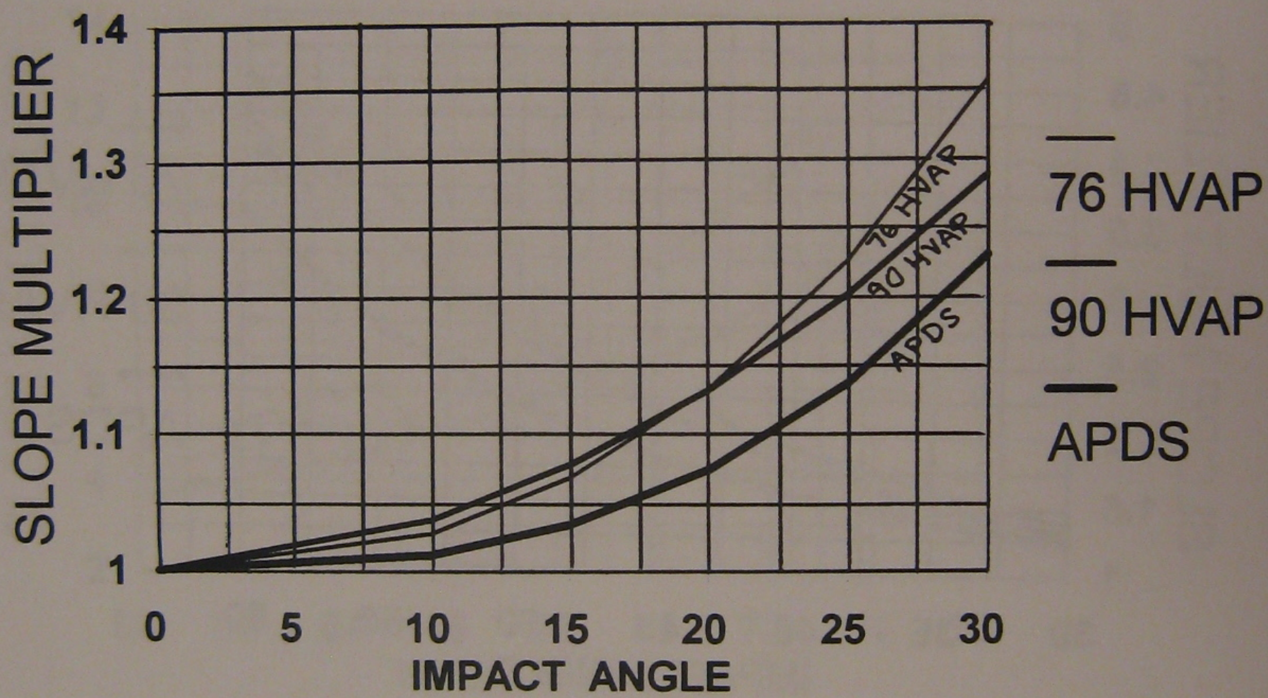
APBC SLOPE EFFECTS

55° TO 80°



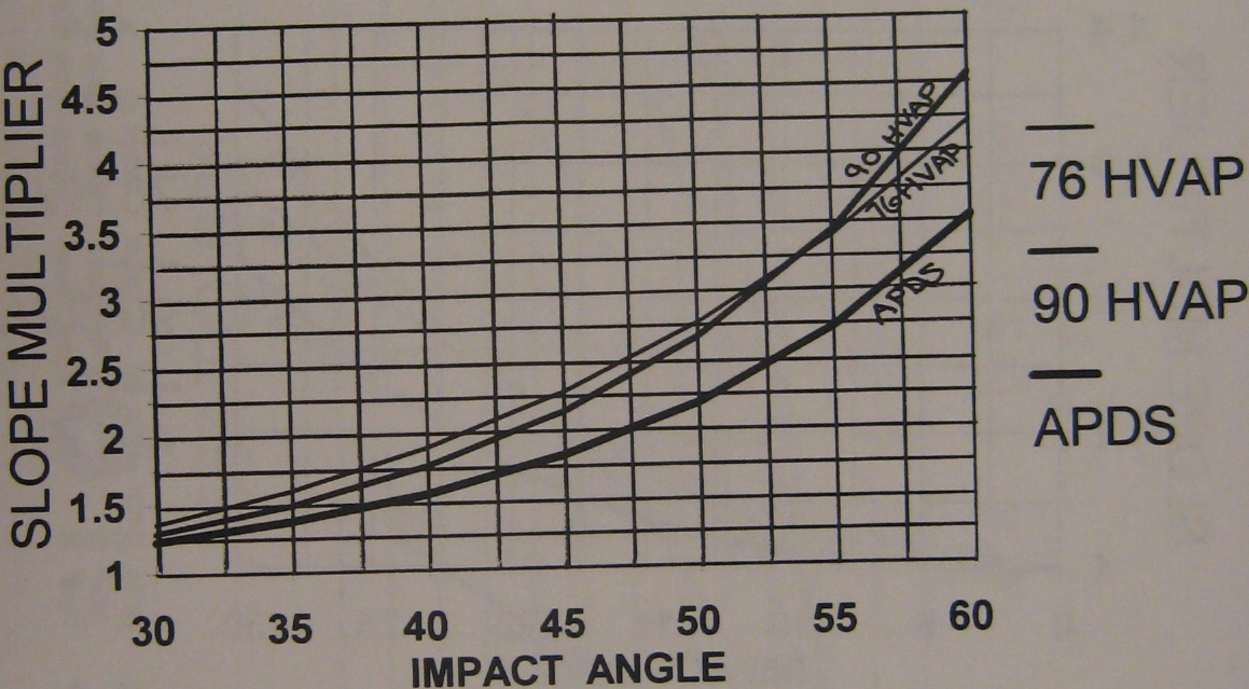
TUNGSTEN SLOPE EFFECTS

APDS, 76mm and 90mm HVAP



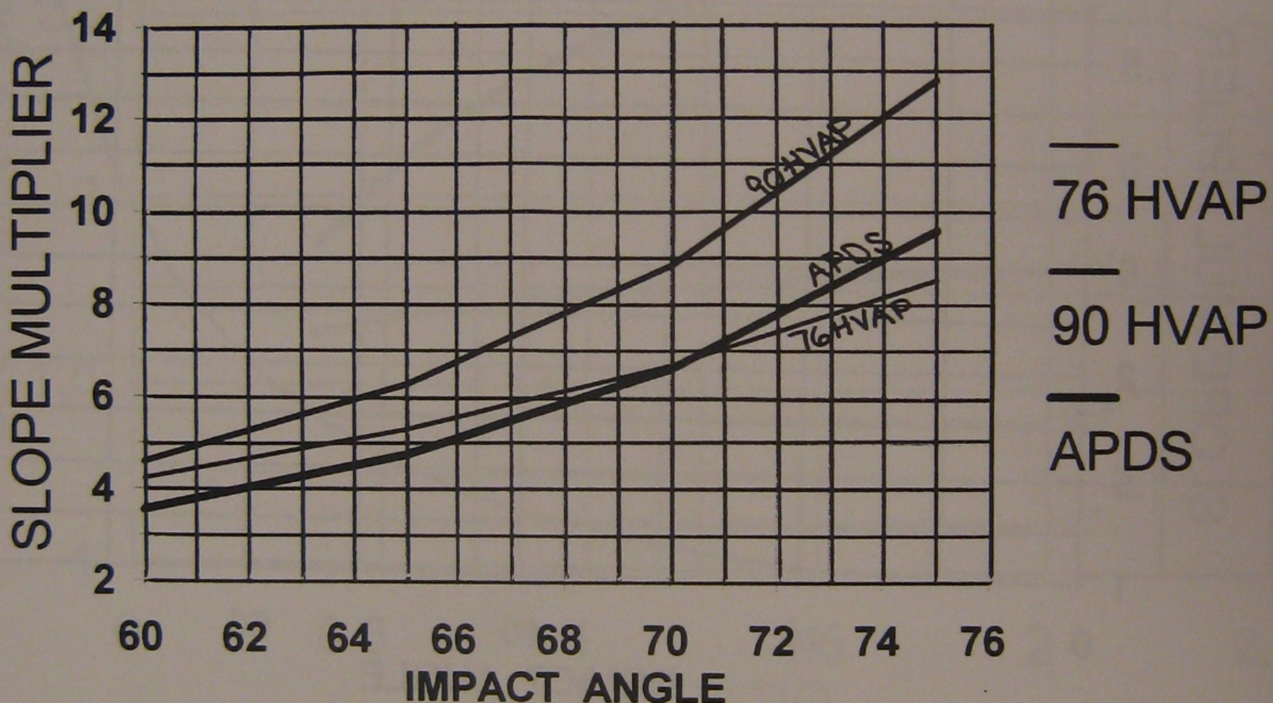
TUNGSTEN SLOPE EFFECTS

APDS, 76mm and 90mm HVAP

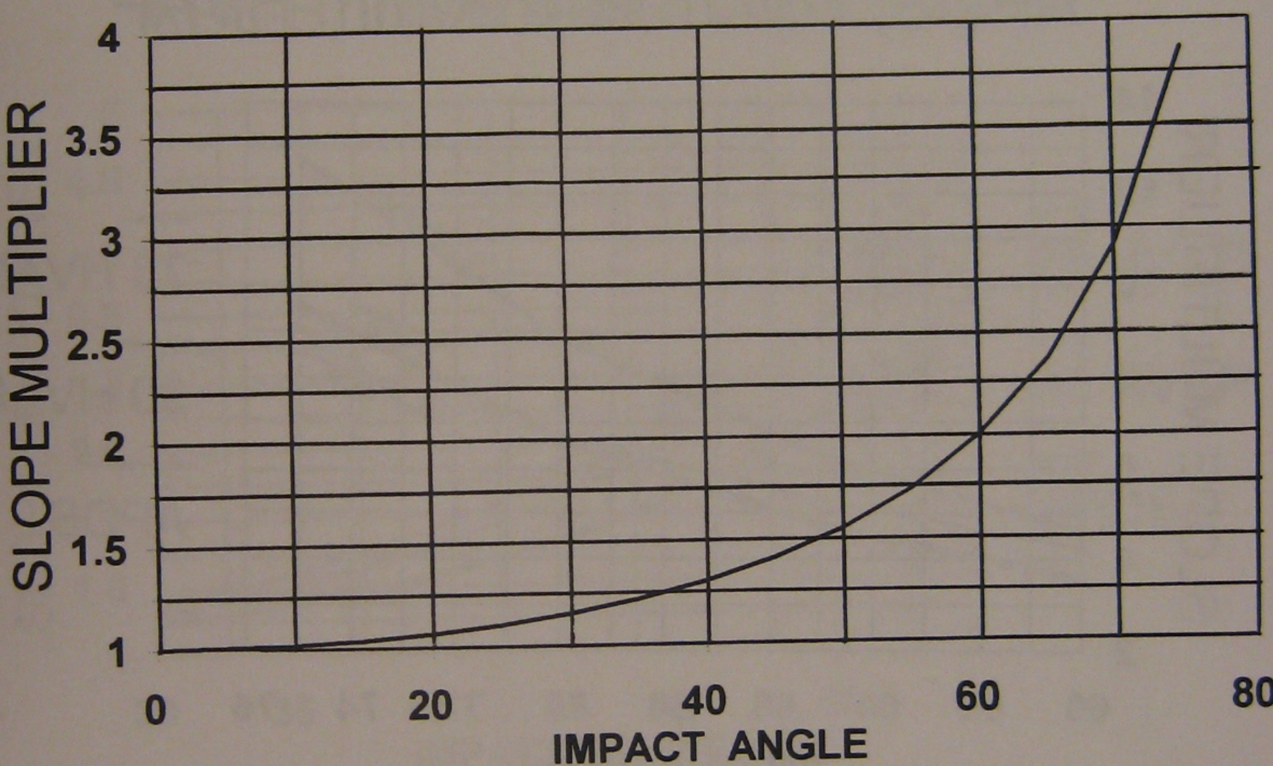


TUNGSTEN SLOPE EFFECTS

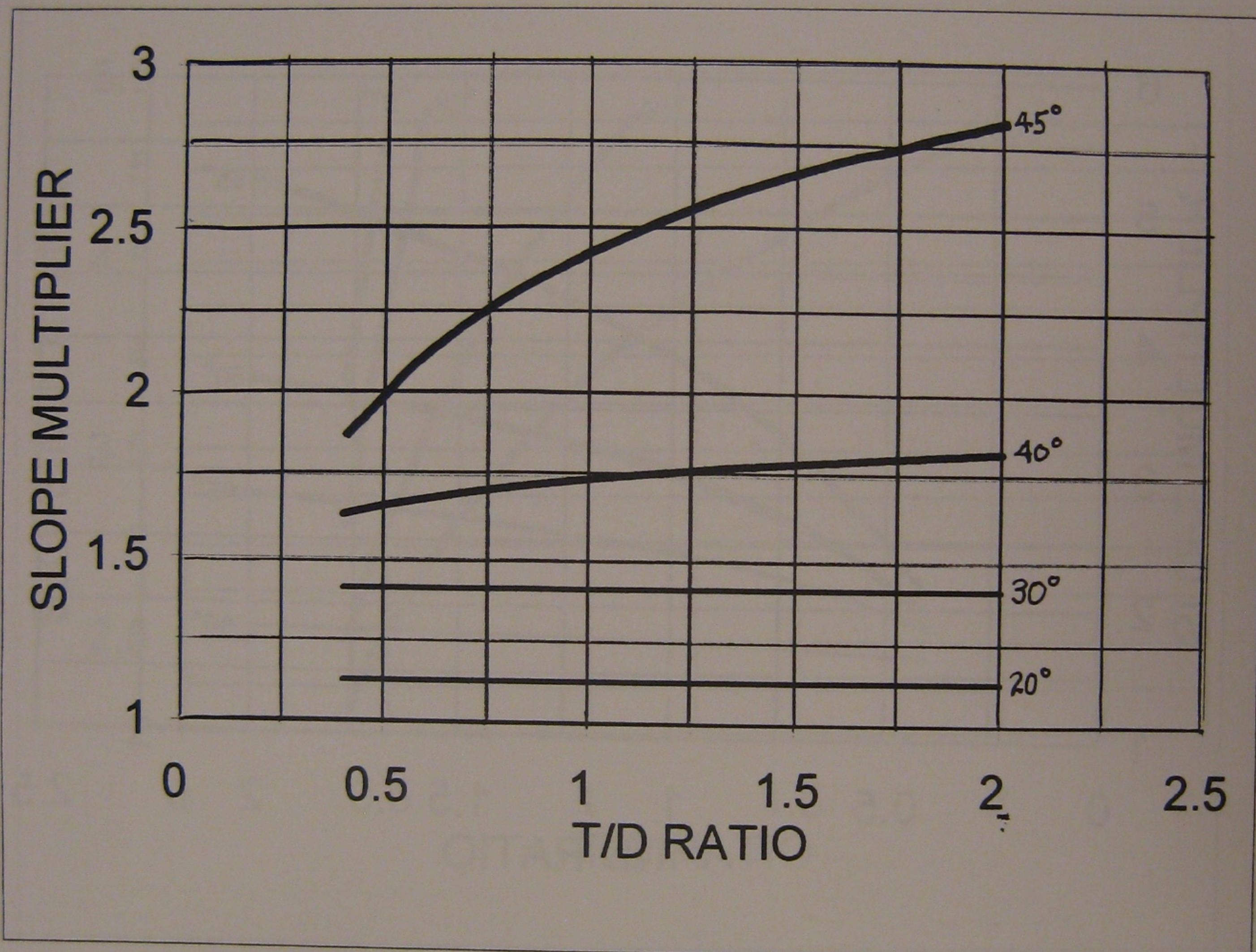
APDS, 76mm and 90mm HVAP



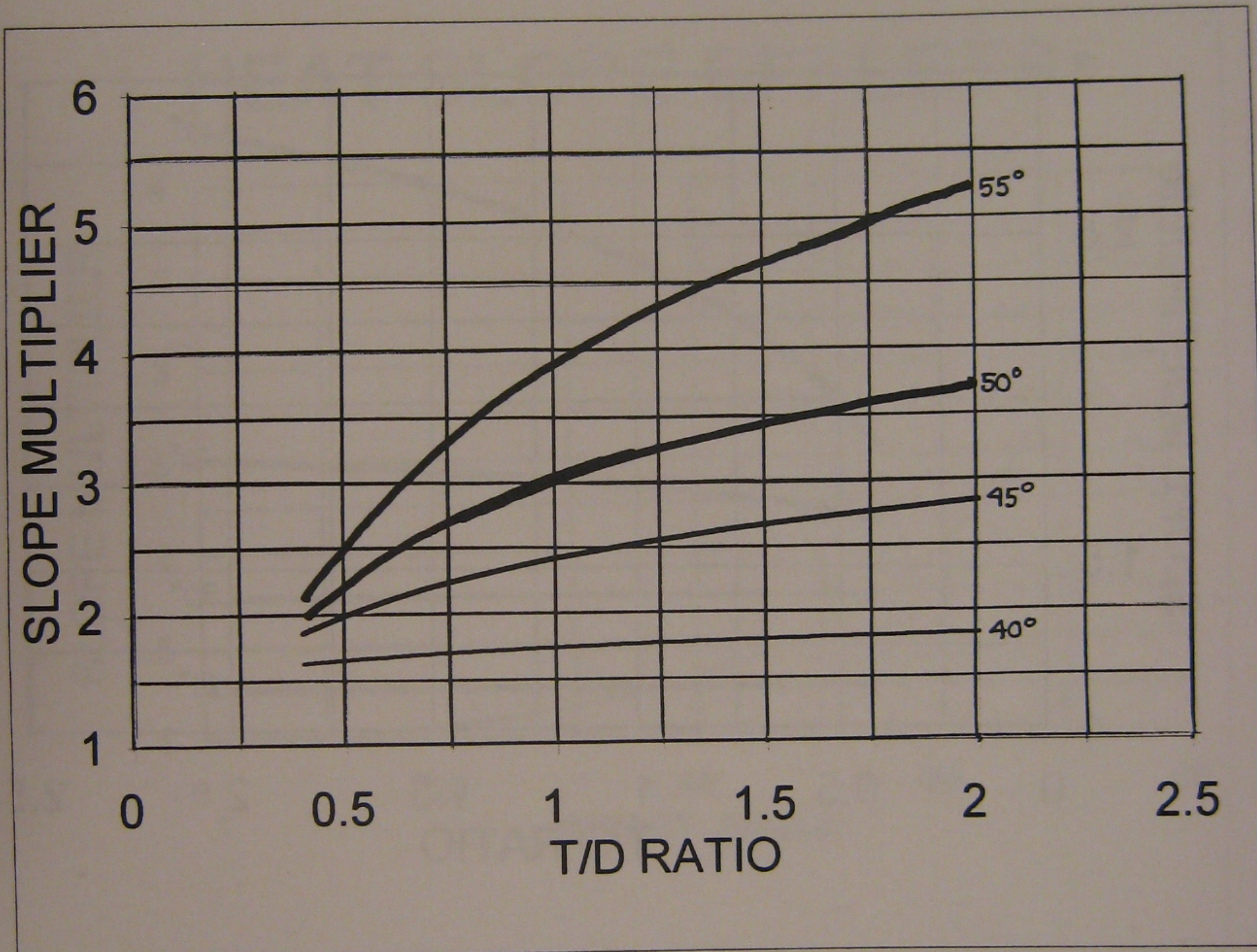
HEAT SLOPE EFFECTS



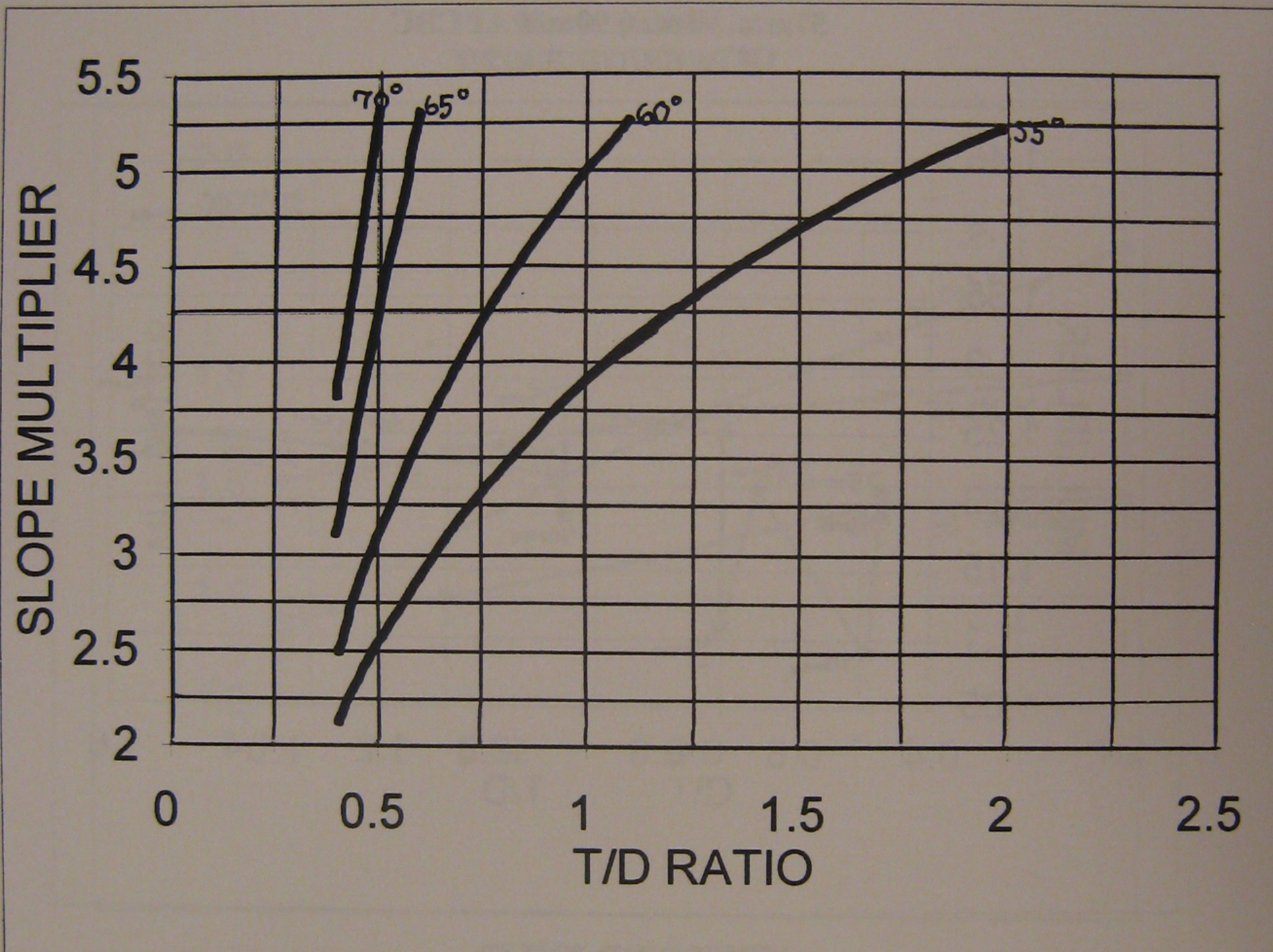
37mm APCBC SLOPE MULTIPLIERS



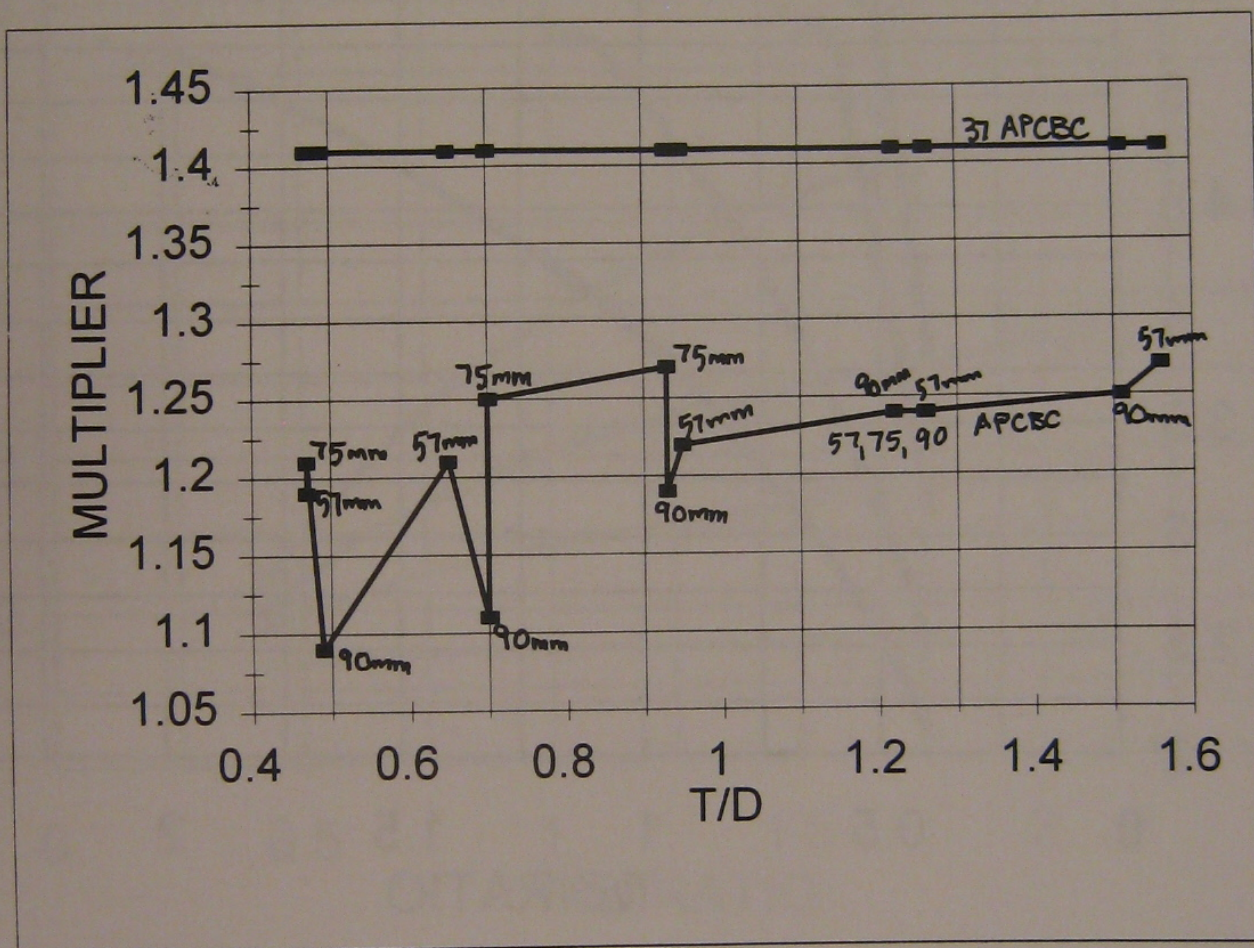
37mm APCBC SLOPE MULTIPLIERS



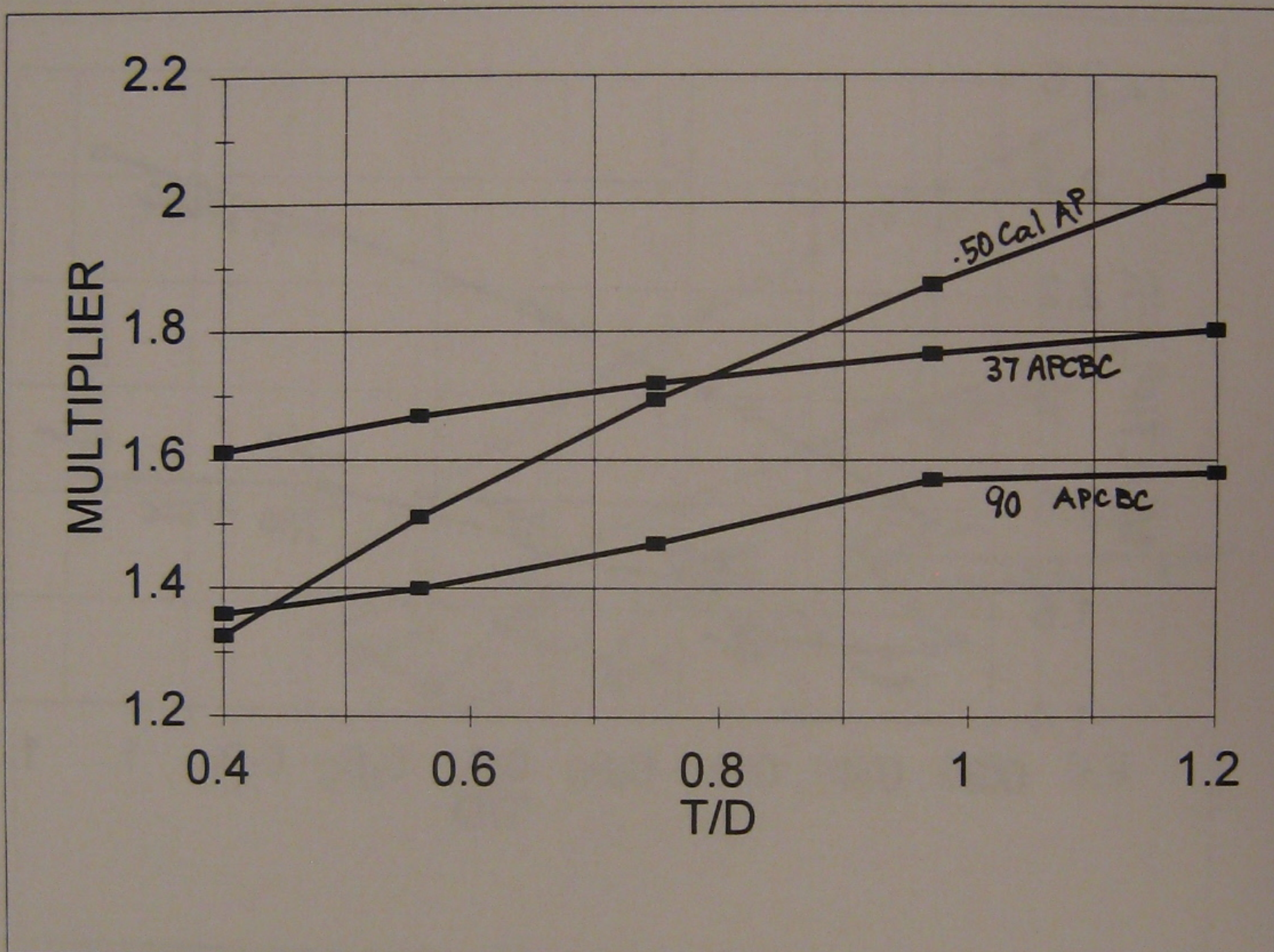
37mm APCBC SLOPE MULTIPLIERS



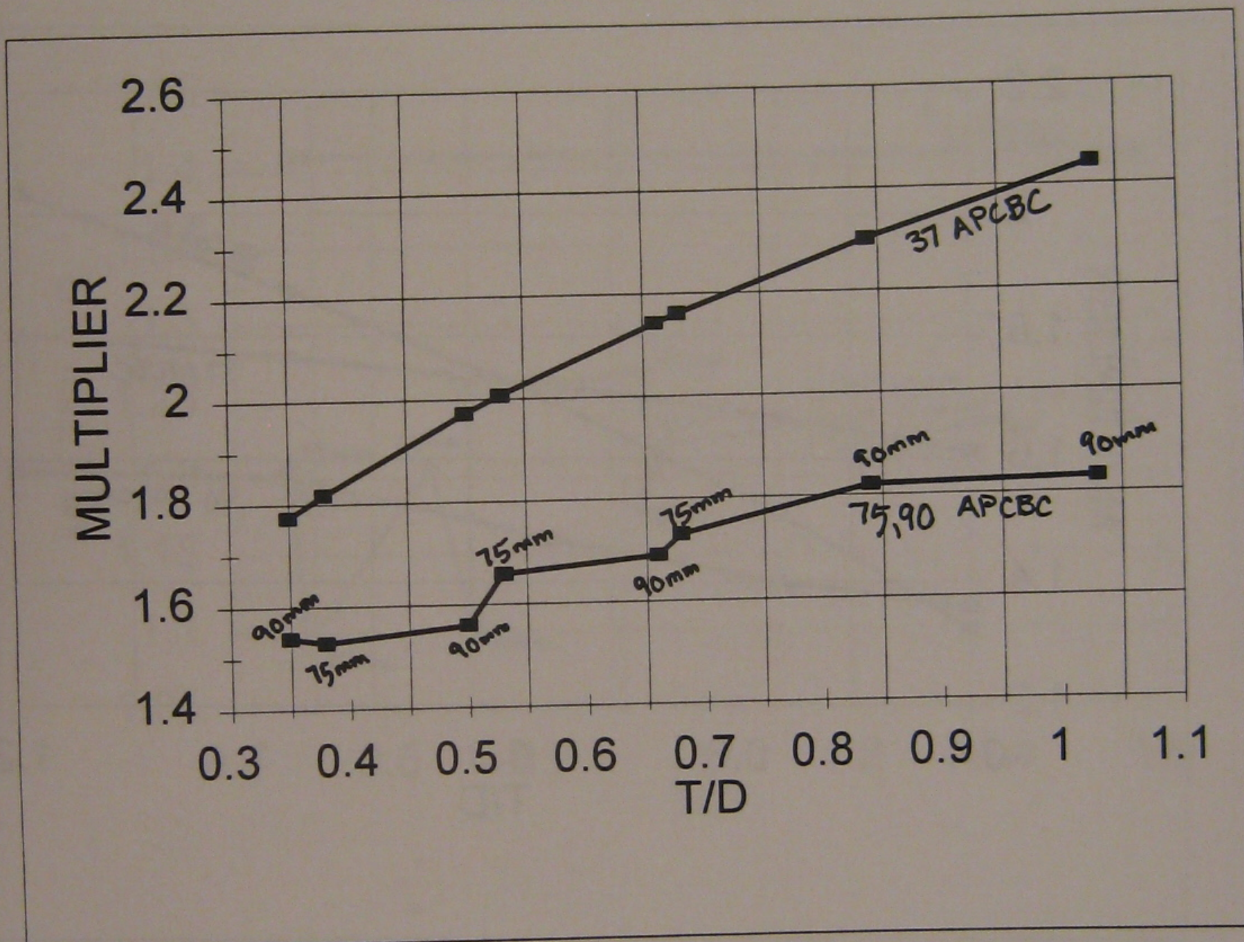
30 DEGREE SLOPE MULTIPLIERS FOR U.S. 37 APCBC AND 57mm, 75mm, 90mm APCBC VERSUS T/D RATIO



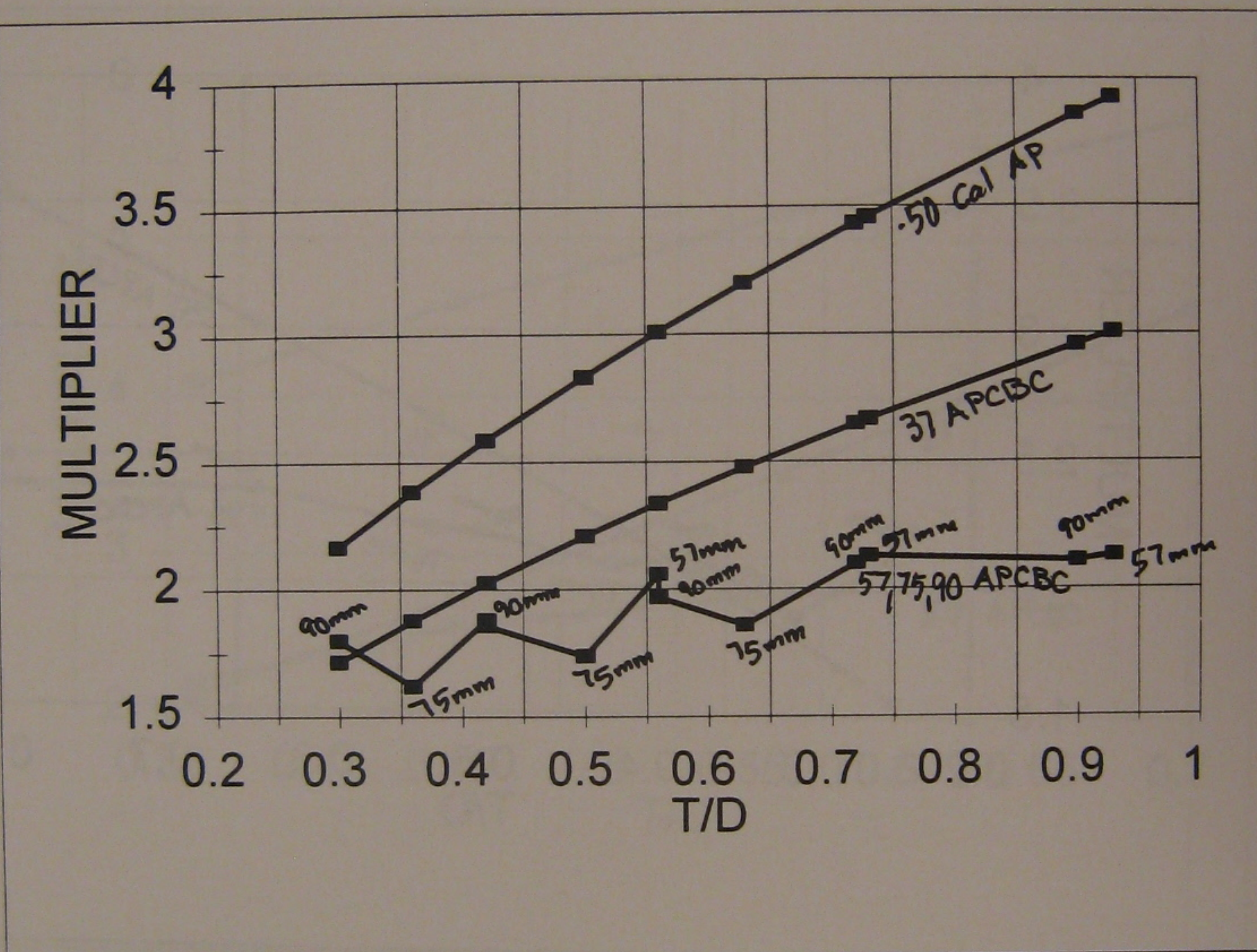
**40 DEGREE SLOPE MULTIPLIERS FOR
U.S. .50 Cal AP, 37mm APCBC AND
90mm APCBC
VERSUS T/D RATIO**



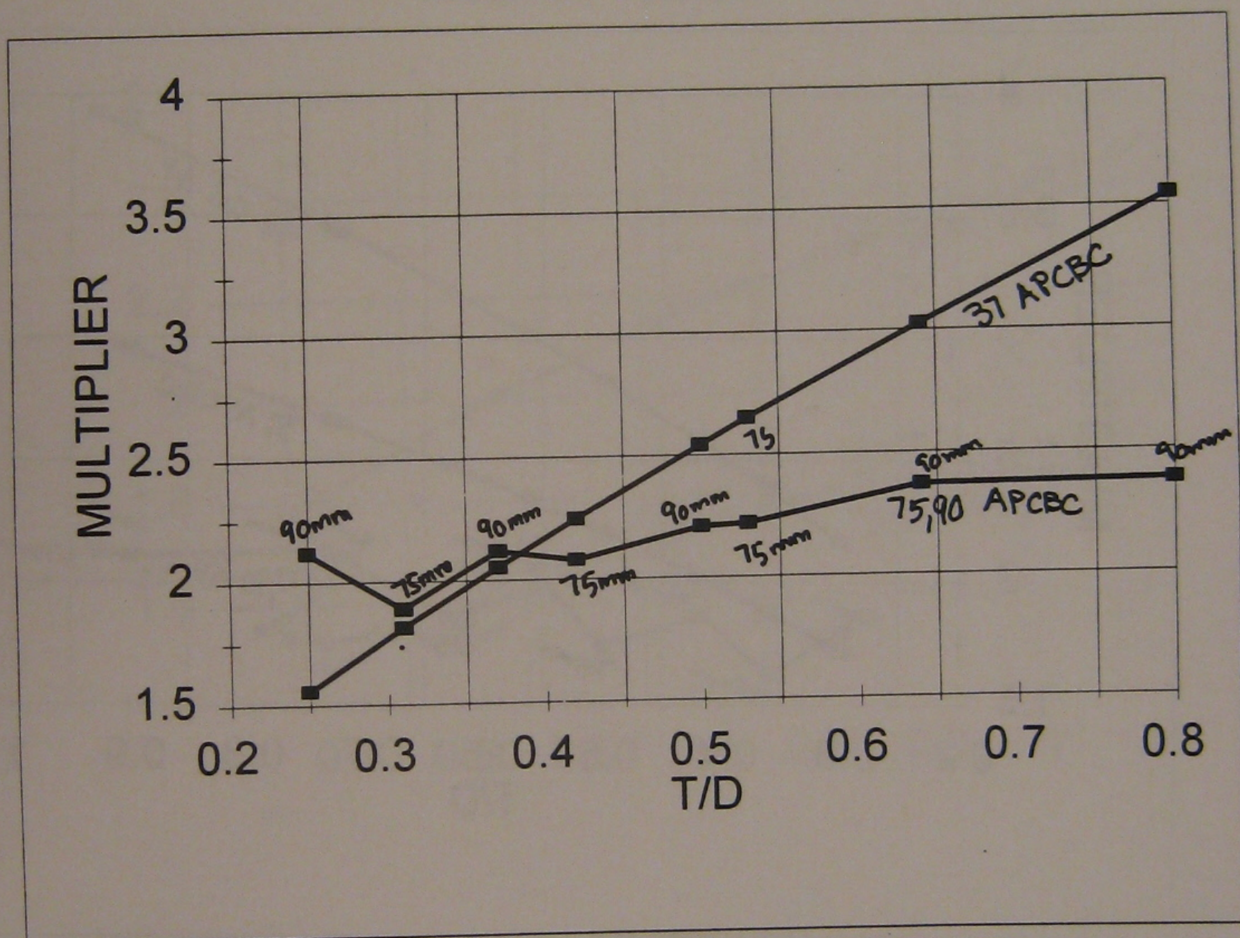
45 DEGREE SLOPE MULTIPLIERS FOR U.S. 37mm APCBC AND 75mm, 90mm APCBC VERSUS T/D RATIO



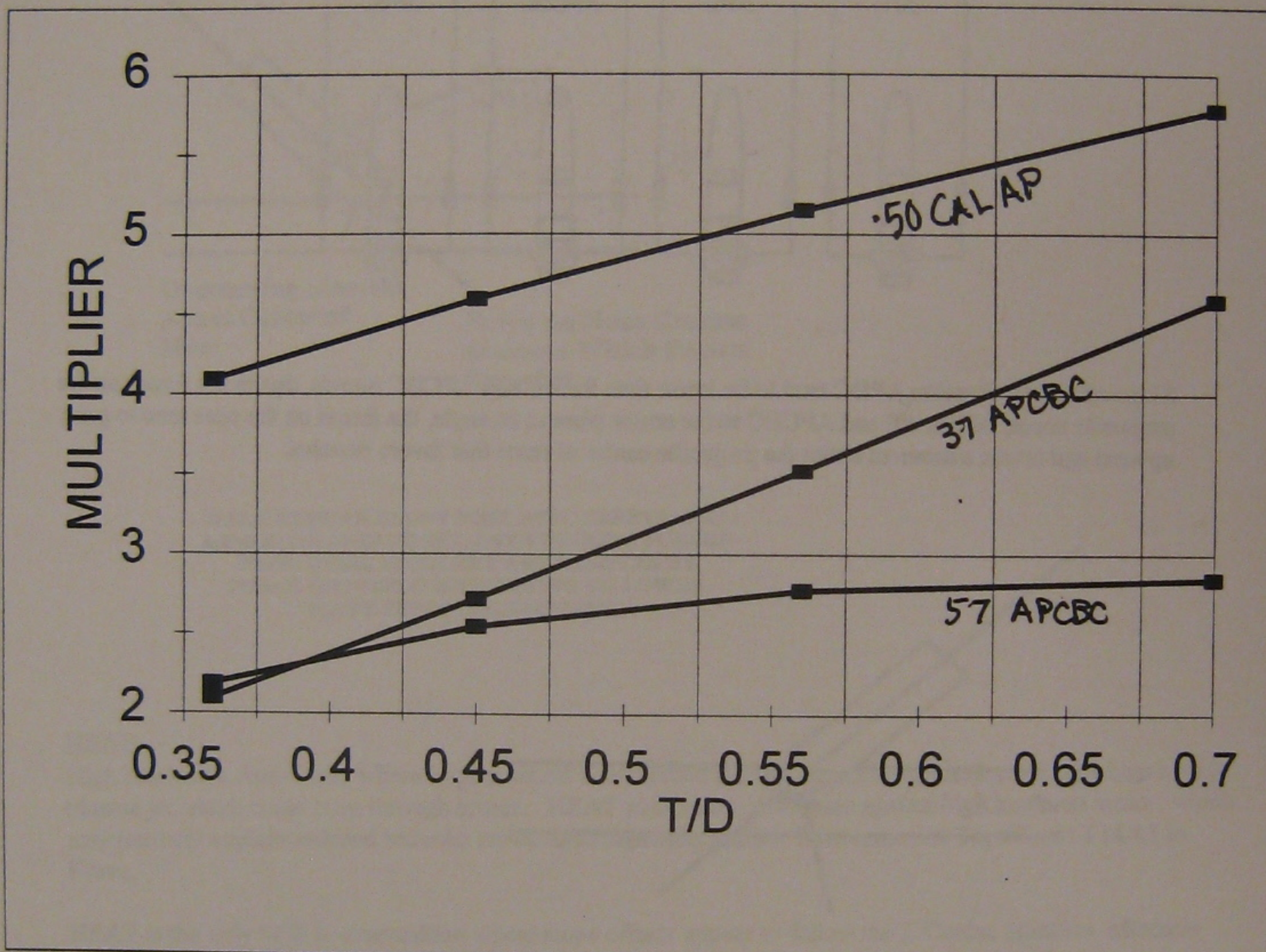
50 DEGREE SLOPE MULTIPLIERS FOR U.S. .50 Cal AP, 37mm APCBC AND 57mm, 75mm, 90mm APCBC VERSUS T/D RATIO

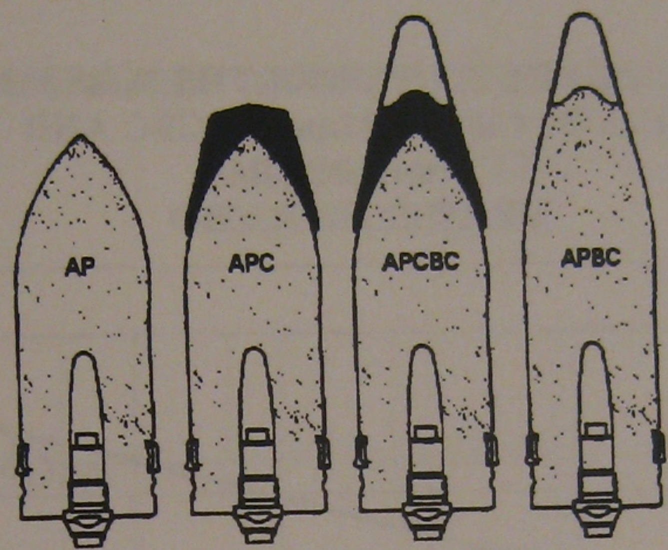


55 DEGREE SLOPE MULTIPLIERS FOR
U.S. 37mm APCBC AND
75mm, 90mm APCBC
VERSUS T/D RATIO

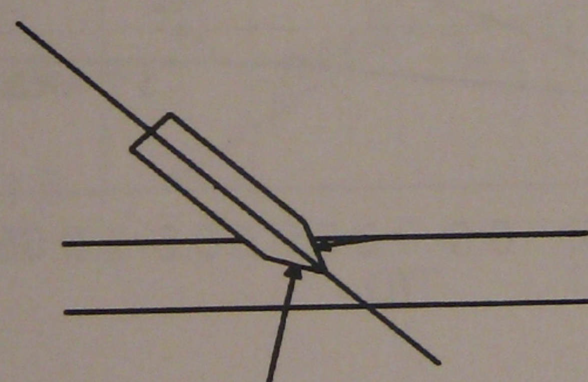


60 DEGREE SLOPE MULTIPLIERS FOR U.S. .50 Cal AP, 37mm APCBC AND 57mm APCBC VERSUS T/D RATIO



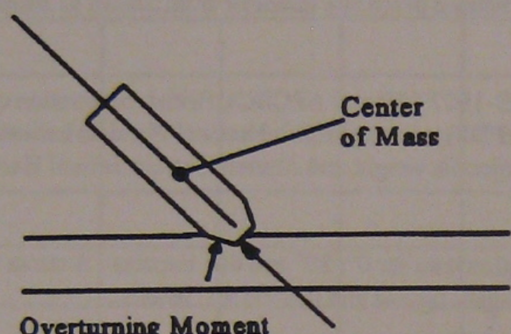


Slope effects for Russian APBC tend to be lower than for AP and APCBC rounds, due to the forces on the projectile noses. When AP and APCBC strike armor plate at an angle, the forces on the nose tend to push upward and create a moment about the projectile center of mass that favors ricochet.



WHEN POINTED OR ROUNDED NOSE PROJECTILES PENETRATE SLOPED ARMOR, THE NET REACTIVE FORCE RESISTS PENETRATION AND ENCOURAGES RICOCHET

When blunt nosed APBC strikes armor at an angle, as the nose digs a net upward force is generated on the nose but the moment about the projectile center of mass tends to rotate the round onto the armor surface.



WHEN RUSSIAN BLUNT NOSE APBC PENETRATES ARMOR ON ANGLED HIT, OVERTURNING FORCES PROMOTING RICOCHET ARE RESISTED BY FORCE ON NOSE,CONTRIBUTING TO LOWER SLOPE EFFECT MULITPLIERS

HEAT:
High Explosive Anti-Tank, where impact set off a detonation that collapsed metal shell, creating a high energy plasma jet which could burn through armor. HEAT penetration decreases against high hardness armor, which may partially explain reduced bazooka penetration capability against front armor on Tiger I and T34/85 in Korea.

HEAT is the only WW II ammunition where slope effects appear to follow the T/Cosine equation, effective resistance at 0° equals the plate or cast thickness divided by the cosine of the angle from vertical.

TUNGSTEN:
Hard, high density material that is brittle but able to hit armor at high velocity and avoid shatter failure, although tungsten slope effects are higher than steel projectile due to brittle nature of tungsten ammunition.

APCR used by Germans and Soviets and stands for Armor Piercing Composite Rigid. 50mm APCR was made up of 50mm wide lightweight carrier holding a smaller tungsten core. British used APDS or Armor Piercing Discarding Sabot, where 6 and 17 Pounder fired a 76.2mm wide round holding a smaller core. The carrier sides fell off as the round exited the gun barrel (discarding sabot), which could endanger personnel

standing near the gun. APDS lost velocity and penetration relatively slowly with range since in-flight diameter and wind resistance was reduced, compared to other tungsten rounds. Americans used HVAP or High Velocity Armor Piercing, which was similar to APCR.

British also used Little john adaptors on 37mm and 40mm guns, which squeezed the carrier down as the round moved down a gradually narrowing barrel. Guns with Little john adaptors could not fire other rounds. Germans used squeezebore guns, where 28/20 gun reduced projectile diameter from 28mm to 20mm, and an HE round was produced for that gun.

Sources for slope effect data include U.S. Army TM9-1907 (AP and APCBC), British penetration curves from Bovington Tank Museum (AP, APC, APCBC and APDS), and the British National Physical Laboratory equation for penetration as a function of velocity, projectile weight and diameter, armor Brinell Hardness and impact angle.

APDS slope effects were taken from British penetration data for 0°, 30° and 60° impacts. A curve was prepared through the data points to estimate intermediate figures and beyond 60° results.

Russian APBC slope effects are taken from a U.S. test of 122mm projectiles against American armor, at angles from 0° through 70°.

The graph following this page presents firing test data for 90mm HVAP against 8" armor plate, with varying armor hardness and impact angles. The interesting point is that armor at 339 Brinell Hardness has greater resistance than 223, 240 and 260 Brinell plate as indicated by a higher penetration velocity, and 339 Brinell armor appears to outperform 390 Brinell at angles below 17°. 390 BHN armor appears to be superior on angled hits.

The effectiveness of 339 Brinell Hardness armor in the 90mm HVAP tests is due to the overmatching character of the armor, where plate thickness is much greater than projectile diameter. When armor overmatches a projectile, the material may tend to be brittle (such as 339 and 390 Brinell Hardness) but the bulk that is contributing to penetration resistance appears to dilute shock effect from projectile impact, and brittle effects are limited. Note that 390 Brinell armor has lower resistance than 339 Brinell at small impact angles, which suggests that low angle hits are taking advantage of the greater brittleness of 390 Brinell plate.

The tests with 90mm HVAP against 203mm armor suggest that hits on hard Tiger armor (over 300 BHN and up to 350 BHN on early models) by small tungsten core rounds might experience increased resistance. Small tungsten cores in this case could include 2 Pounder and 37mm Little john, and 45mm APCR.

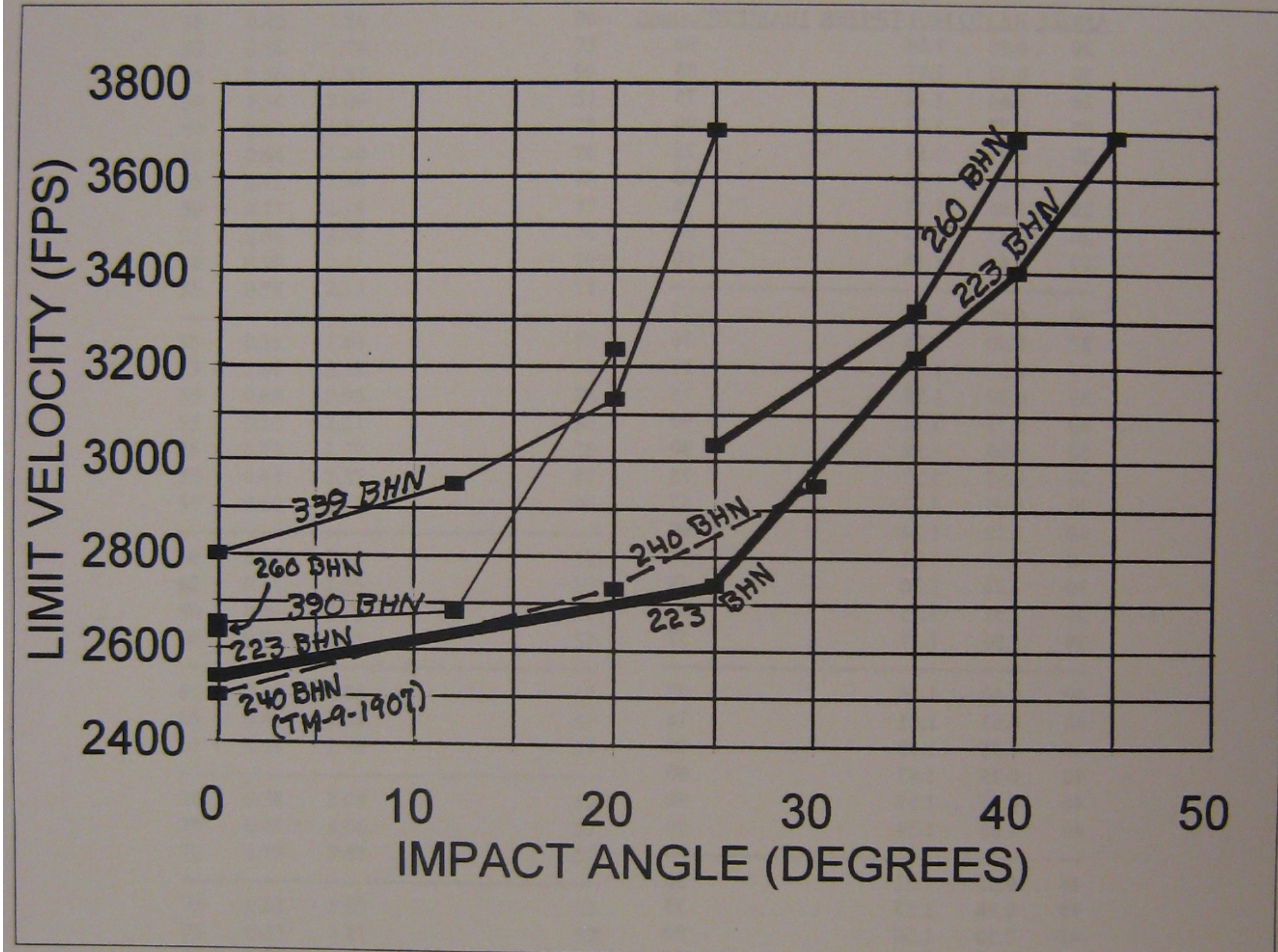
It is also possible that APCR hits by 37mm, 50mm and 75mm German guns against 100mm and 127mm hard armor on IS-2/2m tanks (over 400 BHN) could be resisted with additional resistance when impact angle exceeds 0°. The added resistance of very high hardness armor on angled hits (390 BHN against 90mm HVAP) appears to be related to bending or breaking of brittle tungsten core noses.

BASE DATA FOR APCBC/APC SLOPE EFFECTS

Slope multiplier curves for APCBC and APC ammunition were based in large part on American data, which offers the best data base available, and limited German and British data for APCBC/APC was found to

LIMIT VELOCITY FOR 90mm HVAP

AGAINST 8" ARMOR AT VARIOUS HARDNESS



approximately follow American figures (Panther Fibel has 3.00 slope multiplier for 60° hits). American data used in the slope effect study follows, source is U.S. Army TM9-1907:

ANGLE	T/D RATIO	SLOPE MULTIPLIER	PROJECTILE DIAMETER (mm)
20	0.52	1.04	90
20	0.52	1.11	75
20	0.64	1.12	75
20	0.73	1.07	90
20	0.91	1.12	75
20	0.99	1.12	90
20	1.05	1.13	75
20	1.32	1.15	90
20	1.67	1.14	90
30	0.47	1.21	75
30	0.50	1.15	76
30	0.65	1.21	57
30	0.70	1.25	75
30	0.71	1.11	90
30	0.93	1.19	90
30	0.93	1.27	75
30	0.95	1.22	57
30	1.22	1.24	90
30	1.26	1.24	57
30	1.28	1.30	76
30	1.51	1.25	90
30	1.56	1.27	57
40	0.40	1.36	90
40	0.51	1.41	76
40	0.56	1.40	90
40	0.75	1.47	90
40	0.97	1.57	90
40	1.08	1.54	76
45	0.35	1.52	90
45	0.38	1.53	75
45	0.50	1.56	90
45	0.52	1.65	76
45	0.53	1.66	75
45	0.66	1.69	90
45	0.68	1.73	75
45	0.71	1.70	76
45	0.84	1.82	90
45	0.93	1.79	76
45	1.03	1.83	90

ANGLE	T/D RATIO	SLOPE MULTIPLIER	PROJECTILE DIAMETER (mm)
50	0.36	1.62	75
50	0.38	1.84	90
50	0.42	1.86	90
50	0.50	1.74	75
50	0.56	1.97	90
50	0.56	2.06	57
50	0.63	1.86	75
50	0.64	1.88	76
50	0.72	2.10	90
50	0.73	2.14	57
50	0.80	2.08	76
50	0.90	2.11	90
50	0.93	2.13	57
55	0.31	1.89	75
55	0.37	2.12	90
55	0.42	2.08	75
55	0.50	2.21	90
55	0.53	2.22	75
55	0.64	2.37	90
55	0.80	2.38	90
60	0.36	2.19	57
60	0.45	2.55	57
60	0.56	2.78	57
60	0.70	2.85	57
65	0.41	2.86	57
65	0.45	2.94	57
65	0.49	2.99	57
70	0.38	3.09	57
70	0.41	3.26	57
70	0.43	3.42	57
75	0.32	3.65	57
75	0.33	3.81	57
75	0.34	4.00	57
75	0.36	4.15	57

EQUATIONS FOR PREDICTION OF 0° EFFECTIVE RESISTANCE

Analysis of slope effect multipliers for AP, APCBC/APC and APBC indicates that effective resistance at 0° may be approximately modeled with a limited number of equations for compound angles. The following steps

provide a suggested procedure for estimating 0° equivalent resistance, which may be entered into programmable hand held calculators or computers (for full equations see Appendix 16):

1. Input lateral angle "L" (measured from horizontal armor facing, where 0° to front hull is in line with tank hull orientation)

2. Input vertical angle "V" (armor perpendicular measured from vertical)

3. Compute overall impact angle "A" as arc cosine (cosine (V) x cosine (L))

4. Input armor thickness "T"

5. Input projectile diameter "D"

6. Effective armor resistance at 0° equals : T x F x (T/D)^G

   where X^Y indicates that X is raised to Y power (^ indicates term to left is raised to a power):

   <u>for APCBC and APC</u>

   Angles to 55°
   F = 2.71828^(0.0000408 x A^2.5) G = 0.0101 x 2.71828^(0.1313 x A^0.8)

   Angles 55° to 60°
   F = -3.434 + 0.10856 x A G = 0.2174 + 0.00046 x A

   Angles 60° to 70°
   F = 0.00000518 x A^3.25 G = 0.00002123 x A^2.295

   Angles 70° to 85°
   F = 0.0678 x 1.0634^A G = 0.1017 x 1.0178^A

   <u>for AP</u>

   Angles to 40°
   F = 0.95 x 2.71828^(0.0000539 x A^2.5) G = 0.04433 x 2.71828^(0.04867 x A)

   Angles from 40° to 55°
   Slope multiplier = 0.04754 x (angle)^0.953 x (T/D)^(0.02047164 x (angle)^0.46471)

   Angles from 55° to 65°
   Slope multiplier = 0.0001675 x (angle)^2.3655 x (T/D)^(0.02047164 x (angle)^0.46471)

for APBC

Angles to 55°
F = 2.71828^(0.019925 x 1.06758^A) G = 0.007012 x 1.08289^A

Angles from 55° to 60°
F = 2.71828^(0.002542 x 1.1089^A) G = 0.0004763 x 1.1373^A

Angles from 60° and above
F = 2.71828^(0.03723 x 1.06033^A) G =-3.3667 + 0.07411 x A

Three separate programs are used on our hand held calculators, one each for AP, APCBC/APC and APBC. The APBC program equation is valid within the range of test penetration data, and may produce unrealistic results when used for T/D ratio's below those included in base data.

Equation results will vary from the curves, although the differences appear to be small and within the accuracy of the curve of best fit which was fit through the original data.

Results below the base armor thickness should be treated as the base thickness.

The equation prediction will be for rolled armor without flaws, cast deficiency or high hardness, and the actual armor resistance at 0° would be found by applying the appropriate multipliers for those factors.

Equations for HVAP and APDS are in Appendix 16, where APCR should use HVAP results.

3. FACE-HARDENED ARMOR

GENERAL

German use of face-hardened armor, which was effective during the early stages of WW II when many opposing guns and projectiles used rounds without armor piercing caps, was retained after the Allies went to projectiles with improved performance against face-hardening.

The projectiles used by the Allies during the early stages of WW II were AP rounds, which did not have armor piercing caps, where those caps protect projectile noses against cracking, increasing face-hardened penetration. Without protective caps, British hits on German face-hardened armor would shatter and fail at ranges where homogeneous armor could be defeated. Homogeneous armor has the same hardness all the way through, generally about 220-300 BHN, while face-hardened armor has a thin layer of 450 to 650 BHN hardness in an otherwise homogeneous plate.

German face-hardened armor was produced using flame hardening and electrical induction, and the desired depth of hardened face was 2.5 to 4mm for 30mm plates, and 3 to 5mm for 50mm thick plates.

As an example of face-hardened armor effectiveness, 2 pdr AP could penetrate 86mm of homogenous armor at 0 yards and 0° impact, but was limited to 66mm of face-hardened penetration at that range and angle. Although PzKpfw III used face-hardened armor prior to 1942, official policy release during that year indicated that all German tanks were to carry face-hardened armor on hull front and side plates in the 30-50mm range, although thicker plates were face-hardened on Panther and PzKpfw IVH. British analysis of a captured Panther A disclosed that the front nose plate, and the 40mm hull and superstructure side, were face-hardened to around 500 BHN. Panther D tanks appear to have carried face-hardened glacis armor.

The most effective German use of face-hardened armor was on the PzKpfw IIIH, where 32mm face-hardened plates were bolted, and sometimes welded, onto the 30mm face-hardened hull front armor. In U.S. and British tests against captured PzKpfw IIIH's, the 32+30 combination on the hull front resisted penetration like a single face-hardened plate of 69mm thickness. The PzKpfw IIIH effective armor thickness on the front hull was 71mm at 0° driver plate resistance, and 77mm at 0° bow.

The PzKpfw IIIH front hull held 6 pdr AP, 37mm APCBC and 75mm AP projectiles to less than 600 yard penetration range, and 2 pdr AP failed at 200 yards against the PzKpfw IIIH driver plate and should fail at point blank. 75mm APCBC, which included armor piercing and ballistic windshield caps, penetrated PzKpfw IIIH hull front at 1000 yards in the same tests using the 75mm/L31 Grant gun with 1850 fps muzzle velocity.

The early success of face-hardened armor in the desert was turned around once American and British guns started firing capped ammunition. British APC was first used during early 1943, while 75mm and 37mm APCBC were available on U.S. rounds during 1942. Despite widespread use of armor piercing caps on Allied projectiles, German production still emphasized 30mm and 50mm face-hardened armor throughout the war, and many PzKpfw IVG carried 32mm face-hardened plates on 50mm face-hardened hull armor, which may have resisted penetration like 84mm of face-hardened plate.

The effectiveness of armor piercing caps against face-hardened armor may be illustrated by comparing the armor resistance on the PzKpfw IVH driver plate to 75mm APCBC penetration. If the PzKpfw IVH driver plate were homogeneous plate, the 85mm at 10° armor would limit Sherman 75mm penetration to 150m, whereas face-hardened armor could be penetrated at 940m.

German continuation of face-hardened armor use on tanks such as Panther, PzKpfw IVF,G,H, PzKpfw III and StuG III may have been due to Russian ammunition, which did not carry armor piercing caps during WW II and was assumed to have inferior penetration against face-hardened plate.

Face-hardening and high hardness armor are very effective against bullets and small caliber uncapped AP when the T/D ratio equals or exceeds 1.00, and high hardness armor was used extensively on armored cars and halftracks, and early war tanks. Thin armor gains significant resistance from face-hardening and high hardness against 20mm and smaller rounds given favorable T/D ratio's, and high hardness armor was also used on aircraft, gun shields the conning towers of U-boats.

FACE HARDENED ARMOR SLOPE EFFECTS

The failure mechanism against face hardened armor is completely different from homogeneous armor. To be successful in defeating hits, face hardened armor must shatter the projectile nose before the round digs in too far, whereas homogeneous armor defeats hits by permitting penetration which aborbs energy as armor is pushed out of the way.

Given the different mechanisms involved, one might expect face hardened armor to have different slope effects, where angled hits that primarily involve shoulder contact should have higher penetration and lower slope multipliers. Study of Allied slope effect multipliers suggests that face hardened and homogeneous factors are similar for the same T/D ratio and projectile type. These findings would not apply to Russian APBC.

U.S. penetration data for the 90mm M82 APCBC projectile allows comparison of slope multipliers over a wide range of angles, and will be presented as an example of similar slope effects against different armor plate type. In the analysis that follows, the 90mm APCBC slope effect for face hardened penetration at a given angle and T/D ratio will be compared to the predicted slope effect for homogeneous armor. The impact velocities are 2400, 2000 and 1600 fps.

IMPACT ANGLE	FACE HARDENED T/D RATIO	FACE HARDENED SLOPE EFFECT	PREDICTED HOMOGENEOUS SLOPE EFFECT AT T/D RATIO
20°	1.39	1.11	1.12
20°	1.12	1.12	1.10
20°	0.87	1.11	1.10
30°	1.24	1.24	1.28
30°	1.00	1.25	1.27
30°	0.77	1.25	1.25
40°	1.06	1.46	1.58
40°	0.87	1.43	1.53
40°	0.69	1.40	1.49
45°	0.85	1.82	1.75
45°	0.72	1.74	1.70
45°	0.57	1.68	1.63

For the twelve cases presented in the above table, the average error is 3.7% when homogeneous armor slope effect is treated as the base data. In the absence of comprehensive slope effect data for a wide variety of projectiles, angles and T/D ratio's, it appears reasonable to assume that the homogeneous and face hardened armor slope effects are similar and may be modeled with the same equations for AP, APCBC and APC ammunition.

Russian APBC slope effects against face-hardened armor probably fall between the homogeneous multipliers for APBC and APCBC, being closer to APCBC factors. This assumption is based on the fact that the superior slope effects for APBC against homogeneous armor occur when the blunt nose enters the armor, a situation that will not generally occur against face-hardened armor.

TUNGSTEN CORE AMMUNITION AGAINST FACE-HARDENED ARMOR

The John Salt site provides two penetration figures for tungsten core ammunition against face-hardened armor that can be used to estimate relative performance.

"Tank Killers", Hogg (1997), indicates that 17 pdr APDS penetrates 231mm of face-hardened armor at 1000 yards and 30 degrees from vertical. The performance at the same range and angle against medium hardness homogeneous armor is estimated from 188mm to 200mm.

A sentence is also noted where the 28/20 Gerlich gun penetrates 76mm of machineable quality armor at 100 yards and almost defeats 87mm of face-hardened plate at the same range.

For 17 pdr APDS, face-hardened armor appears to be more vulnerable than homogeneous armor by factors of 1.155 to 1.229, and face-hardened vulnerability to the 28/20 gun is about 1.088 times homogeneous plate.

The Russians appear to have tested their AP and APBC rounds against face-hardened armor, and the open question is whether their APCR data is also against face-hardened armor.

Estimates for Russian APCR penetration by 76.2mm and 85mm guns from U.S. 76mm HVAP, based on striking velocity, core weight and core diameter, result in lower figures at range than the Russian published data. This suggests that the Russian penetration for APCR may be against face-hardened armor, and that the rounds would penetrate less homogeneous armor.

At this point, there is insufficient information to tell if Russian APCR penetration data is against face-hardened or homogeneous armor plate.

4. HIGH HARDNESS ARMOR MULTIPLIERS

Armor hardnesses below 375 Brinell Hardness Number (BHN) are normally referred to as machineable quality and are expected to have reasonable impact resistance, allowing them to stand up to repeated hits by large projectiles without cracking or spalling. When hardness equals or exceeds about 375 BHN, armor becomes brittle and loses resistance when projectile diameter approaches, equals or exceeds plate or cast thickness.

In exchange for lowered resistance against overmatching guns, high hardness armor can shorten heat treatment time for armor steel, allowing more tanks to be produced and use of a less skilled workforce. High hardness armor also performs very well when thickness exceeds projectile diameter and small rounds strike the armor.

During WW II, almost all Soviet tanks carried high hardness armor in at least some areas, except for KV-I and KV-II. The following table is based on Allied analysis of Soviet tanks and defines average Soviet armor hardness on the basis of thickness, year and type (rolled versus cast).

ARMOR		BRINELL HARDNESS NUMBER		
TYPE	YEAR	Up to 60mm	61-80mm	81mm+
ROLLED	1942-45	450	340	300
CAST	1942-43	480	300	300
CAST	1944-45	420	420	420

In the previous section, the T34 hull front was determined to have an effective resistance of 122mm at 0° against 75mm APCBC hits. Due to high hardness effects, there will be a 0.76 multiplier for T/D=0.60 (45mm plate divided by 75mm projectile), which lowers the effective resistance to 93mm at 0°.

The graph following this page is based on firing test data from American and German sources, and converts high hardness armor to an equivalent thickness of rolled homogeneous U.S. armor (highest quality and 240 Brinell Hardness Number).

Soviet armor hardnesses of 340 Brinell might be treated as high hardness due to brittle nature of armor specimens that were analyzed.

The curve-of-best fit equation for high hardness multiplier is:

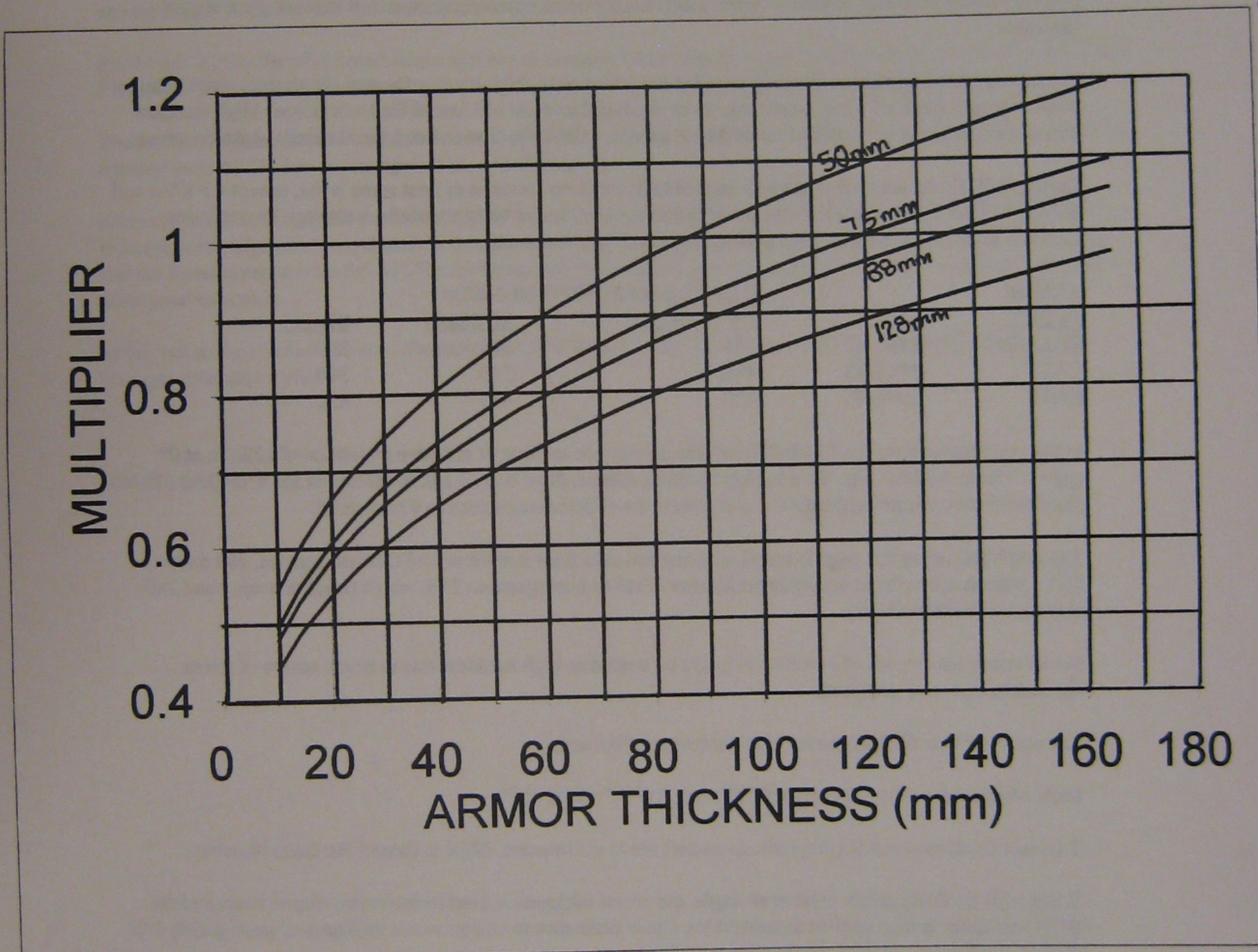
$$\text{BHN Multiplier} = 0.01 \times 977.07 \times D^{0.06111} \times (T/D)^{0.2821} \times BHN^{-0.4363}$$

T (armor thickness) and D (projectile diameter) are in millimeters, BHN is Brinell Hardness Number.

When high-hardness armor is hit at an angle, the actual thickness is used to determine slope effects and the BHN multiplier is then applied to convert the armor resistance to an equivalent thickness of good quality 240 Brinell Hardness plate (U.S. penetration test plate).

When hard armor is hit at relatively low impact velocities, such as 75L24 APCBC, the deficiency may be reduced due to lower impact, although reported penetration ranges against T34 side armor do not suggest major variations from predicted resistance.

HIGH HARDNESS EQUIVALENCY FACTORS



240 BRINELL EQUIVALENCY MULTIPLIERS FOR 460 BRINELL ARMOR

	PROJECTILE DIAMETER (mm)						
Thickness	45	47	50	75	76.2	88	128
10	0.56	0.55	0.54	0.50	0.49	0.48	0.44
14	0.61	0.61	0.60	0.55	0.54	0.53	0.49
15	0.62	0.62	0.61	0.56	0.55	0.54	0.49
20	0.68	0.67	0.66	0.60	0.60	0.58	0.54
25	0.72	0.71	0.70	0.64	0.64	0.62	0.57
30	0.76	0.75	0.74	0.68	0.67	0.65	0.60
35	0.79	0.78	0.77	0.71	0.70	0.68	0.63
40	0.82	0.81	0.80	0.73	0.73	0.71	0.65
45	0.85	0.84	0.83	0.76	0.76	0.73	0.67
50.8	0.88	0.87	0.86	0.79	0.78	0.76	0.70
52	0.88	0.88	0.86	0.79	0.79	0.76	0.70
55	0.90	0.89	0.88	0.80	0.80	0.78	0.71
60	0.92	0.91	0.90	0.82	0.82	0.79	0.73
63.5	0.94	0.93	0.91	0.84	0.83	0.81	0.74
65	0.94	0.93	0.92	0.84	0.84	0.81	0.75
70	0.96	0.95	0.94	0.86	0.86	0.83	0.76
75	0.98	0.97	0.96	0.88	0.87	0.85	0.78
80	1.00	0.99	0.98	0.89	0.89	0.86	0.79
85	1.02	1.01	0.99	0.91	0.90	0.88	0.81
88.9	1.03	1.02	1.01	0.92	0.92	0.89	0.82
90	1.03	1.02	1.01	0.92	0.92	0.89	0.82
95	1.05	1.04	1.02	0.94	0.93	0.90	0.83
100	1.06	1.05	1.04	0.95	0.95	0.92	0.84
101.6	1.07	1.06	1.04	0.95	0.95	0.92	0.85
105	1.08	1.07	1.05	0.96	0.96	0.93	0.86
110	1.09	1.08	1.07	0.98	0.97	0.94	0.87
115	1.11	1.10	1.08	0.99	0.99	0.95	0.88
120	1.12	1.11	1.09	1.00	1.00	0.97	0.89
125	1.13	1.12	1.11	1.01	1.01	0.98	0.90
130	1.15	1.13	1.12	1.02	1.02	0.99	0.91
135	1.16	1.15	1.13	1.03	1.03	1.00	0.92
140	1.17	1.16	1.14	1.05	1.04	1.01	0.93
145	1.18	1.17	1.15	1.06	1.05	1.02	0.94
150	1.19	1.18	1.17	1.07	1.06	1.03	0.95
155	1.20	1.19	1.18	1.08	1.07	1.04	0.96
160	1.22	1.20	1.19	1.09	1.08	1.05	0.96
165	1.23	1.21	1.20	1.09	1.09	1.06	0.97

IMPROVED HIGH HARDNESS ARMOR MULTIPLIERS

In response to comments regarding the difficulty that German 37mm and 50mm gun had against T34 armor, the following two alternative multiplier tables were generated.

The Alternative One table is based on German firing tests against T34 like armor with 37mm and 50 guns, and the revised multipliers apply to 50mm and smaller diameter guns:

The Alternative Two table is designed so that 75L43 APCBC hits on T34 front hull armor are limited to a 1000m range, which is consistent with various reports and severely limits the effectiveness of 37mm through 50mm AP/APC ammunition against T34 armor.
It should be noted that the original high hardness multiplier table was consistent with reports where 75L43 knocked out attacking T34 tanks at 1200m at any angle, and 1600m maximum.

	ALTERNATIVE ONE			ALTERNATIVE TWO						
Plate	Projectile Diameter			Projectile Diameter						Plate
Thickness	37mm	47mm	50mm	37mm	47mm	50mm	75mm	76.2mm	88mm	Thickness
10	0.59	0.55	0.55	0.68	0.72	0.72	0.68	0.67	0.63	10
15	0.72	0.64	0.63	0.83	0.83	0.83	0.74	0.73	0.67	15
20	0.83	0.72	0.70	0.96	0.93	0.91	0.78	0.77	0.71	20
25	0.93	0.78	0.75	1.08	1.01	0.99	0.82	0.80	0.73	25
30	1.02	0.84	0.80	1.18	1.08	1.05	0.85	0.83	0.76	30
35	1.10	0.89	0.85	1.27	1.14	1.11	0.88	0.86	0.77	35
40	1.17	0.94	0.89	1.36	1.20	1.17	0.90	0.88	0.79	40
45	1.24	0.99	0.93	1.45	1.25	1.21	0.92	0.90	0.81	45
50	1.31	1.03	0.96	1.52	1.30	1.26	0.94	0.92	0.82	50
55	1.37	1.07	1.00	1.60	1.35	1.30	0.96	0.94	0.83	55
60	1.44	1.10	1.03	1.67	1.39	1.34	0.98	0.95	0.85	60
65	1.49	1.14	1.06	1.74	1.43	1.38	0.99	0.97	0.86	65
70	1.55	1.17	1.09	1.80	1.47	1.42	1.00	0.98	0.87	70
75	1.60	1.20	1.11	1.87	1.51	1.45	1.00	1.00	0.88	75
80	1.66	1.23	1.14	1.93	1.55	1.49	1.00	1.00	0.89	80
85	1.71	1.26	1.16	1.99	1.58	1.52	1.00	1.00	0.89	85
90	1.76	1.29	1.19	2.05	1.62	1.55	1.00	1.00	0.90	90
95	1.81	1.32	1.21	2.10	1.65	1.58	1.00	1.00	0.91	95
100	1.85	1.34	1.23	2.16	1.68	1.61	1.00	1.00	0.92	100
110				2.26	1.74	1.66	1.00	1.00	0.93	110
120				2.36	1.80	1.71	1.00	1.00	0.95	120
127				2.43	1.83	1.75	1.00	1.00	0.96	127

Direct combat evidence in support of the high hardness multipliers is suggestive rather than definitive. German reports included in Jentz' *Panzertruppen, Vol. 2* indicate that the 75mm L43 gun on PzKpfw IV could penetrate T34 at a variety of impact angles beyond 1000m range and up to 1600m. Since a large number of T34 were fired on and the Russians were on the offensive when the action took place (February through March 1943), it seems reasonable to assume that some of the penetrations were on T34 front hull hits.

The 0° penetration of 75mm L43 APCBC is listed in this book as 102mm at 1200m, and 93mm at 1600m. After slope effects and high hardness modifiers are applied, the 45mm front hull of T34 has an effective 0° resistance of 93mm against head-on hits (no side angle). In general, penetration ranges predicted with the data in this book are consistent with the reported front hull penetrations of T34 beyond 1100m.

It is also notable that other German reports in Jentz' work limit the penetration range of 75L43 to less than 1100m. If T34's were constructed with American made armor of 250-300 Brinell Hardness, or the thickness range varied from 42mm to 50mm(see page 12 ranges in SU 100 armor thickness) , it is possible that a percentage of T34 had effective resistance approaching 107mm at 0° effective.

5. CAST ARMOR MULTIPLIERS

GENERAL

American, British and German firing test results indicate that cast armor is, as a general rule, less resistant than rolled armor, due to beneficial structural changes that take place when armor is rolled.

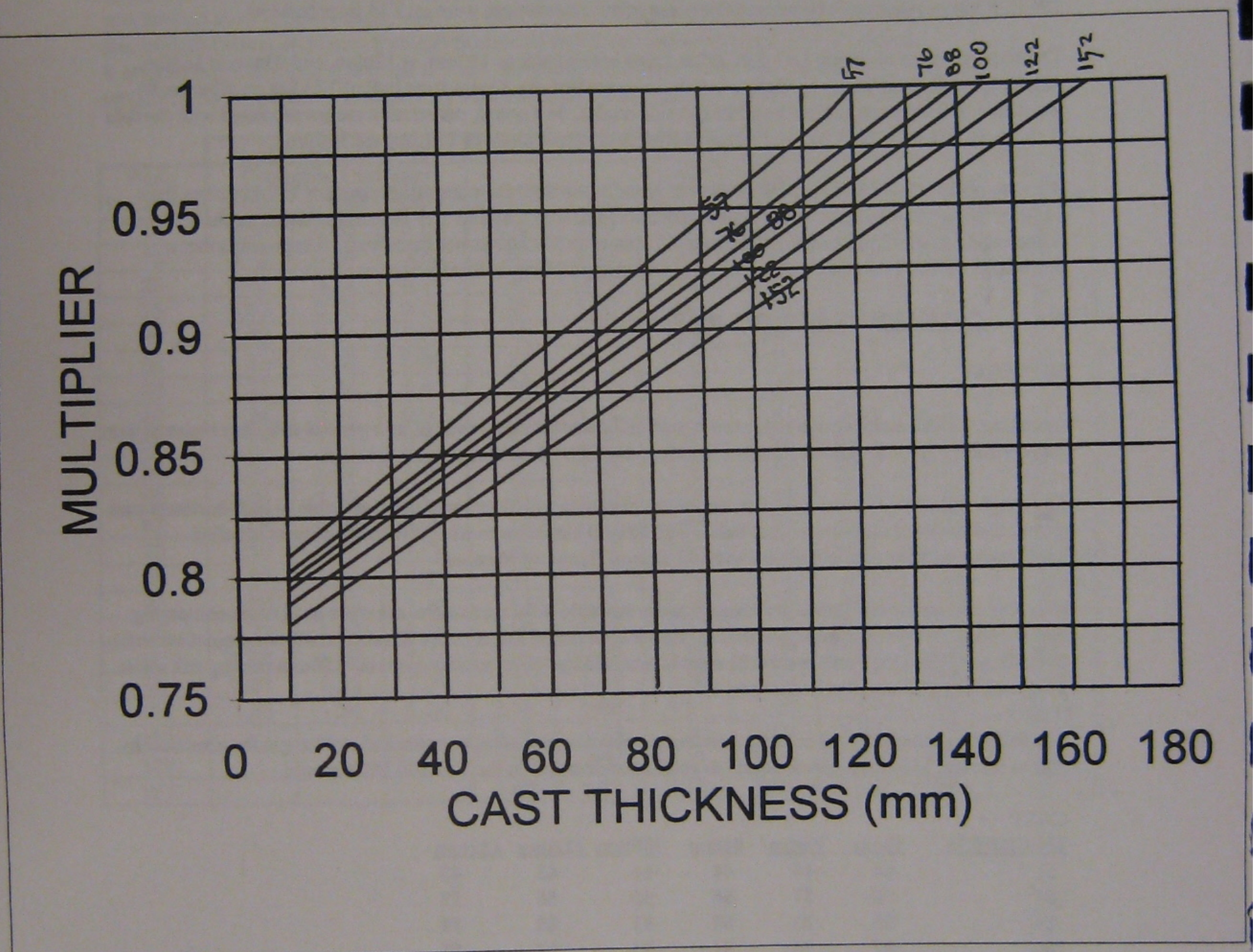
The graph following this page for cast armor deficiency to rolled armor is not applicable to high-hardness cast armor, and converts cast armor at or below 300 Brinell Hardness to an equivalent thickness of rolled homogeneous armor of good quality and 240 Brinell Hardness Number.

Note that cast armor resistance generally exceeds the 80%-85% factors that are often used when comparing cast to rolled plate armor, except when cast armor is overmatched as when 75mm and 88mm projectiles strike 2" castings. When the Panther mantlet apex is attacked by 76mm ammunition, the 100mm casting will resist penetration like 95mm of rolled armor.

The following table presents rolled equivalency estimates for cast armor attacked at 0° angle from vertical by 50mm through 152mm projectiles, and is valid for cast armor in the 220-300 BHN range:

CAST THICKNESS	50mm	75mm	88mm	100mm	122mm	152mm
51	44	44	44	44	43	43
64	58	57	56	56	56	55
89	85	83	82	81	80	79
100	97	95	94	93	92	91
110	109	106	105	104	103	101
140	140	140	140	139	137	135
175	175	175	175	175	175	175
195	195	195	195	195	195	195

CAST-TO-ROLLED ARMOR MULTIPLIERS



ROLLED ARMOR EQUIVALENCY OF CASTINGS

	PROJECTILE DIAMETER (mm)								
Cast Thickness	20	40	50	57	76	88	100	122	152
10	0.83	0.81	0.81	0.81	0.80	0.80	0.80	0.79	0.78
14	0.84	0.82	0.82	0.82	0.81	0.80	0.80	0.79	0.79
15	0.84	0.82	0.82	0.82	0.81	0.81	0.80	0.80	0.79
20	0.85	0.83	0.83	0.83	0.82	0.81	0.81	0.80	0.79
25	0.87	0.84	0.84	0.83	0.83	0.82	0.82	0.81	0.80
30	0.88	0.85	0.85	0.84	0.83	0.83	0.83	0.82	0.81
35	0.89	0.86	0.86	0.85	0.84	0.84	0.83	0.83	0.82
40	0.90	0.87	0.86	0.86	0.85	0.84	0.84	0.83	0.82
45	0.92	0.88	0.87	0.87	0.86	0.85	0.85	0.84	0.83
50.8	0.93	0.89	0.88	0.88	0.87	0.86	0.86	0.85	0.84
52	0.94	0.90	0.89	0.88	0.87	0.86	0.86	0.85	0.84
55	0.94	0.90	0.89	0.89	0.87	0.87	0.86	0.85	0.84
60	0.96	0.91	0.90	0.89	0.88	0.88	0.87	0.86	0.85
63.5	0.97	0.92	0.91	0.90	0.89	0.88	0.88	0.87	0.86
65	0.97	0.92	0.91	0.90	0.89	0.88	0.88	0.87	0.86
70	0.98	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
75	1.00	0.94	0.93	0.92	0.91	0.90	0.89	0.88	0.87
80	1.00	0.95	0.94	0.93	0.91	0.91	0.90	0.89	0.88
85	1.00	0.96	0.94	0.94	0.92	0.91	0.91	0.90	0.89
88.9	1.00	0.97	0.95	0.94	0.93	0.92	0.91	0.90	0.89
90	1.00	0.97	0.95	0.95	0.93	0.92	0.92	0.91	0.89
95	1.00	0.98	0.96	0.95	0.94	0.93	0.92	0.91	0.90
100	1.00	0.99	0.97	0.96	0.95	0.94	0.93	0.92	0.91
101.6	1.00	0.99	0.97	0.97	0.95	0.94	0.93	0.92	0.91
105	1.00	1.00	0.98	0.97	0.95	0.95	0.94	0.93	0.92
110	1.00	1.00	0.99	0.98	0.96	0.95	0.95	0.93	0.92
115	1.00	1.00	1.00	0.99	0.97	0.96	0.95	0.94	0.93
120	1.00	1.00	1.00	1.00	0.98	0.97	0.96	0.95	0.94
125	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.96	0.94
130	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.96	0.95
135	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.96
140	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.96
145	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97
150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98
155	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
160	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
165	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

When slope effects are calculated for cast armor, the actual thickness is used and the effective resistance is then multiplied by the cast-to-rolled armor modifier. The 51mm @ 52° glacis center on M4A1 presents 107mm at 0° resistance to 75mm hits if rolled armor is assumed, which would be multiplied by 0.87 for cast effects resulting in 93mm at 0° equivalent rolled armor.

The figures presented in the table do not consider flaws, which would further reduce the resistance.

The curve-of-best fit equation for cast armor deficiency compared to rolled armor is:

Cast Deficiency Multiplier = 0.8063 + T x 0.001238 - 0.0002628 * D + (T/D) x 0.02706

where T (armor thickness) and D (projectile diameter) are in millimeters.

GERMAN AND AMERICAN CAST ARMOR RESISTANCE

The assumption is often made that German cast armor presented 80% of the resistance offered by good quality rolled armor, and German test curves in the BIOS report may be presented as evidence. Since the section on cast armor indicates that castings will almost always exceed 80% of rolled armor resistance, this section will provide additional data to disprove the 80% factor.

The German tests that provide support for the 80% factor involve the 50mm AP round, which is uncapped and is fired at a muzzle velocity of 850 m/s at 100m range. The key BIOS curve in Appendix E shows the thickness of rolled and cast armor that provides immunity from 50mm AP hits, where the thickness of rolled armor needed to gain immunity is 80% of the cast Alloy "B" and "D" thickness.

Based on DeMarre penetration estimation from German 75mm projectiles, the 50mm AP round in the German firing tests should completely penetrate over 105mm of rolled armor on 50% of the hits at 100m. Since the round is expected to fail against 100mm or less of rolled and cast armor, it appears that nose failure is occurring in both cases. The source of 50mm AP nose over stressing may be due to a combination of several potential factors:

absence of an armor piercing cap on test rounds, which increases shatter tendencies

impact at a higher velocity than the round is designed for

shatter gap failure may occur when penetration capability exceeds armor by 5% to 40% with uncapped rounds

use of a softer round than standard nose hardness, which increases shatter tendency

If nose over stressing and shatter gap is occurring, comparison of rolled and cast thicknesses for immunity will not indicate the true relationship between the two armor types.

Examination of cast and rolled armor criteria in the BIOS report, based on immunity to 75mm projectile hits, provides an improved comparison of German armor types. From 0° through 30°, German cast armor equals or exceeds rolled armor in terms of the resistance needed to provide acceptable immunity against 75mm hits.

Examination of cast and rolled armor criteria in the BIOS report, based on immunity to 75mm projectile hits, provides an improved comparison of German armor types.

75mm IMPACT ANGLE	ROLLED ARMOR THICKNESS FOR IMMUNITY	CAST ARMOR THICKNESS FOR IMMUNITY
0°	160mm	150mm
15°	149mm	140mm
30°	130mm	130mm
45°	102mm	120mm

From 0° through 30°, German cast armor equals or exceeds rolled armor in terms of the resistance needed to provide acceptable immunity against 75mm hits. These results do not actually imply that cast armor is superior to rolled armor, since that result is not consistent with metallurgical considerations. It appears that acceptance criteria for the two armor types were developed with different test data, which accounts for different immunity thicknesses.

In view of the preceding discussion, cast armor is held to an equal or higher level of quality control than rolled armor in terms of passing ballistic tests, since decreasing cast armor thickness below rolled armor will only allow the best castings to pass firing tests. The high quality of German cast armor, especially Tiger mantlets, has been noted by Allied observers.

However, the 0°-30° trend for cast-vs-rolled armor resistance is reversed at 45° since cast armor is notably inferior to rolled armor, which is an abrupt and difficult to explain change in characteristics. Based on American and British data for cast and rolled armor, 102mm of rolled armor should resist 75mm hits like a 107mm casting. Since the cast armor specification data was not taken from a curve but may have been verbally communicated to British personnel by German armor specialists, the 45° specification may be in error.

Battlefield reports from Normandy suggest that the 100mm cast Panther mantlet was equivalent to almost 100mm of rolled armor against 76mm hits. The U.S. 76mm APCBC projectile was defeated by the Panther mantlet beyond 200 yards, where the failures may be due to shatter gap.

At 200 yards, 76mm APCBC penetration equals 123mm of rolled armor, and the upper shatter gap limit (penetration with shatter) normally occurs when penetration exceeds resistance by a ratio of 1.25. Dividing 123mm penetration by 1.25 indicates that at least 98mm rolled equivalency would be needed to deny penetration beyond 200 yards. If 100mm of cast armor equaled 80mm of rolled armor, 76mm APCBC would not fall within the shatter gap region beyond 200 yards and the penetration range would be greater.

Published data on WW II American armor provides the following relationships between rolled and cast armor at 0° impact:

PROJECTILE	ARMOR THICKNESS	LIMIT VELOCITY FOR ROLLED ARMOR	LIMIT VELOCITY FOR CAST ARMOR	CAST/ROLLED RESISTANCE RATIO
Cal. .50 AP M2	1.0"	2395 fps	2325 fps	95.9%
37mm M74 AP	1.5"	1390 fps	1276 fps	88.5%
37mm M74 AP	2.0"	1720 fps	1600 fps	90.2%
75mm M72 AP	3.0"	1363 fps	1260 fps	89.4%

Note: Cast/Rolled Resistance Ratio is ratio of relative penetration at 0° using DeMarre equation, where ratio equals $(\text{cast limit velocity/rolled limit velocity})^{1.428}$

Use of the equation for cast deficiency prediction results in predictions of 87.2% for 37mm hits on 1.5" armor (88.5% actual), 89.7% versus 2" plate (90.2% actual), and 90.8% for 75mm AP hits on 3" armor (89.4% actual). A prediction for Cal. .50 AP vs 1" cast armor could not be made since the projectile diameter was too far outside the equation data base.

6. <u>ARMOR FLAWS</u>

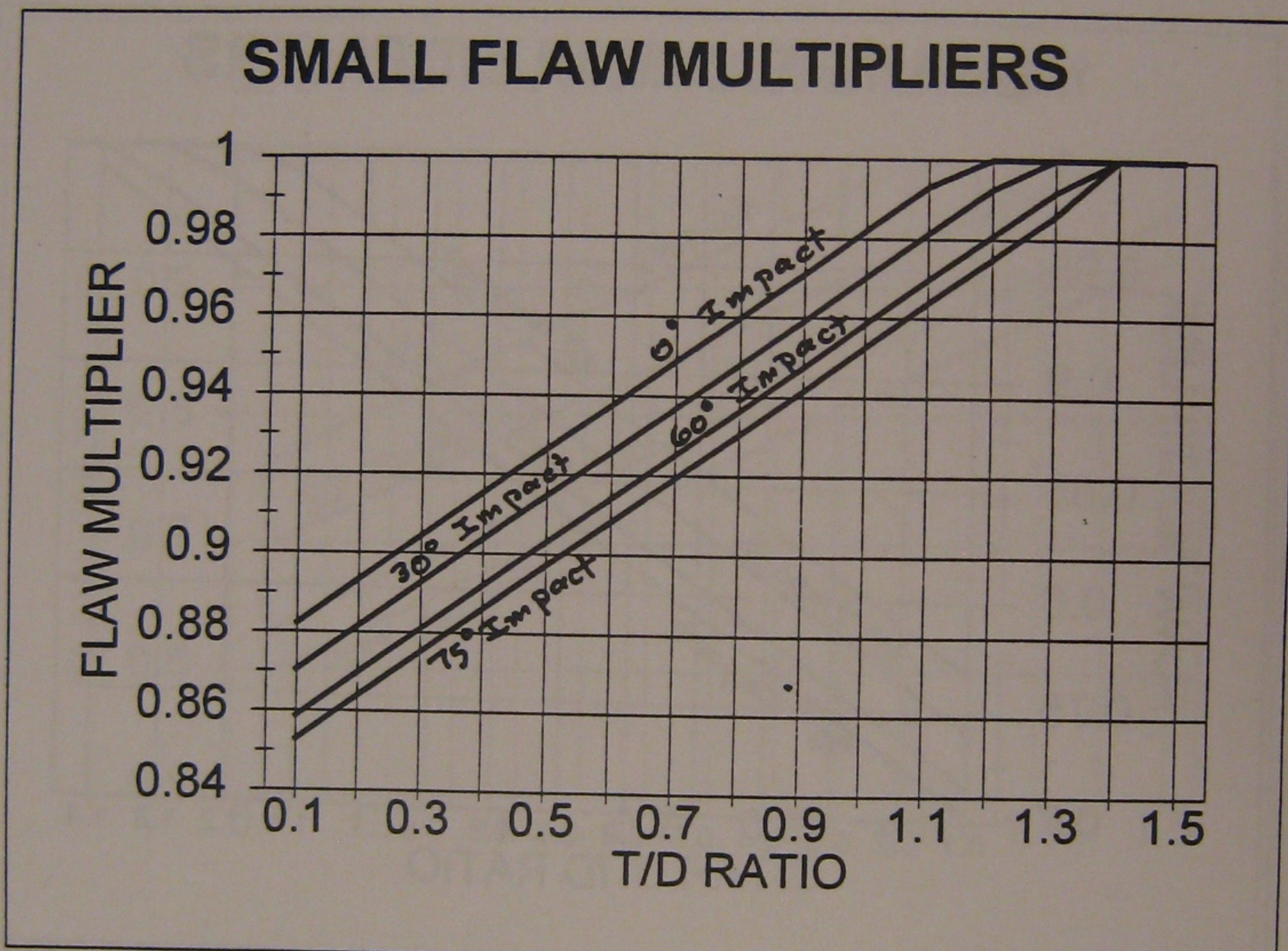
Due to wartime demands, critical alloys were rationed, which could effect armor quality since alloys in steel armor permit good quality armor despite variations in heat treatment.

Prior to October, 1943, American armor production and quality control permitted flawed armor to occur in many tanks, which includes almost all 56° glacis Shermans. British armor may have undergone major quality control improvements during 1944, designed to reduce or eliminate previous flaw problems. Flaws consist of laminations and undesirable heat treatment by-products which reduce resistance. U.S. cast armor could become brittle at hardness over 240 Brinell due to chemical composition, resulting in a brittle crystalline structure at relatively low Brinell Hardness.

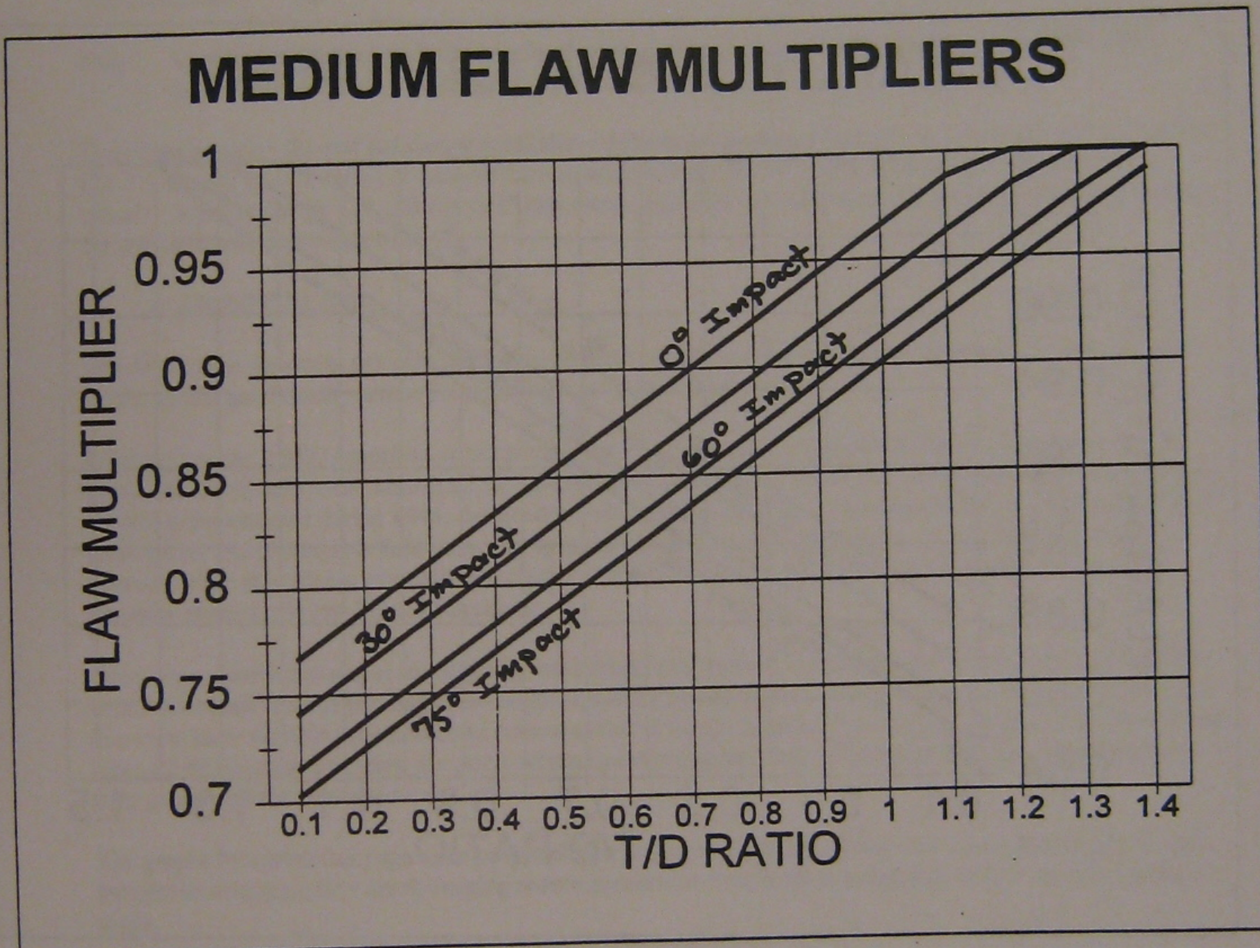
Germany responded to nickel shortages by instituting timed quench procedures and multiple quenches, where small deviations from prescribed times might significantly effect armor quality. The Panther glacis plate was known to have variable resistance, and American test firings at Isigny, France during August 1944 showed that hits on 2 of 3 Panthers cracked the glacis without penetrating the plate. Follow-up hits on or near the cracks fully penetrated the weakened areas.

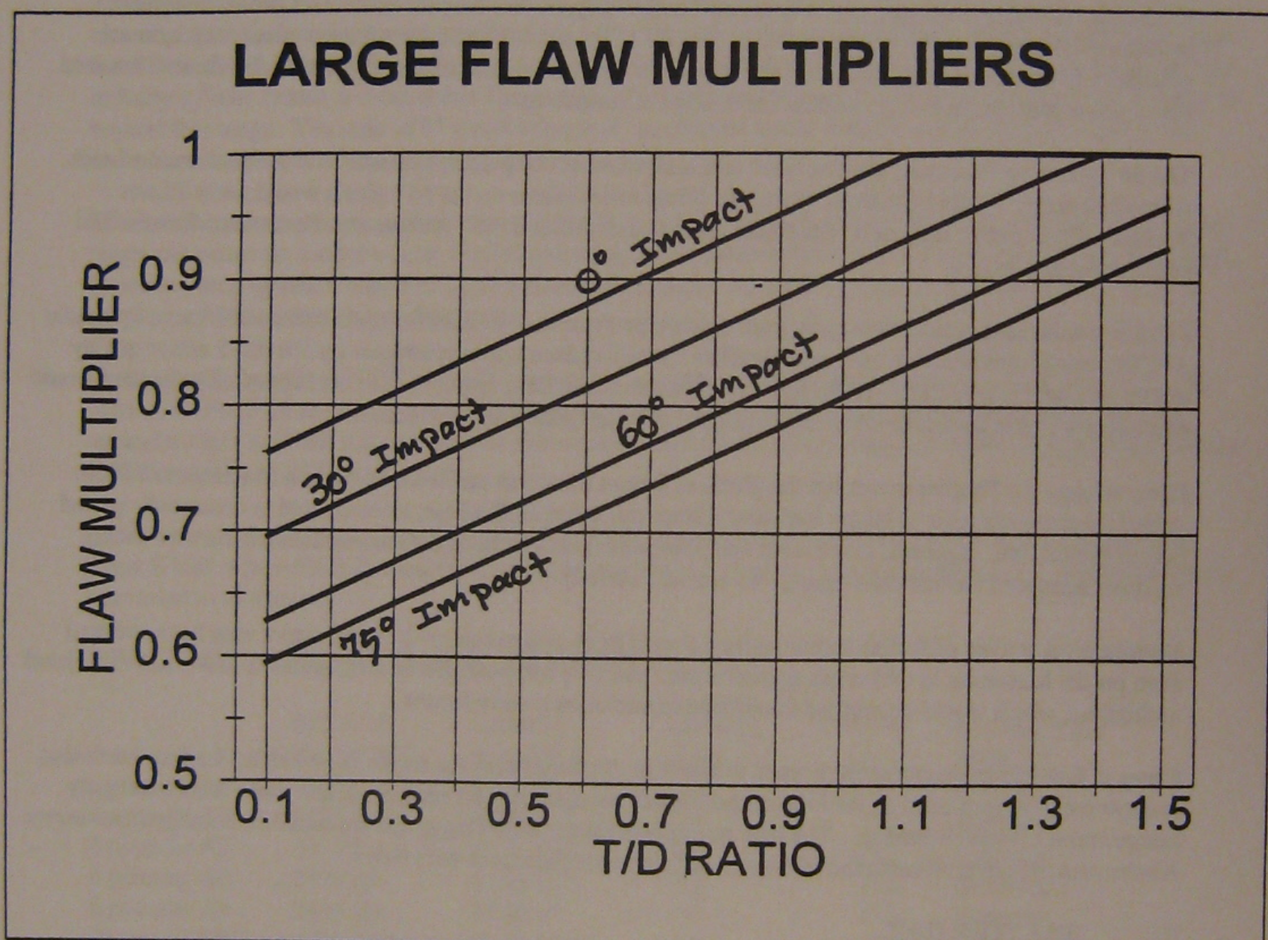
The graphs following this page were prepared after analysis of U.S. test firing data versus flawed plates, and indicate how varying flaw levels ranging reduce penetration resistance as a function of T/D ratio and impact angle.

When cast armor has flaws, the flaw level is lowered by one level but will always be at least "small". The M4A1 had an all-cast hull and mid-glacis armor was 51mm at 53°. Against 75mm APCBC, the M4A1 glacis middle resistance with medium flaws would equal 51mm thickness x 2.25 slope effect x 0.86 cast multiplier x 0.93 flaw factor. The effective thickness of the M4A1 mid-glacis would equal 92mm at 0° equivalent thickness of good quality rolled homogeneous armor. In comparison, unflawed 2.5" at 47° glacis armor on Shermans produced after October 1943 would provide an equivalent 0° thickness of 63.5mm x 1.80 slope effect, or 118mm at 0°.



SMALL FLAW MULTIPLIERS
FLAW MULTIPLIER
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
T/D RATIO
0° Impact
30° Impact
60° Impact
75° Impact


MEDIUM FLAW MULTIPLIERS
FLAW MULTIPLIER
1
0.95
0.9
0.85
0.8
0.75
0.7
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4
T/D RATIO
0° Impact
30° Impact
60° Impact
75° Impact


LARGE FLAW MULTIPLIERS
FLAW MULTIPLIER
T/D RATIO
1
0.9
0.8
0.7
0.6
0.5
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
0° Impact
30° Impact
60° Impact
75° Impact

Based on flaw considerations, the German 75mm L48 gun on PzKpfw IV and StuG IIIG could penetrate M4A1 mid-glacis area to 1600 meters, whereas unflawed 47° Sherman glacis reduces penetration range to under 800 meters. Panther glacis flaws appear to average medium severity although about half of the tanks hit in published firing test results were resisted by good quality armor (no cracking or premature penetration defeat). For war gaming and research purposes, it might be reasonable to assume that 50% of Panther glacis armor is good quality, with rest varying from low to high severity flaws.

Firing test results against other armor areas on Panther suggest that only the glacis was prone to regular resistance deficiencies, which may be due to the size of the glacis plate (size of armor piece may increase sensitivity to treatment changes). Panther front lower hull (nose) and mantlet did not exhibit flaw or lowered resistance tendencies in firing tests and under combat conditions.

The 56° glacis on Shermans also included cast and rolled armor pieces, sometimes with equal areas of each, where cast armor would be inferior to rolled. While rolled plates on the 56° glacis would resist 75mm APCBC with about 104mm at 0° resistance, 51mm cast armor at 56° resistance with medium flaws would equal about 96mm at 0°.

Panther glacis flaws would have most impact when projectiles overmatch armor thickness. When 17 pounder APCBC hits 85mm at 55° armor, medium flaws would reduce armor resistance by 5% (0.95 armor quality multiplier), whereas 152mm APBC hits would overmatch 85mm armor to the point where effectiveness would decrease by 17.5% due to medium flaws (82.5% of good quality armor resistance).

Many sources for Panther armor list the glacis as 85mm thickness and front lower hull as 65mm to 75mm. American measurements at Isigny indicated 67mm thickness on the nose, as compared to commonly quoted 60mm figure. It is suggested that 85mm and 65mm thickness be used for Panther hull front armor during analyses instead of the standard figures (80mm and 60mm).

Metallurgical studies of British armor suggest that as thickness exceeded 2.5", the armor may have suffered from partial hardening in mid-cross section areas. British plate may also be susceptible to flaws and associated multipliers, which would be applied in addition to thickness quality factors.

Flaws in face-hardened plates may result in lower multipliers, since the armor layer behind the face hardening is expected to absorb most of the impact and exhibit excellent impact resistance, and flaws would seriously compromise overall resistance. The flaw multipliers on the following graph are based on homogeneous armor results, and may overestimate the resistance of face-hardened armor with flaws.

7. SHATTER GAP

GENERAL

When armor piercing rounds penetrate armor on 50% of the hits (the basis of most but not all penetration data), resisting forces act on the projectile nose due to acceleration of armor material. As the velocity of the round increases above the 50% penetration limit, armor is forced to move out of the way at an increased rate, which increases projectile nose forces.

U.S. tests of projectile nose hardness effects indicated that when 0° penetration exceeded 0° equivalent resistance of armor by 5% to 25%, rounds within a certain nose hardness region would shatter and fail to

penetrate if armor thickness was close to or exceeded projectile diameter. Above that penetration range, momentum of the shattered round would carry it through the armor and complete penetration would occur.

Based on the U.S. tests and British test firings against a captured Tiger, "shatter gap" failure would be expected to occur with Russian, British, Italian and American steel projectiles. Early war German rounds used in Russia may have used sufficiently low nose hardness to allow "shatter gap" failure.

The classic case of "shatter gap" failure involves hits on Tiger I in France with 76mm APCBC. Based on classic penetration-versus-armor computations using the data in this booklet, 76mm APCBC should penetrate the 100mm at 9° Tiger driver plate from 0 to 1125 meters. Allied experience in Normandy, which is detailed in Baily's *Faint Praise*, indicated that 76mm APCBC rounds would penetrate at up to 50 yards, but would fail beyond that range. The ratio of 0° penetration to 0° equivalent armor resistance at 50 yards is close to the theoretical threshold for "shatter gap" failure.

The British put armor caps on their rounds when they noticed that 2 pounder AP hits would often fail at close range and penetrate further out, or would have a gap in the penetration range where all hits would be defeated. However, tests against a captured Tiger indicated that shatter failure would still occur with 6 pounder APC when penetration data suggested success.

Shatter gap failure for APCBC and APC projectiles appears to require over-penetration by 5% to 25%, T/D ratio of at least 0.80 and impact velocity equal to or greater than 2000 fps. The following firing test data against a Tiger in North Africa discloses some additional insights into uncapped AP shatter gap failure and the ballistic resistance of Tiger E armor.

Pages 12 and 15 in Thomas Jentz' *Tiger I And II: Combat Tactics* present British test data for attack on a Tiger E hull, where the following table analyzes the data and presents penetration and armor resistance figures converted to 0° impact:

FIRING TEST AGAINST TIGER AT 100 YARDS RANGE

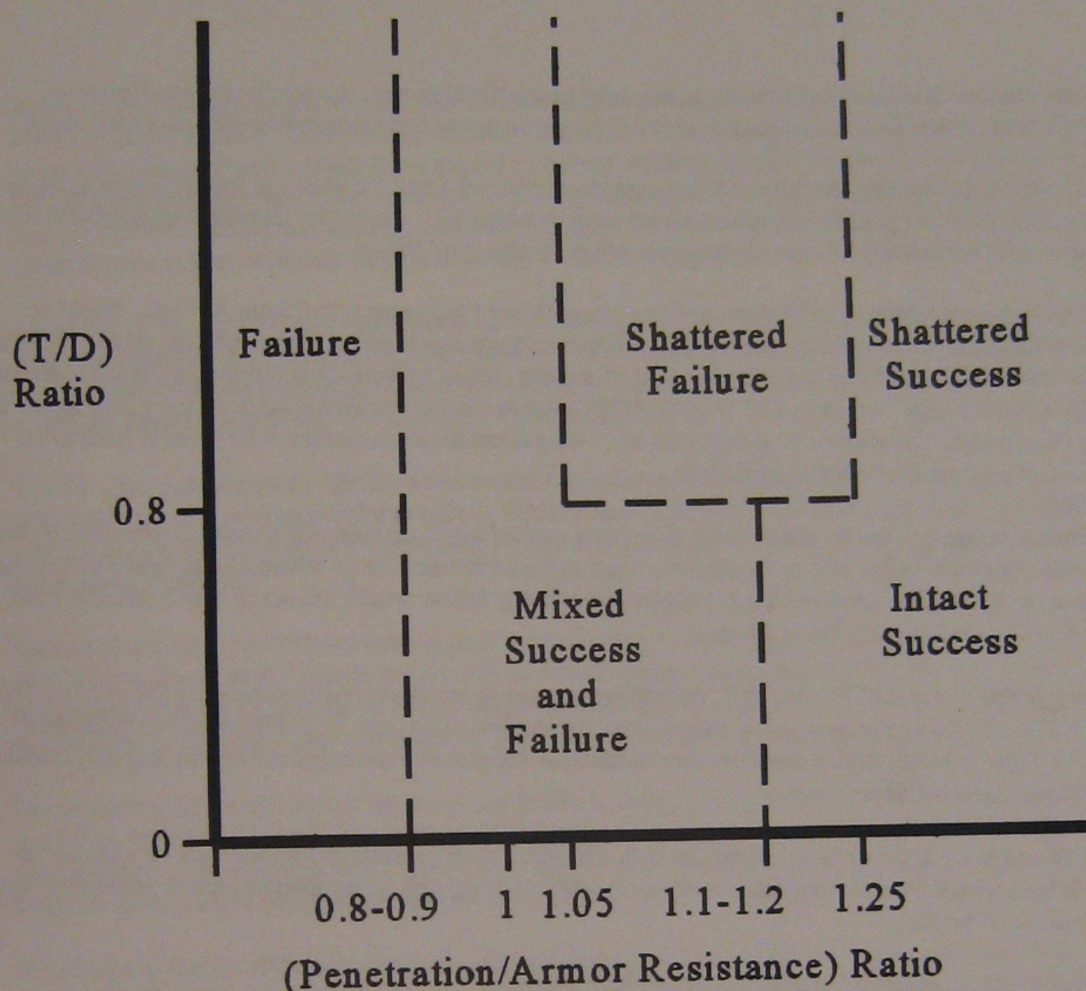
	IMPACT VELOCITY	ARMOR & ANGLE.	ARMOR @ 0°	PEN. @ 0°	PROJECTILE RESULT
2 pounder AP	2590 fps	62 @ 5°	62	86	Lodged
6 pounder AP	2475 fps	82 @ 30°	108	112	Shattered
6 pounder AP	2475 fps	82 @ 20°	89	112	Shattered
6 pounder AP	2475 fps	82 @ 10°	83	112	Shattered
6 pounder AP	2475 fps	82 @ 5°	83	112	Shattered
75mm APCBC	2000 fps*	82 @ 17.5°	88	88	50% Pen.

Notes:*-2000 fps is actual impact velocity at 100 yards from U.S. Army TM9-1907.

75mm penetration angle is average of angles for failure and success, and should be reasonable figure for 50% penetration.

Penetration figures at 0° are from data presented in this book (TM9-1907 for U.S. 75mm APCBC)

75mm penetration data does not illustrate shatter gap failure but is notable in that it indicates that Tiger armor equals American test plate resistance



GRAPHICAL DEPICTION OF "SHATTER GAP" REGION WHICH DIVIDES RANGES WHERE HITS WILL SUCCEED

Since U.S. and British penetration data in this book is based on 50% success (average of lowest velocity for success and highest velocity failure against a given plate thickness), above noted test results with 75mm APCBC indicate that the Tiger 82mm side armor had same resistance as U.S. 240 Brinell Hardness test plate despite harder armor (over 320 Brinell).

AP results suggest that shatter gap may occur when the "Penetration/Armor Resistance" ratio exceeds 1.25, and may occur with ratio's as high as 1.39 (86/62) and 1.35 (112/83). It appears that the velocity of 2 pounder AP may have been sufficient to overcome nose shatter and resulted in projectile lodging, and complete penetration may have occurred at slightly higher impact velocity (or increased penetration/armor ratio). This suggests that shatter gap for AP failure may occur at "penetration/armor" ratio's between 1.04 and 1.40 if T/D ratio is sufficiently large. The lowest AP ratio for shatter failure, 1.04, is close to 1.05 threshold for APCBC shatter failure.

The following data is from U.S. Navy tests with 3" M62 APCBC against 3" plate at 30°, and illustrates the typical "shatter gap" progression against good quality plate;

IMPACT VELOCITY	IMPACT RESULT	PROJECTILE CONDITION
1954 fps	Plate bulge	Bent, swollen
2065 fps	Penetrated	Side deformed
2073 fps	Base stuck in plate	Nose broken off
2160 fps	Stuck in plate	Split
2205 fps	Not through	Split in two
2376 fps	Not through	Broken up

NOTE: Velocity for 50% penetration with intact projectile is 2045 fps.

If projectile nose hardness is less than 59 Rockwell Hardness, increasing nose forces due to over-penetration may initiate projectile nose cracking and flatten it out, leading to shattered failure (the armor is being quickly thrown out of the way, leading to large nose stresses). Further increases in the velocity above the 50% penetration limit will eventually reach a point where shattered projectile starts to pierce the plate.

ADVANCED SHATTER GAP ANALYSIS

U. S. Navy tests during 1943 with 3" M62 projectiles resulted in defeated hits when impact velocity exceeded the 50% success limit, which suggests shatter gap failure. The following data is from Navy Report No. 14-46:

IMPACT ANGLE	PLATE THICKNESS & BHN	PEN. VELO.	PEN. VELO. RATIO	DEFEAT VELO.	DEFEAT RATIO	50% PEN. VELO
40°	3.0" @ 226	2745	1.15	2478	1.04	2380
40°	3.0" @ 226	2701	1.13			2380
40°	3.0" @ 268	2662	1.12			2380
40°	3.0" @ 285	2701	1.13	2536	1.07	2380
40°	3.0" @ 285	2616	1.10			2380
40°	3.0" @ 321	2700	1.13	2616	1.10	2380
40°	3.0" @ 321	2542	1.07			2380
30°	3.0" @ 268	2115	1.06			1990
30°	3.0" @ 285	2181	1.10	2094	1.05	1990
30°	3.0" @ 321	2396	1.20	2230	1.12	1990
30°	3.0" @ 321	2324	1.17			1990
20°	3.8" @ 322	2634	1.18	2586	1.15	2240

NOTES: "PEN. RATIO" is ratio of "test penetration velocity/50% success limit in TM9-1907" (240 BHN plate)

"DEFEAT RATIO" is ratio of test failure velocity/50% success limit in TM9-1907 (240 BHN plate)

If the shatter gap results for 3" M62 against 3" plate at 30° are analyzed for penetration and defeat ratio's, the following results are obtained:

IMPACT VELOCITY	PEN. RATIO	DEFEAT RATIO
2065 fps	1.04	
2073 fps		1.04
2103 fps	1.06	
2160 fps		1.09
2205 fps		1.11
2376 fps		1.19

Based on the penetration data in this appendix, the average PEN. RATIO for shatter success is 1.15, and the minimum DEFEAT RATIO for shatter failure is 1.04. Using the DeMarre equation to convert the ratio's to 0° involves raising each ratio to the 1.428 power, for:

Shatter penetration occurs when "0° penetration/0° armor resistance" ratio is 1.22
Shatter failure occurs when "0° penetration/0° armor resistance" ratio is 1.06

Based on consideration of additional data on shatter gap, recommended procedures for advanced estimation of APC/APCBC shatter gap region are:

Normal penetration up to "penetration/resistance" ratio of 1.05
Shatter gap failure from 1.06 to 1.22 "penetration/resistance" ratio
Shatter penetration when "penetration/resistance" ratio exceeds 1.22

The above recommendations apply when projectile nose hardness is below 59 Rockwell C, unless other data suggests otherwise. Based on data in preceding appendix, 90mm APCBC may not be vulnerable to shatter gap failure, since nose damage appears minimal at all impact velocities.

On 10° lateral impact hits on the Tiger E driver plate (100mm at 10° assumed vertical), effective armor resistance is 103mm at 0°. Above suggestions for shatter gap failure suggest that 76mm APCBC hits would fail when penetration ranged from 109mm to 126mm, producing failures from 50m through 900m.

76mm APCBC hits on the 100mm cast Panther mantlet at 10° impact would be resisted by 98mm of equivalent rolled armor, and shatter failure would be expected when penetration equaled 98mm x 1.22, or 120mm. 76mm would penetrate at ranges below 300m, whereas U.S. tests resulted in 200 yard penetration ranges.

Since the above recommendations for shatter gap failure are based on average values, variations will occur and the methodology is less precise than other procedures in this booklet.

8. SPECIAL CAST ARMOR AREAS

Tiger I Mantlet

For purposes of ballistic study, estimates were prepared of the thickness of areas of the Tiger I gun mantlet. Measurements of the mantlet of an early Tiger I (Fgst. Nr. 250031, formerly at the Aberdeen Proving Grounds) indicated 97mm top edge thickness, tapering out to approximately 127mm thickness where the taper meets the top surface of the cylindrical interior shield. Measurements of a later production Tiger were taken by Frederic Erk at Saumur (Fgst. Nr. 251114). Original diagrams in the Tiger turret manual were studied along with interior and exterior photographic views. The result is the drawing that follows this page, which shows likely thickness of mantlets produced from November 1942 through March 1944.

Note that there are recesses in the inner face of the mantlet to provide clearance for the gun cradle and recoil cylinders surrounding the main gun, and behind the sight ports where the telescopes are attached to the mantlet inner face. Trunnion areas provided narrow bands of reinforcement in the areas shown.

90mm areas at mantlet edges are backed by turret sides, and the tapered, 100-125mm mantlet top and bottom edges are backed by 100mm/10° turret front bars. The mantlet can generally resist projectiles capable of penetrating less than 135mm, except for the weak areas between and immediately around the sight ports. Some degree of weakening is introduced by the holes, with effective resistance expected to be less than 110mm.

The first 130 Tiger mantlets were not thickened on the outer face at the sight holes, which would result in a 75mm thickness in the area immediately around the holes, and 90mm in the adjoining recessed area. The shape of the thickener around the sight ports changed as production continued, and beginning March 1944 the outboard sight hole was deleted. The first mantlets to have one sight port were simply plugged and welded

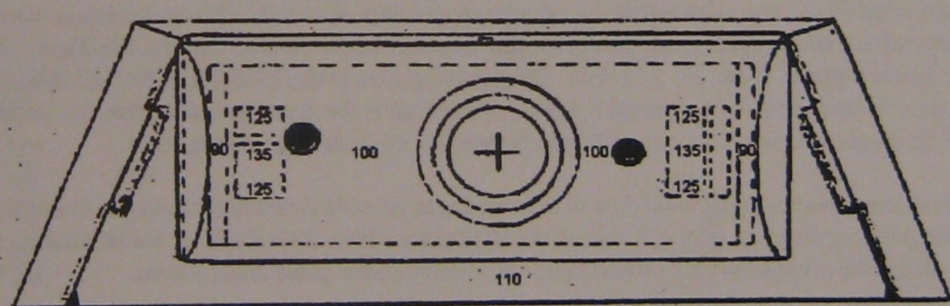
shut, while later mantlets were cast with only one sight port. The Byrden web site for Tiger E presents scale drawings of the plug used to block one of the sight openings, as well as information on plug installation procedures.

The pictures following the Tiger mantlet drawing is presented by permission of Mr. Frédéric W. Erk, Curator e-IHSD, Technical Consultant CDEB, and courtesy of Colonel Olmer, Director CDEB/Musée des Blindés, Saumur, France. The Saumur Intranets site has been discontinued.

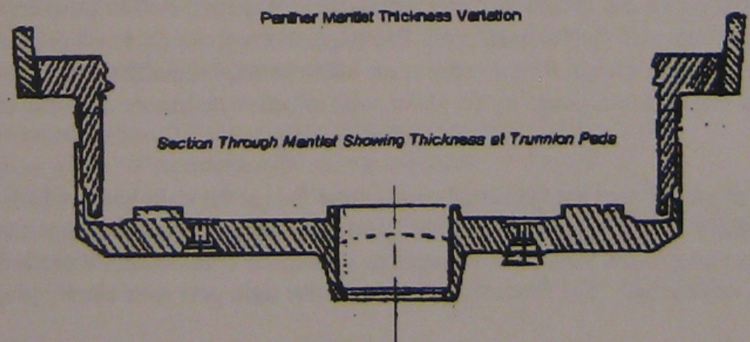
The photo's depict several of the issues that have been identified in the Tiger mantlet drawing, such as the tapered area leading to the mantlet top edge and the location of turret front armor behind the tapered mantlet edge.

Panther Mantlet

The Panther mantlet drawing that follows is based on a series of photographs and diagrams of a Panther Ausf. G mantlet appearing in the BIOS report *German Tank Armor*. Measurements were also taken of two Panther G mantlets at the Aberdeen Proving Grounds. The photographed mantlet had been through ballistic acceptance tests, but had not been machined.

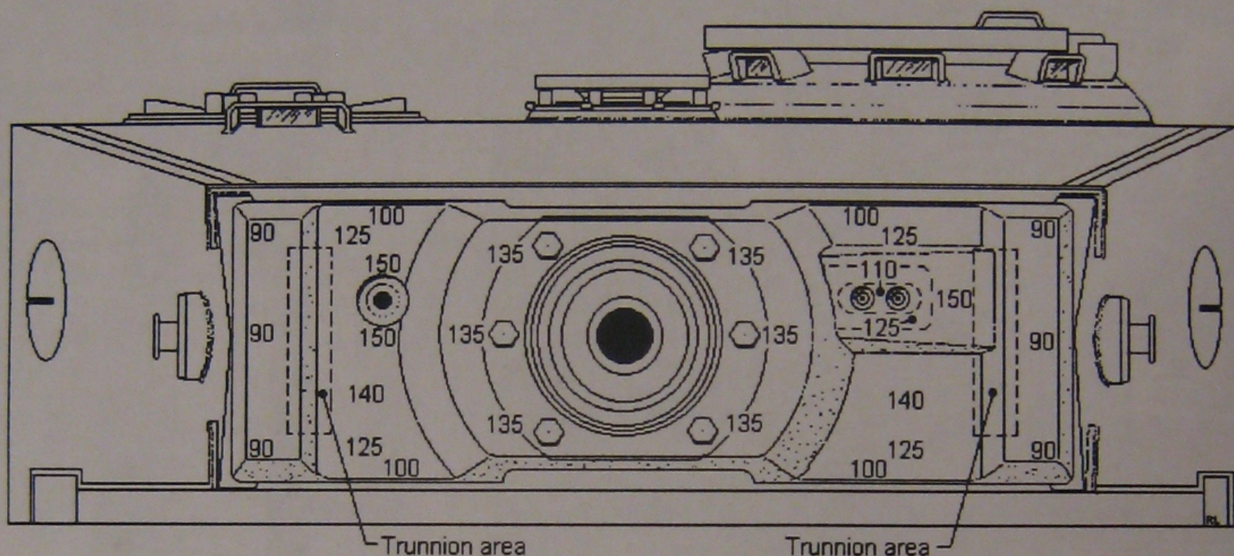


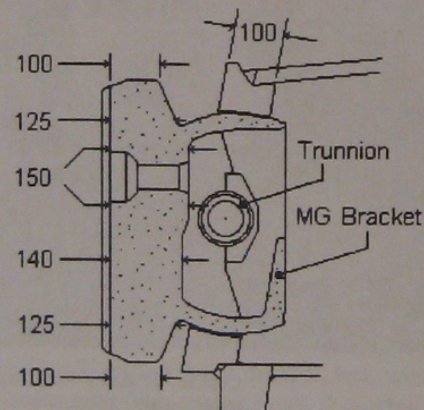
Panther Mantlet Thickness Variation



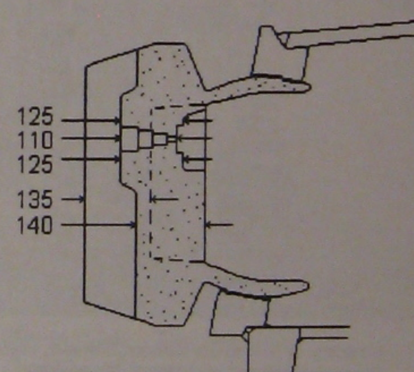
Section Through Mantlet Showing Thickness at Trunnion Pads

TIGER MANTLET
Armor Thickness in Millimeters





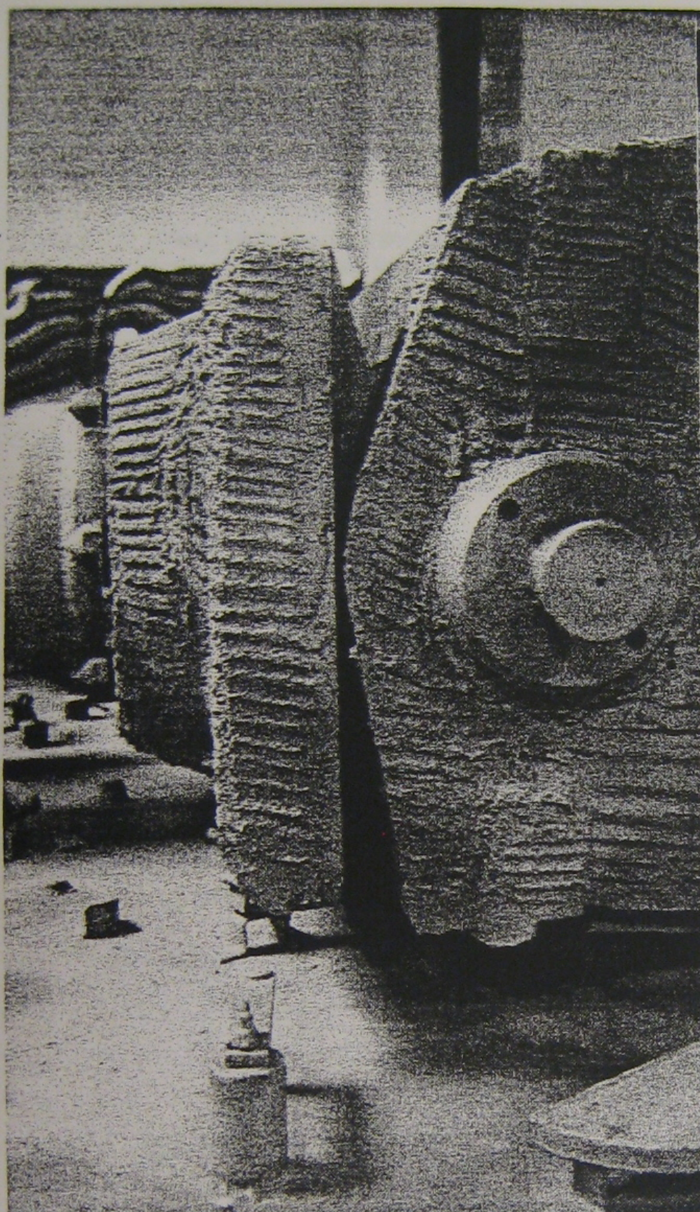
Section Through MG Port



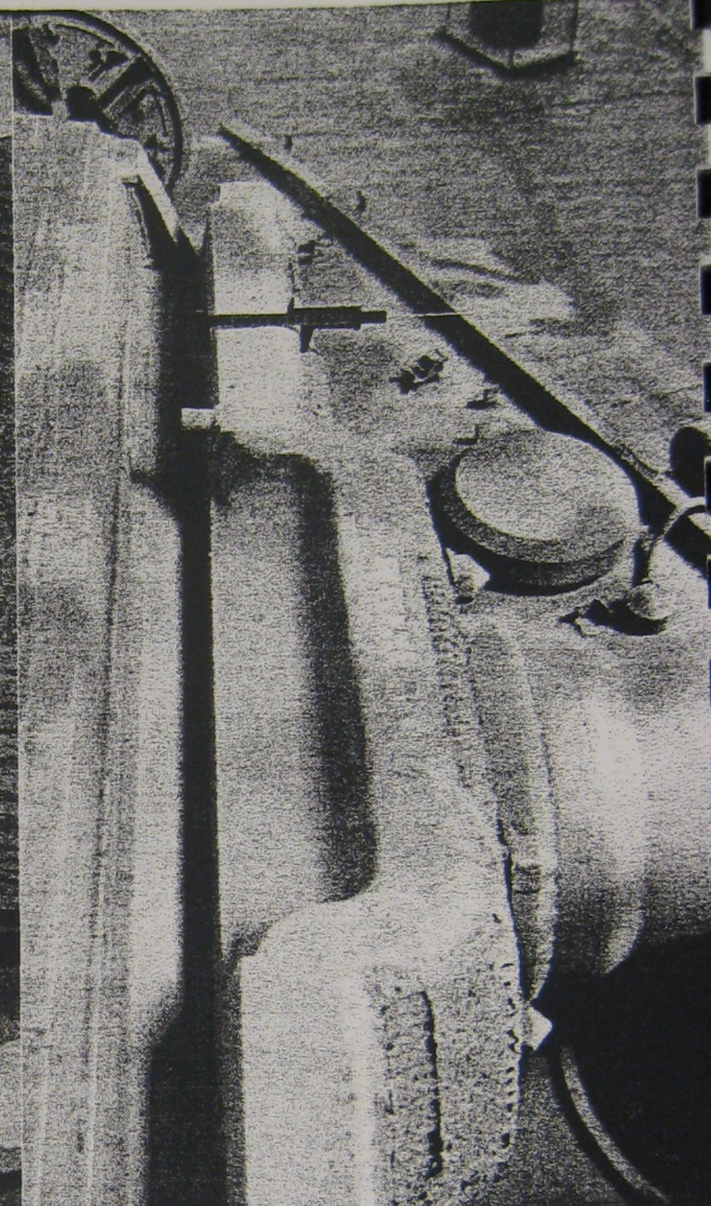
Section Through Sight Ports

0 1 2 3 400mm

Approximate Scale



Courtesy of Musee des Blindes, Saumur, France
Photo Frederic Erk (e-IHSD 21/1-311000)



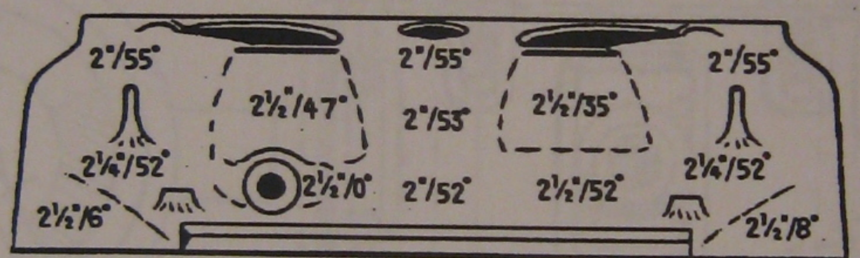
Courtesy of Musee des Blindes, Saumur, France
Photo Frederic Erk (e-IHSD 27/1-311000)

Thickness at the apex of the mantlet was assumed to be exactly 100mm. Photographs in the report show the interior surface. The flat pads where the mantlet was to be bolted to the trunnions were scaled, and measured for thickness, length, width, and height. It is possible that the trunnion mounting pads would be machined to finished thickness approximately 5mm less than the 125 to 135mm dimensions shown on the drawing.

Vertical grooves were visible at the interior corners, obviously intended to provide clearance for the turret front casting where it projects inside the mantlet. The mantlet is beveled on its outer surface at these corners, resulted in an estimated 90mm thickness, in comparison to the assumed 100mm thickness at the apex.

Late Production M4A1 Cast Hull

Measurements were made of the obliquity of external surfaces of a Sherman hull of this type. These angles were combined with specified thickness dimensions on a casting drawing in Ordnance Corps *Armor Handbook, The Development and Manufacture of the Types of Cast Armor Employed by the Army During World War II*. The resulting drawing follows this paragraph. Note that the bow gunner's hood presents greater obliquity than the driver's hood, due to the forward protrusion of the MG mount at the base of the hood.



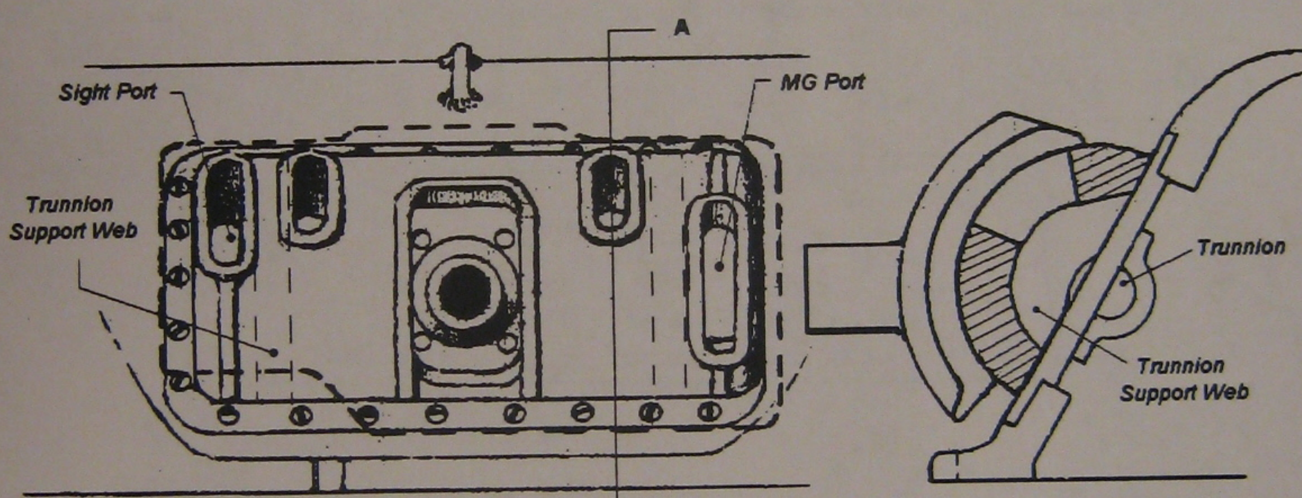
Sherman 75mm Gun Mount

Inspection of official manual illustrations and actual vehicles equipped with mid and later production M34A1 gun mounts was undertaken, and the drawing follows this page. The Rotor Shield, or outer mantlet, was nominally 51mm thick, and the Gun Shield, or inner mantlet, was nominally 89mm thick.. The two slots closest to the main gun were for Rotor Shield support bolts. Tapering of the Gun Shield to approximately 60mm at the upper end of these two openings was indicated by measurement of one mantlet.

The earlier M34 mount was similar, except the outer Rotor Shield was narrower, covering only the hole for the 75mm gun. The inner Gun Shield was nominally 76mm thick, and was pierced by holes for the main gun and coaxial machine gun.

Casting pattern numbers observed on several mantlets are given on the drawing.

Sherman 75mm GUN MOUNT M34A1
Rotor Shield D63454/D68454
Gun Shield E5721



Rotor Shield Outline Shown as Dashed Line

Section Through Gun Shield at A-A

BALLISTIC RESISTANCE OF SHERMAN GUN MOUNT M34A1 (75mm GUN)

Using the curves and procedures in this book, effective resistance of the M34A1 gun mount was analyzed for a variety of impact angles and locations. The calculations used estimates based on edge effects and spaced armor factors.

The following breakdown addresses the effective armor resistance at 0° when hits are randomly distributed over the gun mount surface:

8% hit 45mm resistance
6% hit 65mm
22% hit 75mm
25% hit 85mm
18% hit 95mm
6% hit 105mm
4% hit 115mm
3% hit 125mm
4% hit 145mm
1% hit 155mm
3% hit 165mm

When shots strike a combined armor resistance that denies complete penetration, there is still a good chance that penetration of the outer shield will freeze the mantlet in place ("keying"), resulting in weapon immobilization.

When 75mm armed Shermans carry a 47° glacis or good quality armor, the above figures will increase by 5%.

American Multi-Piece Glacis on Shermans

By permission from Mr. Dyer, his *AFV News* work on multi-piece Sherman glacis armor is presented following this page. The number and relative area of cast glacis armor pieces is notable.

9. SPACED PLATES, LAYERED ARMOR AND EDGE EFFECTS

SPACED ARMOR

American penetration data may be used to illustrate how two spaced 40mm plates at vertical provide less penetration resistance than a single 80mm plate at the same angle.

Using data for 75mm M61 APCBC, a velocity of 1850 fps is required to penetrate a single 80mm plate on half the hits. Against a single 40mm plate, 1140 fps will succeed on half the hits and about 1257 fps is required to penetrate on all hits.

If 1257 fps is required to defeat the first 40mm plate on all hits, 75mm hits on the first plate at 1850 fps will leave the armor at 1357 fps without an armor piercing cap but lighter in weight, which is sufficient to defeat a 52mm plate on half of the hits. A single 80mm plate is therefore equivalent in resistance to spaced plates with 40mm and 52mm thickness.

Nathan Okun has published equations on the single plate equivalence of two spaced plates. The following equation extends Mr. Okun's work and reproduces the above logic for spaced plates, predicting single plate equivalence:

Equivalent Single Plate Resistance on 0° hits =

$$[(1.15 \times \text{First Plate Thickness})^{1.4} + A^{1.4} \times (\text{Second Plate Thickness})^{1.4}]^{(1/1.4)}$$

where,

A = 1.00 for APC and APCBC against homogeneous armor

A = 1.10 for AP and AP/APCBC when second plate is face-hardened and first plate is homogeneous, where first plate blunts AP projectile nose or removes armor piercing cap, reducing remaining penetration

A = 1.05 for AP against two homogeneous plates due to nose blunting

A = 1.00 for APBC

The inferiority of two spaced 40mm plates to a single 80mm plate is based on armor defeat mechanisms. As projectile diameter exceeds thickness, such as 75mm hits on 40mm armor, armor defeat tends to occur by plugging. Plugging is related to shear failure around the impact perimeter, drives out a good sized piece of metal and is low energy failure.

Sherman Glacis Plates

BY PHIL DYER

It is not usually realised quite how many alternative designs of glacis plate were utilised in the production of the welded hull Shermans. This takes into account all models other than the M4A1 with it's cast upper hull.

There were a number of reasons for the great diversity of layouts. The first of these was the aim of evening out the ballistic properties of the front plate by reducing the number and length of welds. This was affected both by bottlenecks in the supply of castings, man hour requirements, and possibly utilisation of plate. When it is then taken into account that there were five different models of the welded hull Shermans, all of which entered production at different times, and a total of eight different companies manufacturing these, one begins to appreciate the reasons for the lack of conformity.

The following sketches show the component parts of each front plate that I have come across to date. Whilst there could posibly be other variations, (other than where mentioned in the text), it is thought to be very unlikely. Each front plate is drawn viewed at right angles to it. Castins are shown shaded to differentiate them from rolled plate.

(1) The M4A2 was the first of the welded hull Shermans to enter production, and as such, the front plate originally allowed for the twin fixed forward firing machine guns as well as the ball mount.

(2) With the elimination of the fixed machine guns one method of dispensing with the appertures was to replace half of the erlier casting with a further piece of plate. This resulted in what must have been the weakest and most extravagent glacis of them all. (Photo cast bow MG mount).

(3) By replacing four of the plates in the earlier design by one shaped plate, a considerable improvement was effected still utilising the small bow machine gun casting.

(4) An alternative design whereby the casting for the bow machine guns merely had the apertures for these removed. One weld on the original design is obviated by cutting one of the side plates to an L shape. Whether an interim design with the same plate arrangement as previously ever appeared is not known up to the present.

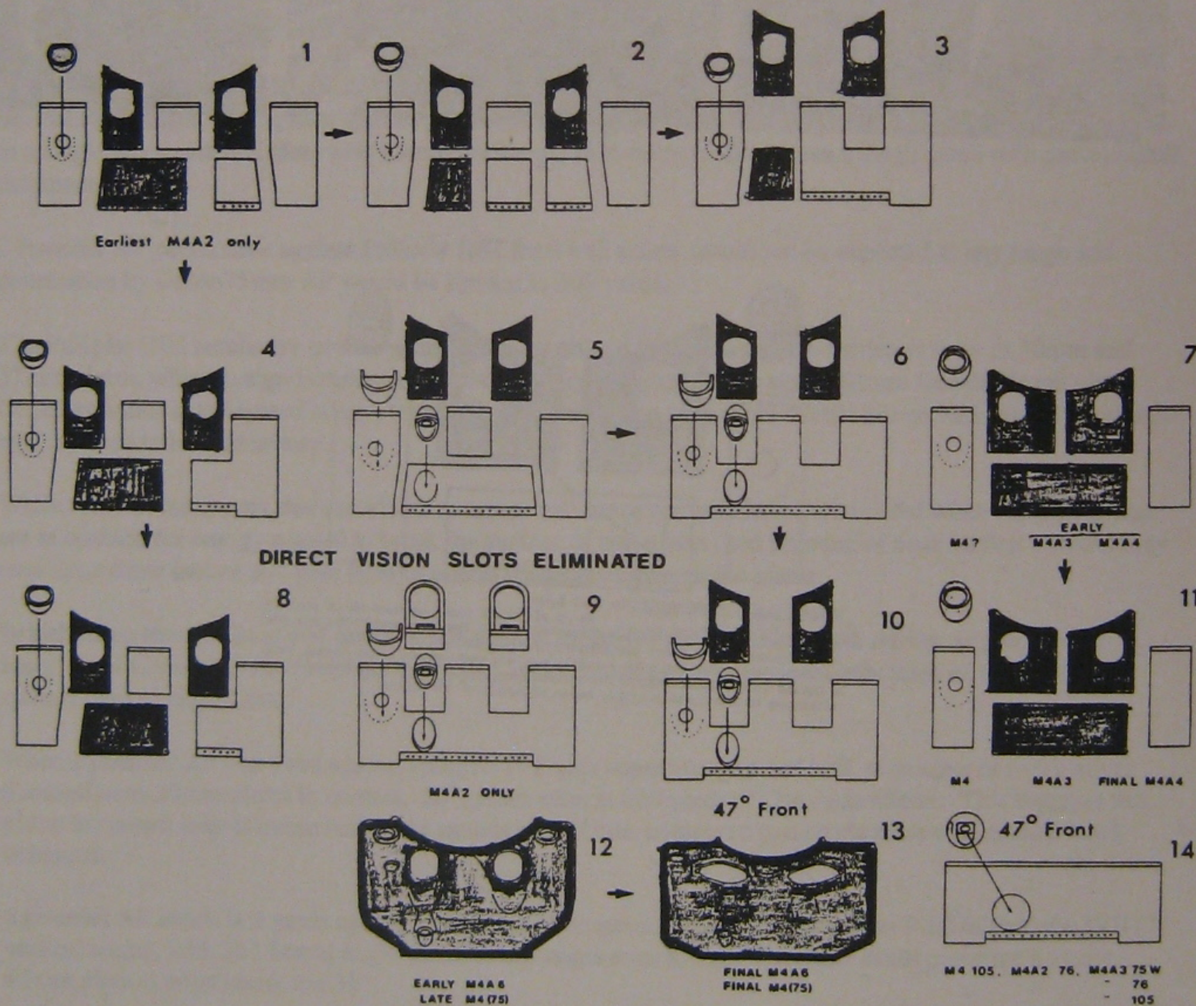
(5) This arrangement which appears on an early M4 (The M4 entered production five months after the M4A2) utilises both a bow machine gun mount, and an antenna base, prefabricated from rolled plate, but still has four pieces of plate to be welded together.

(6) By shaping one large plate it was possible to cut down the welding required on this front very considerably.

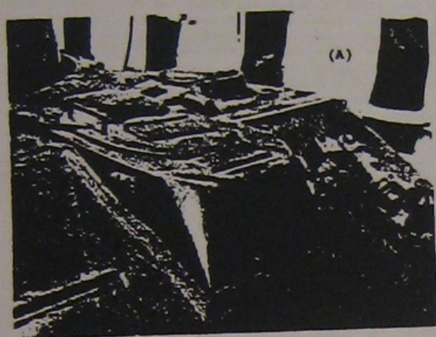
(7) With the advent of the M4A3 and M4A4 in mid 1942 a frontal layout was introduced which was standard for both tanks. Although the drivers hoods with peep slots looked exactly the same as those on the M4/M4A2 the overall width of the castings was greater, obviating a piece of plate between them. The bow machine gun casting extended the width of the final drive and differential housing and a heavy type of antenna guard casting was used (Photo B) instead of the light type of casting introduced on the M4A2. It is possible that this layout was also used on some M4s.

(ELIMINATION OF PEEP SLOTS: When peep slots were eliminated, the same improved frontal layouts as had been developed previously were utilised, but with the drivers hoods suitably modified to contain fixed periscopes.

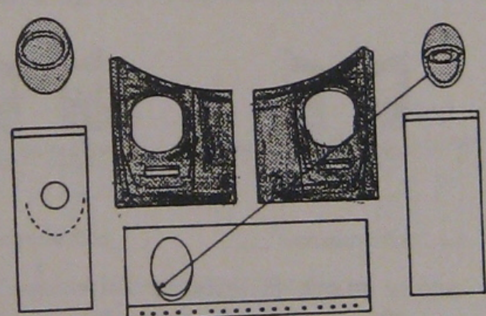
(8 & 10) The patterns for the narrow head covers as used on the M4/M4A2 were quite crudely modified by adding material to the front to contain the periscope. This gave a sloped form with taper chamfered corners. On castings produced from these patterns it is quite



simple to see how the pattern was altered.(Photo A)
(11) Completely new patterns appear to have been made for the wide
drivers hoods used on the M4A3/M4A4 giving a vertical front face
with parallel radiused corners on the top and sides.(Photo B)
(9) To avoid using any castings whatsoever after the abolition of
the peep slots,head covers prefabricated entirely from rolled plate
were produced purely for the M4A2. This gave these vehicles a very
distinctive appearance.
(12) The front of the cast hull M4A1 gave far more even protection
than any of the 56° welded fronts. This was partly due to being in
one piece,partly due to the smooth rounded surfaces offering less.
obvious shot traps,and partly due to the thickness of a casting
being able to be varied as the angles altered. When Detroit Arsenal
commenced production of the M4 in August 1943 and the M4A6 in Oct-
ober,a single casting exactly the same as the front of the cast
hull M4A1 was utilised. At first this was of the old design with
57° front and narrow drivers hatches after the peep slots were
eliminated.
(13) Within a very short time the redesign work that was being
undertaken on the Sherman fronts was incorporated on the composite
hull Shermans making the M4 and M4A6 the first vehicles with the
47° front and large drivers hatches.
(14) The redesigned welded hull Shermans started coming off the
assembly lines during the early part of 1944 and at last conformity
was achieved amongst the restricted number of models produced from
then on. These all had the 47° rolled plate front with an inserted
cast bow machine gun mount. As nearly two thirds of the total number
of welded hull Shermans had already been produced however,the earl-
ier designs were the most common for a very long time.
In an effort to improve protection to the front of the drivers
hoods,which were always very vulnerable,partly due to the reduced
angle,and partly to them being shot traps,additional plates of 1½"
armour were welded on in front. This addition was included on
production vehicles from the middle of 1943,and kits were supplied
for fitting to earlier tanks in the field which nearly doubles the
number of possible permutations of front plates.
I would like to express my thanks to M.A.Roseberg for his assist-
ance in locating existing Shermans for this project.


(A)


(B)



<u>SHERMAN GLACIS PLATE UPDATE</u> by Phil Dyer

As is often the case, as soon as an article is printed further information comes to hand. A 75mm gun armed M4A3 has now been located with a front plate configuration similar to layout 11 in my May-Aug/84 article, but with a small cast bow machine gun mount welded into a rolled lower glacis plate. The accompanying illustration shows what I am referring to and could possibly be an alternative for layout 7.

In comparison to plugging, when 75mm rounds strike 80mm thick armor the armor has sufficient shear resistance to result in failure mechanisms where the projectile has to locally defeat the armor in front of the nose as it moves through the plate or casting. Local armor defeat requires more energy than plugging failure.

However, spaced armor may defeat hits by detonating HE bursters as the round emerges from the first armor, if the second armor is capable of defeating fragments and the first plate has sufficient thickness.

British tests with angled hits on PzKpfw III spaced armor showed that 20mm spaced outer plate would cause detonation of the 75mm HE burster as the round passed through the space between plates, with the inner 50mm face-hardened plate defeating the fragments even though the outer plate turned the round towards the inner armor. Recommendations were made to disable the HE burster against spaced armor.

LAYERED ARMOR PLATES IN CONTACT

When two homogeneous armor plates or cast are bolted or welded together, the combined resistance may be different than the sum of the thicknesses.

In North Africa, PzKpfw IIIH with 32mm bolted atop 30mm, both face-hardened, presented a difficult target for British gunners. Firing tests against the front hull suggested that the two plates in contact were equivalent to a single face-hardened plate with 69mm thickness, 11% more resistant than a single plate with same overall thickness.

2 Pounder AP penetration against PzKpfw IIIH front hull armor would not be expected at any range and penetration by Grant 75mm AP would be limited to 500 yards.

The PzKpfw IIIH results are probably due to the combined thickness of face-hardened layer in 30mm and 32mm plates, which is significantly greater than the layer thickness in a single 62mm face-hardened plate. Crusader armor used layered armor, with high hardness plates over more ductile armor, and overall resistance was reported to be satisfactory.

While some of the factors that contribute to armor resistance are reduced or eliminated when separate plates are in contact, the energy needed to break the surface of two plates (and blunting of nose on first section) may overcome other factors and give layered armor advantages over single plates.

British firing test results at 30° lateral angle against PzKpfw IVD and E in North Africa, as published in Jentz' *Tank Combat In North Africa* (page 46), can be analyzed to provide an indication of how plates in contact react to angled hits.

When 2 pounder AP was fired against PzKpfw IVE side superstructure and hull, consisting of two vertical homogeneous 20mm plates in contact, 30° penetration at 800 yards (732m) was 45mm. This suggests that plates in contact may increase resistance against angled hits, compared to a single plate with same overall thickness.

2 pounder AP attack at 0 yards against two 30mm homogeneous plates in contact on front of PzKpfw IVE (7° vertical angle), with 30° lateral angle, failed at all ranges even though 2 pounder could penetrate a single 67mm plate at point blank and 30°.

In contrast to the British tests against North African panzers, U.S. Navy tests for layered homogeneous deck armor against plunging hits indicates that overall resistance is less than the sum of the individual thicknesses, as noted below:

CASE	LAYERED ARMOR	SINGLE PLATE EQUIVALENCE	NOTE
1	3" OVER 1"	3.7"	3" plate hit first
2	1" OVER 3"	3.5"	1" plate hit first

Source: Ordnance Pamphlet 653, January 1942, U.S. Navy

A U.S. firing test with 90mm M82 APCBC against two 1.5" homogeneous plates in contact (at 45 degrees slope) resulted in a combined effective thickness of 2.28".

If the two Navy results are combined with the 90mm M82 tests, the results for homogeneous armor suggest that:

1.5" over 1.5" resists with 76.0% of total thickness
3.0" over 1.0" resists with 92.5% of total thickness
1.0" over 3.0" resists with 87.5% of total thickness

Regression analysis of the three points for homogeneous armor provided the following equation for the single plate equivalent multiplier:

Effective Thickness Multiplier = 0.3129 x (plate ratio)^0.02527 x (maximum thickness)^0.2439

where "plate ratio" is thickness of first plate hit by projectile over underlying thickness, and "maximum thickness" is thickness in millimeters of thickest plate.

The above equation has the following limits:
minimum effective thickness equals 0.3 x thinnest plate plus thickest
maximum effective thickness is 96% of total combined thickness

When 38mm applique is added to the Sherman 38mm side hull armor, the above equation predicts equivalent thickness multiplier of :

0.3129 x (38/38)^0.02527 x (38)^0.2439, or 0.76. 0.76 x (38 + 38) = 58mm.

When scrap armor was placed on the T34 hull front, the effectiveness may be estimated from the preceding equation. Adding 15mm of relatively thin and very hard (over 400 BHN) plate over 45mm produces a plate ratio of 0.333 and a maximum thickness of 45mm. The effective thickness multiplier for 15mm over 45mm would be 0.77, which estimates a single plate resistance of 0.77 x (15 + 45), or 46mm. Since 46mm is less than 0.3 x 15mm + 45mm, 50mm would be used as the single plate resistance of 15mm over 45mm.

Adding 30mm to the 75mm driver plate on KV-1 would resist penetration like a single plate thickness of:
105mm x 0.3128 x (30/75)^0.02527 x (75mm)^0.2439, or 92mm

Nathan Okun, who has researched Naval armor and penetration characteristics, has presented equations for the prediction of resistance from two homogeneous plates in contact. The Naval rule of thumb takes 70% of the first plate thickness to be hit and adds the underlying thickness. An equation used by Mr. Okun splits the difference between a single plate with the same combined thickness and two spaced plates, where the results are fairly consistent with the Naval rule of thumb:

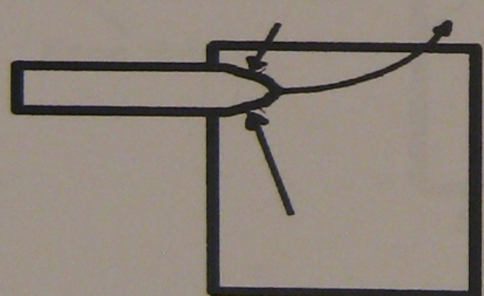
Single Plate Resistance = 0.50 x ((T1 + T2) + (T1^1.4 +T2^1.4)^(1/1.4))

The following analysis compares the three approaches to estimating single plate resistance of two homogeneous plates in contact to the three data points on page 38:

	Naval Rule of Thumb	Split The Difference	Page 38 Equation
3.0" over 1.0" equals 3.7"	3.1"	3.4"	3.7"
1.0" over 3.0" equals 3.5"	3.7"	3.4"	3.5"
1.5" over 1.5" equals 2.3"	2.6"	2.5"	2.3"

EDGE EFFECTS

Edge effects occur quite often in armor tests and during battlefield combat, and penetration tests are normally discounted if rounds strike within three to four projectile diameters of edges or previous impacts.



VARIATION IN MATERIAL THICKNESS
ABOVE AND BELOW PROJECTILE
CREATES NET FORCE TOWARDS EDGE

When rifle bullets are fired into sand boxes near the surface, or nails are driven into wood a short distance from the top, bullets and nails will tend to move towards the closest surface. This occurs because resisting pressure on one side of the nose will be less, due to reduced backing material. A similar phenomena occurs with armor.

The Sherman 75mm gun mount has a 50.8mm cast shield protecting an 88.9mm inner shield, which adds to nearly 140mm total combined thickness and exceeds the penetration of 75mm L48 APCBC at all ranges. Consideration of cast deficiency and medium flaw factors reduces the effective shield thicknesses to 40.5mm and 80.6mm on 0° hits, which combine for a single plate equivalence of 104.5mm.

Since the Sherman inner shield has numerous holes and hits on the outer shield may also generate edge effects, the effective resistance of the combination is further reduced and the two shields may combine for an average single plate resistance of about 90mm to 95mm of good quality rolled armor at 0°.

German and Soviet tank armor analysis also requires consideration of spaced armor and edge effect modifiers. Both T34/85 and IS-2/2m mantlets have small underlying armor areas that protrude a short distance under the mantlet edge, on IS-2/2m this small area has an opening for sight. Hits on the mantlet edge on T34/85 and IS-2/2m would offer far less effective resistance than the nominal thickness, and assuming mantlet thickness may approximate total resistance.

Tiger E has a 100mm turret front bar that underlies the 97mm to 127mm armor on the upper and lower edges of the mid-production mantlet, which requires application of spaced armor and edge effects.

If one assumes that projectile nose strikes on armor edge face 25% resistance (equivalent thickness equals 25% of actual thickness), hits where nose is one radii from edge face 75% resistance and hits at three diameters (six radii) result in full 100% armor effectiveness, the following table provides estimated resistance on hits within three diameters of edge:

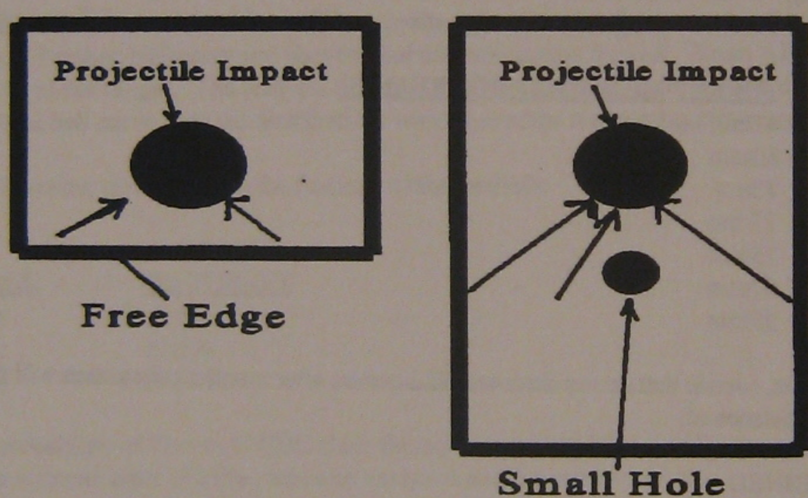
Edge resistance as function of nose hit position in radii from edge is estimated on following table, based on visual review of potential armor resistance:

# RADII TO ARMOR EDGE	MULTIPLIER
0.00	0.25
0.10	0.30
0.20	0.35
0.30	0.40
0.40	0.45
0.50	0.50
0.60	0.55
0.70	0.60
0.80	0.65
0.90	0.70
1.00	0.75
1.25	0.79
1.50	0.83
1.75	0.86
2.00	0.90
3.00	0.93
4.00	0.95
5.00	0.98
6.00	1.00

The traditional edge effect applies to a free edge, where the armor is free to move away from the projectile path through the armor, which lowers the overall resistance. Where an armor plate is restrained from moving away from the projectile path, by welding or bolting to another plate, the reduction in armor resistance is less than with a free edge.

The near vertical driver plates on PzKpfw III and Tiger E represent armor with relatively small height, where one might expect edge effects to reduce armor resistance. However, penetration tests against the driver plate on both tanks and reported penetration ranges suggest full resistance. In addition, if hits near driver plate edges did substantially reduce armor resistance, frontal penetrations of Tiger E by 76.2mm APBC and 75mm APCBC would have occurred and been noted.

The effect of vision and machine gun holes on armor resistance should also result in less impact that a free edge, since the material around the hole aids in penetration resistance, giving small holes an advantage when the hole outline is the same distance from impact center as a free edge. In addition, the vision holes on Tiger E mantlet are about 1" to 1.25" diameter, so hits would almost have to touch the hole edge to gain a reduced form of free edge effect, and the circular shape of the hole may add to resistance due to classical arch support.



SMALL HOLES IN ARMOR, SUCH AS VISION OPENINGS IN A MANTLET, HAVE MORE MATERIAL RESISTING PENETRATION THAN FREE EDGES

The penetration resistance of armor holes can be visualized by considering that an infinite radius hole is a free edge or straight line, and a zero radius hole is so small that armor resistance is not affected. Intermediate radius holes would appear to present considerably greater resistance than a free edge, based on review of the drawing following this page, as long as the projectile impacted some distance from the armor opening.

10. EDGE HITS ON TIGER E MANTLET

The upper and lower 4" of the Tiger mantlet varies in thickness from 97mm at edge to 127mm at cylindrical interior shield (actual measurements from one tank). If mantlet edge hits are assumed to land at mid-point of the 4" distance, the number of radii from edge and effective armor resistance for various projectile sizes follows (cast thickness at impact point is assumed to be 112mm):

PROJ. SIZE	RADII TO EDGE	EDGE EFFECT	EFFECTIVE RESISTANCE
57	1.78	0.87	94mm
76	1.33	0.80	85mm
85	1.20	0.78	83mm
90	1.13	0.77	83mm
100	1.02	0.75	79mm
122	0.83	0.67	71mm
152	0.67	0.59	61mm

Penetrations of mantlet edge would strike 100mm turret front bar at about 2" from edge. Following table predicts resistance of turret front bar, using the same edge effect modifier as lower edge of Tiger mantlet:

PROJ. SIZE	TURRET FRONT BAR RESISTANCE
57	87mm
76	80mm
85	78mm
90	77mm
100	75mm
122	67mm
152	59mm

Due to spaced armor effects, rounds that do not detonate HE bursters after mantlet penetration will face an overall effective armor resistance of:

SIZE	COMBINED RESISTANCE	NOTES
57	157mm	APC or APCBC
76	143mm	APC or APCBC
90	139mm	APC or APCBC
85	139mm	APBC
100	133mm	APBC
122	119mm	APBC
152	104mm	APBC
85	142mm	AP
100	135mm	AP
122	121mm	AP
152	105mm	AP

Above table valid for rounds striking without lateral angle.

Hits near mantlet edge may also be deflected away from armor edge, with hits on upper edge deflected towards top of tank. Hits on lower mantlet edge may be deflected downwards and may strike hull top, resulting in possible penetrate. The chance also exists that armor piercing projectiles with HE filler may detonate upon leaving the mantlet but prior to hitting the turret front bar, resulting in a defeated hit.

Hits on IS-2 and IS-2m mantlet edge by 75mm and 88mm rounds would occur at about one radii on each, resulting in an effective thickness of approximately 100mm.

11. TURRET HIT PROBABILITY AND ROUNDED MANTLETS

At close range, hits tend to bunch around the aim point, which suggests that turret hits might represent a small percentage when the aim point is on the hull of a fully exposed target.

Anecdotal stories from Europe include cases where a 75mm Sherman was within 100 yards of a Panther and hit after hit struck the same place on the panzer glacis. The Panther crew realized that the first Sherman crew was not altering the aim point and would continue to hit the same location, so the Panther turret was traversed and a more serious threat was engaged.

To examine the situation where close range shots are aimed at the vertical and horizontal center of a fully exposed Panther, trajectory and shot-to-shot dispersion data for U.S. 76mm APCBC was analyzed at 100, 200 and 300 meter ranges. The analysis assumed that range estimation errors were randomly selected based on a statistical bell curve (normal distribution) with an average range estimating error of 25%.

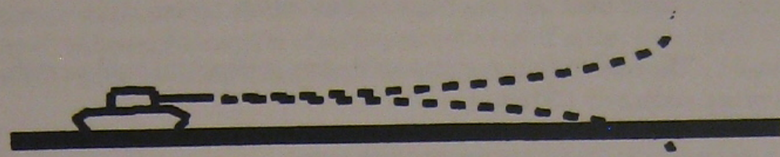
The following chart presents the findings of the analysis:

RANGE	% OF HITS ON TURRET
100m	2.5%
200m	12.5%
300m	25.1%

The probability of 76mm APCBC shots falling within 1' (0.305m) of the target aim point, with an average range estimate error of 25% , was also analyzed and the results follow:

TARGET RANGE	% OF SHOTS WITHIN 0.305m OF AIM POINT
50m	99%
100m	97%
150m	93%
200m	88%
250m	82%
300m	74%

Note: Probability for hit bunching around aim point would be higher with 76mm HVAP.



95% DISTRIBUTION OF SHOT TRAJECTORIES, DUE TO RANGE ESTIMATION ERRORS AND DISPERSION, IS A FUNCTION OF TARGET RANGE AND WILL BE SMALL AT CLOSE RANGE

In addition to the low percentages, a high proportion of turret hits struck the bottom of the rounded Panther mantlet and were far from the vulnerable middle mantlet section (near vertical angles).

Reports from the 899th Tank Destroyer Bn include battles where 3" armed M10's fought Panthers at close range in the bocage country in face-to-face confrontation. No penetrations of Panther frontal hull or turret armor were noted, although several penetrations did occur through the hull MG port or when hits on the mantlet bottom were deflected onto the hull top and penetrated.

These stories support the above calculations for estimated percentage of hits against Panther turret armor.

Following data is based on analysis of impact angles on a rounded mantlet when the hits are evenly distributed, which might occur at medium to long range or against hull down vehicles. The data has been converted to a 1-100 decimal dice system for use in war games:

IMPACT ANGLE	DECIMAL DICE SCORE
75°	1
70	2-4
65	5-8
60	9-13
55	14-18
50	19-24
45	25-30
40	31-37

35	38-44
30	45-52
25	53-60
20	61-68
15	69-77
10	78-86
5	87-95
0	96-00

The following table presents estimates impact angle probability when hits at 200m range strike the Panther mantlet:

ANGLE RANGE	PROBABILITY
65°-75°	20.0%
50°-60°	31.2%
35°-45°	24.8%
20°-30°	14.4%
0°-15°	9.6%

12. COMPOUND ANGLES

Hits on armor with vertical slope often occur with horizontal or lateral side angles, and armor may also have vertical and lateral slope at the same time. Computing the effective armor resistance requires use of the compound angle equation, and important combinations are presented on the following page.

When armor has a vertical angle "V" and a lateral angle "L" on hits, the resulting impact angle is:

Cosine (compound angle) = Cosine (V) x Cosine (L)

The implications of this equation are interesting and indicate that lateral angle has less impact of highly sloped armor than near vertical plate or cast.

If a vertical 45mm plate is hit at 40 degrees lateral angle by 75mm APCBC,
the slope effect is 1.48 and the 0° equivalent resistance is 67mm, an increase of 48% over the resistance offered at 0° lateral angle.

When 45mm armor has 60° vertical slope, the 0° equivalent resistance to 75mm APCBC hits without lateral angle is 122mm at 0°. If 60° vertical slope is hit at 40° lateral angle, the compound angle is 67.5°, and the slope effect against 75mm APCBC is 3.9. The resulting armor resistance at 60° vertical and 40° lateral angle is 156mm at 0°, which represents a 28% increase over the 0° lateral angle situation.

In the above case with 45mm armor attacked by 75mm APCBC, a 40° side angle increased vertical plate resistance by 48% and 60° vertical slope effectiveness by 26%.

13. <u>PENETRATION DATA</u>

GENERAL

The tables in this section present penetration data for British, American, German, Italian and Soviet anti-tank ammunition that is keyed to a constant standard, the equivalent resistance of good quality U.S. 240 BHN rolled test plate or U.S. face-hardened armor, as used for ballistic testing.

Published penetration data is often based on test firings at 30° slope and then converted to 0° using assumed and constant slope effects, which may result in variations from actual penetration. In many cases a constant slope effect is used against all thicknesses even though slope effect is clearly dependent upon T/D.

Published Soviet penetration data may, in some cases, be based on DeMarre equation estimates from face-hardened test results, although most of the penetration figures on *The Russian Battlefield* site appear to be test data (IP or CP figures are test data, a superscript 2 is computed tabular) . Russian APBC penetration data in this report is based on U.S. test firing with captured 122mm rounds and has been estimated for other APBC rounds using the DeMarre equation. Soviet AP required another approach, based on comparison to Allied AP penetration with modifiers for lowered nose hardness and an HE filler.

U.S. nose hardness tests with 20mm AP resulted in data for penetration velocity versus nose hardness in the 56 to 64 Rockwell range, and the velocities were converted to relative thicknesses at 0°. The curve of best fit through the data was extrapolated to 52 Rockwell hardness, which appears to represent the average measured nose hardness of Soviet anti-tank ammunition.

Soviet penetration for all sizes of uncapped APHE ammunition was estimated using the DeMarre equation and U.S. 75mm AP solid shot data, with modifiers for HE bursters and Russian projectile hardness. The U.S. nose hardness tests suggested that Russian ammo had about 90% of American penetration if rounds were similar in every other way, and impacted at same velocity against same armor. Estimated data was checked against firing test results on captured tanks and was found to be reasonably accurate.

Published German data appears to be based on superior quality test plate and highest quality ammunition, which out penetrated service rounds by about 8% to 10%. However, U.S. tests of German and American 75mm ammunition at common velocities showed that German combat grade 75mm APCBC out penetrated 75mm M61 APCBC. Since American ammunition was considerably softer than German projectiles, based on work presented by Miles Krogfus in *AFV News*, penetration differences would be expected.

Review of German penetration data on several web sites has raised questions regarding 75mm L46 data, where the gun had a higher muzzle velocity and greater penetration than the longer barreled 75mm L48. In general, as barrel length increases muzzle velocity and penetration also increase.

Comparing 75mm barrel length and muzzle velocity, the German 75mm L43 fired 15# APCBC at 2427 fps, which is 20% higher than the muzzle velocity on Shermans (14.96# projectile at 2030 fps), and is associated with a 7.5% increase in barrel length. When 75mm L48 was placed on PzKpfw IV, the 12% increase in barrel length only produced a 1% increase in velocity over the L43 gun.

COMPOUND ANGLE TABLE

VERTICAL ANGLE	LATERAL ANGLE															
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**
0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
5	7	11	16	21	25	30	35	40	45	50	55	60	65	70	75	80
9	10	13	17	22	26	31	36	41	46	51	55	60	65	70	75	80
10	11	14	18	22	27	31	36	41	46	51	56	61	65	70	75	80
14	15	17	20	24	28	33	37	42	47	51	56	61	66	71	75	80
15	16	18	21	25	29	33	38	42	47	52	56	61	66	71	76	80
20	21	22	25	28	32	36	40	44	48	53	57	62	67	71	76	81
25	25	27	29	32	35	38	42	46	50	54	59	63	67	72	76	81
30	30	31	33	36	38	41	45	48	52	56	60	64	69	73	77	81
35	35	36	38	40	42	45	48	51	55	58	62	66	70	74	78	82
40	40	41	42	44	46	48	51	54	57	61	64	67	71	75	79	82
45	45	46	47	48	50	52	55	57	60	63	66	69	73	76	79	83
47	47	48	49	50	52	54	56	59	61	64	67	70	73	77	80	83
50	50	51	52	53	54	56	58	61	63	66	68	71	74	77	80	84
52	52	53	54	55	56	58	60	62	64	67	69	72	75	78	81	84
53	53	54	54	56	57	59	60	63	65	67	70	72	75	78	81	84
55	55	56	56	57	59	60	62	64	66	68	71	73	76	79	81	84
56	56	57	57	58	60	61	63	65	67	69	71	74	76	79	82	84
60	60	61	61	62	63	64	66	67	69	71	73	76	78	80	83	85
65	65	65	66	67	67	69	70	71	73	74	76	78	80	82	84	86
70	70	70	71	71	72	73	74	75	76	77	79	80	82	83	85	87
72	72	72	73	73	74	74	75	76	77	79	80	81	82	84	85	87
75	75	75	76	76	76	77	78	79	79	80	81	83	84	85	86	87
80	80	80	80	81	81	81	82	82	83	84	84	85	86	87	87	88

Space and weight related factors appear to have placed constraints on 75mm L48 performance, since higher muzzle velocity would be associated with a heavier gun, larger ammunition casings, longer weapon recoil and other factors. It appears that weight restrictions may have limited the armor that could be carried on the PzKpfw IV turret front, and weight additions associated with increased muzzle velocity, along with space limits, may have been responsible for the small increase in velocity between L43 and L48 versions of the 75mm gun.

75L46 German guns were used on anti-tank or self-propelled mountings where space and weight limitations may have been less severe, which allowed 2600 fps muzzle velocity on vehicles such as Marder.

Space constraints due to higher velocity rounds may be quite severe, where the Sherman Firefly functioned without a bow machine gun and associated crew member to provide added space for the larger projectiles and their cases. German ammunition for the 75mm L43 and L48 guns was 74.3cm long (29.25") and contained 2.43 kg of charge, whereas L46 and L70 rounds were 96.2cm long (37.87"). The charges for the L46 and L70 rounds weighed 3.48 and 3.71 kg, respectively.

Compared to other medium tanks, PzKpfw III and IV appear to have been severely constrained with regard to gun size and muzzle velocity. T34 was up gunned from the 76.2mm at 2230 fps to an 85mm weapon firing at 2600 fps, while the PzKpfw IV muzzle velocity with 75mm guns was restricted to 2460 fps. Sherman tanks started with the 75mm L40 at 2030 fps, accepted the 76mm at 2600 fps and were then further upgraded to the Firefly 17 pounder (76.2mm at 2900 fps), and M36B1 with a 90mm gun in a different turret (2670 fps).

American 57mm anti-tank gun may fire APDS ammunition starting June 1944, with same penetration data and accuracy problems as British 6 pounder APDS, but limited availability. Firing test reports on the Mycenius internet site indicate 57mm M1 APDS as available to First U.S. Army at the time of the test, and was considered a "normal" ammunition type similar to 57mm M86 APCBC and 75mm M61 APCBC. 75mm HEAT, fired by the M3 Sherman gun, is designated as "special", which suggests that 57mm APDS was not an experimental round. Definitive data proving that U.S. forces fired 57mm APDS in combat was located by Robert McNamara during preparation of Advanced Squad Leader rulebook, where he found evidence in U.S. Army ammunition use tables (also see first article in errata section).

PROJECTILE NOSE HARDNESS ISSUES

The U.S. Ordnance Corps report, *Penetration Performance versus Projectile Nose Hardness*, fired uncapped 20mm AP at various nose hardnesses against a wide spectrum of armor thicknesses and angles. The results are summarized below:

> When projectiles remain intact during penetration, increased nose hardness decreases the velocity required for success, which translates into increased penetration for the same velocity
>
> When projectiles shatter during penetration, nose hardness is not a factor in penetration success or is of minor consequence
>
> Projectile nose hardnesses below 59 Rockwell C Hardness may have two distinct penetration thicknesses for 50% success, based on shattered and intact projectile condition, where failures occur between the two ballistic limits (failure occurs within the "shatter gap" region)

The advantage of German APCBC projectiles over American ammunition, which relates to about 17% greater penetration on the basis of nose hardness, was evident during American tests when 75mm German rounds were compared to U.S. 75mm APCBC. While 20mm AP shattered during most of the Ordnance Corps firing tests, which would suggest that nose hardness is not really a factor in many cases, the following factors do not apply to most German APCBC rounds:

> 20mm AP was usually fired at 3000 fps or greater, and high velocity promotes nose shatter
>
> AP ammunition did not have armor piercing caps, where those caps reduce shatter tendency
>
> 20mm is much smaller than most WW II combat rounds, and small projectiles are more vulnerable to many factors, including nose shatter
>
> The T/D ratio's in the Ordnance Corps tests ranged from 0.95 to 1.11 at 55°-60° impact angles

German 75mm and 88mm APCBC would not be expected to shatter as often as the 20mm AP in the Ordnance Corps tests, and in most cases intact penetration would justify use of the penetration figures published in this booklet. As an example, 75mm APCBC attack on Sherman and T34 glacis armor will result in T/D ratio's of 0.68 and 0.60 against reduced resistance armor (flaws or overmatched and brittle high hardness). However, there may be cases where angled hits with high T/D ratio's may result in shattered penetration by German APC and APCBC, which would effectively reduce the penetration figure used during analysis. There is insufficient data to predict when this will occur.

The following table illustrates several of the key factors regarding nose hardness impact on intact and shattered projectile penetration, and the absence of shatter gaps with high nose hardness:

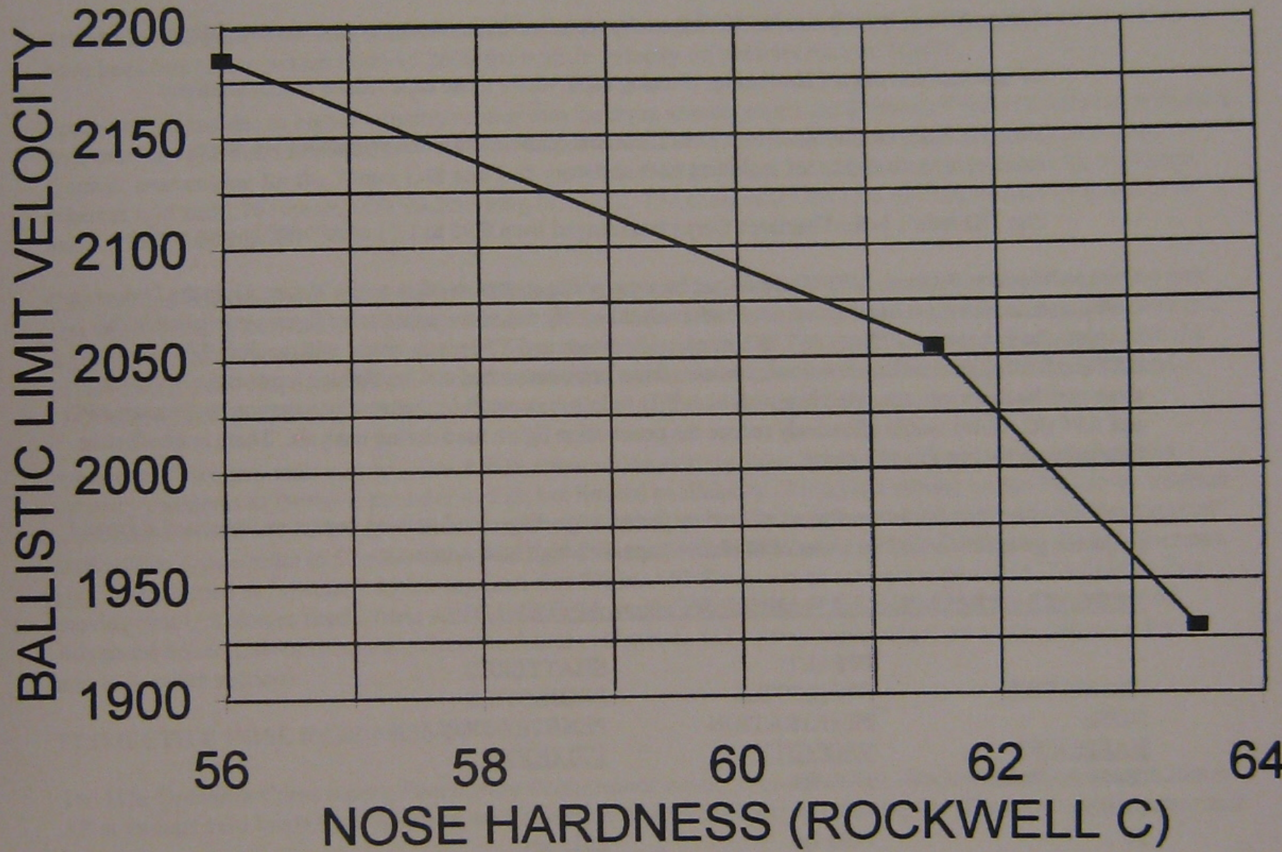
<u>7/8"PLATE ATTACKED AT 20° ANGLE BY 20mm AP (T/D=1.11)</u>

PROJECTILE NOSE HARDNESS	INTACT PROJECTILE PENETRATION VELOCITY	SHATTERED PROJECTILE PENETRATION VELOCITY
63-64 Rockwell C	1930 fps	
61-62	2055 fps	
56	2185 fps	2515 fps
49		2610 fps

<u>7/8"PLATE ATTACKED AT 30° ANGLE BY 20mm AP (T/D=1.11)</u>

PROJECTILE NOSE HARDNESS	SHATTERED PENETRATION VELOCITY
63-64 Rockwell C	2670 fps
61-62	2640 fps
56	2635 fps
49	2740 fps

BALLISTIC LIMIT VELOCITY
VERSUS NOSE HARDNESS
FOR 20mm T33 AP
AGAINST OVERMATCHING ARMOR



3/4"PLATE ATTACKED AT 55° ANGLE BY 20mm AP (T/D=0.95)

PROJECTILE NOSE HARDNESS	SHATTERED PENETRATION VELOCITY
63-64 Rockwell C	2960 fps
61-62	3000 fps
56	2965 fps
49	3020 fps

RUSSIAN PENETRATION DATA

Commonly quoted penetration figures for Russian ammunition during WW II present 500m figures of 69mm for 76.2mm APBC and 111mm for 85mm APBC, with 155mm penetration for 122mm APBC at that range. These figures appear to be estimates as opposed to test results, due to German documents which state that the aforementioned Russian penetration figures were based on a DeMarre equation for "zementen platten", or cemented armor (a term often applied to face-hardening).

Preparation of penetration estimates for Russian APBC ammunition against homogeneous armor plate was based on firing test curves for 122mm APBC against American armor at angles from 0° to 70°.

If 122mm APBC penetrates 206mm at 2600 fps impact velocity, 85mm APBC should penetrate 206mm x $(85/122)^{1.000}$ at the same velocity, or about 143mm, based on a simplified version of the DeMarre equation for equal velocity impacts. The W/D^3 term in the DeMarre equation has not been applied, and the diameter ratio has been simplified, since APBC does not appear to strictly follow the DeMarre equation assumptions on velocity exponents. Analysis of 122mm APBC data for penetration versus impact velocity indicated that the following relationships should hold for other APBC projectiles:

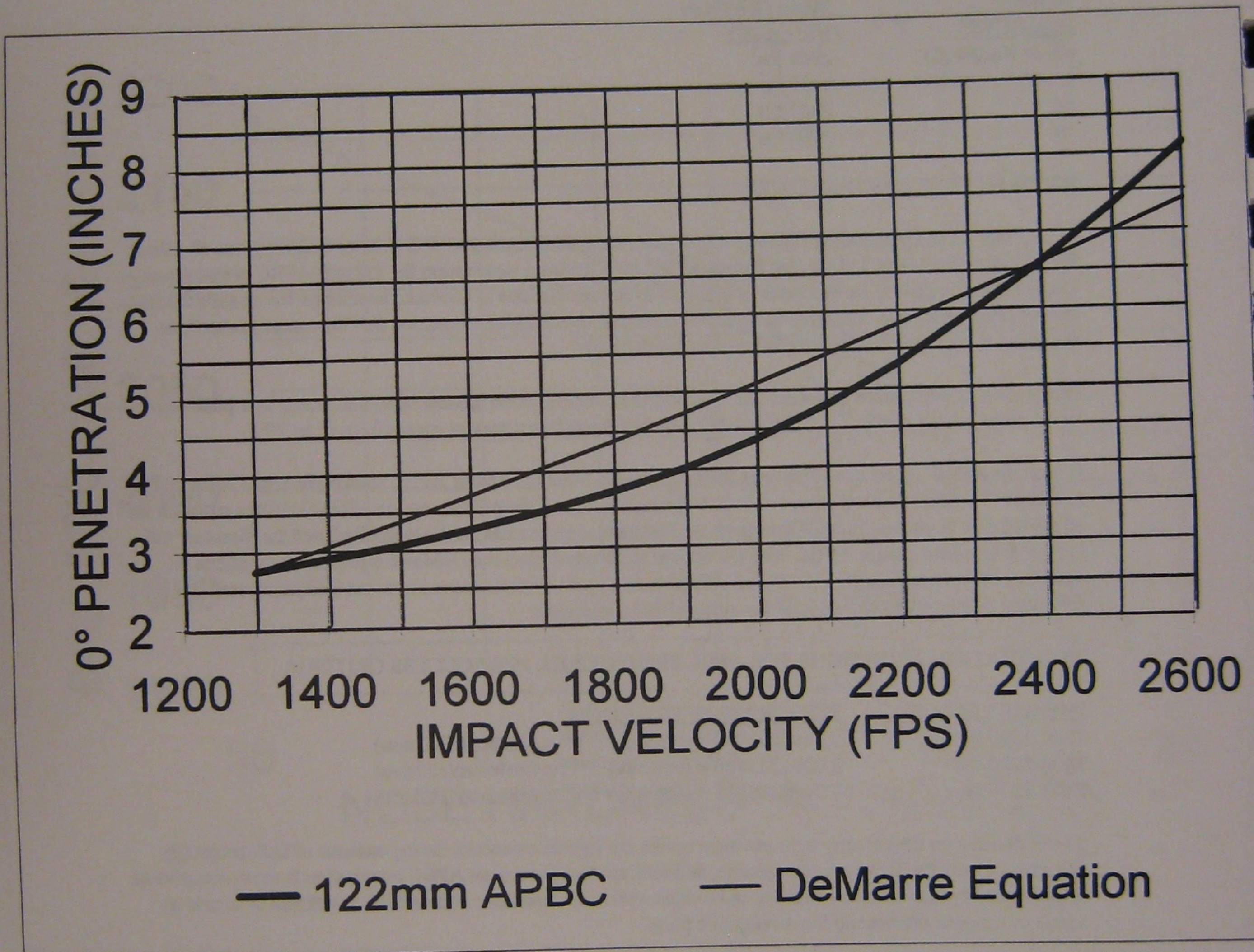
PENETRATION EQUATIONS FOR APBC PROJECTILES, 50% SUCCESS CRITERIA

IMPACT VELOCITY	PENETRATION EQUATION
1400-1800 fps	$0.0568400000 \times (\text{velocity})^{0.988812} \times (\text{diameter}/122\text{mm})$
1800-2200 fps	$0.0001243400 \times (\text{velocity})^{1.805080} \times (\text{diameter}/122\text{mm})$
2200-2600 fps	$0.0000005806 \times (\text{velocity})^{2.503640} \times (\text{diameter}/122\text{mm})$

The exponents on the velocity term are most unlike the figures examined during analysis of U.S. projectile consistency with the DeMarre formulation, and indicate that blunt nose APBC penetration is more sensitive to impact velocity than round or sharp nosed rounds, which is reasonable since APBC penetrates 0° armor by virtue of extreme impact and the driving of a plug.

Using the above equations for the various Russian APBC results in the following estimates for point blank penetration of homogeneous armor at 0°:

COMPARISON OF 122mm APBC
PENETRATION VS. VELOCITY CURVE
TO DeMARRE EQUATION ESTIMATE FROM 1300 FPS



APBC	MUZZLE VELOCITY	0m/0° PENETRATION	NOTES
45mm	760 m/s	68mm	
45mm	820 m/s	83mm	
57mm	990 m/s	168mm	Estimate is high compared to other figures
76.2mm	655 m/s	80mm	76.2mm field guns ZIS-3 and USV
76.2mm	680 m/s	87mm	76.2mm tank guns F-34 and ZIS-5
85mm	792 m/s	143mm	
100mm	915 m/s	242mm	
100mm	895 m/s	229mm	Muzzle velocity often quoted at 895 m/s
122mm	792 m/s	206mm	
152mm	600 m/s	137mm	

Comparison of the above figures with penetration data on *The Russian Battlefield* web site results in a number of interesting results.

Penetration curves and gun data on the aforementioned site present the following figures for 57mm, 76.2mm, 85mm and 122mm ammunition, with extrapolation to the 0m penetration figure. The rate at which the projectiles lost penetration with range on the curves (or in 57mm data tables) is consistent with APBC ammunition:

APBC PROJECTILE	Russian Battlefront 0° PENETRATION 100m	500m	1000m	EXTRAPOLATED PENETRATION 0m	APBC PENETRATION EQUATION ESTIMATE AT 0m
57mm*	102	94	86	110	168
57mm**	115	105	95	125	168
76.2mm F-34*	90	80	73	91	87
76.2mm F-34#	84	74	59	87	87
85mm	141	128	110	145	143
122mm	212	200	182	216	206

NOTES:*- from tank gun data
**-from artillery data
#-from penetration curves in Archives section
American penetration and velocity estimates for 122mm APBC vary from Russian at all ranges beyond point blank, and this book uses the American figures
Russian data converted to 50% success criteria by averaging CP (20% success) and IP (80% success) figures

The difference between the 57mm penetration data in the tank gun and artillery sections of The Russian Battlefield and the APBC equations is significant, and is probably due to projectile nose shatter against thick armor at high velocity, since the nose hardness is estimated at 52 Rockwell C Hardness and falls within the shatter region for steel projectiles.

Penetration estimates from the APBC equations compare favorably with data from *The Russian Battlefield* in most cases, and appear to be consistent with reported penetration ranges against Ferdinand, Panthers and

Tigers. Penetration estimates for Russian AP ammunition against homogeneous and face-hardened armor were prepared from nose hardness analysis, and vary from data published on *The Russian Battlefield*.

The following analysis estimates the 0° penetration of 45mm APBC (760 m/s muzzle velocity) against American penetration test plate from German tests of captured 45mm ammunition, where the source of the original base data is Appendix D in Jentz' *Panzertruppen, Volume 1*. 30° penetration data has been converted to 0° using appropriate slope multipliers, and German armor hardness has been coverted to 240 Brinell basis:

45mm APBC PENETRATION ESTIMATES

DATA CONDITION	0m	100m	500m	1000m	1500m	NOTES
0°, 240 Brinell	52	49	38	28	22	0m figure is extrapolated
0°, 240 Brinell	57	54	42	31	24	10% increase for German test plate
Impact Velocity	2493	2428	2185	1916	1679	

NOTES: APBC round was assumed due to character of penetration loss with range.

The 45mm APBC tested by the Germans would penetrate 57mm of American quality test plate at 0m and 0° (760 m/s muzzle velocity), while estimates from U.S. tests of 122mm APBC resulted in 68mm. The difference may be due to ammunition quality variations, where *The Russian Battlefield* indicates that 45mm projectile quality decreased from late 1941 through early 1942. If the Germans tested 45mm ammunition produced during the aforementioned period, then the variation between German test results and 122mm APBC based estimates would be explained.

The Russian AP penetration figures in this book for 50% success appear to be about 11% higher than comparable figures from *The Russian Battlefield*. If the homogeneous armor penetration figures for Russian AP in this book are decreased by 12% to attain consistency with Russian figures, the face-hardened armor penetration figures should also be modified by an equal factor.

HOMOGENEOUS PENETRATION ESTIMATES FOR RUSSIAN AP

PROJECTILE	BOOK AP PEN. @ 100m	RATIO OF AP PEN. @ 100m	BASIS OF COMPARISON
85mm AP	136	1.10:1	124mm @ 100m on *The Russian Battlefield*
100mm AP	202	1.09:1	186mm @ 100m on *The Russian Battlefield*
122mm AP	192	1.13:1	170mm @ 100m on *The Russian Battlefield*

NOTE: Data from *The Russian Battlefield* site was converted to 50% success criteria by increasing the CP figure (20% success) by 6%.

Data from *Artillery of the World*, by C. Foss and I. Allen, is available on the John Salt site and presents penetration figures for Russian projectiles which appear to be APBC with HE filler. Comparison of Russian penetration data from *Artillery of the World* with APBC equation estimates results in exact or very close agreement for 76.2, 85, 100 and 152mm APBC, and fair sized differences for 57 and 122mm APBC.

The 57mm penetration difference may be attributable to nose shatter (106mm penetration at 500m is a common estimate for 57mm ammunition among many sources), and the 122mm APBC variation may be due to different estimates of 122mm APBC velocity at 1000m (penetration tests are normally conducted at 100 meters and velocity is varied to determine penetration versus velocity, estimates of velocity vs range are then used to determine penetration as a function of range).

Critical penetration data for Russian APBC is currently unavailable, namely performance against face-hardened armor. Since many German tanks, including PzKpfw IIIF-M, PzKpfw IVF-H, Panther A and D, StuG III and even Tiger II carried face-hardened armor (FHA) in critical areas, the absence of FHA penetration data for the primary Russian round is a serious handicap. Slope effects for blunt nose APBC against face-hardened armor is also not available, and may fall between homogeneous slope effects for APBC and APCBC.

A measure of Russian APBC penetration against FHA may be gained from a report contained on in the Archives section of *The Russian Battlefield* web site, entitled *Damages of "Panther" tanks examined by the commission NIIBT Poligon from 20 to 28 July 1943*, which analyzes 31 Panthers captured at Kursk. Penetrations by 45mm, 76.2mm and 85mm field guns are indicated, and very short ranges are suggested by 45mm sabot penetration of Panther mantlet which may have occurred at 50 meters. The 45mm guns appear to be the Model 1942 version with L66 barrel length.

The face-hardened upper side hull armor on Panther number 170 was penetrated once by 76.2mm APBC at an engagement angle of 60°. Engagement angle in this report appears to represent lateral angle from horizontal armor facing, where 60° engagement angle against side armor would equal 30° from front hull facing. This interpretation is supported by comparison of engagement angles to armor vertical slope, where 85mm gun penetrated 40° vertical slope upper side hull armor at 10° engagement angle.

76.2mm penetration of 40mm side armor at 60° engagement angle represents a compound angle of 60° or 67.5°, depending upon which areas were hit. Impacts at 60° and 67.5° result in over 100mm effective armor resistance at 0°. It seems unlikely that 76.2mm APBC field gun rounds could penetrate 40mm FHA at 60° or 67.5°, and the actual angle may have been lower due to the various factors that may impact engagement angle estimates (tank may have been turning during the penetration and final angle to gun is different from impact angle).

The close range penetration by a 76.2mm field gun against Panther side armor, at a wide lateral angle (may have been between 50° and 65°), suggests that 76.2mm field guns could penetrate between 80mm and 90mm FHA at close range as opposed to about 80mm homogeneous. It is normally assumed that the Germans continued to use face-hardened armor through 1944 due to Russian ammunition, where AP and APBC did not have armor piercing caps and were assumed to have reduced FHA penetration. Due to a blunt nose on APBC, estimates of FHA penetration based on sharp nosed AP figures may not be valid, and may underestimate actual performance.

Strict interpretation of the 60° engagement angle penetration of Panther upper side armor, by 76.2mm field cannon, is also impacted by the near-vertical armor area at the rear of the tank, as well as the questions regarding slope effects for APBC against face-hardened armor. If the round went through the near vertical 40mm armor, the compound angle is close to 60° and the effective armor resistance at 0° might vary from 64mm (APBC slope effects) to 107mm (AP slope effects).

GERMAN PENETRATION DATA

Comparative American tests with U.S. and German 75mm rounds resulted in the conclusion that German projectiles penetrated more armor. This conclusion is consistent with nose hardness data, as American APCBC projectiles appear to have averaged 54.5 Rockwell C hardness, based on Miles Krogfus' article in *AFV News*, and analysis of captured German rounds averaged 60.7. American analysis of various size Russian projectiles indicates 52 average Rockwell C nose hardness:

PROJECTILE	ROCKWELL C HARDNESS
75mm Pak 40	58.5
75mm L70	57.5
88mm Pak 41	60.0
88mm Pak 43	61.75
50mm APC	61.5
50mm APC	61.5
75mm L48	64.0

Source: Various reports from Watertown Arsenal Laboratory (WAL)
Miles Krogfus reports 57 to 69 Rockwell C range for German projectile noses, average of 63.

From the limited sample noted above, German projectile nose hardness varied from 57.5 to 64.0 Rockwell C hardness. In addition to the relatively wide spread in nose hardness, quality control measures for ammunition inspected a small percentage of rounds, and battlefield reports note that hits that should have penetrated sometimes failed. Besides the possibility of cracked rounds, later German ammunition, such as 75mm L70 APCBC, might use welded-on noses, and weld weaknesses could also decrease or rule out penetration.

The above paragraph suggests that hits may fail on a random basis, without apparent reason.

The dependence of penetration on nose hardness might be likened to using two knives against butter, one steel and one Styrofoam, where steel transmits practically all applied force to butter and butter absorbs energy by splitting. The Styrofoam knife absorbs much of the applied force and may bend and suffer damage during the attempt. The following graph is a plot of the velocity required for 50% penetration probability as a function of projectile nose hardness (Rockwell C Hardness), where higher nose hardness results in lower velocity. The 20mm T33 AP tests were conducted against armor with Brinell Hardness over 300.

If the straight line from 61.5 to 56 Rockwell C Hardness is assumed to extend to 52 Rockwell C (Russian projectile hardness), the velocities for 61 (German average), 54.5 (American average) and 52 (Russian average) are:

61.0 Rockwell C 2066 fps
54.5 Rockwell C 2220 fps
52.0 Rockwell C 2280 fps

If the DeMarre equation is used to convert velocity differences into penetration ratio's, German projectiles at 61 Rockwell C would penetrate $(2220/2066)^{1.4283}$, or 11% more armor than 54.5 Rockwell C projectiles at the same velocity. Due to scale effects, armor hardness considerations and comparison with Mark Diehl's data,

German projectiles were assumed to have a greater penetration advantage (about 17%) over American ammunition.

The following table is based on an analysis of German 30° penetration data for 75L70, 75L43 and 88L56 APCBC that has been converted to an estimate of 0° penetration, using the slope multipliers that are presented in this book. The 30° penetration data was derived from the British BIOS report and the *Encyclopedia of German Tanks of WW II*:

0° PENETRATION ANALYSIS
BEST QUALITY AMMUNITION AGAINST GERMAN TEST PLATE

RANGE	75L70 PEN.	75L43 PEN.	88L56 PEN.
100m	182	127	157
500m	162	117	143
1000m	144	105	128
1500m	129	91	116
2000m	114	79	106

As an example of the procedure used to prepare the above table, if 75mm APCBC penetrates 99mm of armor at 30° impact, the slope effect will be 1.27 and the resulting armor resistance at 0° will be 127mm.

Based on above figures, DeMarre estimates for penetration at 0m/0° are:

50L60 102mm estimate from 75L43, 104mm estimate from 75L70
75L70 186mm
75L46 143mm estimate from 75L43, 147mm estimate from 75L70
75L48 133mm estimate from 75L43, 136mm estimate from 75L70
75L43 130mm
88L56 161mm
88L71 233mm estimate from 88L56

German penetration figures are based on test quality projectiles that exceed service ammunition penetration by 8% to 10% at 0°, which suggests that combat quality ammunition should penetrate about 9% less than penetration figures in *The Encyclopedia of German Tanks of WW II (EGT)*. The similarity of 0° penetration figures generated from *EGT* and American estimates for combat rounds suggests that German penetration test plate may be more resistant than Allied and Soviet machineable quality homogeneous armor. While 75L70 combat quality APCBC should penetrate about 186 x 0.91 or 169mm, it penetrates 190mm of American plate, which suggests a 12% increase due to German plate resistance superiority over American.

Mark Diehl published extensive data in *AFV-G2* magazine on German projectiles, including penetration data that appears to be derived from American tests with captured German guns and ammunition. The point blank penetration data at 0° in the *AFV-G2* article exceeds the DeMarre estimates presented above, and German penetration figures in this book combine the DeMarre and *AFV-G2* estimates. Listed penetration data in Mark Diehl's work is presented below for 0m hits at 0° impact:

PROJECTILE	*AFV-G2* 0m & 0° PENETRATION	NOTES
37L45 AP	68mm	DeMarre from 75L43 yields 67mm after cap adjustment
50L42 APC	85mm	DeMarre from 75L43 yields 82mm
50L60 APC	99mm	DeMarre from 75L43 yields 109mm, suggests nose over stress
75L24 APCBC	62mm	DeMarre from 75L43 yields 55mm at 385 m/s muzzle velocity
75L43 APCBC	139mm	Base data for DeMarre equation analysis
75L46 APCBC	149mm	DeMarre from 75L43 yields 153mm
75L48 APCBC	141mm	DeMarre from 75L43 yields 142mm
75L70 APCBC	190mm	DeMarre from 75L43 yields 194mm
88L56 APCBC	159mm*	DeMarre from 75L43 yields 169mm
88L71 APCBC	225mm*	DeMarre from 75L43 yields 241mm, suggests nose over stress
128L55 APCBC	275mm	DeMarre from 75L43 yields 264mm at 845 m/s muzzle velocity
128L55 APCBC	275mm	DeMarre from 75L43 yields 298mm at 920 m/s muzzle velocity

NOTE: *-extrapolated penetration at 0m

Failure of rounds to equal DeMarre penetration estimates may be due to nose over stress.

Penetration estimates in this book for German projectiles are based on DeMarre estimates from 75mm APCBC, using velocity-vs.-range data from various German sources. The 75L70 penetration at 0m/0° is average of DeMarre estimate from Diehl figure for 75L43 APCBC and 0° figure derived from 30° penetration data in *Encyclopedia of German Tanks of WW II*, or 190mm.

The assumed superiority of German projectiles over American ammunition may be analyzed through use of the DeMarre equation. U.S. 75mm L40 APCBC penetrates 90mm of U.S. plate at 2030 fps and 14.96#, while Panther 75mm L70 APCBC is fired at 3068 fps and weighs 15#. If 75mm L40 is used as base data and German ammunition had same penetration characteristics, DeMarre estimate for 75mm L70 penetration at 0m/0° is 163mm. Since Panther 75mm is estimated to penetrate 190mm, German projectiles penetrate about 16.6% more armor than American (190/163), due to nose hardness and other advantages..

Applying slope effect multipliers to the 30° penetration data for 50mm and 128mm rounds in the *Encyclopedia of German Tanks of WW II* provides the following 0° penetration estimates:

	MUZZLE	0° PENETRATION					
AMMUNITION	VELOCITY	0m*	100m	500m	1000m	1500m	2000m
128L61 Pzgr APC	880 m/s	271	262	228	192	168	151
128L55 Pzgr APC	860 m/s	254	246	214	182	161	147
128L55 Pzgr 43 APCBC	845 m/s	246	243	230	215	202	189
50L42 Pzgr 39 APC	685 m/s	73	70	59	46	34	
50L60 Pzgr 39 APC	835 m/s	92	89	76	59	46	

NOTES:*-0m penetration is by simple extrapolation from 100m and 500m figures
Muzzle velocity of 128mm round listed at 919 m/s in several sources

Reviewing rates of penetration loss with range, 128mm APCBC penetration decreases by 23% from point blank to 2000m, while the two APC rounds lose 43% and 42%, which points out the advantage of placing ballistic windscreens on rounds with relatively blunt armor piercing caps.

If the assumption that German test plate is 10% more resistant than U.S. test plate is applied, the above figures should be multiplied by 1.10 for conversion to the basis used in this book, which results in 0m penetration of:

128L61 Pzgr APC	298mm	880 m/s muzzle velocity
128L55 Pzgr APC	279mm	860 m/s
128L55 Pzgr 43 APCBC	271mm	845 m/s
50L42 Pzgr 39 APC	80mm	685 m/s
50L60 Pzgr 39 APC	101mm	835 m/s

The 0m penetration figures for both 50mmAPC projectiles and 128mm APCBC are close to the American estimates presented in Diehl's work.

One additional issue regarding German ammunition concerns the penetration of 50mm Pzgr and Pzgr. 39 ammunition, which is similar despite one round being uncapped (Pzgr) and the other APC. Data presented in the *Encyclopedia of German Tanks of WW II* indicates that 50mm Pzgr AP penetration at 30° is less than Pzgr 39 APC at all ranges, which suggests that the AP round has lower nose hardness and may be subject to shatter gap failure (everything else being equal, capped rounds should penetrate less homogeneous armor due to the caps absorbing energy and contributing less to penetration than main projectile material)..

ALLIED PENETRATION DATA

The American penetration data used in this book is based on TM9-1907, which appears reasonable and is consistent with reported penetration ranges against German tanks. Penetration data and test results exist that present higher figures, particularly for 75mm and 76mm APCBC. British report WO 291/741 presents data for 75mm and 76mm APCBC that has the same 30°penetration figures as TM9-1907 at 2000 yards. However, the data in WO 291/741 becomes progressively larger as range decreases until the estimated penetration at 0° exceeds TM9-1907 by 10% at point blank.

British report WO 291/741, which is in the custody of the Public Records Office and is exhibited on the John Salt site, presents 30° data for 75mm and 76mm APCBC every 200 yards, which is compared to TM9-1907 data in the following table, along with an estimated penetration at 0° for WO 291/741 data using slope multipliers:

	75mm L40 APCBC				76mm L52 APCBC			
	WO	TM9-	WO	TM9-	WO	TM-9-	WO	TM9-
RANGE	291/741	1907	291/741	1907	291/741	1907	291/741	1907
YARDS	30°	30°	0°	0°	30°	30°	0°	0°
0	79.5	71.1	101	90	108.2	96.5	140	127
200	75.3	69.1	95		104.2	95.5	135	124
400	72.0	66.5	91		100.2		129	
600	68.5	64.8	86		96.7		124	
800	65.5	62.2	82		93.0		119	
1000	63.0	60.2	79	76	89.7	89.0	115	111
1200	60.3	58.4	75		86.3		110	
1400	57.8	56.4	72		83.1		106	
1600	55.0	54.1	68		80.0		102	
1800	52.6	52.1	65		77.0		98	
2000	50.0	50.3	62	62	74.0	75.2	94	93

Notes: 0° penetration estimate for WO 271/741 based on slope multiplier equation for APCBC,
0° penetration equals 30° penetration x 1.2667 x $(T/D)^{0.0655}$.
Data from John Salt site and TM9-1907.

The two sources for 30° penetration data vary by 12% for 75mm and 76mm APCBC at point blank, then draw closer as range increases and are approximately equal at 2000 yards. The section on DeMarre equation analysis presents data on U.S. armor piercing ammunition which may offer an explanation for the difference between the figures in WO 291/741 and TM9-1907.

DeMarre equation analysis of U.S. APCBC ammunition suggests that U.S. 75mm and 76mm APCBC lost penetration at higher velocities (closer range), which may have been due to nose over stress. If the rounds used to generate the data in WO 291/741 were of higher quality and greater nose hardness than TM9-1907 test projectiles, the data in the WO report would have been higher.

Firing tests conducted at Shoeburyness, England during May 1944 produced results that, upon comparison with TM9-1907 data, provide conflicting indications. The comparison of Shoeburyness test results with TM9-1907 indicates that 75mm APCBC performance against 70mm @ 30° exceeds TM9-1907 data by about 7%, while 0° test results show 75mm ammunition penetrating about 5% less armor than TM9-1907 figures.

The fact that 75mm penetration at Shoeburyness exceeds TM9-1907 in one series of tests by 7% (70mm at 30°) and then under performs by almost the same percentage (5%) in another series (70mm at 0°) suggests that the differences may have been due to random variations from the mean, where TM9-1907 could be the average value.

Russian penetration data from *The Russian Battlefield* site, and AP test data, suggest that a 7% standard deviation might be expected for the ballistic limit during penetration tests. If TM9-1907 represents the average performance of 75mm APCBC ammunition and penetration variations have a standard deviation of 7%, there is a 16% probability that the 30° penetration tests will exceed TM9-1907 figures by at least 7%, and a 24% chance that the 0° tests will result in at least 5% less penetration than TM9-1907.

Based on the flaw curves presented in an earlier section of this booklet, 70mm plates with medium flaws would have armor quality multipliers of 0.925 at 30° and 0.95 at 0°. The impact of armor flaws could account for the difference between TM9-1907 and other tests, and it is possible that test armor used during 1944 could have been produced prior to improved quality control measures. The variation in 30° penetration between 70mm and 65.5mm is 7%.

Variations between published penetration data may also be due to the criteria used, where complete penetration may be defined as anywhere between a hole showing light to complete passage of the entire projection. It is also possible that the higher 30°penetration figures in the British WO reports may, as an alternative explanation, be associated with less stringent success criteria than the U.S. Navy Ballistic Limit.

The data presented in this book uses TM9-1907 figures due to closer agreement with reported penetration ranges against panzers and firing range tests against captured German tanks. As an example, the 100 yard penetration of Tiger 80mm armor by 75mm APCBC, which is analyzed in the shatter gap section, indicates that TM9-1907 data exactly predicts the range and angle for success, while other tests against Tiger armor show small variations between TM9-1907 based predictions and actual ranges.

British penetration data has been taken from a variety of sources and was checked against firing test results against German armor. The data includes DeMarre estimates for penetration against homogeneous and face-hardened armor where published figures were not available or were questionable. The consistency of predicted penetration ranges against German armor with actual test results appears to support the approach that was taken.

IMPACT OF CAPS AND HE BURSTERS ON HOMOGENEOUS ARMOR PENETRATION

The approximate impact of caps and HE bursters on homogeneous armor penetration may be estimated by comparing the penetration of different rounds. The 37mm M74 solid AP shot penetrates about 94mm at 2900 fps and 0° impact, while solid shot 37mm M51 APCBC penetrates 81mm at the same velocity and projectile weight. The comparison of 37mm rounds suggests that placing caps on the M51 round reduced penetration by 14% (81/94).

75mm M61 APCBC-HE penetrates 90mm at 0m and 0°, while 75mm M72 solid shot AP penetrates 114mm, both striking at 2030 fps. If the 75mm AP shot penetration is increased to account for the weight difference, the solid shot would penetrate 120mm.

To equal 75mm M61 penetration, the solid shot penetration will be reduced due to cap addition and the cavity for the HE burster. If the 75mm M72 AP shot had armor piercing and ballistic caps, the 120mm penetration would be reduced by 14% if it followed the 37mm example, resulting in 103mm penetration. To equal 75mm M61 penetration, an additional 13% reduction in 75mm AP penetration is required (103mm to 90mm), which would be associated with weakening of the projectile structure due to the HE burster cavity.

When HE cavities weaken the steel structure, the armor piercing projectile absorbs energy that would otherwise be used to defeat armor plate, so penetration decreases.

PENETRATION TABLES

The following tables present penetration estimates for tank, anti-tank and field guns:

IMPORTANT NOTES ON RUSSIAN PENETRATION DATA AND TIGER ARMOR RESISTANCE

Miles Krogfus published an article on Russian penetration estimates in the May-Aug. 2003 issue of AFV News which helps to answer many of the open questions regarding how to interpret Russian data.

According to Miles' article, ARTKOM tested Russian AP and APBC against high hardness armor and fit the data to the DeMarre equation by determining the penetration constant for each round. Early war Russian AP penetrated less than later projectiles due to chemical composition and HE burster size, and some later war rounds were specially heat treated to increase penetration performance. The Russian penetration figures were keyed to 80% success, which penetrates about 6% less than 50% success criteria.

When one reviews Russian penetration data for 122mm AP (BR-471) and sees 152mm at 500m, 142mm at 1000m and 122mm at 2000m for vertical plate performance, the numbers are consistent with the ARTKOM equation estimates against high hardness armor. The key question is what is high hardness armor?

A German Intelligence report on SU 85 presents Russian penetration figures for 85mm ammo and indicates that the penetration numbers were generated using a DeMarre equation estimate with 2400 constant (same as ARTKOM used). The target armor for the estimate is cemented armor. Cemented armor is another term for face-hardened armor.

So the 122mm AP would penetrate about 163mm of face-hardened armor if the Russian data is extrapolated to 0m, which is clearly not enough to piece the good quality glacis of a Panther tank. Russian Battlefield information states that IS-2 tanks defeated the Panther glacis at 700m during initial combats.

The actual penetration range for 122mm AP against Panther glacis armor probably occurred against Panthers with homogeneous armor, and uncapped AP rounds will usually penetrate much more homogeneous armor than face-hardened. By comparison with Allied uncapped AP rounds the 122mm AP would penetrate about 201mm of homogeneous armor at 0m and about 170mm at 700m, which would allow some glacis penetrations at 700m against a Panther.

The Russian penetration data for 76.2mm APBC also appears to be against face-hardened armor, since it is consistent with ARTKOM equation estimates although some variations do occur and some later war data appears to be based on the special heat treatment BR-350B that would penetrate about 10% more than the typical round.

The figures listed on page 59 and the ADDITIONAL DETAILS FOR RUSSIAN PENETRATION ESTIMATES use U.S. firing trials with 122mm APBC to establish homogeneous armor penetration for APBC rounds, and use the ARTKOM equation for face-hardened armor performance. The homogeneous penetration of Russian AP rounds is derived by using the face-hardened data to estimate homogeneous effectiveness through Allied AP ratio's.

The above methods appear to produce reasonable results that are fairly consistent with firing trials and combat reports.

For instance, in correspondence with John Waters regarding the first live fire tests against the Tiger E armor conducted by NIIBT at Kubinka April 25 - 30th 1943, the 76.2mm F-34 reportedly failed to penetrate the Tiger E side hull and turret armor "even at 200 meters".

During the second live fire tests conducted in September 1943 the 76.2mm F-22 USV, F-34, and Zis-3 reportedly failed to penetrate the Tiger E side hull and turret armor at 500 meters at 60 degrees or even at 100 meters at 0 degrees

The T34 and 76.2mm field gun would have fired BR-350A and BR-350B APBC against the Tiger side, and no penetrations were obtained at 100m. Comparing the estimated penetration figures for 76.2mm APBC (derived from U.S. tests with 122mm APBC) against 82mm armor shows that the round has less than a 50% chance of succeeding:

76.2mm APBC Homogeneous Penetration at 100m
75mm for BR-350A and 81mm for BR-350B

The failures at 100m range for 76.2mm BR-350B might be explained on the basis of Allied firing tests against the harder than usual side armor on Tiger, which appeared to result in better armor resistance than medium hardness armor. Firing 57mm through 90mm APC at Tiger 82mm side plates at angles from 0 degrees from vertical through 55 degrees, in 12 of 14 cases the 82mm plates equalled or exceeded the resistance of good quality medium hardness homogeneous armor. The average 82mm plate during the tests against five captured Tigers resisted with 3.3% more effective thickness than medium hardness armor, and the maximum resistance was 13% greater.

So in the Allied tests, Tiger 82mm side plates which ranged from 315 to 360 Brinell Hardness usually resisted like a greater thickness of armor. If the Russian tests were conducted against one of the early Tiger 82mm plates with added resistance that could explain why a round with 81mm penetration at 100m failed against an 82mm plate.

The Allied tests against Tiger 82mm side plates resulted in the following equivalent thickness multipliers:

1.13, 1.11, 1.08, 1.06, 1.05, 1.05, 1.02, 1.02, 1.01, 1.00, 1.00, 1.00, 0.95 and 0.94.

SOVIET PROJECTILES	M.V.	100	250	500	750	1000	1250	1500	2000	2500	3000
57L73 AP (shatter velocity)	3247	134	125	111	98	87	77	69	54	42	33
57L73 AP FH (shatter velocity)	3247	107	99	88	78	69	61	55	43	34	27
57L73 APBC (shatter velocity)	3247	160	150	134	119	106	95	85	68	56	47
57L73 APBC (consensus data)	3247	119	114	106	98	91	85	78	68	58	50
57L73 APBC FH	3247	121	118	113	108	103	99	94	86	78	71
57L73 APCR	3936	183	169	147	128	111	97	84	64	48	36
76.2L41.5 APCR	3132	130	114	92	75	60	49	39	26	17	11
76.2L41.5 HEAT	1066	75	75	75	75	75	75	75	75	75	75
85L52 AP	2600	142	135	125	116	107	99	92	78	67	57
85L52 AP FH	2600	131	126	116	108	100	93	85	73	62	54
85L52 APBC	2600	139	133	123	114	105	98	91	81	73	65
85L52 APBC FH	2600	124	123	118	111	107	102	98	90	83	76
85L52 APCR	3444	175	159	136	117	100	85	73	54	39	29
100L52 AP	2919	208	200	188	176	164	154	144	126	111	97
100L52 AP FH	2919	178	171	160	150	140	131	123	108	95	83
100L52 APBC	3000	235	226	211	197	185	172	161	141	123	108
100L52 APBC FH	3000	182	178	171	164	158	152	147	136	126	117
122L43 & L46 AP	2600	196	189	179	168	158	150	141	125	111	99
122L43 & L46 AP FH	2600	174	168	158	149	140	132	125	111	98	87
122L43 & L46 APBC	2600	201	194	183	172	162	152	144	129	118	108
122L43 & L46 APBC	2600	175	172	166	160	155	150	144	135	126	117
122 HEAT (SU 122)	1099	120	120	120	120	120	120	120	120	120	120
122 HEAT (ISU 122)	1804	120	120	120	120	120	120	120	120	120	120
152L28 AP	1968	165	160	152	145	137	130	124	111	100	90
152L28 AP FH	1968	146	142	135	128	122	116	109	99	89	81
152L28 APBC	1968	135	131	128	123	119	116	114	110	106	102
152L28 APBC FH	1968	148	146	142	138	135	132	128	122	116	110

NOTE: 100mm APBC availability during WW II is questionable, 122mm APBC availability date has been estimated as September 1944, January 1945 and at the end of WW II, with limited quantities in use. 152mm APBC was available during July 1944 and may have been around earlier than that.

ADDITIONAL DETAILS FOR RUSSIAN PENETRATION ESTIMATES

Various web sites and researchers indicate that early war problems with 45mm gun ammo greatly decreased the penetration capability during 1941 or through-out the 1941-1943 period. Vasiliy Fofanov has indicated that Russian battlefield reports limit 45mm ammunition to a 500m penetration range versus the panzers with 30mm armor during 1941 engagements. This suggests that the penetration of face-hardened and rolled homogeneous armor was decreased by about -29% (multiply by 0.71).

Valera Potapov on the Russian Battlefield site (http://www.battlefield.ru/armaments/20k.html) suggests that brittle projectiles lead to a -50% decrease in expected penetration prior to 1942 due to production problems. Valera mentions a 500m penetration range against panzers during 1941.

The Russian Ammunition Page (http://www.geocities.com/Pentagon/Base/1852/57mm.html#24) indicates that 45mm ammo penetration figures were significantly decreased during the years 1941-1943 due to "low quality ammunition".

76.2mm solid shot AP should have a greatly expanded penetration range against Tiger side armor, although the ammo was relatively rare.

As noted in Miles Krogfus' AFV News article on DeMarre and ARTKOM (May-Aug. 2003 issue), Russians produced a better quality BR-350B round in limited quantities starting late 1943.

A British tabulation of Russian penetration data at 30 degrees impact provides a basis for estimating 45mm APCR performance against vertical armor.

The above information was combined with other factors to generate the following penetration figures (RHA is rolled homogeneous armor and FHA is face-hardened armor):

1941-1943
45mm L46 APHE

	0m	100m	250m	500m	750m	1000m	1500m	2000m
RHA	66	61	55	46	38	32	22	15
FHA	57	53	47	39	33	27	19	13

Modifiers:
Multiply by 1.11 for 45mm L66 AP performance
Multiply by 1.12 for solid AP shot
Multiply by 0.71 for 1941 brittle projectiles (Valera Potapov suggests 0.50)
Multiply by 1.09 for 1943-1945 projectiles

1941-1943
45mm L46 APBC-HE

	0m	100m	250m	500m	750m	1000m	1500m	2000m
RHA	62	59	53	45	39	35	29	26
FHA	57	55	51	46	42	38	31	25

Modifiers:
Multiply by 0.71 for 1941 brittle projectiles (Valera Potapov suggests 0.50)
Multiply by 1.09 for 1943-1945 projectiles

1942-1943
45mm L66 APBC-HE

	0m	100m	250m	500m	750m	1000m	1500m	2000m
RHA	75	71	64	54	46	40	32	28
FHA	64	61	57	51	47	42	32	28

Modifiers:
Multiply by 1.09 for 1943-1945 projectiles

1942 through 1945
45mm L46 and L66 APCR

	0m	100m	250m	500m	750m	1000m
45L46	103	94	81	64	50	40
45L66	118	108	93	74	58	46

1943-1945
76.2mm L41.5 APHE

	0m	100m	250m	500m	750m	1000m	1500m	2000m
RHA	99	95	90	81	73	66	54	44
FHA	86	83	78	70	63	57	47	38

Modifiers:
Multiply by 1.06 for solid AP shot (AP shot more common than APHE)

1942-1943
45mm L66 APBC-HE

	0m	100m	250m	500m	750m	1000m	1500m	2000m
RHA	75	71	64	54	46	40	32	28
FHA	64	61	57	51	47	42	32	28

Modifiers:
Multiply by 1.09 for 1943-1945 projectiles

1942 through 1945
45mm L46 and L66 APCR

	0m	100m	250m	500m	750m	1000m
45L46	103	94	81	64	50	40
45L66	118	108	93	74	58	46

1943-1945
76.2mm L41.5 APHE

	0m	100m	250m	500m	750m	1000m	1500m	2000m
RHA	99	95	90	81	73	66	54	44
FHA	86	83	78	70	63	57	47	38

Modifiers:
Multiply by 1.06 for solid AP shot (AP shot more common than APHE)

RUSSIAN TANK GUN PENETRATION

Miles Krogfus reported on the Yahoo Tankers site that the T34 tank gun fired APBC at 655 m/s. The table following this page presents penetration estimates for the various Russian 76.2mm APBC rounds at 612 and 655 m/s versus rolled homogeneous armor (RHA) and face-hardened armor (FHA).

The last columns for BR-350B with the higher penetration figures are for the special heat treatment round which was available in limited quantities starting late 1943.

The penetration estimates are based on the ARTKOM equation for face-hardened plate and U.S. firing trials with 122mm APBC for rolled homogeneous armor.

While the estimates for T34 tank gun APBC seem consistent with what we know about Russian firing tests against Tiger armor at Kubinka and combat stories, there is no assurance that they are highly accurate.

PENETRATION OF RUSSIAN 76.2mm TANK GUN

	BR-350 612 m/s 2007 fps		BR-350A 612 m/s 2007 fps		BR-350 655 m/s 2418 fps			BR-350A 655 m/s 2418 fps		BR-350B 655 m/s 2418 fps		BR-350B 655 m/s 2418 fps		
	RHA	FHA	RHA	FHA	RHA	FHA		RHA	FHA	RHA	FHA	RHA	FHA	
0	66	70	68	73	75	77	0	77	80	81	84	89	93	0
50	65	69	67	72	73	77	50	76	79	80	83	88	92	50
100	64	69	66	71	72	76	100	75	78	79	82	87	90	100
150	63	68	65	70	71	75	150	74	77	78	81	85	89	150
200	62	67	64	69	70	74	200	73	76	77	81	84	88	200
250	61	66	63	69	69	73	250	72	76	75	80	83	87	250
300	60	65	62	68	68	72	300	71	75	74	79	81	86	300
350	59	65	61	67	67	71	350	69	74	73	78	80	85	350
400	58	64	61	66	66	70	400	68	73	72	77	79	84	400
450	58	63	60	65	65	70	450	67	72	71	76	78	83	450
500	57	62	59	65	64	69	500	66	71	70	75	77	82	500
550	56	62	58	64	63	68	550	65	70	69	74	76	81	550
600	55	61	57	63	62	67	600	64	69	68	73	74	80	600
650	54	60	56	62	61	66	650	63	69	67	72	73	79	650
700	54	59	56	62	60	65	700	62	68	66	71	72	78	700
750	54	59	56	61	59	65	750	62	67	65	71	71	77	750
800	53	58	55	60	59	64	800	61	66	64	70	70	76	800
850	53	57	55	59	58	63	850	60	65	63	69	69	76	850
900	52	57	54	59	57	62	900	59	65	62	68	68	75	900
950	52	56	54	58	56	62	950	58	64	61	67	67	74	950
1000	51	55	53	57	55	61	1000	57	63	60	66	66	73	1000
1050	51	55	53	57	54	60	1050	56	62	59	66	65	72	1050
1100	51	54	52	56	54	59	1100	56	62	59	65	65	71	1100
1150	50	53	52	55	54	59	1150	56	61	59	64	64	70	1150
1200	50	53	52	55	53	58	1200	55	60	58	63	64	69	1200
1250	49	52	51	54	53	57	1250	55	59	58	63	63	69	1250
1500	47	49	49	51	51	54	1500	52	56	55	59	61	65	1500
2000	44	43	45	45	47	48	2000	48	50	51	52	56	57	2000
2500	40	39	42	40	43	42	2500	44	44	47	46	51	51	2500
3000	37	34	38	35	39	38	3000	41	39	43	41	47	45	3000

Special Heat Treatment, Limited Quantity from late 1943

76.2mm APBC PENETRATION AT 662 m/s AND 680 m/s MUZZLE VELOCITIES

Various sources list 76.2mm muzzle velocities as 662 and 680 m/s, and the following table presents penetration estimates at those firing velocities.

PENETRATION OF 76.2mm RUSSIAN APBC at 662 and 680 m/s MUZZLE VELOCITY

			BR-350B 2230 fps 680 m/s		BR-350B Special 2230 fps 680 m/s					BR-350B 2171 fps 662 m/s		BR-350B Special 2171 fps 662 m/s		BR-350A 2171 fps 662 m/s		BR-350 2171 fps 662 m/s		
meters	fps	m/s	RHA	FHA	RHA	FHA	meters	fps	m/s	RHA	FHA	RHA	FHA	RHA	FHA	RHA	FHA	meters
0	2230	680	89	89	97	98	0	2171	662	83	86	91	94	79	81	76	79	0
50	2212	674	86	88	94	97	50	2153	656	82	85	90	93	78	80	75	78	50
100	2193	669	84	87	93	95	100	2135	651	80	84	88	92	76	80	74	77	100
150	2175	663	83	86	91	94	150	2117	646	79	83	87	91	75	79	73	76	150
200	2157	658	82	85	90	93	200	2100	640	78	82	86	90	74	78	72	75	200
250	2139	652	81	84	89	92	250	2082	635	77	81	84	89	73	77	71	74	250
300	2121	647	79	83	87	91	300	2065	629	76	80	83	88	72	76	69	73	300
350	2103	641	78	82	86	90	350	2047	624	75	79	82	86	71	75	68	72	350
400	2085	636	77	81	85	89	400	2030	619	73	78	81	85	70	74	67	71	400
450	2068	630	76	80	83	88	450	2013	614	72	77	79	84	69	73	66	71	450
500	2051	625	75	79	82	87	500	1996	609	71	76	78	83	68	72	65	70	500
550	2034	620	74	78	81	86	550	1980	604	70	75	77	82	67	71	64	69	550
600	2017	615	73	77	80	85	600	1963	599	69	74	76	81	66	71	63	68	600
650	2000	610	71	76	78	84	650	1947	594	68	73	75	80	65	70	62	67	650
700	1983	605	70	75	77	83	700	1930	589	67	73	74	80	64	69	62	66	700
750	1966	599	69	74	76	82	750	1914	584	66	72	72	79	63	68	61	66	750
800	1950	594	68	74	75	81	800	1898	579	65	71	71	78	62	67	60	65	800
850	1934	590	67	73	74	80	850	1882	574	64	70	70	77	61	66	59	64	850
900	1917	585	66	72	73	79	900	1867	569	63	69	69	76	60	66	58	63	900
950	1901	580	65	71	72	78	950	1851	564	62	68	68	75	59	65	57	63	950
1000	1885	575	64	70	70	77	1000	1836	560	61	67	67	74	58	64	56	62	1000
1250	1808	551	60	66	65	72	1250	1760	537	58	64	64	70	55	60	53	58	1250
1500	1734	529	57	62	63	68	1500	1688	515	56	60	61	66	53	57	51	55	1500
2000	1594	486	53	55	58	60	2000	1552	473	51	53	56	58	49	50	47	49	2000
2500	1465	447	49	49	53	54	2500	1427	435	47	47	52	52	45	45	43	43	2500
3000	1347	411	45	43	49	48	3000	1312	400	44	42	48	46	41	40	40	38	3000

U.K. PROJECTILES	M.V.	100	250	500	750	1000	1250	1500	1750	2000	2500	3000
2 Pdr AP	2600	82	74	63	54	46	39	34	29	24	18	13
2 Pdr AP FH	2600	62	57	50	43	38	33	28	25	21	16	12
2 Pdr APCBC	2700	73	70	65	61	57	53	49	46	43	37	33
2 Pdr APCBC FH	2700	76	72	67	62	57	53	49	46	42	36	31
2 Pdr Littlejohn	3900	129	121	109	98	88	79	71	64	57	46	37
37L52 Littlejohn	3600	109	103	94	86	79	72	66	60	55	46	39
6 Pdr L45 AP	2700	117	109	97	87	77	68	61	54	48	38	30
6 Pdr L45 AP FH	2700	93	85	72	62	53	45	39	33	28	21	15
6 Pdr L45 AP	2830	128	119	105	93	83	73	65	58	51	40	32
6 Pdr L45 AP FH	2830	100	91	78	67	57	49	42	36	31	23	17
6 Pdr L52 AP	2950	135	126	112	100	89	79	70	62	55	44	35
6 Pdr L52 AP FH	2950	104	95	82	70	61	52	45	39	33	25	18
6 Pdr L45 APCBC	2600	107	103	96	90	84	78	73	68	64	56	49
6 Pdr L45 APCBC FH	2600	112	108	102	96	91	85	80	76	71	63	56
6 Pdr L52 APCBC	2725	115	110	103	96	90	84	78	73	68	60	52
6 Pdr L52 APCBC FH	2725	119	115	109	103	97	92	86	82	77	69	61
6 Pdr APDS	4000	177	170	160	150	140	131	123	115	108	95	83
	M.V.	100	250	500	750	1000	1250	1500	1750	2000	2500	3000
17 Pdr AP	2900	200	190	175	160	147	135	124	114	105	88	74
17 Pdr AP FH	2900	164	156	144	132	121	112	103	94	87	73	62
17 Pdr APCBC	2900	174	170	163	156	150	143	137	132	126	116	107
17 Pdr APCBC FH	2900	187	182	175	167	161	154	148	141	136	125	115
17 Pdr APDS	3950	275	268	256	244	233	223	213	204	194	178	162
3" HEAT	1066	75	75	75	75	75	75	75	75	75	75	75
77mm APCBC	2575	147	143	137	131	126	121	116	111	106	98	90
77mm APCBC FH	2575	157	153	147	141	135	130	124	119	114	105	96
25 Pdr AP (early)	1550	78	73	66	59	53	48	43	39	35	28	23
25 Pdr AP FH (early)	1550	88	83	74	67	60	54	49	44	39	32	26
25 Pdr AP (late)	1897	103	96	86	77	69	61	55	49	44	35	28
25 Pdr AP FH (late)	1897	114	106	95	85	76	68	60	54	48	38	31
95mm HEAT	1650	127	127	127	127	127	127	127	127	127	127	127

GERMAN PENETRATION EQUATION

The British report, GERMAN STEEL ARMOUR PIERCING PROJECTILES AND THEORY OF PENETRATION, which is held by the British Public Records Office (PRO) and is BIOS Final Report No. 1343 Item No. 2 (ADM 213/951), explains the basis of the published German penetration figures at 30 degrees from vertical.

The following discussion and analysis revises information provided on page 10 and pages 54 through 56.

The Germans tested projectile penetration using best quality proof rounds, and they were required to penetrate on five consecutive hits for 75mm and larger ammo, and ten consecutive hits for smaller rounds. The requirement for such a large number of consecutive penetrations with HE burster intact, and with an increasing velocity within a narrow band, meant that each round would have close to a 100% penetration probability. Test figures were generated for 30 degrees from vertical, which corresponds to a German angle of 60 degrees when vertical is taken as 90 degrees..

To convert the German figures to 50% penetration probability and production performance, the following procedure may be used to obtain an approximate estimate:

75mm Projectiles
Production rounds penetrate 91.4% of best quality proof rounds
50% penetration probability would be obtained against a 14.4% thicker plate than five consecutive penetrations

88mm and Larger Projectiles
Production rounds penetrate 94.3% of best quality proof rounds
50% penetration probability would be obtained against a 14.4% thicker plate than five consecutive penetrations

The following analysis shows how German penetration data at 30 degrees from vertical could be converted to vertical penetration by production ammo at 50% success:

75mm L43 APCBC

30 Degrees by proof rounds with five consecutive sucesses
99mm at 100m, 91mm at 500m, 81mm at 1000m, 72mm at 1500m and 63mm at 2000m

30 degrees by production rounds at 50% success (multiply above figures by 0.914 and 1.144)
104mm at 100m, 95mm at 500m, 85mm at 1000m, 75mm at 1500m and 66mm at 2000m

0 degrees by production rounds at 50% success (multiply above figures by slope effect)
130mm at 100m, 118mm at 500m, 105mm at 1000m, 92mm at 1500m, 80mm at 2000m

The above estimates for vertical armor penetration (0 degrees) are very close to the figures used in this book.

88mm L56 APCBC

30 Degrees by proof rounds with five consecutive sucesses
120mm at 100m, 110mm at 500m, 100mm at 1000m, 91mm at 1500m and 84mm at 2000m

30 degrees by production rounds at 50% success (multiply above figures by 0.943 and 1.144)
129mm at 100m, 119mm at 500m, 108mm at 1000m, 98mm at 1500m and 91mm at 2000m

0 degrees by production rounds at 50% success (multiply above figures by slope effect)
162mm at 100m, 149mm at 500m, 134mm at 1000m, 121mm at 1500m and 112mm at 2000m

The above estimates for vertical armor penetration (0 degrees) are very close to the figures used in this book.

75mm L70 APCBC

30 Degrees by proof rounds with five consecutive sucesses
138mm at 100m, 124mm at 500m, 111mm at 1000m, 99mm at 1500m and 88mm at 2000m

30 degrees by production rounds at 50% success (multiply above figures by 0.914 and 1.144)
144mm at 100m, 130mm at 500m, 116mm at 1000m, 104mm at 1500m and 92mm at 2000m

0 degrees by production rounds at 50% success (multiply above figures by slope effect)
185mm at 100m, 166mm at 500m, 147mm at 1000m, 130mm at 1500m and 114mm at 2000m

The above estimates for vertical armor penetration (0 degrees) are very close to the figures used in this book.

ADDITIONAL DETAILS ON GERMAN PENETRATION EQUATION ESTIMATES

During the end of WW II and afterwards, British groups attempted to interview German researchers and workers in the armaments and armor industries. Documents were also collected. The British Intelligence Objectives Sub-committee (BIOS) publications include a detailed report on German penetration test results.

The report entitled GERMAN STEEL ARMOUR PIERCING PROJECTILES AND THEORY OF PENETRATION, ADM 213/951, provides the following information on the testing procedures:

1. Best quality production ammo or specially manufactured proof rounds were used at 30 degrees from vertical

2. Penetration data required that five straight hits by 75mm thru 105mm projectiles completely penetrate the plate within a narrow velocity band. The highest velocity of the five was used for each plate.

3. For 20mm and 37mm ammo, ten straight penetrations within a narrow velocity band were required.

4. Production projectiles were estimated to require a 5% higher velocity for 75mm ammo, and 3.5% higher for other rounds.

5. The velocity needed for best quality ammo penetration was related to the following equation:

   velocity (m/s) = constant x (diameter/weight) raised to 0.5 power x (plate thickness) raised to 0.8 power,

   where projectile diameter is in centimeters, plate thickness in decimeters, weight in kg.

6. Constant values are:

Plate Thickness	5.0cm APC	7.5cm APCBC	8.8cm APCBC
40mm	695	752	
60mm	695	738	768
80mm		722	752
100mm		710	732
120mm		690	710
140mm		668	682
160mm		640	655
180mm		628	632
200mm		628	620
220mm		655	622
250mm			648

GERMAN PROJECTILES	M.V.	100	250	500	750	1000	1250	1500	2000	2500	3000
20L55 AP	2493	45	40	33	28	23	19	15	11	7	5
20L55 APCR	3300	63	45	26	15	8	5	3	1	0	0
28/20 SQUEEZEBORE	4600	83	72	56	44	34	27	21	13	8	5
37L45	2427	64	59	52	45	40	35	30	23	18	13
37L45 APCR	3100	90	71	48	32	22					
47L43.4 APC	2500	87	80	69	60	52	45	39	29	22	16
50L42 AP	2247	76	68	58	49	41	35	29	21	15	11
50L42 APC	2247	73	67	59	51	45	39	34	26	20	15
50L42/47L43.4 APCR	3444	130	115	94	77	63	51	42	28	19	12
50L60 AP	2738	100	92	79	69	60	52	45	33	25	18
50L60 APC	2738	96	89	79	70	62	55	49	38	30	23
50L60 APCR	3772	149	132	108	88	72	59	48	32	21	14
75L24 APCBC	1263	54	53	50	48	46	44	42	38	35	32
75L24 APCBC (*AFV-G2*)	1263	60	58	55	52	50	47	44	38	33	27
75L24 HEAT "HI"	1476	52	52	52	52	52	52	52	52	52	52
75L24 HEAT "A"	1476	81	81	81	81	81	81	81	81	81	81
75L24 HEAT "B"	1476	87	87	87	87	87	87	87	87	87	87
75L24 HEAT "C"	1476	115	115	115	115	115	115	115	115	115	115
75L43 APCBC	2427	133	128	121	114	107	101	95	85	75	67
75L43 APCR	3018	173	164	151	139	127	117	108	91	77	65
75L46 APCBC	2600	146	141	133	125	118	111	105	93	82	73
	M.V.	100	250	500	750	1000	1250	1500	2000	2500	3000
75L46 APCR	3247	195	186	170	157	144	132	121	102	86	73
75L48 APCBC	2460	135	130	123	116	109	103	97	86	76	68
75L48 APCR	3050	176	167	154	141	130	119	109	92	78	66
75L70 APCBC	3068	185	179	168	158	149	140	132	116	103	91
75L70 APCR	3706	265	253	234	216	199	184	170	145	124	105
75 PaK 97/38 AP	2100	97	91	82	73	66	59	53	43	35	28
76.2L51.5 APCBC	2329	133	128	121	115	108	102	97	86	77	69
76.2L51.5 APCR	3247	188	179	165	151	139	128	117	99	83	70
76.2L51.5 HEAT	1476	90	90	90	90	90	90	90	90	90	90
88L56 APCBC	2558	162	158	151	144	138	132	126	116	106	97
88L56 APCR	3050	219	212	200	190	179	170	160	143	128	115
88L56/88L71 HEAT	1968	110	110	110	110	110	110	110	110	110	110
88L71 APCBC	3280	232	227	219	211	204	196	190	176	164	153
88L71 APCR	3706	304	296	282	269	257	245	234	213	194	177

GERMAN	M.V.	100	250	500	750	1000	1250	1500	1750	2000	2500	3000
105 HEAT "A"	1624	92	92	92	92	92	92	92	92	92	92	92
105 HEAT "B"	1624	104	104	104	104	104	104	104	104	104	104	104
105 HEAT "C"	1624	115	115	115	115	115	115	115	115	115	115	115
128L55 APC	2886	282	270	251	233	217	202	187	174	162	140	121
128L55 APC	2821	264	254	237	221	207	193	180	169	157	137	120
128L55 APCBC	2772	267	262	253	245	237	230	222	215	208	195	182
150L11 HEAT	918	185	185	185	185	185	185	185	185	185	185	185
150L17 HEAT	1509	185	185	185	185	185	185	185	185	185	185	185
150L29.6 HEAT	1509	185	185	185	185	185	185	185	185	185	185	185
Revisions due to HE burster size, projectile weight and possible decrease in early war metal quality												
37L45 AP	2427	49	45	40	35	30	27	23	20	18	14	11
75L24 APCBC	1263	50	49	47	46	44	43	41	40	38	36	33
88L56 APCBC*	2558	123	121	116	112	108	104	100	97	93	87	81
88L56 APCBC**	2558	149	145	139	133	127	122	116	111	106	97	89

Notes: *-refers to early war Flak ammo up to mid-1942, **-refers to later improved Flak ammo
Later war 88L56 Flak APCBC may have used same round as 88L56 APCBC round on page 61

U.S. PROJECTILES	M.V.	100	250	500	750	1000	1250	1500	1750	2000	2500	3000
37L52 AP	2600	76	69	59	50	43	36	31	26	22	16	12
37L52 AP FH	2600	57	52	45	39	34	30	26	22	20	15	11
37L52 APCBC	2600	66	63	58	54	50	46	43	40	37	32	27
37L52 APCBC FH	2600	65	62	57	53	49	46	42	39	36	31	27
37L52 AP	2900	89	81	69	59	50	43	37	31	27	19	14
37L52 AP FH	2900	65	60	52	45	39	34	29	25	22	16	12
37L52 APCBC	2900	78	74	69	64	59	55	51	47	43	37	32
37L52 APCBC FH	2900	73	71	67	61	57	52	48	45	41	35	30
57L52 AP	2950	135	126	112	100	89	79	70	62	55	44	35
57L52 AP FH	2950	104	95	82	70	61	52	45	39	33	25	18
57L52 APCBC	2700	110	105	98	91	85	79	73	68	64	55	48
57L52 APCBC FH	2700	103	101	97	94	91	88	85	82	79	74	69
75L31 AP	1850	95	90	81	73	66	60	54	49	45	36	30
75L31 AP FH	1850	82	76	67	59	52	45	40	35	31	24	19
75L31 APCBC	1850	78	76	72	68	65	61	58	55	52	47	42
75L31 APCBC FH	1850	92	89	84	79	75	71	67	63	59	53	47

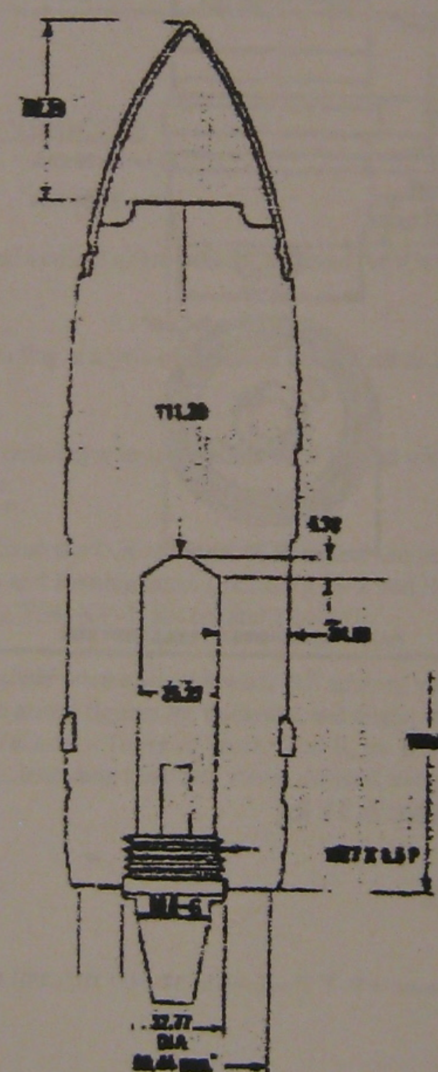
U.S. PROJECTILE	M.V.	100	250	500	750	1000	1250	1500	1750	2000	2500	3000
75L40 AP	2030	109	102	92	84	76	68	62	56	51	41	34
75L40 AP FH	2030	91	85	75	66	58	51	45	40	35	27	21
75L40 APCBC	2030	88	85	81	77	73	69	65	62	59	53	47
75L40 APCBC FH	2030	102	99	95	90	86	82	79	75	72	65	60
3" APCBC	2600	124	121	115	109	103	98	93	88	84	76	68
3" APCBC FH	2600	124	123	121	118	115	111	107	102	97	87	77
76L52 APCBC	2600	125	121	116	111	106	101	97	93	89	81	74
76L52 APCBC FH	2600	124	123	122	119	116	113	110	105	101	92	83
76 HVAP	3400	239	227	208	191	175	160	147	135	124	104	88
3" M79 AP	2600	154	145	131	119	107	97	88	79	72	59	48
3" M79 AP FH	2600	132	124	112	101	92	83	75	68	62	50	41
90L52 APCBC	2650	164	156	150	143	137	131	125	119	114	104	92
90L52 APCBC FH	2650	151	150	147	144	140	135	131	127	123	115	107
90L52 APCBC	2800	169	168	164	157	151	144	138	133	127	115	104
90L52 APCBC FH	2800	161	159	155	151	147	144	140	136	132	123	116
90 M77 AP	2700	188	179	163	150	137	125	115	105	96	81	68
90 M77 AP FH	2700	168	159	146	134	122	112	102	94	86	72	60
90 T33 AP	2800	206	201	193	185	178	170	164	157	150	139	128
90 T33 AP FH	2800	183	179	171	165	158	151	146	139	133	123	114
90 HVAP	3340	306	295	278	262	246	232	218	205	193	171	151
105 HEAT	1020	128	128	128	128	128	128	128	128	128	128	128
105 HEAT	1250	128	128	128	128	128	128	128	128	128	128	128

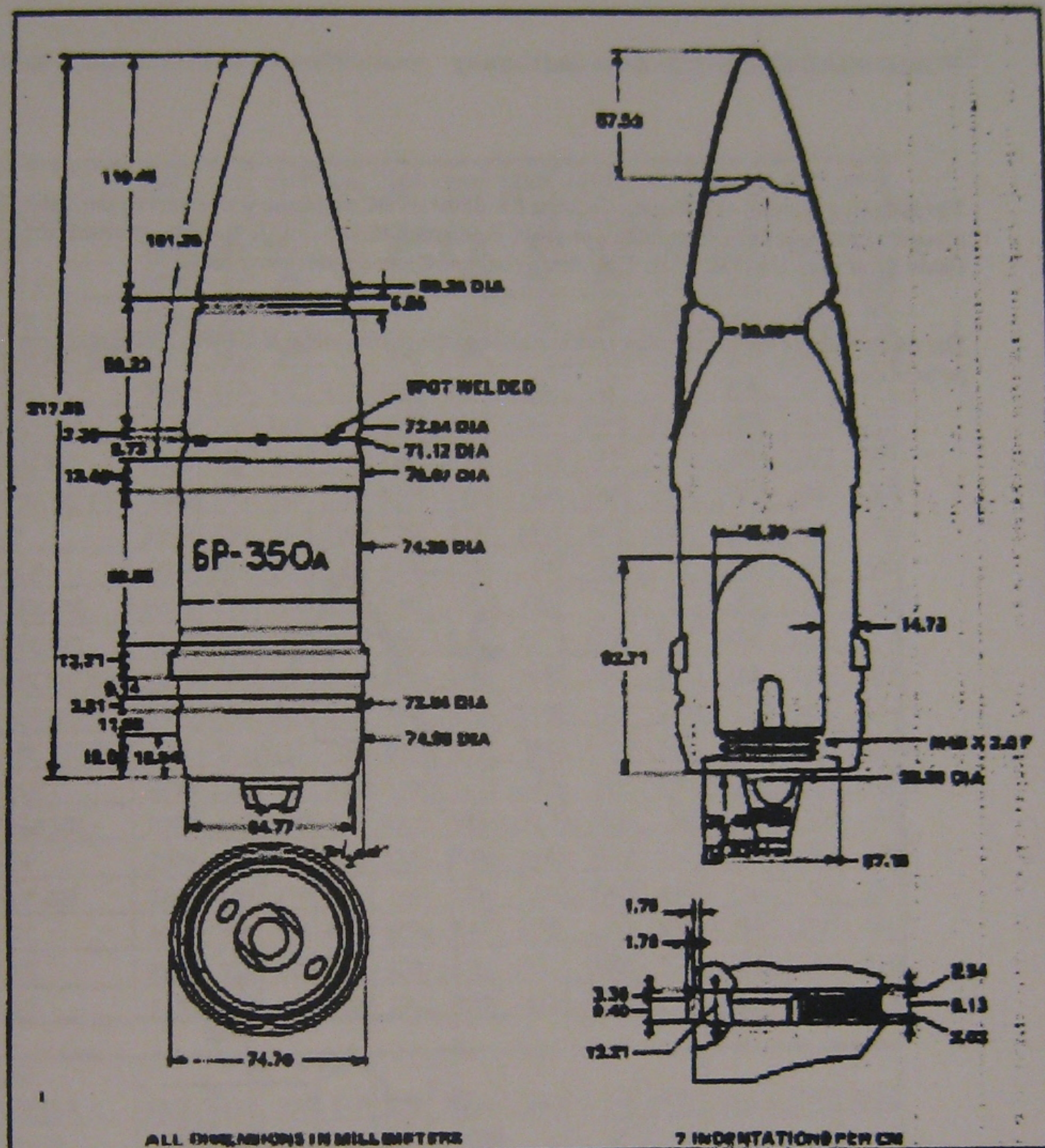
ITALIAN PROJECTILE	M.V.	100	250	500	750	1000	1250	1500	1750	2000	2500	3000
20mm Breda	2755	41	36	29	24	20	16	13	11	7	6	4
47L32 AP	2060	56	51	44	38	33	29	25	21	19	14	10
47L32 APBC (1)	2060	47	45	41	37	34	31	28	26	23	19	16
47L32 APBC (2)	2060	57	54	49	45	41	38	35	32	29	24	20
75L18 AP	1560	57	53	48	44	40	36	32	29	27	22	18
75L18 APBC	1560	57	55	52	48	45	42	39	37	34	30	26

NOTES: 47L32 APBC (1), slope multipliers applied to 30° penetration figures
47L32 APBC (2), assumes AP and APBC have same penetration at 0m

The following drawing of a Russian 76.2mm BR-350B APBC projectile was posted on the Yahoo Tankers group by Paul Lakowski, at http://groups.yahoo.com/group/tankers, and is based on information provided by Gavin Kratz from UXO ID book, U.S. Army/National Ground Intelligence center.

The relative size of the flat (or blunt) nose relative to the overall width is notable, which may have increased penetration.





NEG. 502846

Projectile fuzed mass: 6.31 kg
Fuze: MD-5 BD
Filler: TNT 0.15 kg

Using weapon(s): Field gun ZIS-3 and tank gu
Remarks: Also uses MD-6 and MD-8 fuzes

Figure 37. Russian 76-mm AP-T Projectile Model BR-350A

76.2mm BR-350A DRAWING FROM YAHOO! TANKERS SITE

Posted by Paul Lakowski with information provided by Gavin Kratz

The following table compares firing trial penetration data from *The Russian Battlefield* site at 80% success (CP) to ARTKOM equation predictions against face-hardened armor at 80% success. The Russian figures appear to be above the typical penetration for the rounds, and may be based on above average ammunition:

	M.V.	100m	300m	500m	1000m	1500m
76.2L41.5 APBC (BR-350B)	2171	86	81	75	68	62
76.2L41.5 APBC (BR-350A)	2171	80	76	70	63	58
76.2L41.5 APBC (BR-350B) ARTKOM equation estimate	2171	79	75	72	64	56
76.2L41.5 APBC (BR-350A) ARTKOM equation estimate	2171	75	71	68	60	54

14. <u>ARMOR DATA FOR SELECTED VEHICLES</u>

GENERAL

The following pages present armor thickness and vertical slope data for selected AFV's that represent a cross section of major vehicles.

Data has been gathered from many sources including analysis of captured tanks such as IS-2, IS-2m, Panthers and Tiger E.

Armor that may have lowered resistance due to deficiency modifiers has been tagged with cast (cast or c), face-hardened (fh), high hardness or flaw designators.

Armor data sources include WW II documents from the U.K. on British, America, German and Russian tanks, German intelligence reports on captured British and Russian tanks (including IS-2 and IS-2m), and American analysis of German and Russian tanks (including T34, KV-1, IS-2m and T34/85).

Data from AFV Profiles and *The Russian Battlefield* were also reviewed. All sources were compared and differences were resolved to arrive at reasonable armor figures for thickness and angle. A good source for American and Russian tank armor data is On.War.com - Tanks of World War II, an excellent compilation and analysis of armor data on a wide variety of tanks, including tank data that is difficult to obtain from most sites.

German tanks used face-hardened armor to a very great extent, more so than other nations. Research shows that the first 840 Panther D probably had face-hardened glacis plates in addition to other hull areas. American reports suggest that Panther A production may have face-hardened and all-homogeneous armor versions. The percentage of all-homogeneous armor Panther A's is currently being researched.

Spaced armor is indicated by a "+" sign between thicknesses, and layered armor from plates in contact is denoted by "/" signs between plates. When two face-hardened plates are in contact, the "fh" is used for each.

In many cases, such as PzKpfw IVH and IS-2/2m, the large difference between turret front and hull front armor protection is noticeable. As larger guns were mounted in tanks the weight might become unbalanced, and in several cases the unbalance limited the turret armor.

ARMOR STATISTICS

GERMAN AFV

	PzKpfw IIIE,G	PzKpfw IIIH	PzKpfw IIIJ
Mantlet	:35fh curved	35fh curved	50fh curved
Turret Front	:30fh @ 15	30fh @15	30fh @ 15
Front Vertical Plate	:30fh @ 10	32fh/30fh @ 10	50fh @9
Glacis	:26 @ 87	26 @ 87	26 @ 84
Front Upper Nose	:30fh @ 52	32fh/30fh @ 52	50fh @ 52
Front Lower Nose	:30fh @ 21	32fh/30fh @ 21	50fh @ 21
Turret Side	:30 @ 21	30 @ 21	30 @ 25
Upper Hull Side	:30 @ 0	30 @ 0	30fh @ 0
Lower Hull Side	:30 @ 0	30 @ 0	30 @ 0
Turret Rear Upper	:30 @ 0	30 @ 0	30 @ 12
Turret Rear Lower	:30 @ 17	30 @ 17	30 @ 12
Hull Rear Upper	:30 @ 30	30 @ 30	53fh @ 13
Hull Rear Lower	:30 @ 10	32fh/30 @ 10	53fh @ 10

Note : "32fh/30"fh resists like 69fh in test firings prior to slope effects.

	PzKpfw IIIL,M	PzKpfw IVD	PzKpfw IVE
Mantlet	:20+50fh	30 curved	35 curved
Turret Front	:57fh @ 15	30 @ 11	30 @ 9
Front Vertical Plate	:20+50fh @ 9	30 @ 7	30/30 @ 7
Glacis	:25 @ 84	20 hi-hard @ 75	20 @ 71
Front Upper Nose	:50fh @ 50	30fh @ 12	50 @ 15
Front Lower Nose	:50fh @ 20	20 @ 60	50 @ 62
Turret Side	:30 @ 25	20 @ 25	20 @ 24
Upper Hull Side	:30fh @ 0	20 @ 0	20/20 @ 0
Lower Hull Side	:30 @ 0	20 @ 0	20/20 @ 0
Turret Rear Upper	:30 @ 12	20 @ 0	20 @ 14
Turret Rear Lower	:30 @ 12	20 @ 20	
Hull Rear Upper	:50fh @ 17	20 @ 9	20 @ 15
Hull Rear Lower	:50fh @ 9	20 @ 10	20 @ 10

Note: "20+50" consists of 20 hi-hardness spaced 4" in front of 50fh, at 9

	PzKpfw IVH	PzKpfw IVG	PzKpfw IVf1/f2
Mantlet	:50fh curved	50fh curved	50fh curved
Turret Front	:50fh @ 10	50fh @ 11	50fh @ 11
Driver Plate	:85fh @ 10	30fh/50fh @ 10	50fh @ 10
Glacis	:20 @ 72	25 @ 73	25 @ 73
Upper Nose	:85fh @ 14	30fh/50fh @ 12	50fh @ 12
Lower Nose	:30fh @ 64	50fh @ 64	50fh @ 64
Turret Side	:30 @ 26	30 @ 26	30 @ 26
Upper Hull Side	:30fh @ 0	30fh @ 0	30fh @ 0
Lower Hull Side	:30fh @ 0	30fh @ 0	30fh @ 0
Turret Rear	:30 @ 15-24	30 @ 16-24	30 @ 16-24
Upper Hull Rear	:20 @ 11	20 @ 12	20 @ 12
Lower Hull Rear	:20 @ 9	20 @ 9	20 @ 9

Notes: British and American firing tests against "32/30" face-hardened armor on PzKpfw IIIH show that single plate equivalency of two near equal face-hardened plates in contact is about 11% greater than the sum of the two individual thicknesses.

"30fh/50"fh consists of two fh plates in contact, equivalent resistance about 84fh

PzKpfw IVJ same as IVH except front armor is homogeneous except last half of production is homogeneous armor

PzKpfw IVH has 30fh/50fh prior to 6/43

Various sources list FH turret side and rear for PzKpfw IVF1 and F2, G, H and earlier J

	Panther D	Panther A	Panther G
Mantlet	:100c rounded	100c rounded	100c rounded/flat chin
Turret Front	:100c @ 10	110c @ 10	110c @ 10
Glacis	:85fh @ 55	85 flaw @ 55	85 flaw @ 55
Nose	:65fh @ 55	60fh-75fh @ 55	60-75 @ 55
Turret Side	:45 @ 25	45 @ 25	45 @ 25
Upper Hull Side	:40fh @ 40	40fh @ 40	50 @ 30
Lower Hull Side*	:40fh @ 0	40fh @ 0	40 @ 0
Turret Rear	:45 @ 28	45 @ 28	45 @ 28
Hull Rear	:40 @ 30	40 @ 30	40 @ 30

Note: * wheels cover part of lower hull side and provide added resistance

Early Panther D had mostly face-hardened glacis (fh)

Early Panther A with face-hardened armor in listed areas, all-homogeneous after 9/43

Russian, American and British sources list 85mm as Panther glacis, and list Panther nose at 65-75mm

Panther G nose thickness quoted at 50mm basis in many sources

About half of Panthers with flawed glacis armor starting summer 1944

EFFECTIVE RESISTANCE OF LAYERED ARMOR ON PzKpfw III AND IV

The British firing tests against PzKpfw IIIH suggest that the 32mm/30mm layered combination of face-hardened plates resisted penetration like a single FH plate of 69mm thickness. This would suggest that the 30mm/50mm layered combination on the front of PzKpfw IVG and some IVH would outperform a single 80mm FH plate.

The interpretation of the British tests against PzKpfw IIIH assumed that the shots did not include a side angle from the hull front facing, since none is mentioned in the report. If the tests were conducted at 30 degrees side angle from firer to hull front facing, the effective resistance of the 32mm/30mm combination would be the same as a single 57mm FH plate, which would lead to significant changes in the effective penetration ranges of various weapons against the PzKpfw IIIH hull.

Some German armor experts from WW II have suggested that two rolled plates in contact were inferior to a single plate of the same overall thickness, whether the single plate was rolled or cast. That statement appears somewhat drastic.

A single 62mm cast plate attacked by 50mm and 75mm rounds would resist like rolled plates of 54mm and 55mm thickness. The British test results would result in 57mm single plate equivalent thickness for 32mm/30mm, which is not consistent with the above paragraph.

At this point it is not clear if two face-hardened plates in contact havemore or less equivalent resistance than a single plate of the same combined thickness.

GERMAN AFV

	Tiger E (late)	Tiger B Porsche	Tiger B Henschel
		Mostly flawed	Mostly flawed
Mid Mantlet	:see mantlet section	100fh round	185 @ 10
Mantlet Edges :	:see edge effects		
Driver Plate	:102 @ 9		
Glacis	:60 @ 70	150 @ 50	150 @ 50
Nose	:102@ 25	100 @ 50	100 @ 50
Turret Side	:82 @ 0	80** @ 30	80 @ 20
Upper Hull Side	:82 @ 0	80 @ 25	80 @ 25
Lower Hull Side*	:62 @ 0	80 @ 0	80 @ 0
Turret Rear	:82 @ 0	80 @ 30	80 @ 20
Hull Rear	:82 @ 9	80 @ 30	80 @ 30

Notes: * wheels cover part of lower hull side and provide added resistance
** one side is fh (face-hardened armor on Porsche turret Tiger II is noted in Jentz' work)

	Jagd Tiger	Jagd Panther
Mantlet	:60-130 cast	
Upper Structure Frt	:250 @ 15	80-85 @ 55 (flawed?)
Glacis	:150 flaw @ 50	
Upper Nose	:100 @ 50	50-75 @ 55
Up.Structure Side	:80 @ 25	50 @ 30
Upper Hull Side	:80 @ 25	50 @ 30
Lower Hull Side*	:80 @ 0	40 @ 0
Up. Structure Rear	:80 @ 10	40 @ 35
Upper Hull Rear	:80 @ 30	40 @ 30

Notes: *-Wheels add protection to Lower Hull Side
Nose could be 50mm basis, as Panther G, although actual thicknesses probably would exceed 50mm
Jagdpanther glacis hardness is much lower than Panther A and G, which may have resulted in a lower tendency towards brittle, flawed armor

GERMAN AFV

	Hetzer	StuG IIIG	StuG IV	JgPz IV Later	JgPz IV Early
Mantlet	:60 cast rnd	50 @ 0**	80c rnd	80-130 rnd	80 rnd
Upper Structure Frt	:	30 @ 68	30 @ 68	80 @ 50	60 @ 50
Upper Structure Frt	:	50 @ 51	50 @ 51		
Driver Plate	:	30fh/50fh @ 10	80fh @ 10		
Glacis	:60 @ 60	30 @ 86	20 @ 72		
Upper Nose	:60 @ 40	30fh/50fh @ 52	80fh @ 14	80 @45	60 @ 45
Lower Nose	:	30fh/50fh @ 20	80fh @ 14	51 @ 57	51 @ 55
Upper Structure Side	:20 @ 40	30fh @ 11	30 @ 11	30 @ 30	40 @ 30
Upper Hull Side	:20 @ 15	30fh @ 11	30 @ 11		
Lower Hull Side	:30 @ 0	30 @ 11	30 @ 0	30 @ 0	
Upper Structure Rear	:8 @ 70	30 @ 0	31 @ 0	30 @ 33	30 @ 10
Upper Hull Rear	:20 @ 73	50fh @ 12	20 @ 12	20 @ 12	20 @ 12
Lower Hull Rear	:20 @ 15	50fh @ 10	20 @ 10	20 @ 10	20 @ 10

Notes: ** - Later StuG IIIg versions had cast 80mm Saukopf Mantlet Round 65mm flat mantlet
StuG III and IV fh areas become homogeneous after June 1944 production

USA AFV

	M4A1 (53 Glacis)	M4A3 (56 Glacis)	M4A3 (47 Glacis)
	All Flawed Cast	All Flawed	75mm Gun
Mantlet Rotor Shield	:51 round	51 cast round	51 cast round
Mantlet Gun Shield	:89cast round (holes)	89cast round (holes)	89cast round
Mantlet Spaced .	:Yes	Yes	Yes
Turret Front	:76 @ 30	76 @ 30	76 @ 30
Glacis	:51 @ 53 Middle	51 @ 56	63 @ 47
Glacis	:64 @ 47 MGer		
Glacis	:64 @ 35 Driver		
Glacis Edges	:51 @ 55 & 45 lateral		
Upper Nose	:51 @ 56	51 cast @56	51 cast @ 56
Lower Nose	:51 @ 0	51 cast @ 0	108 cast @ 0
Turret Side	:51 @ 5	51 cast @ 5	51 cast @ 5
Upper Hull Side	:38 @ 0	38 @ 0	38 @ 0
Lower Hull Side	:38 @ 0	38 @ 0	38 @ 0
Turret Rear	:51 @ 0	51 cast @ 0	51 cast @ 0
Upper Hull Rear	:38 @ 10	38 @ 10	38 @ 22
Lower Hull Rear	:38 @ 0	38 @ 0	38 @ 10

Note: Mantlet Add-On Pen. refers to fact that spaced homogeneous armor has less equivalent thickness than a single plate of similar total thickness, and Mantlet Gun Shield has large holes for cannon, machine gun, sighting equipment, etc. Single plate equivalent thickness of 51 Rotor Shield and Gun Shield is roughly equal to 80 Round, prior to any reductions for flawed cast armor.
Outside areas on front of M4A1 glacis have 55° vertical slope and are angled at 45° to hull direction (lateral angle), for 66° compound angle on shots taken directly at tank front. As shot angle to hull direction increases lateral angle decreases and so does compound angle:
0° angle to front hull : 66° compound angle 10° angle to front hull : 62°
20° angle to front hull : 59° compound angle 30° angle to front hull : 56°
Early Sherman mantlet is 76mm cast (with flaws)

	M10	M4A3E8 M4A3 (47 Glacis)	Pershing	Sherman Jumbo
	All Flawed			
Gun Shield	:57 @ 45	91 cast @ 0	114 cast round	89/89c cast
Glacis	:38 @ 55	63 @ 47	102 cast @ 46	38/64 @ 47
Glacis Top	:		102 cast @ 20	
Upper Nose	:51 @ 56	5 1cast @ 56	76 cast @ 53	114@56
Lower Nose	:51 @ 0	108 cast @ 0		140 @ 0
Turret Side	:25 @ 15	51 cast @ 5	76 cast @ 0-8	152 cast @ 0
Upper Hull Side	:19 @ 38	38 @ 0	76 front,51 rear	38/38 @ 0
Lower Hull Side	:25 @ 0	38 @ 0		
Turret Rear	:25 @ 0	51 cast @ 0	76 cast @ 0-5	152 @ 0
Upper Hull Rear	:19 @ 38	38 @ 10	51 @ 10	38 @ 20
Lower Hull Rear	:25 @ 0	38 @ 10	19 @ 62	38 @ 10

USA AFV

	M5A1	M3A3	Chaffee	M4A1(76)W
Mantlet	:51C @ 0-14	51c @ 0-14	38 @ 0-60	89 cast
Turret Front	:44 @ 10	38 @ 10	38 @ 0-60	64 @ 40-45
Glacis	:29 @ 48	25 @ 48	25 @ 60	64 @ 37-55
Upper Nose	:38 @ 23	44 @ 23	25 @ 45	51 @ 56
Lower Nose	:64 @ 0			108 @ 0
Turret Side	:32 @ 0	32 @ 0	25 @ 20 & 25	64 @ 0-13
Upper Hull Side	:29 @ 0	25 @ 20	25 @ 2/19@2	38 @ 0
Lower Hull Side	:15 @ 0	25 @ 0		
Turret Rear	:32 @ 0	32 @ 0	25 @ 0 64 @ 0	
Upper Hull Rear	:25 @ 0 & 49	25 @ 0 & 59	19 @ 0	38 @ 20
Lower Hull Rear	:23 @ 17	25 @ 20	19 @ 42	38 @ 0

SOVIET AFV

	IS - 2	IS - 2m	T34- 85	T34 M42	T34 M43
	Hi-Hardness	Hi-Hardness	Hi-Hardnes	Hi-Hardness	Hi-Hardness
Mantlet	:110* round	110* round	90 round	45 round	45 round
Turret Front	:100 round	100 round	90 round	65 round	70 round
Upper Structure	:95 @ 30	133 @ 30			
Driver Plate	:120* @ 30				
Glacis	:75 @ 74	110 @ 60	45 @ 60	45 @ 60	45 @ 60
Nose	:100 @ 30	100* @ 30	45 @ 60	45 @ 60	45 @ 60
Turret Side	:95 @ 20	95 @ 20	75 @ 18	65 @ 30	52 @ 15
Upper Hull Side	:95 @ 26	133 @ 26	45 @ 40	45 @ 40	45 @ 40
Up. Hull Side	:89 @ 15	89 @ 15	45 @ 40	45 @ 40	45 @ 40
Lower Hull Side	:89 @ 0	89 @ 0	45 @ 0	45 @ 0	45 @ 0
Turret Rear	:95 @ 20	95 @ 20	52 @ 10	45 @ 30	52 @ 15
Upper Hull Rear	:64 @ 50	64 @ 50	45 @ 50	45 @ 50	45 @ 50
Lower Hull Rear	:64 @ 45	64 @ 45	45 @ 45	45 @ 45	45 @ 45

Note: Russian firing tests against IS-2 with Tiger gun firing APCBC suggest IS-2 driver plate has 115mm effective thickness at 30 degrees (800m penetration range), with 103mm effective thickness for nose armor at 30 degrees (1400m penetration range).
Underlined armor on IS-2m, IS-2m and T34 M43 is not high-hardess.
*-British documents have 105mm IS-2 driver plate, 127mm IS-2m nose and 100mm mantlet

	SU-152	SU-85	ISU-122/152	KV-1 M42	KV-1 M43
	Hi-Hardness	Hi-Hardness	See Note		
Mantlet	:60 cast @ 60	75 cast Rnd	190 Round**	90 Round	120 Round
Turret Front	:			82 @ 15	105 @ 15
Upper Structure	:75 @ 30	45 @ 50	90 @ 30		
Driver Plate	:			30/75 @ 30	30/75 @ 30
Glacis	:60 @ 70	45 @ 50	75 @ 74	75 @ 70	75 @ 70
Nose	:60 @ 30	45 @ 60	127 @ 20	20/75 @ 25	30/75 @ 25
Turret Side	:			100 @ 15	120 @ 15
Up. Structure Side	:60 @ 25	45 @ 48	75 @ 15	70/75 @ 0	55/75 @ 0
Upper Hull Side	:45 @ 20	89 @ 15	75 @ 0	90 @ 0	
Lower Hull Side	:60 @ 0	45 @ 0	89 @ 0	75 @ 0	90 @ 0
Turret Rear	:			100 @ 15	120 @ 15
Up. Structure Rear	:60 @ 6	45 @ 0	55 @ 0		
Upper Hull Rear	:60 Round	45 @ 50	64 @ 50	52 Round	52 Round
Lower Hull Rear	:60 Round	45 @ 45	64 @ 45	75 Round	75 Round

Notes: ** - ISU-122 with D-25S gun has 100 Round Mantlet, A-19S gun has 190 Round Mantlet.
Upper Structure Side on KV-1 is basic hull side armor plus added plates to protect turret race and ring.
Underlined armor thickness for ISU-122/152 are high hardness.
SU 100 has 68-78 @ 50 upper superstructure front and 75 rnd mantlet, with 45 @ 50 glacis door
Early KV-I with 75mm @ 30 driver plate

SOVIET AFV

	KV-1s	KV-85	T-70
	Hi-Hardness	Hi-Hardness	Hi-Hardness
Mantlet	:82 round	95 round	60 rnd
Turret Front	:82 rnd	100 round	35 @ 35
Upper Structure Frt	:		
Driver Plate	:75 @ 30	75 @ 30	
Glacis	:50 @ 70	40 @ 65	35 @ 60
Nose	:60 @ 25	75 @ 30	35 @ 30
Turret Side	:75 @ 15	100 @ 15	35 @ 25
Upper Hull Side	:60 @ 0	60 @ 0	15 @ 0
Lower Hull Side	:60 @ 0	60 @ 0	
Turret Rear	:75 @ 15	100 @ 30	35 @ 30
Upper Hull Rear	:60 @ 50	45 @ 45	15 @ 40
Lower Hull Rear	:60 Round	75 round	

Notes: Underlined armor is not high hardness

BRITISH AFV

	Churchill III-VI	Churchill VII	Cromwell	Comet
Mantlet	:89 cast	152 cast	76 @ 0	101 @ 0
Turret Front	:89* @ 0	152 cast	76 @ 0	101 @ 0
Front Driver Plate	:89/12 @ 0	152 @ 0	63 @ 0	76 @ 0
Front MG Plate	:89/89/12 @ 0	152 @ 0		
Glacis	:38 @ 70	57 @ 70	30 @ 70	32 @ 70
Front Nose	:76/13 @ 20	140 @ 20	57 @ 20	63 @ 20
Turret Side	:76* @ 0	95 cast @ 0	63 @ 0	63 @ 0
Hull Side Upper	:51/13 @ 0	83 @ 0	32 @ 0	32 @ 0
Hull Side Lower	:63/13 @ 0	95 @ 0		29+14 spaced
Hull Side Behind Wheels	:38 @ 0	57 @ 0		
Turret Rear	:76* @ 0	95 cast @ 0	57 @ 0	57 @ 0
Hull Rear Upper	:51 @ 0	51 @ 0	32 @ 0	32 @ 0
Hull Rear Lower	:25 @ 62	25 @ 62		

Notes: Some Churchills appear, in photos, to have 20° slope to this plate: see color drawings in AFV Profile and picture of lined up Churchills in Italy, driver plate on first tank has vertical plate sides intersecting top of plate at an angle of about 20°

Turrets may be cast or rolled.

*-models uparmored to Churchill VII standard may carry Churchill VII turret and add 20mm applique to side hull lower and add 51mm to nose.

	Matilda II	Crusader I	Valentine
Mantlet	:75 cast	20/19	65 cast
Turret Front	:		
Driver Plate	:75 @ 0	14/10/5 @ 12	60 @ 0
Front Superstructure	:70 @ 30 & 45 lateral	18/22 @ 0	
Glacis	:47 cast @ 67	14 @ 59	30 @ 67
Front Nose	:75 cast round	14/13 @26	60 @ 20
Lower Nose	:	14 @ 65	
Upper Turret Side	:75 cast	10/10 @ 45	60 cast @ 0
Lower Turret Side	:	10/10 @ 45	
Hull Side Upper	:70 @ 30	14+14 spaced	60 @ 0 Mk I-III 50 @ 0 Mk III & IV
Hull Side Openings	:13 @ 53+40 @ 0 spaced		
Hull Side Lower	:25+40 spaced		
Turret Rear Upper	:75 cast	12/13 @ 35	65 cast @ 0
Turret Rear Lower	:	14 @ 65	
Hull Rear Upper	:14 @ 47	17 @ 59	
Hull Rear Lower	:55 @ 25	14/14	60 @ 0

BRITISH AFV

	Crusader II	Honey	Grant
	flaws (?)	flaws (?)	flaws (?)
Mantlet	:30/19	38 @ 0-14	
Turret Front	:	38 @ 10	76 @ 47
Driver Plate	:20/10/5 @ 12	38 @ 17	
Front Superstructure	:18/22 @ 0		51 @ 30
Glacis	:20 @ 59	16 @ 69	38 @ 53
Front Nose	:20/13 @26	44 @ 23	51 @ 45
Lower Nose	:20 @ 65		51 @ 0
Turret Side	:14/10 @ 45	25 @ 0	51 @ 0 & 30
Hull Side	:14+14 spaced	25 @ 90	38 @ 0
Turret Rear	:18/13 @ 35	25 @ 0	51 @ 0
Turret Rear Lower	:20 @ 65		
Hull Rear Upper	:14 @ 47	25 @ 0 & 20	38 @ 10
Hull Rear Lower	:14+14	25 @ 20	38 @ 0

ITALIAN AFV

	M13/40	SEMOVENTE 75/18	M15/42	M26/40
	Flaws (?)	Flaws (?)		
Mantlet	:37 rnd	50 rnd	37 rnd	60 rnd
Turret Front	:37 @ 16		12/37 @16	60 @ 15
Upper Structure Frt	:30 @ 11	25/25 @ 5	12/30 @ 11	50 @ 45
Driver Plate	:	25 @ 9		
Glacis	:	25 @ 69		
Nose	:30 rnd	30 rnd	30 rnd	50 @ 55
Turret Side	:25 @ 22		25 @ 22	45 @ 25
Superstructure Side	:25 @ 9	25 @ 9	25 @ 9	45 @ 35
Hull Side	:25 @ 0	25 @ 0	25 @ 0	40 @ 0
Turret Rear	:25 @22		25 @ 22	40 @ 25
Superstructure Rear	:25 @ 0	25 @ 9	25 @ 0	40 @ 10
Hull Rear	:25 @ 20	25 @ 20	25 @ 20	40 @ 40

FINE DETAILS FOR AMERICAN AND BRITISH ARMOR STATISTICS

USA AFV armor thickness in millimeters, followed by c if cast, @degrees obliquity from vertical.
Flawed armor produced until late 1943.

Sherman Series, components listed separately due to the large number of combinations.

	Early Cast Hull (M4A1) (Flawed)	**Late Cast Hull (M4A1(76)W)**
Upper Glacis:	51c @55	51c @55
Upper Glacis Corners	51c @55 (@45 to front)	51c @55 (@45 to front)
Drivers' Hoods:	51c @37	64c @35 (driver), 64c @47 (bow gunner)
Lower Glacis:	51c @52	51c @52 (center), 64c @52 (driver), 57c @52 (at lift rings)
Lower Glacis Corners	51c @5 (@40 to front)	64c @7 (@35 to front)
Upper Sides:	38c @0	38c @0
Lower Sides:	38 @0	38 @0
Upper Rear	38c @0	38c @20
Lower Rear	38 @10	38 @10

	Early Welded Hull (M4, M4A2, M4A3, M4A4) (Flawed)	**Late Welded Hull (M4(105), M4A2(75,76), M4A3(75,76)W)**
Glacis	51 @56 (see note)	64 @47
Drivers' Hoods	51c @0 (applique 38 @35) (M4A2 51 @10)	none
Upper Sides	38 @0 (applique 25 @0 at ammo racks)	38 @0 (applique 38 @0 at ammo racks, some M4A2)
Lower Sides	38 @0	38 @0
Upper Rear	38 @0 (M4), 38 @22 (M4A3)	38 @10 (M4), 38 @12 (M4A2), 38 @22 (M4A3)
Lower Rear	38 @10	38 @10

Note: Early welded hull M4A3, M4A4, possibly M4 have all-cast area between and below drivers' hoods.

3-piece Bolted Nose (Flawed)		**Round Nose** (Flawed)	**Sharp Nose**
Upper Flat	51c @45	51c @56	51c @56
Mid	51c, rounded	51c, rounded	108c, rounded
Lower	51c, rounded	51c, rounded	51c @ 70

Early 75mm Mantlet (M34, narrow) (Flawed)		**Late 75mm Mantlet (M34A1**, wide)
Outer Mantlet (Rotor Shield)	51c, rounded	51c, rounded
Inner Mantlet (Gun Shield)	76c, rounded	89c, rounded

Note: 75mm Gun Shield has holes for Rotor Shield mounts, sight, MG, and main gun, reducing resistance to penetration due to edge effects. Total effective thickness of Rotor Shield and Gun Shield is less than their sum, as plates are spaced and are not mutually supporting.

105mm Mantlet (M52)	91c rounded	**76mm Mantlet (M62)**	89c-98c @7

75mm, 105mm Turret (Flawed if early)		**76mm Turret (T23)**
Front	76c @30	64c @42 (@45 to front)
Sides	51c @5	64c @0-13
Rear	51c @0	64c @0

USA AFV armor thickness in millimeters, followed by c if cast, @degrees obliquity from vertical. Flawed armor produced until late 1943.

M4A3E2 Assault (Jumbo)			
Glacis	38/64 @47	Mantlet	89c/89c @7
Upper Nose	114c @56	Turret Front	152c @12 (@45 to front)
Mid, Lower Nose	140c rounded	Turret Sides	152c @6
Upper Sides	38/38 @0	Turret Rear	152c @2
Lower Sides	38 @0		
Upper Rear	38 @22		
Lower Rear	38@10		

M3 Medium	(Flawed)		(Flawed)
Upper Front	51 @30	Turret Mantlet	51c @0-47
Glacis	38 @53	Turret Front	51c @47
Sponson Gun Mount	51c-64c, rounded	Turret Sides, Rear	51c @5
Front opposite Sponson	51 @30 (@60 to front)	Cupola	38c-51c @0-5
Upper, Lower Sides	38 @0		
Upper Rear	38 @0		
Lower Rear	38 @10		

M10 Tank Destroyer	(Flawed)	**M36 Tank Destroyer**
Glacis	38 @55	38 @55
Upper Sides	19 @38	19 @38
Lower Sides	25 @0	25 @0
Upper Rear	19 @38	19 @38
Lower Rear	25 @0	19 @0
Mantlet	57c @45	76c, rounded
Turret Sides	25 @15	32 @5
Turret Rear	25 @0	44-127 @0

T26E3 Medium (Pershing)		M24 Light	M18 Tank Destroyer
Glacis	102c @46, 20° slope at top center	25 @60	13 @64 upper, 38 mid
Nose	76c @53	25 @45	13 @24 mid, 53 lower
Sides	76 front, 51 rear @0	25 front, 19 rear @0	13 @23 upper, 0 lower
Upper Rear	52 @10	19 @0	13 @13
Lower Rear	19 @62	19 @42	13 @35
Mantlet	114c, crescent section	38c, @0-60	19c @0-60
Turret Front	102c, @0	38c, @0-60	25c @23
Turret Sides	76c, @0-8	25 @25 right, 20 left	13 @20
Turret Rear	76c, @0-5	25 @0	13 @9

M3	(Flawed, FH)	M3A1 Light (Flawed, FH Hull*)	M5A1 Light
Upper Front	38 @17	38c @17	none
Glacis	16 @69	16 @69	29 @48
Nose	44c @23	44c @23	38-64c @0-23
Sides	25 @0	25 @0	29 front, 25 rear @0
Upper Rear	25 @59	25 @59	25 @49
Mid Rear	25 @0	25 @0	25 @0
Lower Rear	25 @20	25 @20	25 @17
Mantlet	38c @0-14	51c @0-14	51c @0-14
Turret Front	38c @10	38 @10	44 @10
Turret Sides, Rear	25 @0	32 @0	32 @0
Turret Cupola	25 @0	none	none

*some parts of M3A1 hull are Homogeneous.

British AFV armor thickness in millimeters, followed by c if cast, @degrees obliquity from vertical. Flawed armor produced until late 1944 in thickness over 64mm.

	Cromwell IV	Cromwell VII
Upper Front	63 @0	63/25 @0
Glacis	30 @70	30 @70
Nose	57 @20	25/57 @20
Sides	32 @0	32 @0
Lower Sides	25/14 @0	25/14 @0
Rear	32 @0	32 @0
Mantlet	? @0	? @0
Turret Front	76 @0	25/76 @0
Turret Sides, Rear	51/13 @0	51/13 @0

15. DeMARRE EQUATION

GENERAL

Projectile penetration against homogeneous armor (not face-hardened) at 0° may be estimated for rounds with similar characteristics (material hardness and quality, caps, HE burster and nose shape) using the following equation:

Estimated Homogeneous Armor Penetration equals:

Reference Penetration x $(\text{Velocity}/\text{Ref Velocity})^{1.4283}$ x $(\text{Diameter}/\text{Ref Diameter})^{1.0714}$

x $(\text{Weight}/\text{Diameter}^3)^{0.7143}/(\text{Ref Weight}/\text{Ref Diameter}^3)^{0.7143}$

If a 15# 75mm round penetrates 100mm at 0° and 2500 fps, a 37mm projectile of the same type would have the following penetration at 1.92# and 2900 fps (75mm is used as the reference data or basis):

$100 \times (2900/2500)^{1.4283} \times (37/75)^{1.0714} \times (1.92/37^3)^{0.7143}/(15/75^3)^{0.7143}$,

or 61mm.

Face-hardened armor can be analyzed in a similar fashion through the following substitutions, which converts the DeMarre equation into the Krupp equation and is based on research conducted by Nathan Okun:

1.250 for 1.4283 and 1.0714
0.625 for 0.7143

HE bursters and armor piercing caps reduced penetration by about 10% compared to uncapped solid shot.

The DeMarre equation does not apply to Russian APBC projectiles.

DeMARRE ESTIMATE ISSUES REGARDING U.S. AMMUNITION

DeMarre estimates for 0° penetration were used extensively in the preparation of this booklet, and it is natural to ask about the expected accuracy of the equation. Prior to DeMarre equation use in our research, the ability of the equation to predict American firing test results was tested using data in TM9-1907. Similar tests were also conducted using British data.

The data base used in the analysis of American projectiles is presented on the next page, where penetration at a limited number of velocities were reviewed.

Analysis of penetration versus velocity data resulted in the following equations, where the average velocity exponent of 1.487 is close to the assumed exponent of 1.428 in the DeMarre equation. Projectiles which appeared to experience nose shatter, such as 37M51 and 37M59, were not included in the analysis.

Projectile	DeMarre Equation for Penetration (inches)
37M80	$0.000019111 \times (\text{velocity})^{1.5285}$
40M81	$0.000029678 \times (\text{velocity})^{1.4387}$
57M86	$0.000013980 \times (\text{velocity})^{1.6050}$
75M61	$0.000147000 \times (\text{velocity})^{1.3235}$
76M62	$0.000094310 \times (\text{velocity})^{1.3859}$
90M82	$0.000020818 \times (\text{velocity})^{1.6001}$
76HVAP	$0.000041775 \times (\text{velocity})^{1.5182}$
90HVAP	$0.000066685 \times (\text{velocity})^{1.4958}$

Note : Velocity in fps.

In addition to the preceding analysis and base data presentation, the next page also provides DeMarre penetration estimates for each projectile as a function of velocity, using the 2000 fps figure as the reference for steel projectiles and 2400 fps for Tungsten. The DeMarre penetration estimate at a given velocity equals (penetration at 2000 fps) x $(\text{velocity}/2000)^{1.428}$.

The DeMarre estimates show the following tendencies:

> Errors generally increase with increasing velocity, suggesting that the 1.428 exponent may not be strictly correct at all velocities.
>
> In several cases, the variation between actual and DeMarre figures suggests that projectile performance may be limited by shatter gap failure or nose deterioration: see 37M51 and 37M59 at 2900 fps.

To further examine previously noted issues, DeMarre velocity exponents for APCBC and HVAP were generated within each of the following velocity ranges and are presented on the two graphs after this page (for 37M51, 57M86, 75M61, 76M62 and 90M82 APCBC):

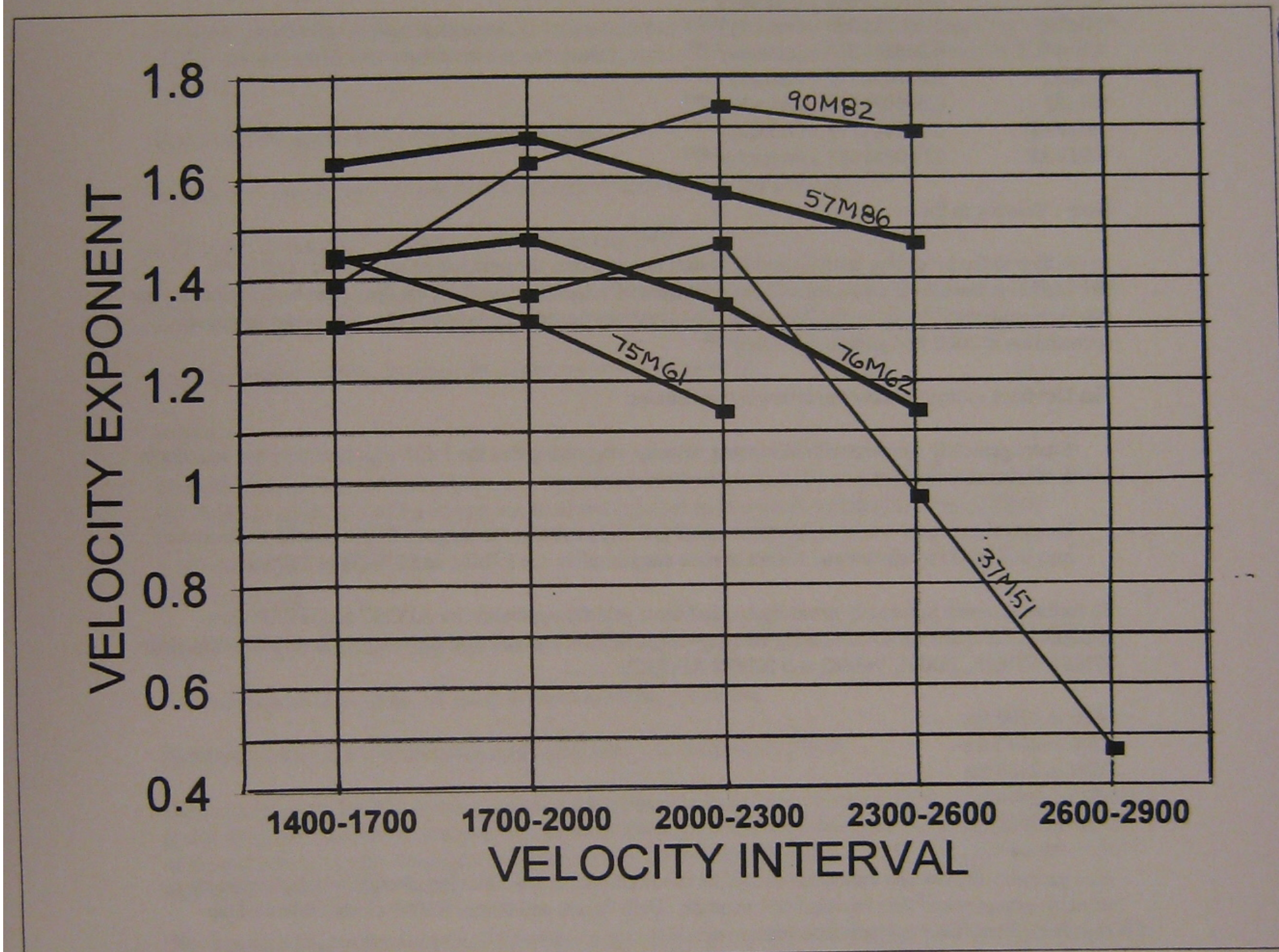
1400 to 1700 fps
1700 to 2000 fps
2000 to 2300 fps
2300 to 2600 fps
2600 to 2900 fps

As a general rule, velocity exponents should be at a minimum at low velocity, increase to a maximum as velocity increases and then remain fairly constant. Both 76mm and 90mm HVAP closely followed the expected pattern for velocity exponents.

If the velocity exponent decreases after the maximum is reached, this suggests that velocity increases result in less penetration than anticipated, which may be due to over stressing of the projectile nose. If the projectile nose is overstressed against armor at the 50% success thickness (penetration equals resistance), shatter gap failure is likely to occur when the penetration/resistance is within the 1.05 to 1.25 range due to increased nose stress (greater acceleration of armor material places higher stresses on nose).

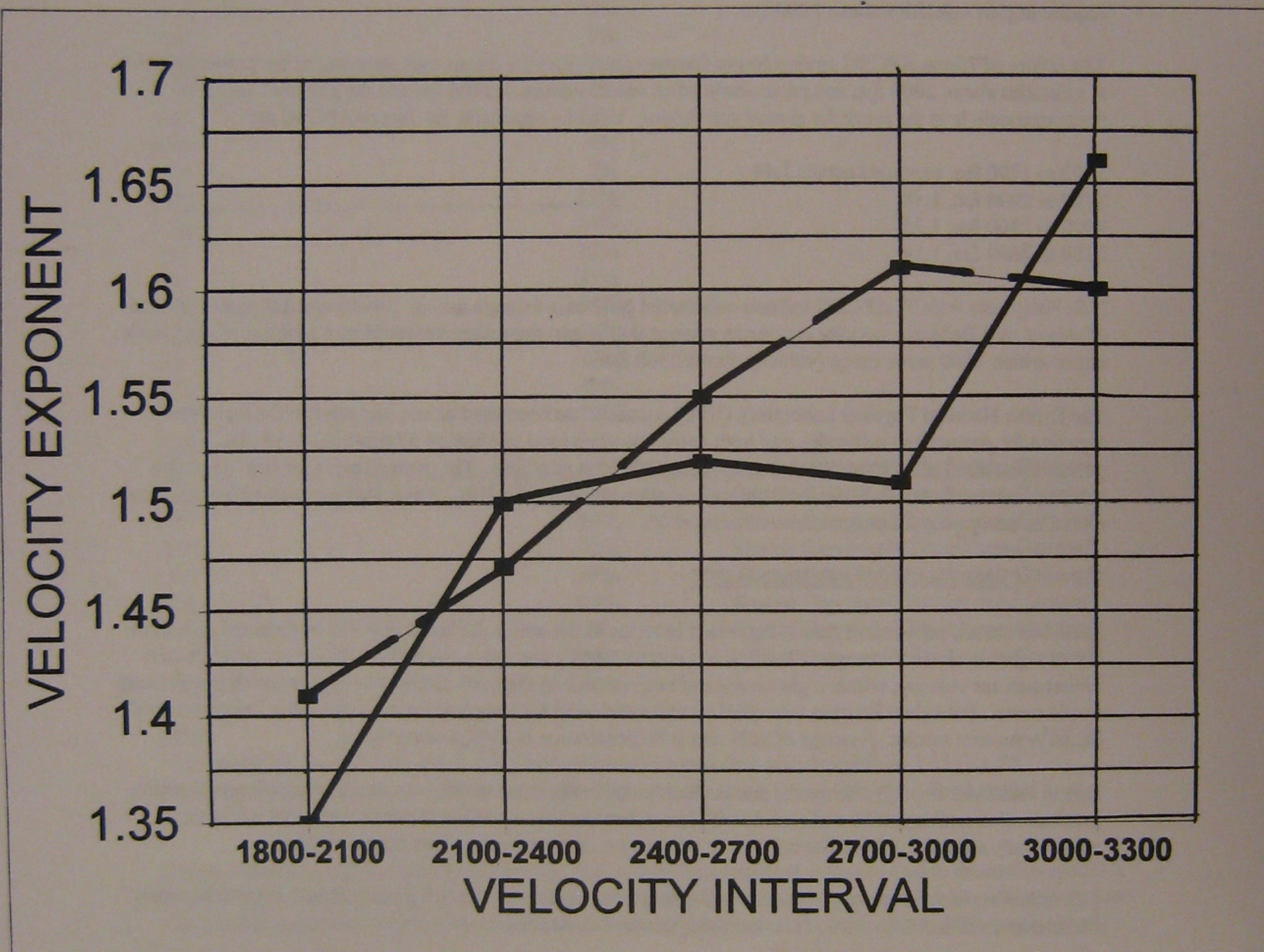
DeMARRE EQUATION VELOCITY EXPONENTS

FOR AMERICAN APCBC AMMUNITION



DeMARRE EQUATION VELOCITY EXPONENTS

FOR AMERICAN HVAP AMMUNITION



While 90mm APCBC follows the anticipated curve shape, the other APCBC projectiles show decreasing exponents after the maximum. In the case of 37mm APCBC, a significant decrease in velocity exponent occurs after 2300 fps, while 57mm and 76mm APCBC show less dramatic exponent decreases after 2000 fps.

75mm APCBC velocity exponents decrease at all velocities over 1400 fps, however, shatter gap appears to require impact velocities above 2000 fps.

The failure of 76mm APCBC against heavy German armor may be due to over stressing of the projectile nose at velocities above 2000 fps, and particularly when velocity exceeds 2300 fps and the penetration/armor resistance ratio is in the range for shatter gap failure. Velocity exponents for 76mm APCBC are:

1400 to 1700 fps, exponent equals 1.44
1700 to 2000 fps, 1.48
2000 to 2300 fps, 1.35
2300 to 2600 fps, 1.14

U.S. Navy tests with 3" APCBC indicate substantial projectile damage during penetrating hits against 3" and 4" armor, and DeMarre velocity exponents suggest that 76mm nose damage would be a problem against thick armor within 1000 yards range (velocity above 2300 fps).

The British National Physical Laboratory (NPL) equation has been used as an alternative to the DeMarre equation for penetration estimates, and both equations were used to estimate 57mm-90mm APCBC penetration within the 1700-2600 fps range using 2000 fps as a base. The average error for both equations was approximately equal, 3.3% for DeMarre equation and 3.1% for NPL, which suggests that either equation would be acceptable for penetration estimates at 0°.

16. PENETRATION PROBABILITY

Most, but not all, penetration data is expressed in terms of the armor thickness that will be defeated on half the hits at a given velocity or range. This figure is determined by averaging the highest failure velocity with the lowest success velocity, within a given range of each other, and then estimating the range at which this velocity would occur. Published Russian data often presents 20% and 80% success criteria, and some British sources list 80% success results. Average of 20% and 80% penetration is 50% success figure.

Due to variations in projectile speed, ammunition metal quality, and armor resistance, penetration probability is not an all or nothing affair and rounds with less penetration than computed armor resistance might occasionally succeed. Projectiles with more penetration than armor thickness may also fail.

The following table presents penetration probability as a function of the "0° penetration/0° equivalent armor resistance" ratio and is based on U.S. test data (standard deviation equals 4%):

PENETRATION PROBABILITY DATA FROM U.S. TESTS

PENETRATION/EFFECTIVE ARMOR RESISTANCE RATIO	PENETRATION PROBABILITY	NOTES
0.88 and less	0%	
0.89	1%	
0.90	1%	
0.91	1%	
0.92	2%	
0.93	4%	
0.94	7%	
0.95	11%	
0.96	16%	
0.97	23%	
0.98	31%	
0.99	40%	
1.00	50%	
1.01	60%	
1.02	69%	
1.03	77%	
1.04	84%	
1.05	89%	Shatter Gap possibility for non-German*
1.06	93%	Shatter Gap possibility for non-German*
1.07	96%	Shatter Gap possibility for non-German*
1.08	98%	Shatter Gap possibility for non-German*
1.09	99%	Shatter Gap possibility for non-German*
1.10	99%	Shatter Gap possibility for non-German*
1.11	99%	Shatter Gap possibility for non-German*
1.12 to 1.25	100%	Shatter Gap possibility for non-German*
1.26 and above	100%	

Note:
*- probabilities marked with asterisk indicate potential Shatter Gap possibility from 1.05 to 1.25 penetration/effective armor resistance ratio, with T/D ratio of at least 0.8 and impact velocity equal to or greater than 2000 fps.

Data presented on *The Russian Battlefield* for 20% and 80% penetration was analyzed to determine specifics of the penetration probability curve, and a penetration probability table was prepared based on the assumption that Russian penetration figures follow the standard normal distribution curve about the 50% success level.

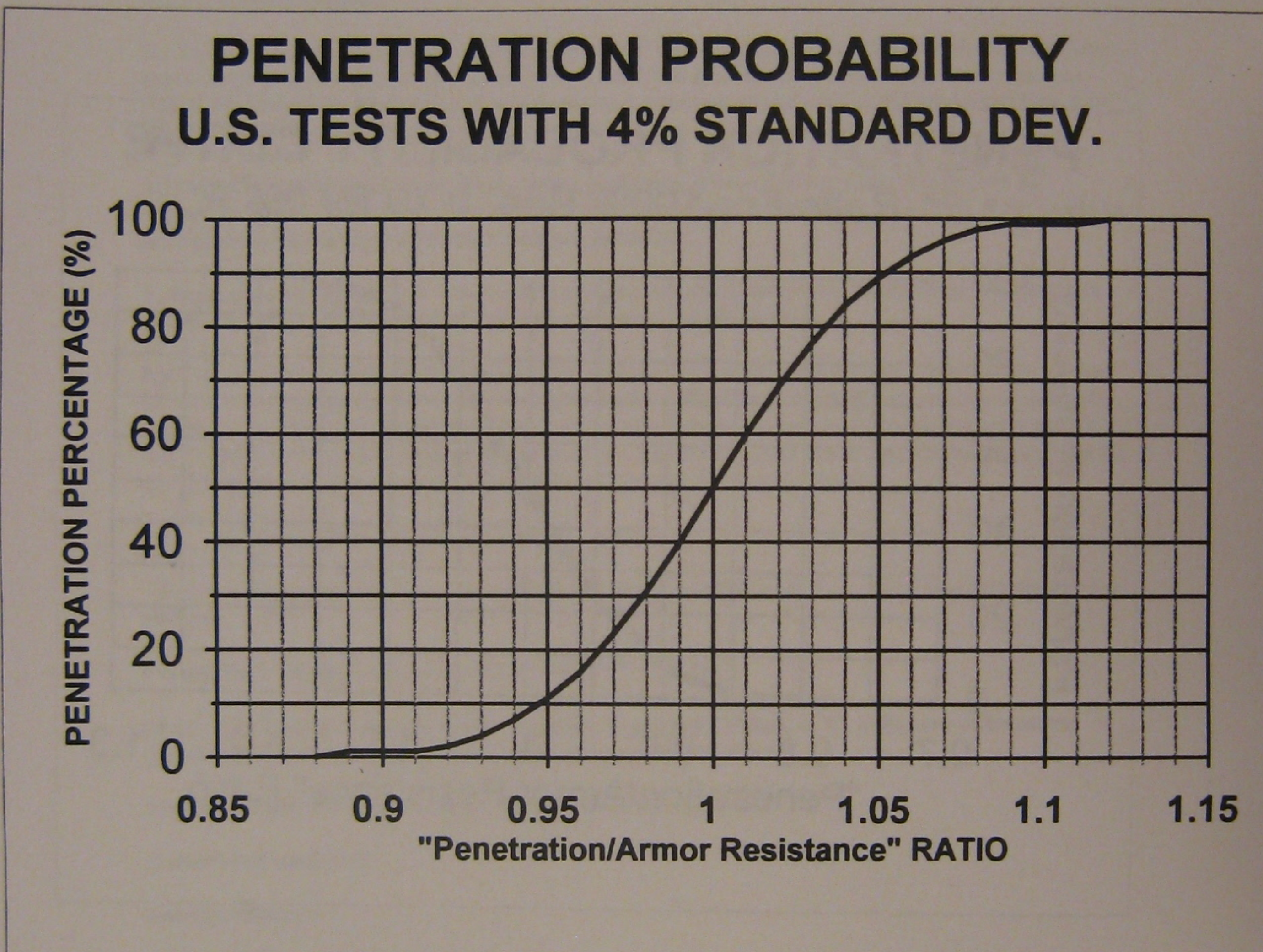
PENETRATION PROBABILITY DATA FOR PROJECTILES ON *THE RUSSIAN BATTLEFIELD*

PENETRATION/EFFECTIVE ARMOR RESISTANCE RATIO	PENETRATION PROBABILITY	PEN./EFFECTIVE ARMOR RESISTANCE RATIO	PENETRATION PROBABILITY
0.78 and below	0%	1.01	56%
0.79	1%	1.02	61%
0.80	1%	1.03	66%
0.81	1%	1.04	72%
0.82	1%	1.05	76%*
0.83	1%	1.06	80%*
0.84	1%	1.07	84%*
0.85	2%	1.08	87%*
0.86	2%	1.09	90%*
0.87	4%	1.10	93%*
0.88	5%	1.11	94%*
0.89	6%	1.12	95%*
0.90	7%	1.13	96%*
0.91	10%	1.14	98%*
0.92	13%	1.15	98%*
0.93	16%	1.16	99%*
0.94	20%	1.17	99%*
0.95	24%	1.18	99%*
0.96	28%	1.19	99%*
0.97	34%	1.20	99%*
0.98	39%	1.21	99%*
0.99	44%	1.22	100%*
1.00	50%	1.23	100%*
		1.24	100%*
		1.25	100%*
		1.26 and above	100%

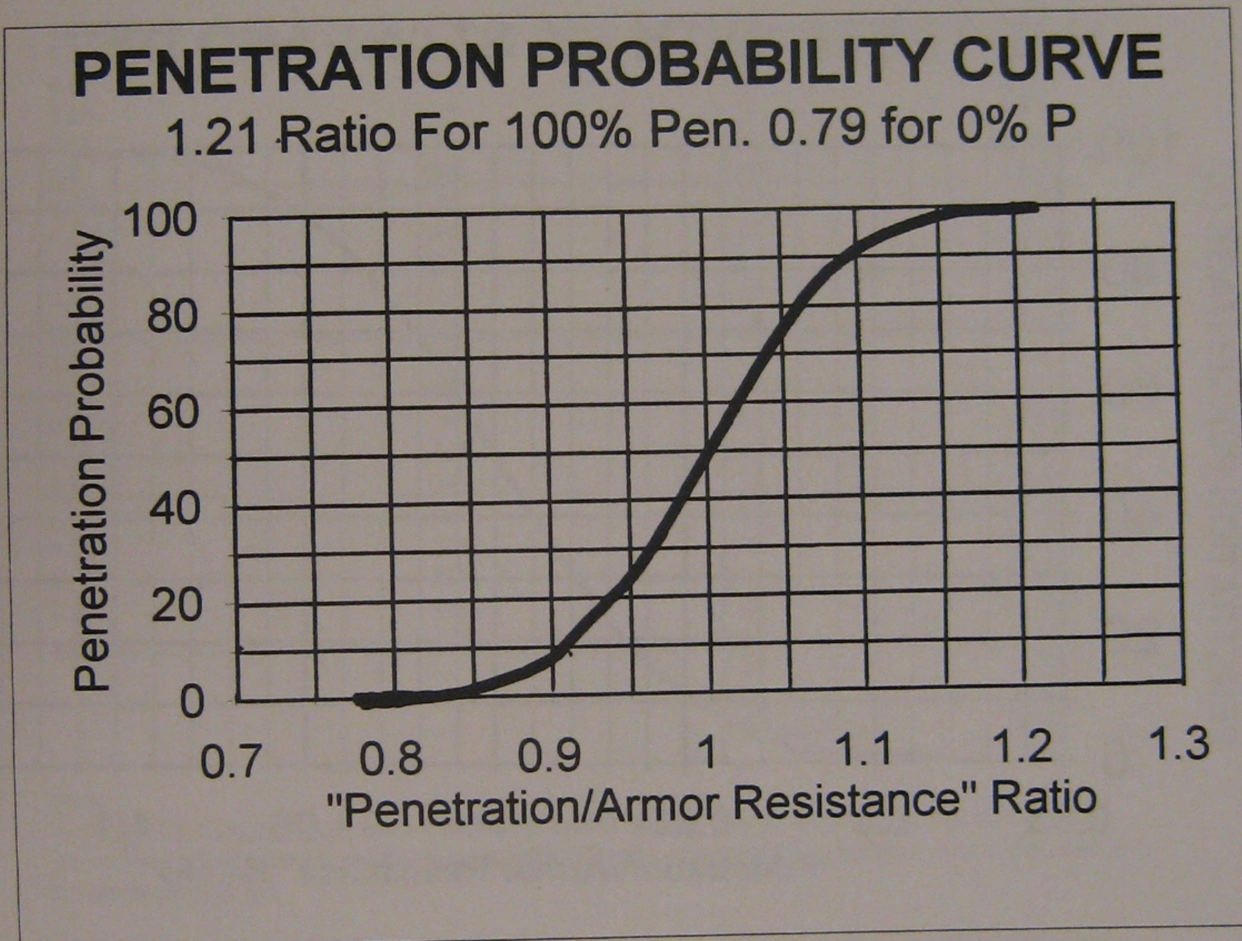
Note:
*- probabilities marked with asterisk indicate potential Shatter Gap possibility from 1.05 to 1.25 penetration/effective armor resistance ratio, with T/D ratio of at least 0.8 and impact velocity equal to or greater than 2000 fps.

It should be noted that sample data for AP ammunition from non-Russian sources is consistent with the analysis for data on *The Russian Battlefield*.

The penetration probability tables presented in this section are notable for the amount of over-penetration needed for 100% success, and the fact that rounds with lesss average penetration than the effective armor resistance they are attacking may have a fair chance for success. When low probability penetration does occur, it is likely that the round will have little residual energy left, and may have suffered projectile body damage that inhibits or eliminates detonation of the HE filler. Thus, low probability penetrations should result in less damage than high penetration/armor resistance ratio successes.



NOTE: Above table appears to present the best fit for Allied firing test data against German tanks, based on analysis of tests against Panther, Tiger E, PzKpfw IIIG and PzKpfw IIIH.


PENETRATION PROBABILITY CURVE
1.21 Ratio For 100% Pen. 0.79 for 0% P
Penetration Probability
100
80
60
40
20
0
0.7
0.8
0.9
1
1.1
1.2
1.3
"Penetration/Armor Resistance" Ratio

17. TACTICS TO MAXIMIZE ARMOR PROTECTION

Tanks with side armor that approaches frontal armor may benefit from angled approaches to known or suspected enemy locations.

If a Tiger approaches a suspected Allied position at a 45° angle, 76mm hits above lower hull level on frontal and side armor will be resisted by at least 180mm (front) and 140mm (side) vertical equivalent resistance. Hits on the 60mm side armor will generally have to move through several wheels, and low ground rises may shield some lower side armor.

In North Africa, PzKpfw III's with 30mm front and side face-hardened armor would benefit from 45° approaches against known or suspected enemy positions. 2 pounder AP hits on 30mm armor at 45° would be resisted with a vertical equivalent armor thickness of 55mm.

Although concerns might be advanced regarding hits on vulnerable turret sides, examination of turret shape reveals that design considered shots from frontal weapons at wide angles.

If a T34 Model 43 is viewed from front corner to opposite rear corner, about 30° from turret facing, the back of the turret side disappears from view. Introduction of a cutback on the back of the turret side significantly reduces the turret target area that can be hit on wide angle shots, and increases the compound angle when hits occur. Tanks with cutbacks on turret side include T34 and T34/85, Tiger E and Tiger II, Panther, PzKpfw III and IV, 56° glacis Sherman, Matilda II, Valentine, Churchill, Cromwell and others.

18. PROJECTILE VELOCITY ESTIMATION

Velocity at range of projectiles can be modeled with equation of following form, which was developed by the authors:

Velocity (m) = Muzzle Velocity x $2{:}718282^{(\text{range (m)} \times 0.7 \times -.0000001 \times K)}$,

where "K" is ballistic factor (see tables on next two pages) and 2.718282 is "e", or the base of the natural logarithm. The average velocity over a range can be approximated by:

Average Velocity = Muzzle Velocity x 0.5 x (1+ Velocity (m)).

A more exact equation is :

Average Velocity =

(Velocity (m) - Muzzle Velocity)/(0.7 x range (m) x -0.0000001 x K)

Flight time to range is then range divided by average velocity.

If the velocity function is raised to the 1.4283 power, the result approximates the fall-off in 0° penetration with range:

Penetration (m) = Point Blank Penetration x $2.718282^{(\text{range (m)} \times -.0000001 \times K)}$

BALLISTIC "K" FACTORS

PROJECTILE	"K"	M.V.
6PR APDS	2828	4000
6PR L45 APCBC	2722	2600
6PR L45 AP	4693	2700
6PR L45 AP	4813	2830
6PR L52 APCBC	2722	2725
6PR L52 AP	4711	2950
75L18 AP	3996	1560
75L18 APBC	2350	1560
75L24 APCBC	2205	1263
75L24 HEAT "A"	2600	1476
75L24 HEAT "B"	2600	1476
75L24 HEAT "C"	2600	1476
75L31 AP	3996	1850
75L31 APCBC	2300	1850
75L34 APBC	2350	1958
75L40 APBC	2321	2030
75L40 AP	4007	2030
75L40 APCBC	2321	2030
75L43 APCBC	2361	2427
75L43 APCR	3395	3018
75L46 APCBC	2400	2600
75L46 APCR	3395	3247
75L48 APCBC	2361	2460
75L48 APCR	3395	3050
75L48 HE	2603	1804
75L70 APCBC	2448	3068
75L70 APCR	3183	3706
75L70 HE	2753	2296
75mm Pak 97/38	4278	2100
76 HVAP	3192	3400

PROJECTILE	"K"	M.V.
76.2L41.5 AP	4000	2148
76.2L51.5 APCBC	2279	2329
76.2L51.5 APCR	3395	3247
76.2L51.5 HE	2659	1804
76.2L51.5 HEAT	3411	1476
76.2mm HEAT	2600	1066
76L41.5 APBC	2407	2148
76L41.5 "Super" APBC	2298	2444
76L41.5 AP	4000	2148
76L41.5 APCR	8971	3132
76L52 APCBC	2321	2600
77mm APCBC	1689	2575
85 AP	3989	2600
85 APBC	1760	2600
85 APCR	6228	3444
88L56 APCBC	1778	2580
88L56 "soft" APCBC	1738	2580
88L56 & 88L71 HEAT	2649	1968
88L56 APCR	2228	3050
88L56 HE	2134	2657
88L71 APCBC	1434	3280
88L71 APCR	1874	3706
88L71 HE	1861	2460
90 HVAP	2484	3340
90 M77 AP	3531	2700
90 T33 APCBC	1651	2700
90L52 APCBC	1622	2800
90L52 APCBC	1622	2650
95mm HEAT	2500	1650
PAK 97/38 FH	4278	2100
PF 50	2600	164

BALLISTIC "K" FACTORS

PROJECTILE	"K"	M.V.
100 AP	2813	3000
100 APBC	1300	3280
100 APBC	1300	3000
100mm APDS	1079	4641
105 HEAT	2241	1020
105 HEAT	2241	1250
105mm APDS (early)	1005	4850
115mm Soviet APFSDS	1868	5297
122 AP	2817	2600
122 APBC	1287	2600
122mm HEAT	2200	1099
122mm HEAT	2200	1804
125mm Soviet APFSDS	2050	5510
128L55 APC	1274	3018
128L55 HE	1714	3018
152 AP	3254	1968
152 APBC	1343	1968
17 Pdr AP	3414	2900
17 PR APCBC	1686	2900
17Pdr APDS	1705	3950
2 Pdr AP	6349	2600
2 Pdr APCBC	2787	2700
20L107 AP	8155	2700
20L107 AP	7282	2900
20L55 AP	7701	2600
20L55 APCR	22470	3300
25 Pdr AP (early)	4237	1550
25 Pdr AP (late)	4520	1897
28/20 APCR	9943	4600
3" M79 AP	4000	2600

PROJECTILE	"K"	M.V.
3" M79 AP	4000	2600
37 AP 2600	6410	2600
37 AP 2900	6349	2900
37 APCBC 2600	3061	2600
37 APCBC 2900	3061	2900
37 Littlejohn	3579	3600
37 SAP 2600	6410	2600
37L45 AP	5395	2427
37L45 APCR	15920	3100
37L45 Soviet	5031	2500
37L52 APBC	3061	2900
40 Littlejohn	4285	3900
45L46 APBC	3613	2493
45L46 APCR	7961	3182
45L60 APBC	3521	2690
45L60 APCR AP	7192	3510
47L32	5733	2060
47L32 APBC	3560	2060
47L40 APBC	3560	2673
47L43.4 APC	5798	2500
50L42 AP	5061	2247
50L42 APC	5061	2247
50L42 APCR	8101	3444
50L60 AP	5061	2739
50L60 APC	5061	2739
50L60 APCR	8101	3772
50mm HE	4620	1804
57L52 APCBC	2722	2700
57L73 APBC	2722	3247
57L73 APCR	5579	3936

If Panther 75L70 penetrates 190mm at 0m and 0°, the penetration at 1100m can be estimated by inputting 1100m and K=2.448 into the above equation, for 145mm.

Equation accuracy is good to between 1000m and 1500m range, with the following average errors after comparison to published German figures:

	ERROR FROM PUBLISHED FLIGHT TIME			
PROJECTILE	1000m	1500m	2000m	3000m
50mm L60 APC	1.7%	3.8%		
75mm L48 APCBC	0.1%	1.2%	2.0%	4.6%
76.2mm L51.5 APCBC	0.1%	0.8%	2.0%	4.2%
88mm L56 APCBC	0.9%	0.6%	1.0%	2.2%
88mm L71 APCBC	1.0%	0.9%	0.1%	1.3%

19. GUN SIGHT MAGNIFICATION

The accuracy of anti-tank fire is determined, in part, by the ability of the gunner to aim at the middle of the target, a point where fall of shot follows a distribution allowing highest chance for hits.

When a Sherman is at 500m and offers a front view, the perceived tank height, when measured with a ruler 1' from the observers' eye, is 1/20th of an inch. If the observer is in PzKpfw IVH with a 2.4x magnification gun sight, perceived Sherman height increases to 1/8th of an inch. To maximize hit probability, the aim should be 1/16th of an inch from the bottom of the hull front.

At 2500m range, the same Sherman profile will appear to be 1/40th of an inch high and the gunner would try to aim 1/80th of an inch above the hull bottom. Given all the factors that may be playing on a gunner and the difficult task in aiming precisely at target mid-height, aim point accuracy at 2500m with PzKpfw IVH would be less than optimum.

Late Jagdpanthers had 10x gun sight magnification, which would present a perceived target height of 1/10th of an inch to the gunner, and allows more accurate aim at target mid-point. Gun sight field of view narrows with increasing magnification. PzKpfw IVH gun sight field of view is 25° compared to 7° for 10x magnifying Jagdpanther gun sight. For long range fire magnification is the key item.

The first Panther D use at Kursk resulted in reported T34 kill beyond 2500m, which would have been associated with a 2.5x magnification gun sight. The small perceived target size (1/40th of an inch) makes the hit quite impressive.

The following list presents gun sight magnification and field of view statistics for a variety of WW II tanks and anti-tank guns, based on review of many sources:

<u>1.0x Magnification, 11° Field of View</u>

U.S. 75mm M2 on Grant and Lee uses roof top periscope, early U.S. 37mm uses periscope beside gun barrel

<u>1.0x Magnification, 50° Field of View</u>

British 3" howitzer

<u>1.44x Magnification, 9° Field of View</u>

U.S. 75mm M3 on early Lee and Shermans, U.S. 37mm, uses roof top periscope to sight barrel

<u>1.9x Magnification, 21° Field of View</u>
British tanks with 2 pounder, 37mm, 75mm Mark V, 3" and 95mm howitzer

<u>2.4x Magnification, 25° Field of View</u>
PzKpfw III and IV

<u>2.5x Magnification, 25° Field of View</u>
Early Panther A, Panther D, Tiger I, Tiger II, T34, KV-1

<u>3.0x Magnification, 8° Field of View</u>
Nashorn, Marder, early Jagdpanther, Elefant, 50mm Pak, 75mm Pak

<u>3.0x Magnification, 12° Field of View</u>
U.S. 75mm M3 on later Shermans

<u>3.0x Magnification, 13° Field of View</u>
British tanks with 75mm Mark V, 6 pounder, 17 pounder and 95mm howitzer, including 75mm guns on Cromwell IV, Centaur III and Churchill VI.

<u>5.0x Magnification, 8° Field of View</u>
StuG III and IV, Jagdpanzer IV, Nashorn, Sd Kfz 234/3, 88mm Flak

<u>5.0x Magnification, 13° Field of View</u>
Chaffee

<u>1.0x/5.0x Interchangeable Magnification, 17.5°/7.5° Field of View</u>
ISU-152

<u>2.5x/5.0x Interchangeable Magnification</u>
Late Panther A, Panther G, Tiger I, Porsche Tiger II

<u>3.0x/5.0x Magnification, Two Complete Sights on 8.8 Pak</u>
88L71 Pak

<u>3.0x or 6.0x Magnification</u>
Firefly (later models could have either 3.0x or 6.0x)

<u>3.0x/6.0x Interchangeable Magnification</u>
Henschel Tiger II

<u>6.0x Magnification, 11° Field of View (low power provides 1.0x and 45° field for finding targets)</u>
Pershing

<u>10.0x Magnification, 7° Field of View</u>
Late Jagdpanther

When 50mm Pak entered the field in North Africa it introduced improved sight magnification and very small shot-to-shot dispersion, which increased the effective range of anti-tank fire. In comparison, 2 pdr gun sight range markings for AP shot limited to 1500 yards with 500 yard increments..

It should be noted that Australian reports from North Africa include a successful initial shot at a German armored car that was well beyond the range markings on 2 pounder anti-tank gun.

A report given to General Eisenhower on the comparative value of German and American tanks contains a large number of references by tankers and officers on superior German gun sights, and how American sights required bright light to adequately see targets (overcast conditions seemed to be the norm on many combat days). Allied sights could also lose alignment after firing, or have limits on accuracy.

German sights contained coated optics and large objective lenses which increased the brightness of the image seen by the gunner. They had lenses which were of superior optical quality to those of other nations, particularly the U.S., resulting in a clearer image.

American tanks had dual device systems, in which a low power telescope was enclosed within a periscope for wide angle target acquisition, and a higher power, coaxial telescope was provided for more precise aiming once a target was acquired.

It is interesting to note that American and British gun sights did not provide range settings for APDS and HVAP ammunition, and gunners were provided with conversion factors. In the case of 17 Pounder, the higher velocity and flatter trajectory of APDS resulted in gun elevation angles equal to 55% of the APCBC figure. Gunners appear to have been instructed to use half the estimated target range when they elevated the gun for APDS using the APCBC range scale.

A Saumur Intranet site thread included Tom Rodwell's post where Michael Wittmann is reported to have destroyed several T34 in a battle at Rowno using a StuG IIIA and its' 75L24 gun, where T-34 frontal defeats were attributed to turret ring hits. The "T-34 Armour and 7,5 cm L/24" thread on the Saumur Intranet Site provides various explanations as to the manner in which a 75L24 gun could defeat a T34, which are related to gun penetration and the accuracy needed to consistently place shots on the turret ring.

Tom Rodwell also noted that Stug IIIA possessed several advantages over PzKpfw IVD which, in the hands of a capable and trained crew, would make the StuG IIIA one of the most effective tanks in the German Army:

1. The StuG IIIA gunner had use of a sight with twice the magnification of the PzKpfw IVD gunner, 5x versus 2.5x, which would allow more accurate aiming at a specific vulnerable area such as the turret ring

2. The StuG IIIA commander could use ambush techniques and spot "turret down" with a totally concealed vehicle due to scissor periscope, which extended well above vehicle top

3. StuG IIIA Commander scissor periscope had higher magnification than PzKpfw IVD gun sight

4. Gunner periscope on StuG IIIA could confirm target while vehicle was out of sight

5. Commander and gunner on StuG IIIA had binocular sights which permit better range estimation and have greater light gathering properties

20. NATIONAL PHYSICAL LABORATORY EQUATION

Based on firing tests with British AP against homogeneous armor at various angles, hardness (250, 300, 350 and 450 Brinell Hardness), and thickness, an equation was prepared which modeled the results (equation is presented in British *Penetration Of Armour Plate* report and Hal Hock's *AFV News article*). The equation is:

$$\text{50\% Success Velocity} = (d^3/w)^{0.5} \times (43.4 \times BHN^{0.5} \times (t/d) \times (\text{cosine}(1.5A))^{-1} + 916$$
$$-(11800/(65-A)) - 54000/(500 - 160 \times \log(d/1.565) - BHN)$$

where,

t is plate thickness in inches
d is projectile diameter in inches
w is projectile weight in pounds
BHN is Brinell Hardness Number
A is impact angle (0° is perpendicular impact)

The equation can be used to estimate penetration at various angles and velocities, such as 2 Pounder AP at 2600 fps against 0° armor at 260 BHN. The result is 86mm at 0 yards range. Or U.S. 75mm AP at 2030 fps against 0° armor at 260 BHN, for 111mm at 0 yards range.

Slope multipliers may also be prepared for various T/D ratio's at angles up to 45°:

2 POUNDER AP SLOPE EFFECTS

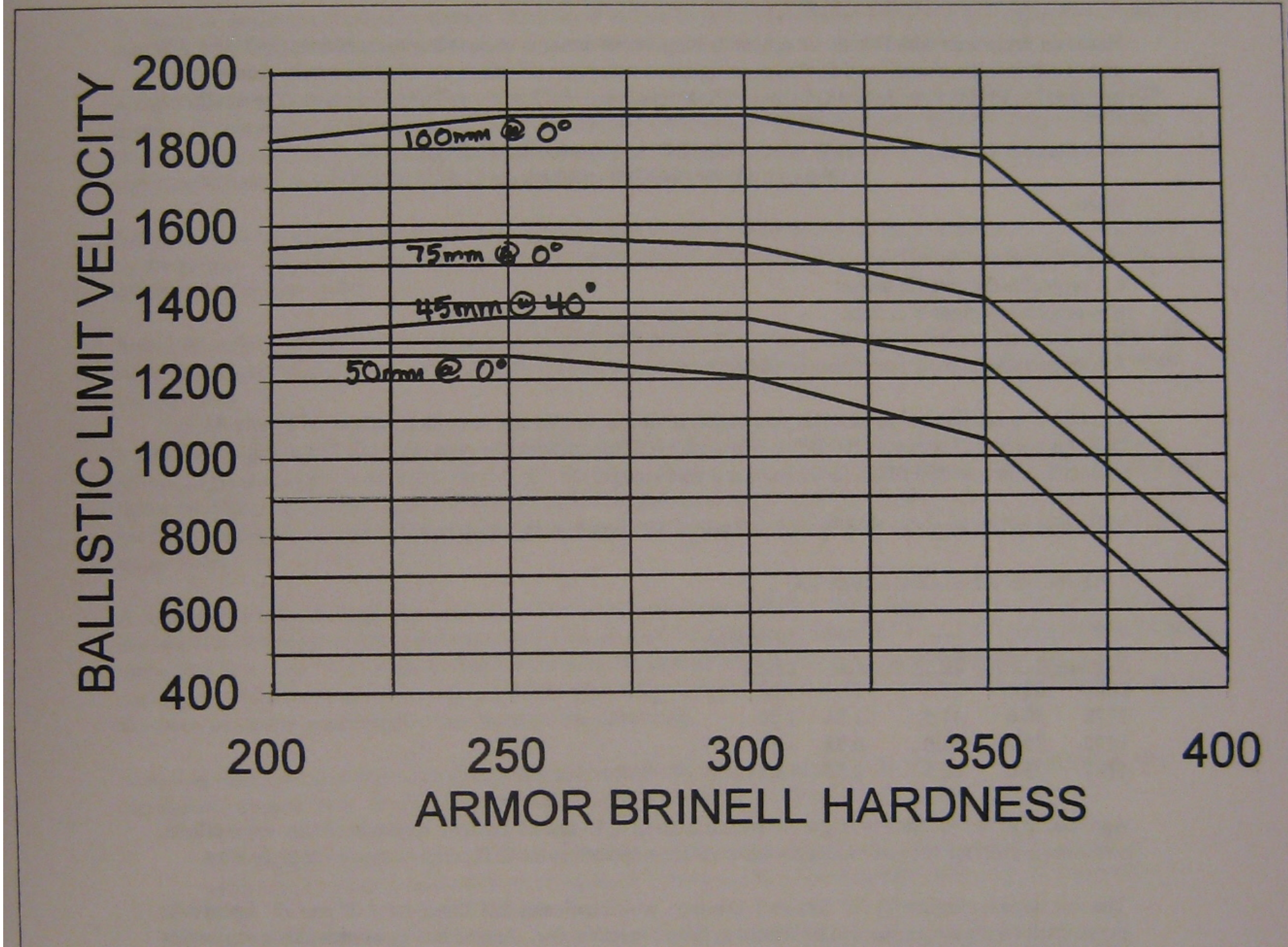
Velocity	0° Pen.	30° Pen.	30° T/D	30° Slope Effect
2600	86.4	67.5	1.69	1.28
1778	50.0	41.5	1.04	1.20
1438	35.0	31.0	0.78	1.13
1167	23.0	22.5	0.56	1.02

Application of the equation to larger AP rounds such as 6, 17 and 25 pounder results in similar slope effects, so 40mm British AP may be modeled with the same slope effect-vs.-T/D curve as larger AP projectiles.

The low slope multiplier for 30° hits on T/D armor, which indicates that 23mm hit at 0° and 30° has similar penetration resistance, appears to be related to failure mechanisms. Angled hits by overmatching projectiles (T/D less than 1.00) tend to penetrate by driving an armor plug through the plate or casting, which is a relatively low energy failure. In comparison, vertical armor may be penetrated by a combination of plugging and push aside.

The energy requirements at 30° and T/D = 0.56 appear to be similar for vertical and 30° plate, which results in a slope multiplier close to 1.00.

NATIONAL PHYSICS LABORATORY EQUATION PREDICTIONS FOR 75mm AP BALLISTIC LIMIT VELOCITY VERSUS BRINELL HARDNESS



Another interesting result is how British 410 BHN armor would resist overmatching hits by 75mm rounds. If a 45mm thick plate at 410 BHN is hit at 40° impact by 75mm AP (somewhat similar to T34 side superstructure under attack with 0° lateral angle), the high hardness armor requires an impact velocity of 452 fps. When 75mm AP attacks the same plate at 260 BHN and 452 fps, 50% penetration is obtained against 9mm armor plate.

Thus, 45mm at 410 BHN is equivalent to 9mm at 260 BHN against 75mm on 40° hits, which suggests that British high hardness armor loses most of its resistance when it is overmatched at T/D=0.6 (45mm/75mm). German and American high hardness armor at 45mm thickness would equal about 34mm of 260 BHN homogeneous armor at T/D=0.6 and 40° impact.

The graph following this page presents computed ballistic limit velocity as a function of armor hardness when 75mm AP strikes British plate. The ballistic limit velocity has a maximum at about 275 Brinell and falls off after 300 Brinell, and decreases rapidly after 350 Brinell. At 400 Brinell Hardness, armor resistance equals about 50% of the maximum except when 45mm at 40° is attacked, where the 400 Brinell resistance is 27% of maximum resistance.

British firing tests against Tiger E armor in North Africa indicated that the 310-330 Brinell side armor resisted penetration with the same resistance as good quality Allied test plate. German and Soviet high hardness armor at 400 Brinell or higher presented superior penetration resistance to British armor at similar hardness.

APPENDIX 1 : <u>KUBINKA TESTS AGAINST PANTHER GLACIS</u>

During September, 1944, Russian firing tests were conducted at Kubinka with 88mm, 100mm and 122mm guns against Panther glacis. Complete details on the test are available on *The Russian Battlefield* Internet site.

Firing at Panther glacis, 88L71 penetrated at 650m, while 100mm and 122mm projectiles penetrated at 1500m and 2500m (report notes that maximum penetration range was greater than 2500m, based on reliable penetration at 2500m).

The listed test results cannot be obtained with 100mm and 122mm AP, due to slope multiplier magnitude. The following calculations and assumptions provide a reasonable match with Kubinka test results:

	88L71 APCBC	100mm APBC	122mm APBC
Pen. Range	625m	1600m	2500m
Armor Thickness	85	85	85
Armor Angle	55°	54.4°	53.4°
T/D Ratio	0.97	0.85	0.70
Slope Multiplier	2.52	1.85	1.64
0° Resistance	214	157	139
Pen. at Range	214	157	118
Armor Quality	1.00	1.00	Less than 0.85

Notes: Various Russian, British and American sources list Panther glacis thickness as 85mm
Armor Quality is 0° weapon penetration at penetration range divided by 0° effective armor resistance when quality is 1.00.

Considers 1.6° descent angle for 122mm and 0.60° for 100mm, and assumes level ground.
Reliable penetrations at 2500m by 122mm suggest that maximum range is greater.
Russian firing test data assumes lower muzzle velocity for 100mm APBC than booklet penetration data, which would decrease estimated penetration range in above table.

The above analysis suggests that 88mm and 100mm hits on Panther glacis struck armor that did not exhibit deficiencies due to flaws or brittleness. The 122mm penetration range is due to lowered plate quality, where armor resistance decreased by at least 15% against the large rounds.

The comment has been raised that the first 800 to 900 Panthers were built with face-hardened glacis armor, and the analysis presented in this section assumes homogeneous armor resistance. The first combat between IS-2 and Panther tanks occurred at a time when Panthers with face-hardened glacis plates were probably widespread.

If the Kubinka test Panthers had face-hardened glacis plates, the predicted penetration range for 88L71 would probably be similar to the above analysis since U.S. tests with 75mm German ammunition suggested equal penetration against homogeneous and face-hardened armor, and slope effects for both armor types might be similar.

Predicting the performance of 100mm and 122mm APBC against 85mm face-hardened plates at 55° is difficult since insufficient data exists to estimate face-hardened penetration. Due to the similarity of reported penetration ranges for 122mm APBC against a number of Panthers during early 1944, it may be reasonable to assume that 100mm and 122mm APBC penetrate the same thickness of face-hardened and homogeneous armor at all ranges.

Since it has been reported that 122mm AP penetrated Panther glacis at about 650m during early 1944, it is likely that a mix of glacis armor types occurred. While 122mm AP has slightly different figures for homogeneous and face-hardened penetration at 650m, the penetration difference is small enough to be less significant than variations in armor quality. The 650m Penetration of a face-hardened Panther glacis by 122mm AP would require an armor quality multiplier of 0.74, which is lower than the predicted homogeneous factor but is consistent with an increased sensitivity of face-hardened armor to flaws.

The penetration range of 122mm ammunition against Panther glacis is often listed as 1500m, which would associated with an armor quality of 1.00 against homogeneous armor (no reduction due to flaws). This suggests that a good percentage of Panther glacis armor was of good to excellent quality, and able to resist overmatching hits by 122mm projectiles without armor cracking or premature plug failure.

APPENDIX 2 : KUBINKA TESTS AGAINST TIGER II

During late 1944, Russian firing tests were conducted at Kubinka with 76mm, 85mm, 88mm, 100mm and 122mm guns against a captured Tiger II. Complete details regarding the test are available on *The Russian Battlefield* Internet site (Archives section, *Was the Tiger really King?; Testing the King Tiger at Kubinka)*.

Firing against the Tiger II turret front, penetrations by 100mm and 122mm guns were obtained at 1000m to 1500m range. Using slope effect data for APBC projectiles, turret front armor resistance would equal 189mm at 0° against both rounds. It is not possible to determine projectile penetration with precision due to

incomplete data on exact ranges, however 122mm APBC penetration at 1000m and 100mm APBC penetration at 1500m equals about 162mm at 0°, which suggests a quality factor of 0.86 (162/189) for Tiger II turret front.

It should be noted that the firing tests against Tiger II turret front were conducted after removal of the gun and mantlet, and resulted in penetrations close to armor openings such as vision slits and gun location. Photo 7 in the article shows a 100mm projectile penetration to the right of the gun opening which may have been influenced by previous hits or armor damage.

On tests against Tiger II turret and superstructure side armor, 800m-2000m penetrations were obtained with 85mm and U.S. 76mm guns, with 76mm APCBC obtaining penetrations at much longer distances than the 85mm projectiles.

Using booklet equations for APCBC slope effect, Tiger II side armor would present 89mm at 0° turret side resistance to 76mm hits, and side superstructure resistance of 94mm at 0°. Comparing 76mm APCBC penetration data to armor resistance results in a 2000m penetration range against the turret side, and 1700m against the superstructure side. Since actual test results at Kubinka yielded a maximum penetration range of 2000m, armor on the Tiger II side superstructure appears to be equal in resistance to good quality American test plate.

Using the stated advantage of U.S. 76mm over 85mm in the article, 85mm penetration ranges during the tests are estimated at 800m against the side superstructure and 1350m versus the turret side. The following table analyzes 85mm penetration and armor resistance at the indicated ranges:

PROJECTILE	800m Pen.	1350m Pen.	Turret Side Armor Resistance	Superstructure Side Armor Resistance
85mm AP	103	83	82	88
85mm APBC	109	91	85	88

The 85mm AP penetration at 1350m matches up well with the armor resistance figure for the turret side. However, 85mm AP penetration at 800m equals 103mm at 0°, which exceeds the side superstructure armor resistance by 17%. If the test was conducted with 85mm AP, it is possible that the 800m penetration range represents a "shatter gap" limit, and penetration would also be possible at ranges exceeding 1050m.

If the test is assumed to have used 85mm APBC, data for the 1350m penetration range compares 91mm penetration to 85mm armor resistance, a 7% variation that might be explained on the basis of random differences and hit location on turret side (angles change). As in the case of 85mm AP, the 800m penetration range results in a wide discrepancy between penetration (109mm) and armor resistance (88) that might be due to any number of factors, including "shatter gap".

The following table compares 85mm APBC and U.S. 76mm APCBC penetration at 0° as a function of range:

	0° PENETRATION			
PROJECTILE	500m	1000m	1500m	2000m
85mm APBC	121	102	88	77
76mm APCBC	116	106	97	89

APPENDIX 3 : U.S. 76mm HVAP VERSUS APCBC

The relative accuracy and penetration of 76mm HVAP and APCBC ammunition is often discussed, since HVAP lost velocity faster which suggests less effectiveness at longer ranges.

The following analysis presents maximum first shot accuracy estimates for both projectiles based on 25% average range estimation error, and penetration against 0° armor:

PROJECTILE	500m Hit %	0° 500m Pen.	1000m Hit %	0° 1000m Pen.	2000m Hit %	0° 2000m Pen.
76mm APCBC	97%	116	41%	106	7%	89
76mm HVAP	100%	208	57%	175	11%	124

Despite higher percentage losses in velocity and 0° penetration with range, 76mm HVAP is superior at all ranges against thick armor at low impact angles, although APCBC may have greater penetration on steeply angled hits beyond 1000m range:

1000m PENETRATION VERSUS COMPOUND IMPACT ANGLE

PROJECTILE	30° Pen.	40° Pen.	50° Pen.	60° Pen.
76mm APCBC	83	69	54	40
76mm HVAP	127	92	63	41

APPENDIX 4 : APDS ACCURACY AND PENETRATION

APDS ammunition is often held to be extremely accurate due to high muzzle velocity and relatively low velocity loss with range. In addition, 17 pounder APDS has exceptional penetration against vertical and sloped armor. Against 57° slope plate with 85mm thickness (typical conditions at Isigny), 17 pounder APDS would be expected to penetrate best quality armor at about 500 meters and deficient armor to further ranges.

Expectations regarding 17 pounder APDS were not borne out by U.S. tests at Isigny, France, during August 1944.

The following is a summary of 17 pounder APDS performance at Isigny:

200 yards, three hits with one penetration
300 yards, three hits without penetration
400 yards, one penetration on six fair hits
600 yards, two hits without penetration
700 yards, two hits without penetration

In terms of being able to hit the tank in a selected location (glacis or nose), 76mm HVAP and 17 pounder APCBC averaged 83% and 87% accuracy while 17 pounder APDS attained 53%.

During U.S. Army tests during July 1944, effectiveness of APDS fired by 57mm gun M1 could not be determined due to "difficulty experienced in obtaining hits".

The reduced effectiveness and accuracy of 17 Pounder APDS has been attributed to a number of factors, including muzzle brake impacts, uneven shedding of sabot pieces, sensitivity to turbulent variations in exhaust gas pressures and bad rounds that escaped quality control measures. While the notes on the Isigny tests include reference to 700 yard penetration of Panther glacis in previous tests at Balleroy, many British firing tests with APDS suggest that inconsistent and occasionally wild performance was not uncommon (which could cause complete misses against Panther targets).

War game or research modeling of WW II APDS should be based on a certain degree of random erratic behavior, where about half of APDS rounds might have reduced accuracy and penetration.

The Isigny test results provide some additional insights into Panther armor characteristics.

Penetrations of Panther weld lines at Isigny, where glacis and nose meet, suggest that resistance is reduced by - 32% from solid armor plate.

The Isigny Panther glacis plates had measured angles from vertical of 57.6°, 57.1° and 56.9°, due to ground slope. Assuming 85mm plate thickness, 0° equivalent resistance of good quality Isigny glacis armor would equal 248mm, 240mm and 236mm against 76mm hits, which would defeat 17 pounder hits despite reductions in armor quality from medium or high severity flaws.

Against Panther glacis with medium flaws and 85mm plate at 55°, armor resistance would still exceed 17 pounder APCBC penetration at all ranges (212mm vertical equivalent resistance after 0.95 flaws multiplier).

In terms of overall armor quality conclusions that might be drawn from Isigny and other tests, two of three target Panthers at Kubinka appear to have had good quality glacis armor, two of three targets at Isigny had brittle glacis armor. Panther fired at during U.S July tests allowed 600 yard glacis penetration by 90mm M77 AP, which would require an armor quality of 0.59 and appears questionable: armor may have contained unobserved cracks prior to hit.

For 76mm HVAP to penetrate Isigny Panther glacis at 200 yards, armor quality of 0.76 is required.

The nose armor on Isigny Panthers resisted penetration in a manner that suggests good quality plate.

Reports presented on *The Russian Battlefield* suggest that Panther glacis armor possessed deficient resistance in a considerable number of cases. For 122mm AP, a penetration range of 700 meters is quoted. Against 85mm of good quality armor at 55° slope, 122mm AP would face equivalent vertical resistance of 213mm, requiring 0.83 armor quality for 10% success at 700m.

The British conducted extensive firing tests with Firefly tanks to compare the dispersion and jump at constant aim of APDS and APCBC. The results are contained in WO 291/770, which is held by the British Public Records Office, and indicate that APDS has 70% higher shot-to-shot scatter than APCBC, on average.

APPENDIX 5 : GENERAL QUALITY OF PANTHER ARMOR

The following items present test penetration ranges against non-glacis Panther armor areas and compare estimated armor resistance to published penetration figures, with the results suggesting that Panther front lower hull and side upper hull armor was equivalent to U.S. good quality penetration test plate.

It should also be noted that the critical penetration ranges during the July 1944 tests were first conducted against damaged or burned Panther tanks, and were then verified against vehicles in good condition, so results are representative of a fair sized sample of Panther tanks.

RHA is rolled homogeneous armor
FHA is face-hardened armor
Panthers apparently came in two versions, where side hull and superstructure armor could be homogeneous or face-hardened, and Panther side hull either 40mm at 40° on Panther A & D, or Panther G 50mm at 30°

1.
37mm APCBC pen. upper hull side at 600 yards (40 @ 40° or 50 @ 30°)

RHA Pen.	:	42mm at 40° & 53mm at 30°
FHA Pen.	:	41mm at 40°
Conclusion	:	Armor equivalent to U.S. test armor quality
Source	:	July 1944 firing test identified in previous appendix

2.
40mm AP pen. upper hull side at 600 yards (40 @ 40° or 50 @ 30°)

RHA Pen.	:	37mm at 40° & 47mm at 30°
FHA Pen.	:	40mm at 40°
Conclusion	:	Armor roughly equivalent to U.S. test armor quality
Source	:	July 1944 firing test identified in previous appendix

3.
76mm HVAP pen. 67mm @ 53° hull front nose at 400 yards, 1 of 2 fair hits

RHA Pen.	:	69mm at 53° (ground slope is 2°)
Conclusion	:	Resistance roughly equal to U.S. test plate
Source	:	August 1944 tests at Isigny

4.
76mm HVAP fails to pen. 67mm @ 53° hull front nose at 600 yards, 2 hits

RHA Pen.	:	65mm at 53° (ground slope is 2°)
Conclusion	:	Armor equivalent to U.S. test plate quality
Source	:	August 1944 tests at Isigny

5.
17 Pounder APCBC pen. 67mm at 53° hull front nose at 600 yards, 1 fair hit

RHA Pen.	:	70mm at 53° (ground slope is 2°)
Conclusion	:	None
Source	:	August 1944 tests at Isigny

6.
17 Pounder APDS pen. 67mm at 53° hull front nose twice at 400 yards, 2 hits

RHA Pen.	:	105mm at 53° (ground slope is 2°)
Conclusion	:	None
Source	:	August 1944 tests at Isigny

7.
76mm APCBC fails to pen. 67mm at 53° hull front at 400 yards, 2 fair hits

RHA Pen.	:	55mm at 53° (ground slope is 2°)
Conclusion	:	Armor exceeds 85% of test plate resistance
Source	:	August 1944 tests at Isigny

8.
17 Pounder APCBC pen. 67mm at 53° hull front nose at 400 yards, 1 fair hit

RHA Pen.	:	73mm at 53° (ground slope is 2°)
Conclusion	:	None
Source	:	August 1944 tests at Isigny

Note: Due to small number of rounds fired and statistical variability in penetration results, above analysis suggests that Panther side hull and front nose armor was equal to U.S. penetration test plate in terms of effective resistance.

British notes on John Salt site suggest that Tiger and Panther armor quality is comparable to British machineable quality armor, and reports on *The Russian Battlefield* imply that Tiger and Panther armor was generally good, although firing tests against Panther glacis suggest inconsistent glacis resistance.

APPENDIX 6 : <u>THEORETICAL HIT PROBABILITY METHOD</u>

The trajectory of WW II anti-tank projectiles may be modeled with the following equation, providing sufficient accuracy to meet war game and research uses:

Trajectory height above at any point = 1.234 x 4 x ((flight time to point under study) x (flight time to gun range setting) - (flight time to point under study)^2)

The equation may be modified to consider the trajectory height over a target aim point and gun elevation differences from target point, as follows:

Estimated aim error =

1.234 x 4 x ((flight time to target) x (flight time to aim range) - (flight time to target)^2)

+ H x (1 - (target range/aim range))

H is gun barrel elevation above target aim point.

If Tiger E is firing at an 800m target, and aims at 1000m due to incorrect range estimation, projectile flight times are 1.07 seconds to 800m and 1.35 to 1000m. Assume gun barrel is at same elevation as target aim point, so H is zero. Flight time to target is 1.07 seconds, flight time to aim range is 1.35 seconds.

Estimated flight error from above equation is 1.48m over aim point.

A more exact solution to the abovementioned problem, using trajectory equations, is 1.53m over aim point.

If Tiger E hit percentage against a 2.0m high by 2.5m wide target at 800m is required for bell-shaped distribution of range estimation errors (25% average), the procedure uses the following steps when gun barrel is at same elevation as target aim point:

1.
Standard deviation for average range estimation error is average error divided by 1.32 (25%/1.32=18.94%).

2.
Procedure aim range equals target range by (100% + step one result), or 800m x 118.94% = 952m.

3.
Determine flight times to target and aim range, 1.07 seconds to 800m and 1.28 to 952m.

4.
Determine aim error for step 3 conditions using Estimated Aim Error equation, for 1.11m over aim point on target.

5.
Determine dispersion standard deviation at target range, which is found to be 0.44m on German ballistic tables.

6.
Combined standard deviation equals:

$((\text{step 4 result})^2+(\text{step 5 result})^2)^{0.5}$, for 1.19m.

7.
Vertical standard deviations equal half target height divided by step 6 result,
1.0/1.19 = 0.84

8.
Define step 7 result as N. Then Hit % equals area under normal distribution curve for N standard deviations, or

$\text{Hit \%} = -.0659 + 80.685 \times N - 2.164 \times N^2 - 13.276 \times N^3 + 3.053 \times N^4$,

and Hit % for N = 0.84 is 60%.

60% probability that vertical trajectory will land within 1.0m of aim point, and hit target vertical height, when average range estimation error is 25%.

9.
Use lateral dispersion to determine number of lateral standard deviations and consult step 8 equation for hit %. Lateral dispersion for 68.26% of shots at 800m is 0.30m. Half of width, or 1.25m, contains 4.17 standard deviations (1.25/0.30), which includes 100% of lateral shot spread.

10.
Overall hit probability equals vertical hit % multiplied by lateral hit %, for 60%.

11.
If 6m wide hull target is moving directly across line of sight, impact on accuracy may be roughly estimated by adding 30% of lead in meters to lateral dispersion using step 6 equation, which considers error in estimating target speed and assigning lead. 30% figure is assumed error in target lead, based on review of British report for average gunners on firing range.

Say target is moving at 12 mph (19.3 kph) across firer view at 800m, lead on target to hit center equals speed across view multiplied by projectile flight time, or 5.74m times 0.30, or 1.72m. Step 6 combination of lateral standard deviations equals 1.75m. Half of hull width divided by combined standard deviation is 1.72, for 91% hit probability against hull.

If turret is 2.2m wide, number of lateral standard deviations within half-width is 1.1/1.75, 0.63 standard deviations and 47% hit chance.

Referring back to the analysis of bunched hits at close range (see table below this paragraph), the statistics would suggest that misses were virtually unknown at range below 250m, and tank crews can be accurately modeled with statistical probabilities and functions.

TARGET RANGE	% OF SHOTS WITHIN 0.305m OF AIM POINT
50m	99%
100m	97%
150m	93%
200m	88%
250m	82%
300m	74%

Note: Probability for hit bunching around aim point would be higher with 76mm HVAP.

Another statistical figure that would tend to support almost 100% hit percentage against targets within 500m is the fact that if a gun is aimed at 1000m range and the target is at 100m, the trajectory will only be 0.77m above target center of mass, which should result in close to 100% hits against most tanks. (gun elevation same as target aim point).

The fact that misses occur at ranges against stationary targets within 500m suggests that various human factors enter the picture and disrupt the statistical purity of tank combat modeling. To fire shots by the side of a

stationary target within 500m, turret rotation must be stopped and the fire command issued before the gun is on the target (unless the target is tilted in a ditch, which is generally not the case).

To fire over or under a target inside 250m, and especially against tanks at 100m, weapon range settings must contain errors that go well beyond what occurs on the test range or would be predicted by a nice bell-shaped statistical curve. Fear, exhaustion, hurry and a host of other factors enter the picture and tend to reduce the hit percentages that are predicted.

It may be prudent to place maximum hit percentages on all crews to model the unexpected and illogical results that sometimes occur, with lower maximums for less experienced crews.

The following maximum hit probabilities have been proposed by researchers and war game players for shots in the 100 to 250m range:

Elite	90%
Veteran	85%
Experienced	80%
Regular	75%
Green	65%
Militia	50%

The above figures are very much lower than would be predicted by equations assuming likely errors in range estimation and aim point, and have been explained by the following reasoning from Conall:

"the ability to operate a weapon system effectively is a combination of training, experience, leadership and morale, with the last factor depending on the situation and whether the firer is under fire or extreme stress. It is quite remarkable how frequently soldiers, even well trained ones, manage to miss easy targets, especially when heavily fatigued and stressed."

It has also been proposed to limit the full theoretical benefits of second shot accuracy increases to Elite and Veteran crews, with lower benefits to other levels and little or no improvements to the lowest crew types.

It is also important to note that prepared defenses often have time to set range markers on likely enemy lines of advance, or prepare range cards based on prominent land marks. These procedures will increase the accuracy of defensive fire and add to first fire advantages.

While Russian hit accuracy is often assumed to be poor, many German reports in Jentz' books point to superior accuracy from T34, KV-II and KV-I tanks at very long ranges, with initial engagement ranges of 1200 to 1800 meters and a high probability of first round hits.

APPENDIX 7 : ADDITIONAL NOTES ON GUN ACCURACY

The trajectory of anti-tank gun fire can also be reasonably modeled with the following equation:

Trajectory height above aim point =

A x (target distance)^2 + B x (target distance)

+ H x (1 - (target distance/aim range))

Where;

$$A = \frac{\text{max trajectory height}}{(C - D)}$$

B = -A x Aim Range (equals descent angle in radians),

E = gun elevation above target aim point

max trajectory height equals 1.234 x (flight time)$^{1.998}$

C equals 0.4443^2 x Aim Range$^{2.0448}$

D equals 0.4443 x Aim Range$^{2.0224}$

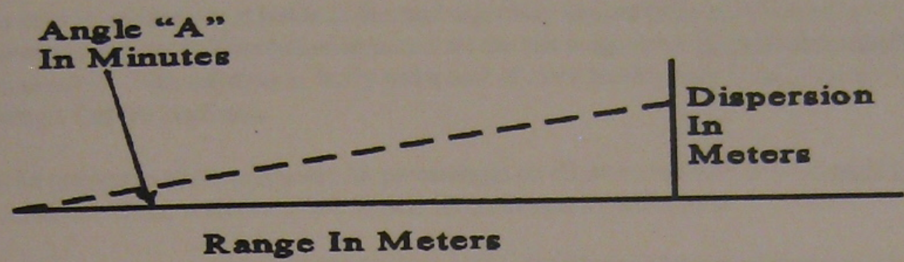
Assume target at 1000m, aim point at same elevation as gun, commander estimates aim range as 800m (+25% error, which is typical for average crews) and flight time to 800m is 1.10 seconds. Max trajectory height is 1.49m.

A = -0.000009340

B = 0.007472 (this figure is also the descent gradient at the aim range of 800m, which is equal to 0.428°, 0.007472 radians and 7.47 mils)

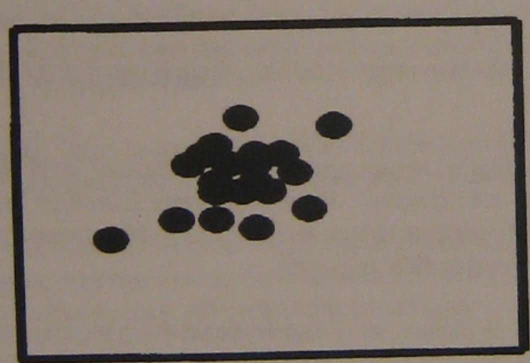
The trajectory height above aim point at 1000m with 800m weapon range setting would equal -0.000009340 x 1000^2 + 0.007472 x 800, or 1.87m below aim point (-1.87m result). If the target were 2.2m high from hull bottom to turret top, aiming at the middle of a 2.2m high target at 1000m and estimating 800m range would put the shot 0.77m below target aim point (shot hits ground in front of target).

Random shot-to-shot variations in trajectory height, due to dispersion or scatter, could bring the trajectory back onto the target. When dispersion is given in terms of minutes at a given range for 68.26% of shots, this means that the product of the range and the tangent of the angle in degrees (divide minutes by 60) yields the distance from aim center which includes 68.26% of scatter.



Dispersion = Range x Tangent ("A"/60)

RELATIONSHIP BETWEEN DISPERSION CURVE FIGURE IN MINUTES AND DISPERSION DISTANCE IN METERS



WHEN REPEATED SHOTS ARE FIRED WITH CONSTANT AIM, IMPACT POINTS WILL SCATTER AROUND PATTERN CENTER : DISPERSION IS DEFINED BY DISTANCE FROM CENTER THAT INCLUDES A SPECIFIED PERCENTAGE OF SHOTS

The accuracy figures that are often quoted for guns and ammunition at constant aim represent the probability that the weapon scatter will fall within a certain target size, and are not related to actual battlefield hit probability. The ability to hit a target is a function of range estimation error, cant, wind and shot-to-shot dispersion.

A vertical dispersion of 1.5 minutes at 1000m for 68.26% of scatter would represent a distance of 1000m x tangent (1.5/60), or 68.26% of shots will land within 0.44m of aim center.

The following projectiles appear to qualify for dispersion patterns smaller than "average", based on review of dispersion pattern hit percentages in Thomas Jentz series of books:

88L71 APCBC	good
Tank 88L56 APCBC	very good
50mm APC	very good
75L70 APCBC	very good
76mm APCBC	excellent
76mm HVAP	excellent
17 Pounder APCBC	good
128mm APC	excellent

Graphs following this page depict actual dispersion data for WW II weapons. APDS dispersion with "bad" ammunition would tend to be several times larger than average figure, based on analysis of accuracy data.

Graphs following the dispersion information explore accuracy considerations regarding flight time and gun elevation relative to target.

88L71 APCBC has lower flight time than 75L48 APCBC, and trajectory will be lower for "88". Comparison of trajectory graphs for 88L71 and 75L48 shows that flatter trajectory will result in hits against an 800m target with a larger allowable set of range estimation errors.

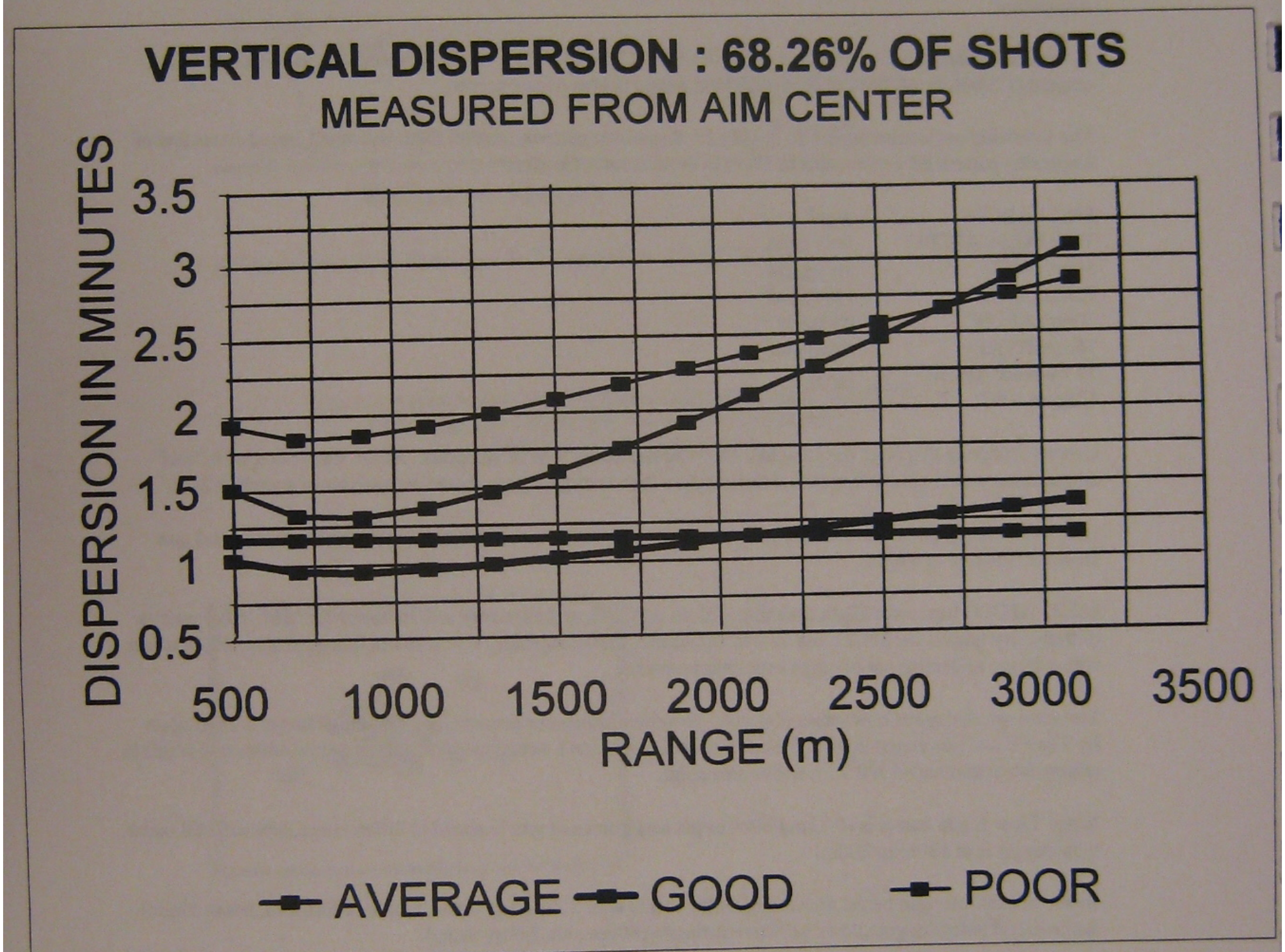
The third graph depicts how target aim point elevation influences accuracy. If 2.2m high target is fired upon by Tiger E and gun range is set at 800m (aim at target center), actual target distances below 640m will result in misses when gun barrel is 0.73m above aim point.

When Tiger E gun barrel is -0.73m below target aim point and gun is aimed at 800m range, hits will still occur when target is at 530m to 800m.

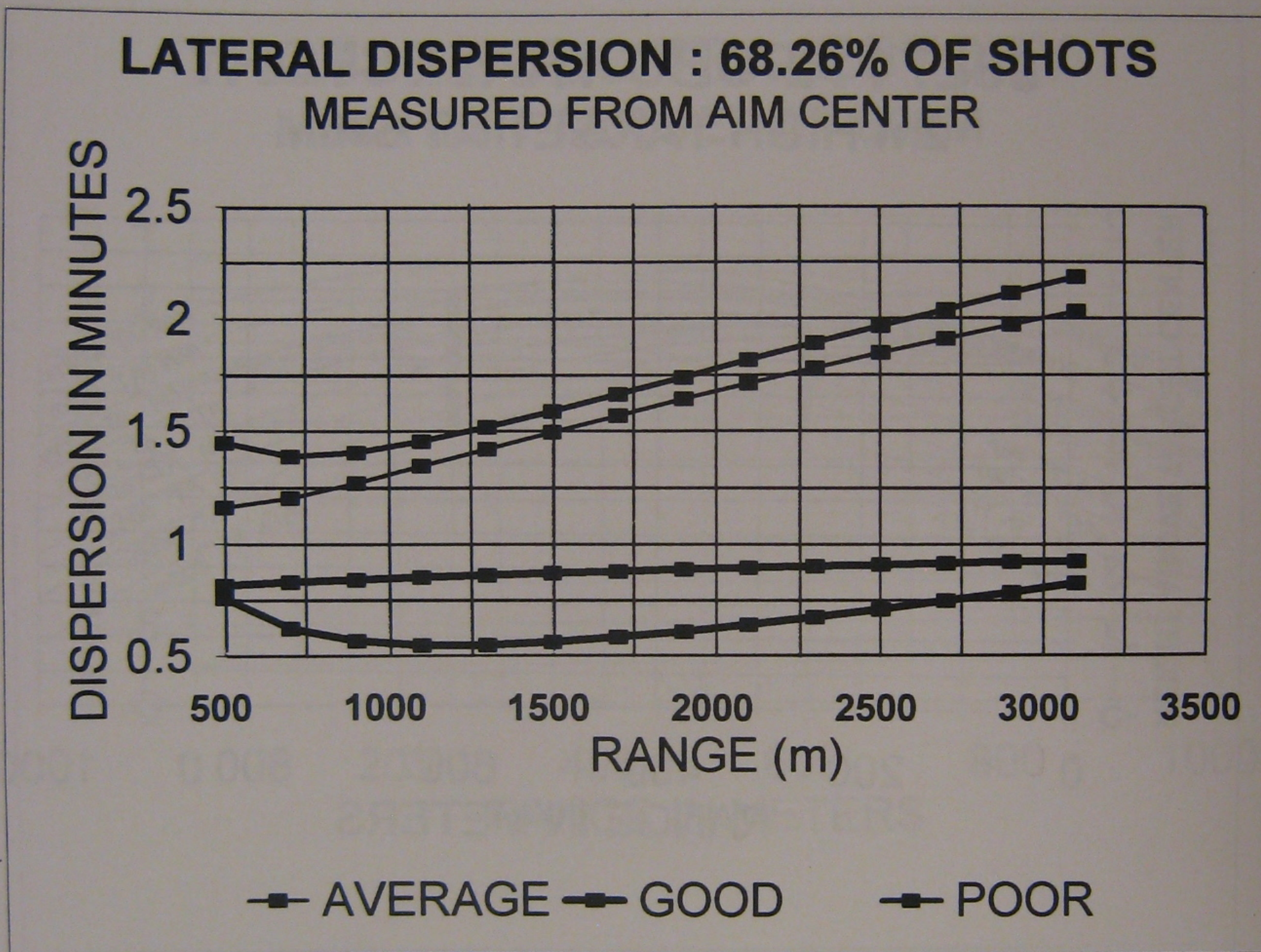
In above example, gun barrel above target allows hits with 25% range overestimate (800m aim, 640m target) while barrel below target allows 51% overestimate (800m aim, 530m target).

Combining trajectory equations for target aim points at gun barrel elevation with double dispersion data results in the first shot hit probability curves that follow gun elevation graphs. German sources suggest that dispersion figures be doubled to simulate battlefield problems and errors that do not show up on test firing ranges.

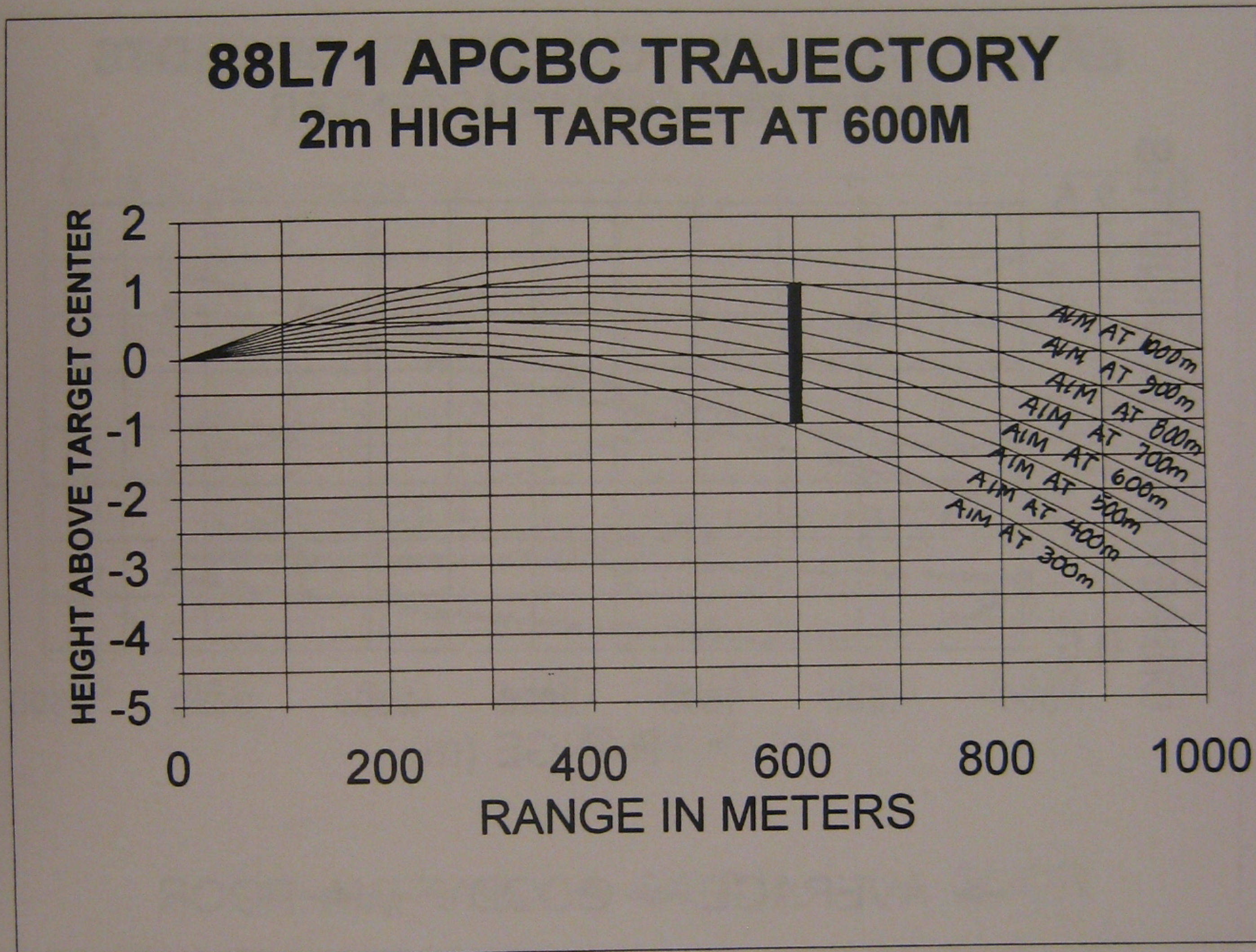
Dispersion is a random factor that will vary from 0 to three times the 68.26% distance on a shot-to-shot basis, and may occur left or right, and high to low.



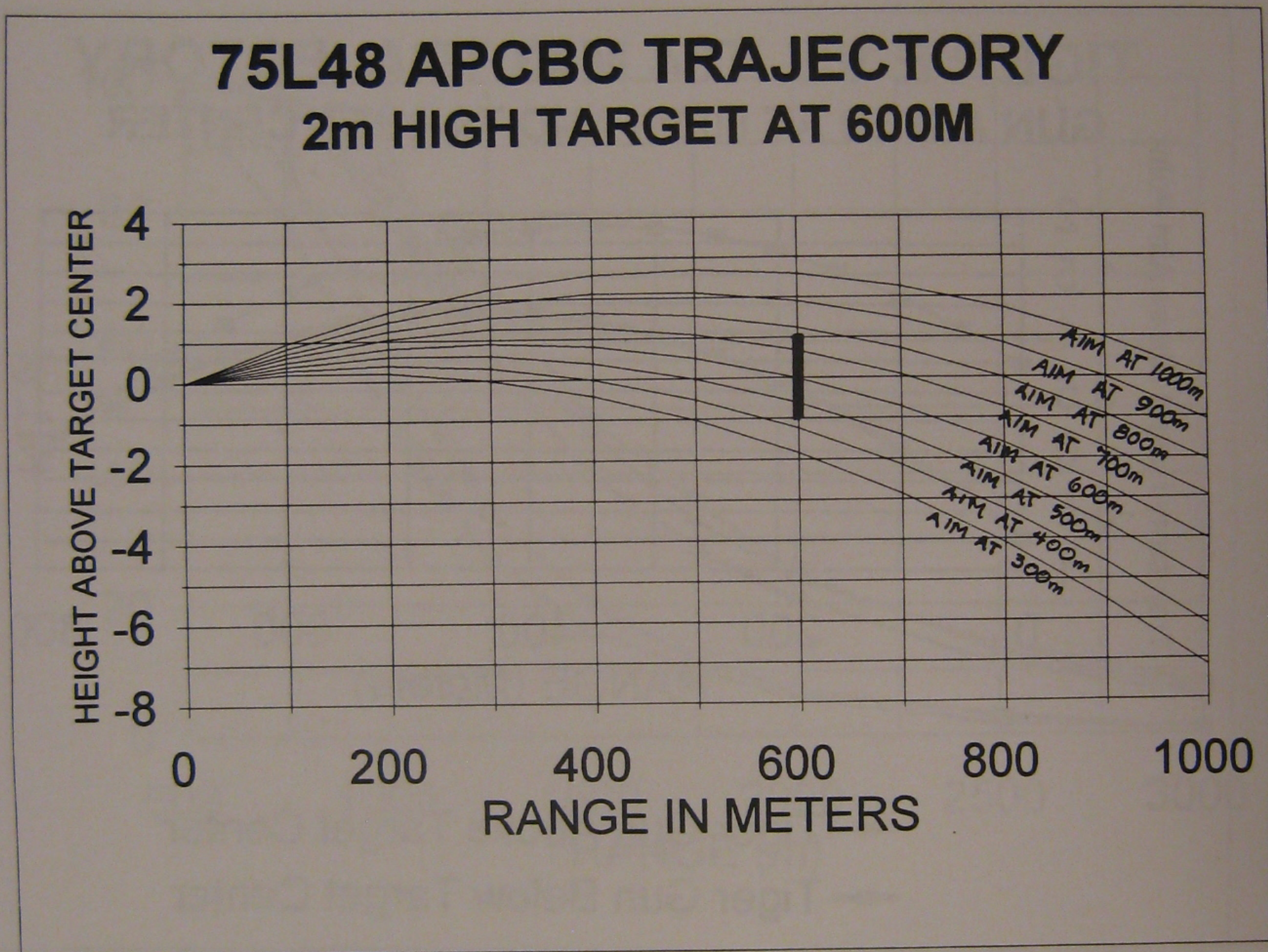
VERTICAL DISPERSION : 68.26% OF SHOTS
MEASURED FROM AIM CENTER
DISPERSION IN MINUTES
3.5
3
2.5
2
1.5
1
0.5
500
1000
1500
2000
2500
3000
3500
RANGE (m)
AVERAGE
GOOD
POOR



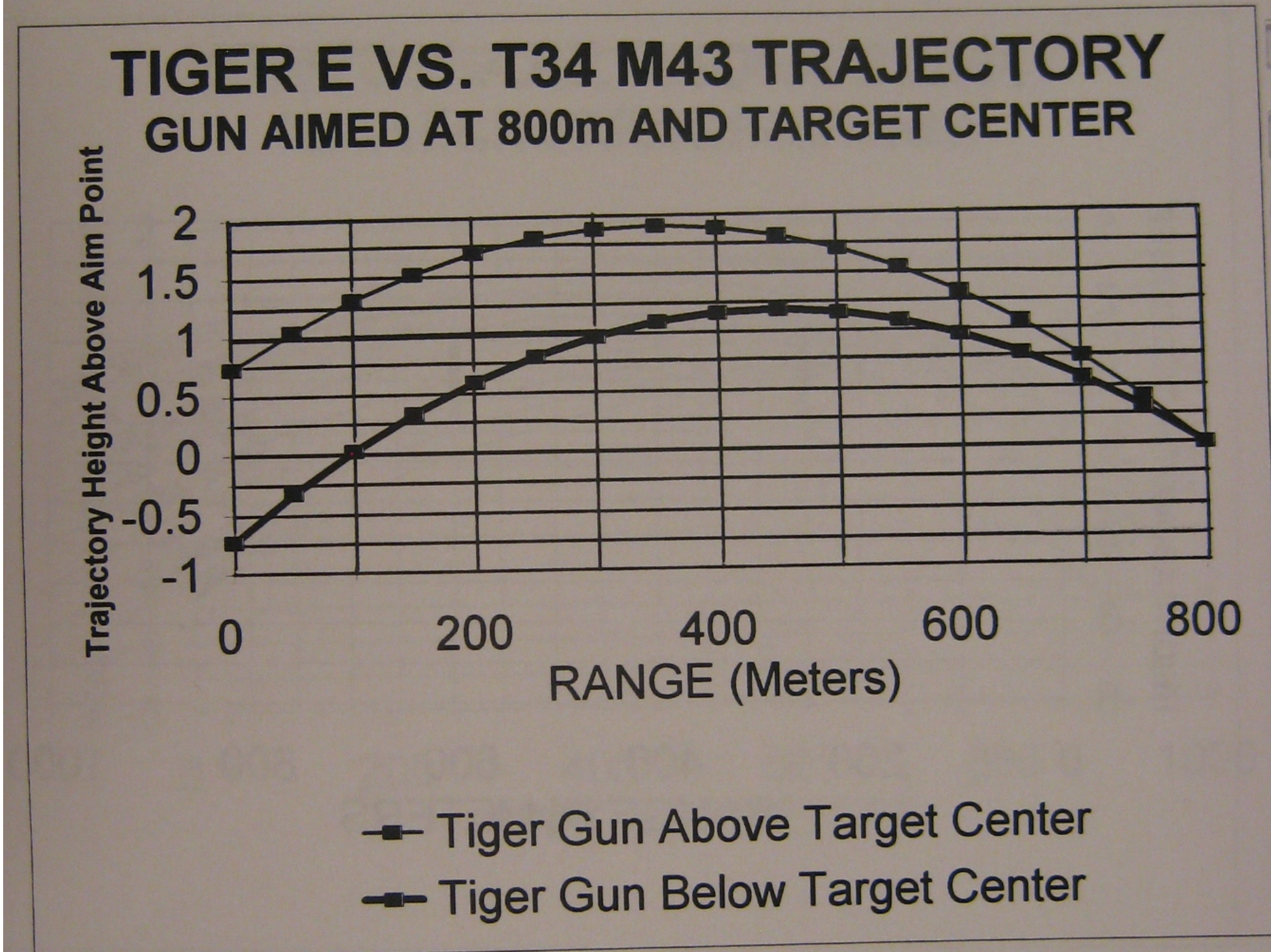
LATERAL DISPERSION : 68.26% OF SHOTS
MEASURED FROM AIM CENTER
DISPERSION IN MINUTES
2.5
2
1.5
1
0.5
500
1000
1500
2000
2500
3000
3500
RANGE (m)
AVERAGE
GOOD
POOR



AGAINST 2m HIGH TARGET AT 600m, 88L71 APCBC TRAJECTORY WILL PASS THRU TARGET ON RANGE SETTINGS FROM 318m TO 900m

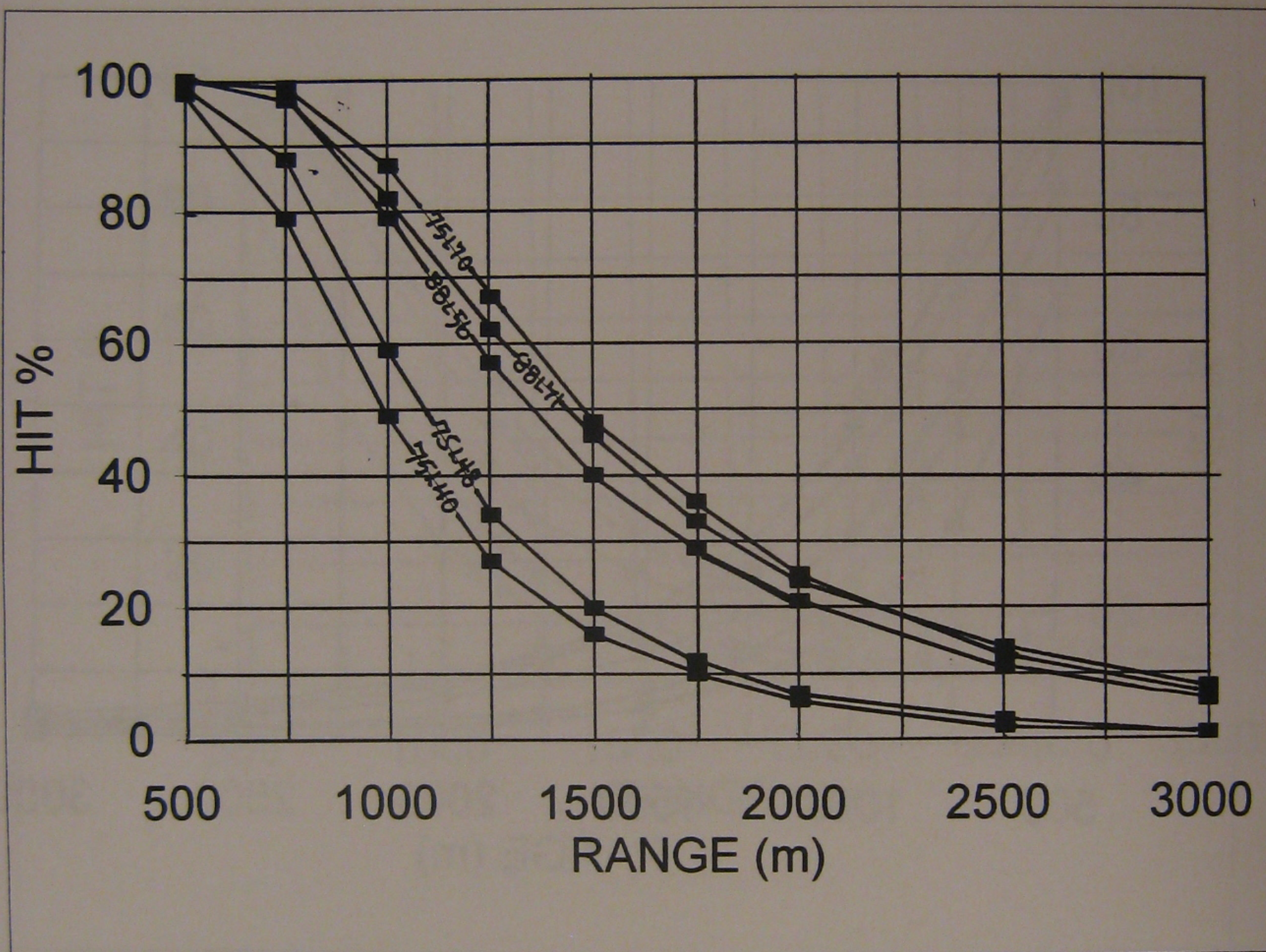


AGAINST 2m HIGH TARGET AT 600m, 75L48 APCBC TRAJECTORY WILL PASS THRU TARGET ON RANGE SETTINGS FROM 435m TO 765m



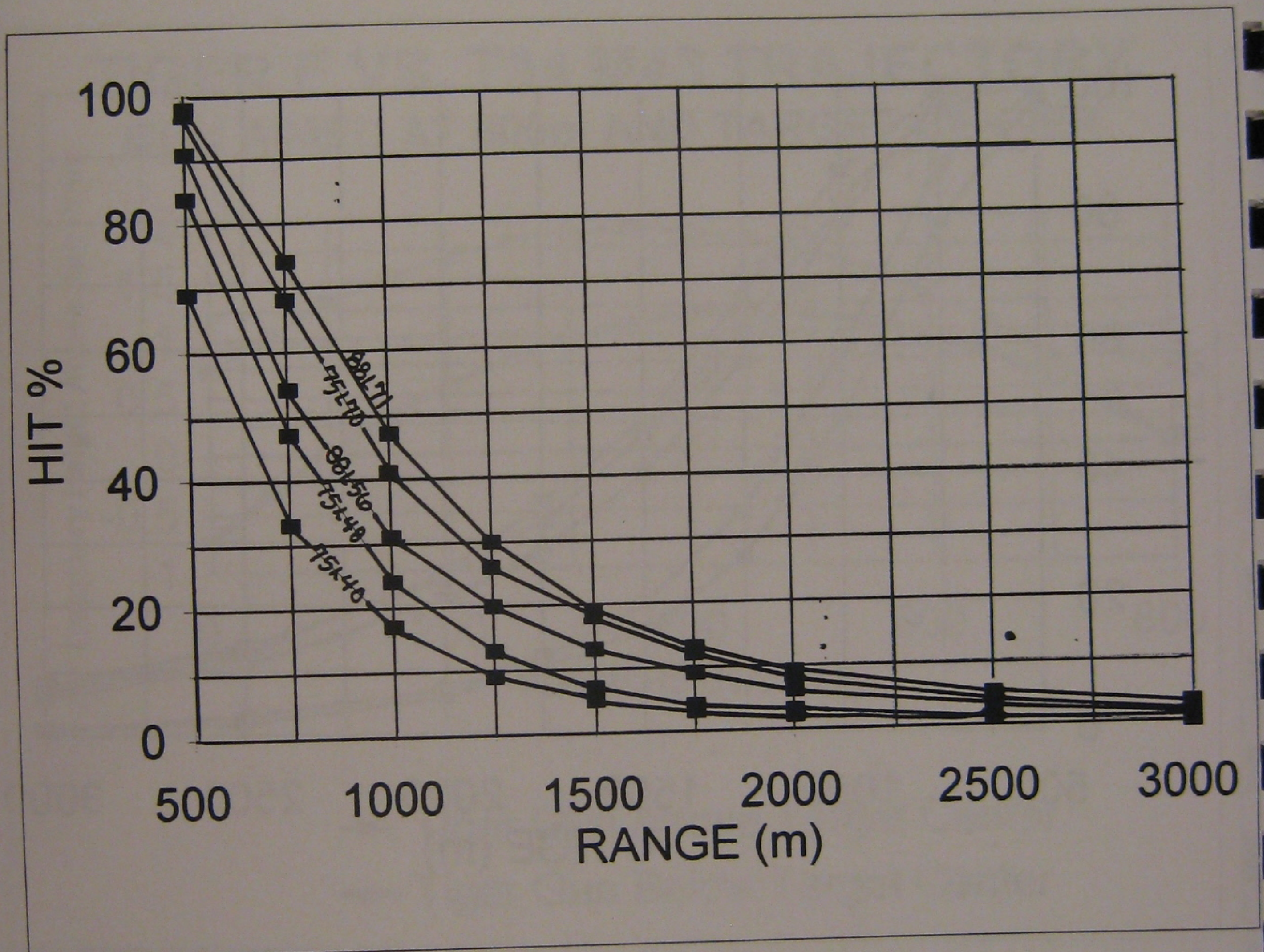
TIGER E VS. T34 M43 TRAJECTORY
GUN AIMED AT 800m AND TARGET CENTER
Trajectory Height Above Aim Point
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
RANGE (Meters)
Tiger Gun Above Target Center
Tiger Gun Below Target Center

HIT PROBABILITY VS. 2m X 2.5m TARGET



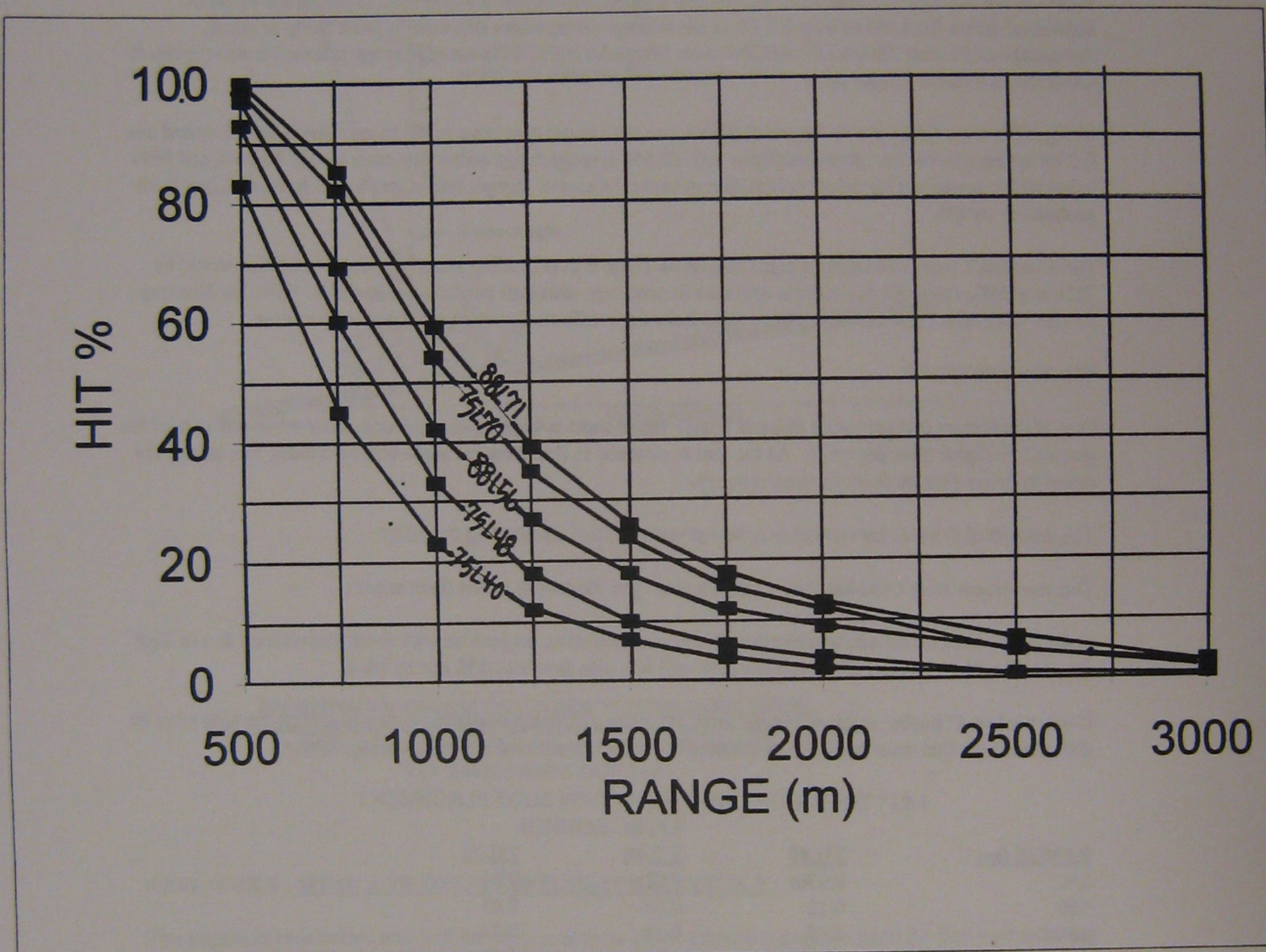
MAXIMUM COMPUTED HIT PROBABILITY
VS. STATIONARY TARGET
BASED ON ACTUAL DISPERSION, IDEAL CONDITIONS
AND 10% AVERAGE RANGE ESTIMATION ERROR

HIT PROBABILITY VS. 2m X 2.5m TARGET



MAXIMUM COMPUTED HIT PROBABILITY
VS. STATIONARY TARGET
BASED ON ACTUAL DISPERSION, IDEAL CONDITIONS
AND 35% AVERAGE RANGE ESTIMATION ERROR

HIT PROBABILITY VS. 2m X 2.5m TARGET



MAXIMUM COMPUTED HIT PROBABILITY
VS. STATIONARY TARGET
BASED ON ACTUAL DISPERSION, IDEAL CONDITIONS
AND 25% AVERAGE RANGE ESTIMATION ERROR

The hit probability curves represent maximum percentages that are obtained under ideal conditions: no wind, moderate temperature, fairly new gun, even ground under vehicle, clearly observed vehicle, aligned gun and sight, etc. Average range estimation errors of 10%, 25% and 35% were used to develop the curves, which relates to the average estimate error when a bell-shaped distribution curve is used to model the range of individual errors from 0% to over 2.5 times the average error, where 0% error is most likely to occur. Advantage of Panther 75mm L70 APCBC over 88mm L71 with 10% average range estimation error is due to lower dispersion for 75mm gun.

If Tiger E's were firing at two targets at 500m, one with target aim point equal to gun barrel elevation and one 0.73m below gun barrel, hit probabilities with 26.4% average range estimation error would be 94% and 88% using above equation (2m target height, aim at center of mass). Target below gun barrel lowered Tiger E hit probability by 6%.

For Sherman 75mm L40 firing at same targets as Tiger E in preceding situation, hit probabilities would be 75% and 69%, resulting in a similar decrease in accuracy, although percentage change is -8.0% for Sherman 75 and -6.4% for Tiger 88. Target elevation below gun affects slower moving projectiles more.

TRUNNION CANT

One of the factors that primarily impacts longer range shots is trunnion cant, which occur when one side of the gun will be higher than the other. As the gun is elevated to fire, a lateral angle will be created that causes the round to move sidewards along the trajectory.

The amount of the side movement may be estimated with the following equation:

Side movement from trunnion cant = range x sine (gun elevation) x sine (cant angle).

Since lower velocity rounds will require greater gun elevation, projectiles with flatter trajectories due to high speed will be less impacted by trunnion cant, and will also face less drift due to wind.

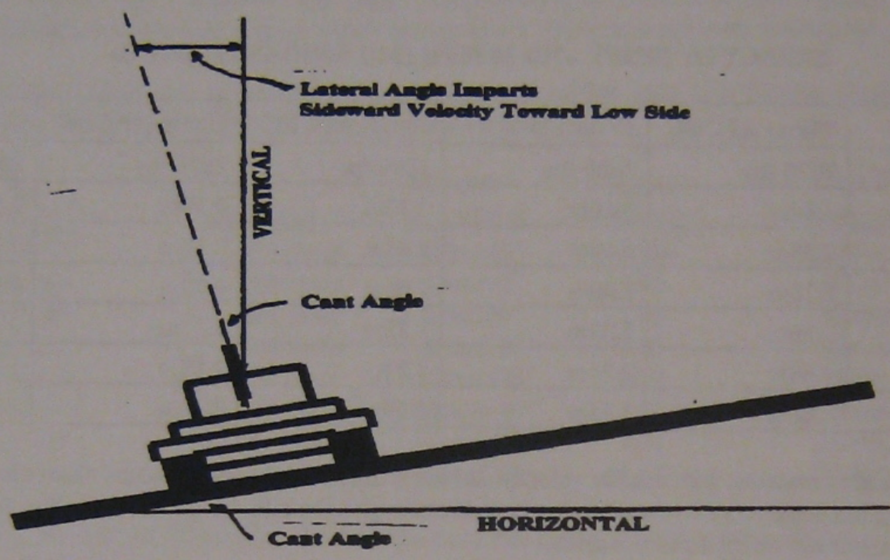
If one track is 4" higher and is 10' away from the other, and turret is aligned with hull facing, the side error in shot placement that must be added to lateral dispersion is presented in the following table:

1.91° TRUNNION CANT IMPACT ON SHOT PLACEMENT

APCBC ROUNDS

RANGE (m)	75L40	75L48	75L70
250	0.03m	0.02m	0.01m
500	0.12	0.08	0.05
1000	0.52	0.36	0.23
1500	1.24	0.87	0.60
2000	2.28	1.63	1.06

Trunnion cant effects, like wind drift, would primarily act to lower first shot accuracy and then would be adjusted for on second and later shots.



TRUNNION CANT OCCURS WHEN ONE SIDE OF AN ELEVATED GUN IS HIGHER, AND A LATERAL VELOCITY COMPONENT IS IMPARTED TO THE PROJECTILE

APPENDIX 8 : WIND AND DRIFT EFFECTS ON ACCURACY

The impact of crosswinds and drift on weapon accuracy is an important consideration for first shot accuracy. The following table presents analysis of U.S. data for 75mm, 3", 76mm and 90mm APCBC projectiles subjected to a 10 mph (16.1 kph) lateral wind and drift:

IMPACT OF DRIFT AND 10 MPH (16.1 KPH) CROSSWIND

.	75mm APCBC	3" APCBC	76mm APCBC	90mm APCBC	90mm APCBC
Muzzle Velocity	2030 fps	2600 fps	2600 fps	2670 fps	2800 fps
915m drift	0.64m	0.20m	0.20m	0.18m	0.18m
915m wind	0.55m	0.46m	0.46m	0.32m	0.24m
1829m drift	2.20m	1.06m	1.06m	0.77m	0.77m
1829m wind	2.20m	1.83m	1.83m	1.35m	0.99m
2744m drift	4.66m	2.74m	3.24m	1.87m	1.87m
2744m wind	4.66m	4.53m	4.09m	3.13m	2.25m

The table results are consistent with muzzle velocity and flight time considerations, where slower and lighter rounds should be impacted more by crosswinds. Listed results give the offset from aim point due to the factor, and wind deviation could be opposite gun drift.

APPENDIX 9 : FIRING TEST RESULTS AGAINST TIGER E

Germany's Tiger Tanks, Tiger I & II: Combat Tactics, by Thomas Jentz, presents firing test results against Tigers in Europe, which strongly suggest that Tiger hull armor was equivalent to Allied penetration test plate in terms of resistance.

TEST RESULTS AGAINST TIGER ARMOR

ARMOR THICKNESS & ANGLE	GUN AMMO	IMPACT VELO.	PEN.	RESULT
82 @ 50°	17 Pdr APCBC	2700 fps	76 @ 50°	No pen.
82 @ 50°	17 Pdr APCBC	2858	82 @ 50°	Lodged
82 @ 50°	17 Pdr APDS	3511	108 @ 50°	No pen.
82 @ 50°	17 Pdr APDS	3131	91 @ 50°	Pen.
102 @ 48°	17 Pdr APDS	3437	115 @ 48°	No pen.
102 @ 48°	17 Pdr APDS	3215	105 @ 48°	No pen.
102 @ 41°	17 Pdr APDS	3427	143 @ 41°	No pen.
102 @ 41°	17 Pdr APDS	3602	153 @ 41°	No pen.
102 @ 40°	17 Pdr APCBC	2595	94 @ 40°	No pen.
102 @ 10°	17 Pdr APCBC	1923	98 @ 10°	Lodged
82 @ 50°	17 Pdr APCBC	3035	87 @ 50°	No pen.
82 @ 30°	6 Pdr APCBC	2575	83 @ 30°	No pen.

The above analysis suggests that Tiger side armor resists like good quality Allied penetration test plate, and APDS rounds appear to have lost most of penetration capability in underlined cases, which may be due to excessive angle between nose and flight path. The possibility also exists that APDS shatter fails when penetration exceeds armor resistance within certain limits which have not been determined.

The John Salt site presents additional firing test penetration ranges Tiger E in Tunisia, which also suggest that Tiger armor resistance was equal to Allied penetration test plate:

PROJECTILE	RANGE	ARMOR & ANGLE	SLOPE EFFECT	0° ARMOR	0° PEN.
6 Pdr HV AP	1250 yards	82mm/0°	1.00	82mm	83mm
6 Pdr LV AP	900 yards	82mm/0°	1.00	82mm	84mm
75mm APCBC	800 yards	82mm/0°	1.00	82mm	78mm
6 Pdr HV AP	1000 yards	82mm/20°	1.10	90mm	93mm
6 Pdr LV AP	650 yards	82mm/20°	1.10	90mm	93mm
6 Pdr HV AP	700 yards	102mm/10°	1.01	103mm	105mm
6 Pdr LV AP	350 yards	102mm/10°	1.01	103mm	106mm
17 Pdr AP	1600 yards	102mm/25°	1.17	119mm	126mm

NOTES: 6 Pdr LV AP is low velocity round fired at 2700 fps, while HV is high velocity with 2950 fps muzzle velocity.

Comments added to the test results indicate that German armor on Tiger is, for the most part, of good quality although an occasional low quality plate may occur.

Since the 0° armor resistance is approximately equal to 0° penetration, the armor appears to be equivalent to Allied penetration test plate. Where Tiger armor seems to be slightly superior, variations in projectile penetration from lot to lot, or round to round, may be responsible.

The slight superiority of Tiger armor against 6 and 17 Pounder hits may also be due, in part, to hardness effects, where 82mm and 102mm plates were in 310-340 Brinell Hardness range while penetration data was against 240 Brinell armor. The difference in Tiger armor hardness may require from 1% to 3% additional penetration for defeat.

British use of U.S. 75mm APCBC projectiles entailed removal of HE burster and replacement with inert filler, which increased penetration capability by about 4%, according to published ballistic test figures. If 75mm APCBC used in above test contained inert filler than 800 yard penetration would be close to armor thickness (81mm penetration versus 82mm armor thickness), supporting concept that Tiger E armor resistance was equivalent to Allied penetration test plate.

David Fletcher's book, *Tiger! The Tiger Tank: A British View*, presents combat and test results for 6 pdr AP against front and sidearmor of the first Tiger knocked out in North Africa:

6 POUNDER MARK II AP VERSUS TIGER ARMOR

SITUATION AND LATERAL ANGLE	RANGE	ARMOR	0° ANGLE EFFECTIVE ARMOR	6 Pdr PEN.	RESULT
Combat @ 30°	650 yards	80mm @ 0°	104	100 @ 0°	Penetration
Combat @ 15°	650 yards	80mm @ 0°	83	100 @ 0°	Penetration
Combat @ 25° to 30°	650 yards	80mm @ 0°	95 to 104	100 @ 0°	Not through
Combat @ 35° to 45°	650 yards	80mm @ 0°	123 to 182	100 @ 0°	Not through
Firing Test @ 0°	300 yards	100mm @ 21°	114	118 @ 0°	Not through

NOTES: On combat shots at 25° to 30° where armor prevents full penetration, one shot is almost through and second creates scoops equal to 2" and 2.5" (plate is 3.15" thick)

On firing test results where armor prevents full penetration, first shot penetrates 3" into plate and second penetrates 3.5" (plate thickness is about 4").

The 100mm nose plate appears to have superior penetration resistance since 6 pounder rounds were stopped well short of complete penetration, despite overpenetration (118 versus 114). The National Physical Laboratory equation predicts that when 6 pounder AP strikes 100mm at 320 Brinell Hardness armor, the resistance should be about 3% greater than 275 Brinell test plate. The 100mm plate resistance advantage appears to be greater than 3%.

Against 80mm armor at angles from 25° to 30°, Tiger armor resistance appears to equal penetration test quality.

Tiger 80mm side armor measured at 325-345 Brinell Hardness, and 100mm armor at 315-324 Brinell Hardness.

APPENDIX 10 : GUN ELEVATION AND PROJECTILE DESCENT ANGLE

Projectile descent angle is a factor that may modify highly sloped armor resistance by a significant amount at longer ranges, and the angle may be estimated from the trajectory equation presented in an earlier appendix.

The following tables present descent angle estimates for guns and projectiles that may hit sloped armor at ranges where descent angle is likely to be important. The angles are based on an equation provided by , assume that gun barrel and target aim point are at same elevation, and compares favorably with published data for German APC and APCBC projectiles. The average error in descent angle between German data and computed figures, for ranges from 1000m through 3000m, was less than 1 mil (corresponds to a maximum error of about 0.0573°).

While descent angles add to armor analysis, terrain grade and angle from firer to target cannot be accurately determined during combat, and the impact of terrain and firer-target considerations may equal or exceed descent angle.

Sine (Descent Angle) = $(19.6 \times \text{Maximum Trajectory Height}/(\text{Velocity at Range})^2)^{0.5}$

BRITISH AP, APCBC AND APDS DESCENT ANGLES

Range (m)	2 Pdr	2 Pdr	6Pdr(2600)	6Pdr(2725)	6Pdr APDS	17Pdr	17Pdr APDS	77mm
Ammo	AP	APCBC	APCBC	APCBC	APDS	APCBC	APDS	APCBC
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1
300	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
400	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.2
500	0.3	0.3	0.3	0.2	0.1	0.2	0.1	0.2
600	0.4	0.3	0.3	0.3	0.1	0.2	0.1	0.3
700	0.5	0.4	0.4	0.3	0.2	0.3	0.2	0.4
800	0.6	0.5	0.4	0.4	0.2	0.3	0.2	0.4
900	0.7	0.5	0.5	0.5	0.2	0.4	0.2	0.5
1000	0.9	0.6	0.6	0.5	0.3	0.4	0.2	0.5
1100	1.0	0.7	0.7	0.6	0.3	0.5	0.3	0.6
1200	1.2	0.8	0.8	0.7	0.3	0.5	0.3	0.7
1300	1.3	0.8	0.8	0.8	0.4	0.6	0.3	0.7
1400	1.5	0.9	0.9	0.8	0.4	0.6	0.3	0.8
1500	1.7	1.0	1.0	0.9	0.4	0.7	0.4	0.9
1600	2.0	1.1	1.1	1.0	0.5	0.8	0.4	1.0
1700	2.2	1.2	1.2	1.1	0.5	0.8	0.4	1.0
1800	2.5	1.3	1.3	1.2	0.6	0.9	0.5	1.1
1900	2.8	1.5	1.4	1.3	0.6	1.0	0.5	1.2
2000	3.1	1.6	1.6	1.4	0.7	1.0	0.6	1.3
2100	3.4	1.7	1.7	1.5	0.7	1.1	0.6	1.4
2200	3.8	1.8	1.8	1.6	0.8	1.2	0.6	1.5
2300	4.2	2.0	1.9	1.8	0.8	1.2	0.7	1.6
2400	4.7	2.1	2.1	1.9	0.9	1.3	0.7	1.7
2500	5.1	2.3	2.2	2.0	1.0	1.4	0.8	1.8
2600	5.6	2.4	2.4	2.2	1.0	1.5	0.8	1.9
2700	6.2	2.6	2.5	2.3	1.1	1.5	0.8	2.0
2800	6.8	2.7	2.7	2.5	1.2	1.6	0.9	2.1
2900	7.4	2.9	2.9	2.6	1.2	1.7	0.9	2.2
3000	8.1	3.1	3.0	2.8	1.3	1.8	1.0	2.3

RUSSIAN AP AND APBC DESCENT ANGLES

Range (m)	85 AP	85 APBC	100 AP	100 APBC	122 AP	122 APBC	152 AP	152 APBC
100	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
200	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
300	0.2	0.1	0.1	0.1	0.1	0.1	0.3	0.2
400	0.2	0.2	0.2	0.1	0.2	0.2	0.4	0.3
500	0.3	0.2	0.2	0.2	0.3	0.2	0.5	0.4
600	0.3	0.3	0.2	0.2	0.3	0.3	0.6	0.5
700	0.4	0.4	0.3	0.3	0.4	0.3	0.7	0.6
800	0.5	0.4	0.3	0.3	0.5	0.4	0.8	0.7
900	0.6	0.5	0.4	0.3	0.5	0.5	1.0	0.8
1000	0.7	0.5	0.5	0.4	0.6	0.5	1.1	0.9
1100	0.8	0.6	0.5	0.4	0.7	0.6	1.2	1.0
1200	0.9	0.7	0.6	0.5	0.8	0.6	1.4	1.1
1300	1.0	0.7	0.6	0.5	0.8	0.7	1.6	1.2
1400	1.1	0.8	0.7	0.6	0.9	0.8	1.7	1.3
1500	1.2	0.9	0.8	0.6	1.0	0.8	1.9	1.4
1600	1.4	1.0	0.9	0.7	1.1	0.9	2.1	1.6
1700	1.5	1.0	0.9	0.7	1.2	1.0	2.3	1.7
1800	1.7	1.1	1.0	0.8	1.4	1.0	2.5	1.8
1900	1.8	1.2	1.1	0.8	1.5	1.1	2.8	1.9
2000	2.0	1.3	1.2	0.9	1.6	1.2	3.0	2.1
2100	2.2	1.4	1.3	0.9	1.7	1.2	3.3	2.2
2200	2.4	1.5	1.4	1.0	1.8	1.3	3.5	2.3
2300	2.6	1.6	1.5	1.1	2.0	1.4	3.8	2.5
2400	2.8	1.7	1.6	1.1	2.1	1.5	4.1	2.6
2500	3.0	1.8	1.7	1.2	2.3	1.6	4.4	2.8
2600	3.2	1.9	1.8	1.2	2.4	1.6	4.7	2.9
2700	3.5	2.0	1.9	1.3	2.6	1.7	5.1	3.1
2800	3.8	2.1	2.1	1.4	2.8	1.8	5.4	3.2
2900	4.0	2.2	2.2	1.4	2.9	1.9	5.8	3.4
3000	4.3	2.3	2.3	1.5	3.1	2.0	6.2	3.5

U.S. APCBC AND HVAP DESCENT ANGLES

Range (m)	37	57	75	3"	76	90(2670)	90(2800)	76 HVAP	90 HVAP
100	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
200	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
300	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
400	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1
500	0.2	0.2	0.4	0.3	0.2	0.2	0.2	0.2	0.2
600	0.3	0.3	0.5	0.3	0.3	0.3	0.3	0.2	0.2
700	0.3	0.3	0.6	0.4	0.4	0.3	0.3	0.2	0.2
800	0.4	0.4	0.7	0.4	0.4	0.4	0.3	0.3	0.3
900	0.4	0.5	0.8	0.5	0.5	0.4	0.4	0.3	0.3
1000	0.5	0.5	0.9	0.6	0.5	0.5	0.4	0.4	0.4
1100	0.6	0.6	1.0	0.6	0.6	0.6	0.5	0.4	0.4
1200	0.6	0.7	1.2	0.7	0.7	0.6	0.6	0.5	0.4
1300	0.7	0.8	1.3	0.8	0.8	0.7	0.6	0.5	0.5
1400	0.8	0.8	1.4	0.9	0.8	0.7	0.7	0.6	0.5
1500	0.9	0.9	1.5	0.9	0.9	0.8	0.7	0.6	0.6
1600	1.0	1.0	1.7	1.0	1.0	0.9	0.8	0.7	0.7
1700	1.1	1.1	1.8	1.1	1.1	0.9	0.8	0.8	0.7
1800	1.2	1.2	2.0	1.2	1.2	1.0	0.9	0.8	0.8
1900	1.3	1.3	2.1	1.3	1.2	1.1	1.0	0.9	0.8
2000	1.4	1.4	2.3	1.4	1.3	1.1	1.0	1.0	0.9
2100	1.5	1.5	2.4	1.5	1.4	1.2	1.1	1.1	1.0
2200	1.6	1.6	2.6	1.6	1.5	1.3	1.2	1.2	1.0
2300	1.7	1.7	2.8	1.7	1.6	1.4	1.3	1.3	1.1
2400	1.8	1.8	3.0	1.8	1.7	1.5	1.3	1.4	1.2
2500	2.0	1.9	3.2	2.0	1.8	1.5	1.4	1.5	1.3
2600	2.1	2.1	3.4	2.1	1.9	1.6	1.5	1.6	1.4
2700	2.3	2.2	3.6	2.2	2.1	1.7	1.6	1.7	1.4
2800	2.4	2.3	3.8	2.3	2.2	1.8	1.6	1.8	1.5
2900	2.6	2.5	4.0	2.5	2.3	1.9	1.7	1.9	1.6
3000	2.8	2.6	4.2	2.6	2.4	2.0	1.8	2.0	1.7

GERMAN APC and APCBC DESCENT ANGLES

Range (m)	50L60	75L48	75L46	75L70	76.2L51.5	88L56	88L71	128L55
100	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
200	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
300	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1
400	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1
500	0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.2
600	0.3	0.3	0.3	0.2	0.4	0.3	0.2	0.2
700	0.4	0.4	0.4	0.3	0.5	0.4	0.2	0.3
800	0.5	0.5	0.4	0.3	0.5	0.4	0.3	0.3
900	0.6	0.6	0.5	0.4	0.6	0.5	0.3	0.3
1000	0.7	0.6	0.6	0.4	0.7	0.6	0.3	0.4
1100	0.8	0.7	0.6	0.5	0.8	0.6	0.4	0.4
1200	0.9	0.8	0.7	0.5	0.9	0.7	0.4	0.5
1300	1.0	0.9	0.8	0.6	1.0	0.8	0.4	0.5
1400	1.2	1.0	0.9	0.6	1.1	0.8	0.5	0.6
1500	1.3	1.1	1.0	0.7	1.2	0.9	0.5	0.6
1600	1.5	1.2	1.1	0.8	1.3	1.0	0.6	0.7
1700	1.6	1.3	1.2	0.8	1.4	1.1	0.6	0.7
1800	1.8	1.4	1.3	0.9	1.5	1.2	0.7	0.8
1900	2.0	1.5	1.4	1.0	1.7	1.2	0.7	0.8
2000	2.2	1.6	1.5	1.1	1.8	1.3	0.8	0.9
2100	2.4	1.7	1.6	1.1	1.9	1.4	0.8	0.9
2200	2.7	1.9	1.7	1.2	2.0	1.5	0.9	1.0
2300	2.9	2.0	1.8	1.3	2.2	1.6	0.9	1.0
2400	3.2	2.1	1.9	1.4	2.3	1.7	1.0	1.1
2500	3.5	2.3	2.1	1.5	2.5	1.8	1.0	1.2
2600	3.8	2.4	2.2	1.6	2.6	1.9	1.1	1.2
2700	4.1	2.6	2.3	1.7	2.8	2.0	1.1	1.3
2800	4.4	2.7	2.5	1.8	3.0	2.2	1.2	1.3
2900	4.8	2.9	2.6	1.9	3.2	2.3	1.2	1.4
3000	5.2	3.1	2.8	2.0	3.3	2.4	1.3	1.5

Gun elevation angle may be estimated from the following equation:

Sine (Gun Elevation Angle) = $(27.7 \times \text{Maximum Trajectory Height}/((\text{Muzzle Velocity})^{1.5} \times (\text{Velocity at Range} + \text{Muzzle Velocity})))^{0.5}$

The above equations were developed by Alvaro G. Figueiras and are used with his permission

APPENDIX 11 : GERMAN ARMOR ACCEPTANCE TESTING

Analysis of the German procedures for armor acceptance testing provides various insights into the potential for high quality material and defective armor passes.

Using the firing test curves in the BIOS report, the following table was prepared, where all firing tests take place at 100m. The analysis covers armor thicknesses from 30mm to 150mm.

ARMOR THICKNESS	ARMOR TYPE	ARMOR ANGLE	FIRING WEAPON	0° PEN. AT RANGE	0° ARMOR RESISTANCE
60mm	Rolled	50°	50mm	>100mm	176mm
80mm	Rolled	0°	50mm	>100mm	80mm
100mm	Rolled	45°	75mm	121-135mm	188mm
120mm	Rolled	35°	75mm	121-135mm	175mm
150mm	Rolled	13°	75mm	121-135mm	159mm
100mm	Cast	0°	50mm	>100mm	100mm
120mm	Cast	35°	75mm	121-135mm	171mm
120mm	Cast	45°	75mm	121-135mm	227mm
140mm	Cast	15°	75mm	121-135mm	150mm

NOTES: 50mm AP muzzle velocity is 900 m/s against rolled armor and 850 m/s against cast armor, which increases nose over stress probability at higher velocity.

75mm Pz Gr 39 muzzle velocity listed at 750 m/s, 700 m/s during velocity test allows gun to be used for another 1000 shots with possible further decrease in muzzle velocity.

The tests were based on immunity criteria, where failure would occur when cracks passed light, fragments were ejected or a complete penetration was allowed. American acceptance tests for rolled and cast armor used the Army Ballistic Limit, which is similar to the German immunity criteria.

50mm AP tests against 80mm rolled and 100mm cast armor appear to require projectile nose failure, since projectile penetration would normally be sufficient for a complete defeat. If shatter gap occurred during the tests, which is likely, cast-versus-rolled armor comparisons cannot be based on the 80mm and 100mm thicknesses.

For the cases where test projectile penetration is fairly close to effective armor resistance at 0°, such as 75mm gun vs. 150mm rolled and 140mm cast armor, the probability that flawed armor will pass firing tests is decreased due to a limited margin of error. When 50mm AP attacks 50mm and 60mm rolled plate, an

increased potential exists that flawed armor will pass firing tests due to the large difference between armor resistance and penetration.

CRITERIA FOR 75mm FIRING TESTS

Criteria used to test armor with 75mm Pz Gr 39 are indicated in BIOS report and can be summarized as follows:

1. 75mm muzzle velocity is stated as 750 m/s but can be as low as 700 m/s during measurements and be acceptable for next 1000 shots

2. Choose one ingot and prepare a 1000mm x 1200mm test plate

3. Fire 5 rounds at the test plate, first 3 at specification angle and next two at 10° less, where following criteria must be met for plate to pass:

   On first 3 rounds, back side of plate may only show smooth bulges or bulges with small cracks, and failure occurs if bulge looks like a plug, material is broken out, crack passes light or shatter cracks appear.

   On next 2 rounds with reduced angle, complete penetration may occur but average diameter of broken out area must be 150mm or less.

4. Hits within 300mm of edge or previous hit location, measured from center of impact, do not count (4 diameter criteria for edge effects or armor changes due to previous hits, whether or not armor is cracked on back side).

5. If any hits fail to meet criteria in note 3, another test plate is prepared from same ingot. If the new test plate fails, the ingot is discarded and a new ingot is used to prepare a test plate. If the new plate fails the entire heat is rejected.

If the average muzzle velocity of 75mm Pz Gr 39 is 725 m/s, the 100m figure for 50% probability of complete penetration would be about 131mm, and 150mm of rolled armor would be attacked at 13° from vertical, producing 160mm effective resistance at 0°. The probability of a complete penetration would be approximately zero when projectiles with 131mm penetration strike 160mm resistance, however, the probability of a crack showing light would be about 1%.

If the 150mm rolled armor is good quality, probability that round fails immunity criteria during first three shots would be about 3%. However, if 150mm armor is 10% less resistant than good quality, failure probability on first shot would be 50%, with 75% failure during two shots and 88% with three shots.

If the deficient 150mm plates (10% less resistance than good quality) passed the three first shots, the firing angle would be reduced to 3° and complete penetrations would occur on about 23% of the hits, resulting in a 41% chance for a complete penetration after two hits. Since reduced penetration resistance is normally associated with the characteristics that favor flaking, disk release and other causes of excessive diameter exit holes, there is about a 7% probability that a plate with a 10% resistance deficiency will pass the firing tests after 5 shots (assumes all penetrations fail hole diameter criteria).

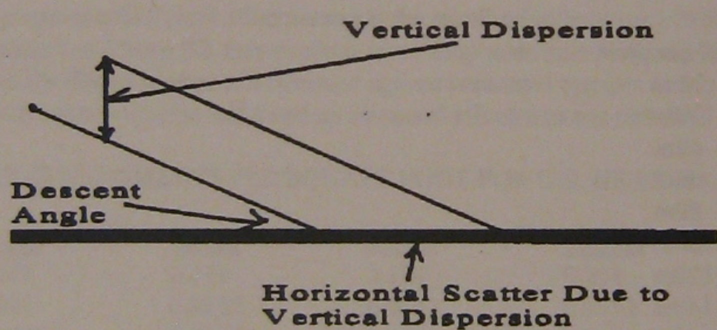
After plate failure, another plate would be fired upon, which would result in a combined 13% chance that two plates with 10% resistance deficiency would pass. If the third plate from another ingot was also 10% deficient, there would be a 19% chance that the deficient plates would pass.

If 15% of the armor plates are 10% deficient and 19% pass firing tests, which seems high, 3% of all plates would be 10% deficient.

APPENDIX 12 : HE ACCURACY AND RELATIVE EFFECTIVENESS

Review of German ballistic tables for HE fire reveals one unusual aspect, rounds with low muzzle velocities have a small ground dispersion pattern than higher velocity HE, which suggests that low velocity HE fire may be more accurate when a round has to be placed near a specific ground point.

From a simple viewpoint, the smaller ground dispersion pattern of low velocity HE may be explained on the basis of dispersion effects. If an HE shell is fired at low velocity, the round will have a greater descent angle as it approaches the ground, and vertical dispersion effects on horizontal placement will be smaller. Consider HE fire at a ground point 500m distant, where one round reaches the target in 1 second and the other takes 0.6 seconds, and 68.3% of the rounds are within 1m vertical of the mean trajectory for low velocity and 0.75m for high velocity.



INCREASING THE DESCENT ANGLE DECREASES THE HORIZONTAL SCATTER DUE TO VERTICAL DISPERSION

ESTIMATED GROUND DISPERSION AGAINST 500m TARGET

HE FLIGHT TIME	HE DESCENT ANGLE	HORIZONTAL DISPERSION EFFECT
1.0 sec.	0.566°	1.00m/TAN(0.566°) = 101m (68.3% of shots within this distance)
0.6 sec.	0.204°	0.75m/TAN(0.204°) = 211m (68.3% of shots within this distance)

If both rounds are fired at a ground point 500m away and the range estimate is 500m, the high velocity HE shells will be spread over a greater distance in front of and behind the aim point, leading to less effective HE accuracy in terms of the probability for casualties or pinning.

The previous example considered the case where the firing gun was at the same elevation as the ground target, however, the relative difference in descent angle will be reduced as the gun elevation increases over the target. Consider the preceding example where both HE shells are fired from a gun 2m above the target.

ESTIMATED GROUND DISPERSION AGAINST 500m TARGET, ELEVATED GUN

HE FLIGHT TIME	HE DESCENT ANGLE	HORIZONTAL DISPERSION EFFECT	
1.0 sec.	0.795°	1.00m/TAN(0.795°) =	68.3% within 72m of aim point
0.6 sec.	0.433°	0.75m/TAN(0.433°) =	68.3% within 99m of aim point

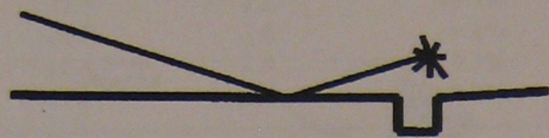
Firing HE from a gun that is above the target point decreases the horizontal scatter, which increases accuracy. As in the case where the guns and target were at the same elevation, low velocity HE is more accurate in terms of relative shot placement along the line of fire.

If 68.3% of HE ricochet shots fall within 72m of aim point, the statistical distribution would breakdown in the following manner:

6% within 5m of aim point
5% within 5 to 10m
11% within 10 to 20m
20% within 20 to 40m
17% within 40 to 60m
14% within 60 to 80m
10% within 80 to 100m
7% within 100 to 120m
4% within 120 to 140m
3% within 140 to 160m
3% within 160 to 180m

When guns use ricochet fire against ground targets to neutralize cover, by bouncing rounds off the ground in front of the target so they explode overhead, the above analysis findings are still relevant. U.S. 75mm HE, when set on delay, will explode 0.05 seconds after striking the ground. The 0.05 second delay indicates that the round has to hit the ground within 20 to 25 yards (18 to 23 meters) of the target to be effective, which still requires that rounds land close to a specific ground point. The HE shell with the smallest horizontal ground scatter will be more effective during ricochet fire attempts.

German HE rounds appear to have had a minimum 0.10 second fuze delay on HE shells, which would increase the height of the projectile explosion, reducing German ricochet fire effectiveness since fragment density



RICOCHET HE FIRE RESULTS IN AN AIR BURST THAT NEUTRALIZES VERTICAL COVER

would decrease compared to 0.05 second fuse delay on American HE. Doubling the distance from the explosion, due to twice the fuze delay time, reduces the number of effective fragments by about 75%.

One of the interesting aspects of HE shell effectiveness is the relationship between effective fragments and shell size, which indicates that 75mm HE may produce more fragments than 76mm and 90mm shells. The cause of smaller HE shells having greater effectiveness against personnel appears to be related to lower muzzle velocity, which allows thinner projectile walls and an increased HE charge per unit shell weight.

AVERAGE EFFECTIVE FRAGMENTS PER SQUARE FOOT FOR U.S. HE SHELLS

DISTANCE	75mm	76mm	90mm	105mm
20'	0.189	0.111	0.134	0.201
50'	0.021	0.0135	0.0163	0.0312
80'	0.00653	0.00454	0.00537	0.0112
100'	0.00366	0.00269	0.00318	0.00681
150'	0.00129	0.00102	0.00124	0.00272
200'	0.000650	0.000500	0.000640	0.00134

Despite lower diameter, at 20' distance from blast 75mm HE has a 70% advantage over 76mm in terms of effective fragments, a 41% advantage over 90mm and is only 6% less productive than 105mm. At 200' distance from blast, 75mm is still more productive than 76mm and 90mm HE, but the advantage is much smaller, and 105mm HE is more than twice as productive. It appears that while 75mm HE generates more high velocity fragments at close range, the fragments are smaller and lose velocity faster, which closes the effective fragment advantage as range increases.

As noted above, low muzzle velocity is usually associated with thinner walls and greater HE filler, which may combine to produce a higher number of effective fragments. While 105mm HE has the highest percentage of

total weight as HE filler on the above table, and the highest HE filler weight, 75mm HE is almost able to produce the same number of effective fragments at 20' distance.

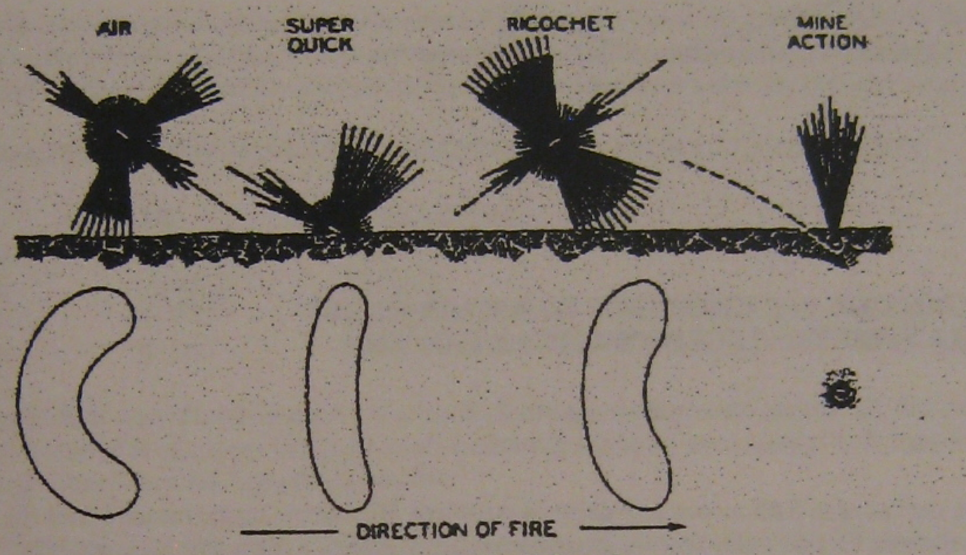


Figure 5. HE shell bursts.

The drawing presented above is from U.S. Army Technical Manual TM9-1907.

The following table, which is based on WO 291/955 (document held by British Public Record Office (PRO) and exhibited on the John Salt site), and listed sources for Russian and German ammunition, lists particulars for projectile and explosive filler weight of HE shells:

HE SHELL	TOTAL WEIGHT	HE FILLER	HE FILLER % OF WEIGHT	NOTES
75mm	14.6 lbs	1.7 lbs	11.6%	WO 291/955
76mm	12.9	0.9	7.0%	WO 291/955
90mm	23.4	2.7	11.5%	WO 291/955
105mm	33.0	4.9	14.8%	WO 291/955
6 Pounder	6.2	0.4	6.5%	WO 291/955
17 Pounder	13.4	1.1	8.2%	WO 291/955
95mm	25.0	3.1	12.4%	WO 291/955
50mm	4.5	0.4	8.0%	Pzgr.Patr. KwK
50mm	4.2	0.4	8.8%	Sprgr. Patr. 38
50mm	4.6	0.5	11.8%	Pzgr. Patr.KwK 38
75mm	9.8	1.0	10.2%	Sprgr. 34
75mm	12.6	1.9	14.9%	Sprgr. Patr. KwK(34)
75mm	12.7	1.4	11.3%	Sprgr.42

HE SHELL	TOTAL WEIGHT	HE FILLER	HE FILLER % OF WEIGHT	NOTES
88mm	21.0	2.2	10.5%	Sprgr. 43
88mm	20.5	2.0	9.8%	Sprgr. L/4.5
88mm	20.4	1.9	9.3%	Sprgr. Patr.
88mm	21.0	2.0	9.5%	Sprgr. L/4.5
45mm	4.7	0.6	12.8%	*The Russian Battlefield*
57mm	8.3	1.1	13.3%	*The Russian Battlefield*
76.2mm	13.7	1.6	11.7%	*The Russian Battlefield*
85mm	21.0	1.4	6.7%	*The Russian Battlefield*
85mm	21.0	1.6	7.8%	*The Russian Battlefield*
100mm	34.4	3.2	9.3%	*The Russian Battlefield*
122mm	55.0	8.4	15.2%	*The Russian Battlefield*
152mm	90.2	13.0	14.5%	*The Russian Battlefield*

The data on German HE shells is based on figures presented in Mark Diehl's *AFV-G2* series on German projectiles.

Sprgr.42 is fired by Panther weapon, while Sprgr. 34 and Sprgr.Patr.Kwk(34) is fired from other 75mm tank and anti-tank guns. Panther HE fired at 750 m/s, while PzKpfw IVH fires HE at 550 m/s. Also note that German HE filler may not be equivalent to Allied HE, which could lead to changes in relative effect.

As noted above, low muzzle velocity is usually associated with thinner walls and greater HE filler, which may combine to produce a higher number of effective fragments. While 105mm HE has the highest percentage of total weight as HE filler on the above table, and the highest HE filler weight, 75mm HE is almost able to produce the same number of effective fragments at 20' distance.

APPENDIX 13 : BALLISTIC LIMITS

Note that ballistic limits discussed here represent minimal differences in assessing plate. For example, changing from a 50% to 67% limit, all other factors unchanged, represents a decrease in thickness penetrated of one to two percent.

Three types of Ballistic Limit (BL) were in use in the United States by the end of World War II:

1) Army BL, computed by averaging velocity (V_{50}) of shot penetrating part way through plate without any back damage, and shot velocity causing crack which passes light or allows lodged projectile to be seen from back. This is analogous to German immunity criteria for assessment of plate except German plate must not allow a success in terms of crack passing light, fragments thrown off the armor back or worse.

2) Protection BL, average of shot velocity penetrating without back damage as in Army BL, with shot velocity penetrating with back damage, spalls or pieces of nose thrown, those fragments penetrating a thin sheet of aluminum behind plate.

3) Navy BL, average of shot velocity penetrating with nose protruding, or back spalls as in PBL, with velocity of projectile passing completely through plate. More than half of the projectile body was required to pass through the plate.

Note that the U.S Navy did not necessarily use the Navy Limit, nor did the Army necessarily use the Army Limit. Ordnance Field Guide (1945 revision) presents penetration data in terms of Navy Limit.

Army and Protection BL were intended to literally assess armor protection afforded a tank crew, while Navy BL was used to assess projectiles, and describes at what maximum range or velocity significant damage to an armored vehicle can be expected.

At increasing obliquity the velocities for the three types begin to coincide. Failure mode of projectile also influences differences between the three measurements, with shattering projectiles also causing the velocity for the three types to be more similar. All three types of BL are an average of the lowest pass and the highest fail, but the fail must be lower than the pass used to compute the average (only two hits are sufficient to derive average, although frequently more hits were used). Below 37mm projectile diameter the difference must be no more than 50 fps, while above it must be no more than 30 fps. Variation often exceeded this range, with high fails and low passes, variation increasing as obliquity increases and with shattering projectiles.
Ductile plate has the widest spread between onset of penetration and completion of pass-through. Brittle plate fails suddenly so the difference between partial defeat and complete defeat is slight.

British ballistic limits are:

1) D.T.D W/R Limit, which gives critical velocity for 50% success, each success defined as passing of the entire projectile through the plate. Corresponds approximately to Navy limit used in the U. S, but represents a slightly higher level of projectile performance. Also corresponds approximately to German perforation criteria for the performance of projectiles.

2) D.T.D Ballistic Limit, which gives critical velocity for 50% success, each success defined as bulges on the back of the plate with cracks allowing light to pass. Corresponds to Army Limit used in the U.S.

3) O.B. C.V Limit (Ordnance Board Critical Velocity) required that 50% success occur at the level of partial or complete penetration, with at least one fifth of the projectile body passing through. This criteria was used from early 1943 through war's end, and yearly updates were issued for most or all British guns showing penetration a 0 and 30 degrees obliquity. This criteria is analogous to the Navy Limit used in the United States. British armor plate was specified according to these curves of penetration, expressed as IT 80D and IT 80E specification. Care was taken to ensure that unflawed, well made ammunition was fired at plate accepted under these criteria.

Other ballistic limits were used according to the needs of test programs. Reference has been found to a so-called Perforation Limit, originating in small arms assessment, which requires that 60% (and later 80%) of rounds fired at a given range with full service charge will fully penetrate a given type of armor.

German plate was assessed by firing upon it from 100m range, with the caliber shell as determined by thickness of plate:

5-14.5mm	Sm.K 7.92mm
16-30mm	2cm PzGr (without tracer)
35-50mm	3.7cm PzGr
55-80mm	5cm OK (*ohne kappe*, without cap)
85-160mm	7.5cm PzGr 39

The above applied to homogeneous and face hardened plate. The plate was required to demonstrate immunity at a specified angle of obliquity, the criteria for immunity being nearly the same as the Army Limit employed in the United States.

APPENDIX 14 : U. S. TEST DATA FOR 122mm APBC

The following data is based on U. S. firing test data for 122mm APBC against American homogeneous test plate. The data has been analyzed to provide penetration at various angles as a function of impact velocity and range, as well as slope multiplier and T/D ratio for angled hits.

The 122mm APBC penetration data can be used to estimate penetration data for other APBC rounds using the DeMarre equation, and a simplified version where the 122mm APBC penetration at a given velocity is multiplied by the diameter ratio (if 122mm APBC penetrates 207mm at 0° and 2600 fps, than 85mm APBC penetration at 2600 fps equals 207mm x (85/122), or 144mm).

ESTIMATED APBC PENETRATION AT 0m AND 0°

APBC ROUND	PROJECTILE WEIGHT (kg)	IMPACT VELOCITY	STANDARD DeMARRE ESTIMATE	SIMPLIFIED DeMARRE ESTIMATE
45mm	1.43	760 m/s	70mm	68mm
45mm	1.43	820 m/s	85mm	83mm
57mm	3.14	990 m/s	184mm	168mm
76.2mm	6.30	655 m/s	80mm	80mm
76.2mm	6.30	662 m/s	81mm	82mm
76.2mm	6.30	680 m/s	87mm	88mm
85mm	9.20	793 m/s	149mm	144mm
100mm	15.88	915 m/s	264mm	242mm
100mm	15.88	895 m/s	250mm	229mm
122mm	25.00	793 m/s	206mm	206mm
152mm	48.90	600 m/s	140mm	137mm

NOTE: Both DeMarre estimates based on penetration-vs-velocity equations presented in Russian Penetration section.

The estimated impact velocity of 76.2mm APBC (680 m/s muzzle velocity from T34) is 632 m/s at 500m, which results in a standard and simplified DeMarre penetration estimate of 75mm.

The following tables present the penetration versus range and impact velocity data for 122mm APBC against American homogeneous armor, and the computed slope effects and associated T/D ratio's.

122mm APBC PENETRATION TEST RESULTS

RANGE (m)	VELOCITY	0°	30°	45°	50°	55°	60°	65°	70°
0	2600	207	174	140	124	106	86	77	66
430	2500	186	158	128	114	99	82	73	64
841	2400	168	143	117	105	93	78	70	61
1299	2300	151	130	108	97	87	73	67	59
1756	2200	136	117	99	89	81	70	64	57
2213	2100	122	107	91	84	76	67	62	55
2671	2000	111	98	85	79	71	64	60	53

NOTE: Many sources list 122mm APBC penetration range against Panther glacis (85mm @ 55°) as 1500m, and above statistics for 55° penetration predict that good quality Panther glacis would be penetrated at 1451m. This suggests that many Panthers had good quality glacis armor that was able to withstand significant impact from 122mm hits (25 kg or 55# projectile).

122mm SLOPE EFFECT MULTIPLIERS

RANGE (m)	VELOCITY	0°	30°	45°	50°	55°	60°	65°	70°
0	2600	1.00	1.18	1.48	1.67	1.95	2.40	2.69	3.12
430	2500	1.00	1.17	1.46	1.64	1.88	2.26	2.54	2.92
841	2400	1.00	1.17	1.43	1.59	1.81	2.16	2.39	2.73
1299	2300	1.00	1.17	1.41	1.56	1.74	2.08	2.26	2.56
1756	2200	1.00	1.16	1.38	1.52	1.67	1.93	2.11	2.38
2213	2100	1.00	1.14	1.34	1.45	1.60	1.81	1.97	2.23
2671	2000	1.00	1.13	1.31	1.40	1.57	1.74	1.86	2.08

122mm T/D RATIO'S FOR SLOPE MULTIPLIERS

RANGE (m)	VELOCITY	0°	30°	45°	50°	55°	60°	65°	70°
0	2600	1.69	1.43	1.15	1.01	0.87	0.71	0.63	0.54
430	2500	1.53	1.30	1.05	0.93	0.81	0.67	0.60	0.52
841	2400	1.37	1.17	0.96	0.86	0.76	0.64	0.57	0.50
1299	2300	1.24	1.06	0.88	0.79	0.71	0.60	0.55	0.49
1756	2200	1.11	0.96	0.81	0.73	0.67	0.57	0.53	0.47
2213	2100	1.00	0.87	0.75	0.69	0.62	0.55	0.51	0.45
2671	2000	0.91	0.80	0.70	0.65	0.58	0.52	0.49	0.44

Kursk 1943: A Statistical Analysis, by Zetterling and Frankson, presents penetration ranges for Russian field, anti-aircraft and anti-tank guns against the front, side and rear of German Tiger, Panther, PzKpfw IV and PzKpfw III. The data presented by Zetterling and Frankson combines firing test and calculated results after consideration of reported combat penetration ranges for 45mm, 57mm, 76.2mm and 85mm guns.

The 122mm APBC penetration equations were used to estimate penetration ranges against a variety of panzers, and the results were compared to the figures in Appendix 13 of *Kursk 1943: A Statistical Analysis.* Against homogeneous armor areas, the 122mm equation predictions are in close agreement with many of the ranges in Appendix 13.

APPENDIX 15 : SHOT PLACEMENT SYSTEM

As noted in previous sections, when hit probability is high rounds tend to bunch closely around the target aim point, which may significantly impact penetration chances. A system will be presented for estimating hit location as a function of overall hit probability.

The system is based on an assumed overall hit probability against a stationary 2m x 2m target area. The table that follows this page is used to determine the vertical and lateral hit percentages. The next table determines the shot placement from aim point in meters, and requires two decimal dice rolls for lateral and

SIMPLIFIED HIT PROBABILITY BREAKDOWN
STATIONARY TARGET

OVERALL HIT %	LATERAL HIT %	VERTICAL HIT %
95	98	95
90	98	90
85	98	85
80	95	85
75	95	80
70	95	75
65	90	70
60	85	70
55	85	65
50	80	65
45	75	60
40	70	55
35	65	55
30	60	50
25	55	45
20	50	40
15	45	35
10	40	25
5	35	15

SHOT PLACEMENT TABLE

AIM / ERR	0	5	10	15	20	25	30	35	40	45	50
0.0	0	0	0	1	1	1	2	2	2	2	3
0.1	0	1	1	2	2	3	3	4	4	5	5
0.2	0	1	2	3	4	5	6	7	8	10	11
0.3	1	2	3	5	6	8	9	11	13	14	16
0.4	1	2	4	6	8	10	12	14	17	19	21
0.5	1	3	5	8	10	13	15	18	21	24	26
0.6	1	3	6	9	12	15	18	22	25	28	31
0.7	2	4	7	11	14	18	21	25	29	33	36
0.8	2	4	8	12	16	20	24	28	33	37	41
0.9	2	5	9	14	18	23	27	32	36	41	46
1.0	2	5	10	15	20	25	30	35	40	45	50
1.1	3	6	11	17	22	28	33	38	44	49	54
1.2	3	6	12	18	24	30	36	41	47	53	58
1.3	3	7	13	20	26	32	38	45	50	56	62
1.4	3	7	14	21	28	35	41	48	54	60	66
1.5	4	8	15	22	30	37	44	50	57	63	69
1.6	4	8	16	24	32	39	46	53	60	66	72
1.7	4	9	17	25	34	41	49	56	63	69	75
1.8	4	9	18	27	35	44	51	59	66	72	78
1.9	5	10	19	28	37	46	54	61	68	75	80
2.0	5	10	20	30	39	48	56	64	71	77	82
2.1	5	11	21	31	41	50	58	66	73	79	84
2.2	5	11	22	32	43	52	60	68	75	81	86
2.3	6	12	23	34	44	54	62	70	77	83	88
2.4	6	12	24	35	46	56	64	73	79	85	90
	0	5	10	15	20	25	30	35	40	45	50
2.5	6	13	25	37	48	58	66	74	81	87	91
2.6	6	13	25	38	49	59	68	76	83	88	92
2.7	7	14	26	39	51	61	70	78	84	90	93
2.8	7	14	27	41	52	63	72	80	86	91	94
2.9	7	15	28	42	54	65	74	81	87	92	95
3.0	7	15	29	43	56	66	75	83	89	93	96
3.1	8	16	30	44	57	68	77	84	90	94	96
3.2	8	16	31	46	59	69	78	86	91	95	97
3.3	8	17	32	47	60	71	80	87	92	95	97
3.4	8	17	33	48	61	72	81	88	93	96	98
3.5	9	18	34	49	63	74	82	89	93	96	98
3.6	9	19	35	51	64	75	84	90	94	97	98
3.7	9	19	36	52	65	76	85	91	95	97	98
3.8	9	20	37	53	67	78	86	92	95	97	99
3.9	10	20	37	54	68	79	87	93	96	98	99
4.0	10	21	38	55	69	80	88	93	96	98	99
4.1	10	21	39	56	70	81	89	94	97	98	99
4.2	10	22	40	57	72	82	90	94	97	98	99
4.3	11	22	41	59	73	83	90	95	97	99	99
4.4	11	23	42	60	74	84	91	95	98	99	00
4.5	11	23	43	61	75	85	92	96	98	99	00
4.6	11	24	43	62	76	86	92	96	98	99	00
4.7	12	24	44	63	77	87	93	97	98	99	00
4.8	12	25	45	64	78	88	94	97	98	99	00
4.9	12	25	46	65	79	88	94	97	99	00	00
5.0	12	25	47	66	80	89	95	97	99	00	00
	0	5	10	15	20	25	30	35	40	45	50

AIM / ERR	55	60	65	70	75	80	85	90	95	98	AIM / ERR
0.0	3	3	4	4	5	5	6	7	8	9	0.0
0.1	6	7	7	8	9	10	11	13	16	18	0.1
0.2	12	13	15	16	18	20	23	26	31	36	0.2
0.3	18	20	22	24	27	30	33	38	44	52	0.3
0.4	24	26	29	32	35	39	44	49	57	65	0.4
0.5	29	33	36	40	43	48	53	59	67	76	0.5
0.6	35	39	43	47	51	56	61	68	76	84	0.6
0.7	40	44	49	53	58	63	69	75	83	90	0.7
0.8	45	50	55	59	64	69	75	81	88	94	0.8
0.9	50	55	60	65	70	75	81	86	92	96	0.9
1.0	55	60	65	70	75	80	85	90	95	98	1.0
1.1	59	65	70	75	79	84	89	93	97	99	1.1
1.2	63	69	74	79	83	88	92	95	98	99	1.2
1.3	67	73	78	82	86	91	94	97	98	00	1.3
1.4	71	76	81	85	89	93	96	98	99	00	1.4
1.5	74	79	84	88	92	95	97	98	00	00	1.5
1.6	77	82	87	90	93	96	98	99	00	00	1.6
1.7	80	85	89	92	95	97	98	99	00	00	1.7
1.8	83	87	91	94	96	98	99	00	00	00	1.8
1.9	85	89	93	95	97	98	99	00	00	00	1.9
2.0	87	91	94	96	98	99	99	00	00	00	2.0
2.1	89	92	95	97	98	99	00	00	00	00	2.1
2.2	90	94	96	97	98	99	00	00	00	00	2.2
2.3	92	95	97	98	99	00	00	00	00	00	2.3
2.4	93	96	97	98	99	00	00	00	00	00	2.4
	55	60	65	70	75	80	85	90	95	98	
2.5	94	96	98	99	99	00	00	00	00	00	2.5
2.6	95	97	98	99	00	00	00	00	00	00	2.6
2.7	96	97	98	99	00	00	00	00	00	00	2.7
2.8	96	98	99	99	00	00	00	00	00	00	2.8
2.9	97	98	99	00	00	00	00	00	00	00	2.9
3.0	97	98	99	00	00	00	00	00	00	00	3.0
3.1	98	99	99	00	00	00	00	00	00	00	3.1
3.2	98	99	00	00	00	00	00	00	00	00	3.2
3.3	98	99	00	00	00	00	00	00	00	00	3.3
3.4	99	99	00	00	00	00	00	00	00	00	3.4
3.5	99	00	00	00	00	00	00	00	00	00	3.5
3.6	99	00	00	00	00	00	00	00	00	00	3.6
3.7	99	00	00	00	00	00	00	00	00	00	3.7
3.8	99	00	00	00	00	00	00	00	00	00	3.8
3.9	00	00	00	00	00	00	00	00	00	00	3.9
4.0	00	00	00	00	00	00	00	00	00	00	4.0
4.1	00	00	00	00	00	00	00	00	00	00	4.1
4.2	00	00	00	00	00	00	00	00	00	00	4.2
4.3	00	00	00	00	00	00	00	00	00	00	4.3
4.4	00	00	00	00	00	00	00	00	00	00	4.4
4.5	00	00	00	00	00	00	00	00	00	00	4.5
4.6	00	00	00	00	00	00	00	00	00	00	4.6
4.7	00	00	00	00	00	00	00	00	00	00	4.7
4.8	00	00	00	00	00	00	00	00	00	00	4.8
4.9	00	00	00	00	00	00	00	00	00	00	4.9
5.0	00	00	00	00	00	00	00	00	00	00	5.0
	55	60	65	70	75	80	85	90	95	98	

vertical shot placement, with a third dice rolled for error direction (up or down for vertical, left or right for lateral). An example will serve to illustrate how the method works.

Assume that a Tiger is firing on an IS-2m at 200m, and the overall hit probability is 90%. The first table indicates that the vertical and lateral hit probability against a 2m x 2m target is 95%. Say that the vertical roll is 22 and the error is high, and the lateral roll is 50 and the shot is left of aim point.

Referring to the second table, the vertical shot placement is 0.2m above aim point and 0.4m left, which is determined by identifying the column heading for the hit % and then moving down the column until the score equals or exceeds the dice. For 95% accuracy and a roll of 22, the first score in the column to equal or exceed 22 is 31, which is associated with 0.2m (go to first column in that row for shot placement relative to aim location). The first score in the 95 column to equal or exceed 50 is 57, which results in a shot placement 0.4m left of aim point.

If the Tiger were aiming at the front of the IS-2m and specifically targeted the point where turret and hull met, shots that are 0.2m above aim location and 0.4m left will strike the underside of the turret mantlet curvature.

Consideration of shot placement indicates that if German tanks and anti-tank guns aim at the turret ring, as many crews were trained to do, the percentage of hits striking the turret at close range may approach 50% of the total. While tracks on tanks such as KV-I and Tiger II make up a high percentage of the total frontal area, at close range most shots will be bunched around the aim point, resulting in few track hits if the close range aim is at target center of mass.

As an alternative to table use that supports hand calculator and computer use, one can use the following equations to determine shot placement:

1. Use first table to define vertical and lateral hit scores against 2m x 2m target
   As an alternative one can use the data from hit probability calculations against a similar target

2. Roll decimal dice and another dice for vertical and lateral placement score and direction

3. Divide "A" figure for dice score by "A" figure for step 1. hit score to determine shot placement relative to aim location, where:

   A = 2.71828^-22.7614 x 2.71828^(18.416 x score^0.05) if score 80 or lower

   A = 2.71828^0.193090 x 2.71828^(2.665 x 10^-21 x score^10.25) if score 81 or higher

The "A" figure based on the dice score indicates the displacement from aim point in terms of the number of standard deviations that the shot varies by, assuming a normal distribution. The "A" figure associated with the hit score is the inverse of the standard deviation for the hit probability against a 2m target distance.

The following example will illustrate use of the equations. Assume hit score against 2m x 2m target is 85 vertical, and corresponding dice score for vertical shot placement is 66. The "A" scores and shot placement will be:

"A" figure for 66 dice score = 2.71828^-22.7614 x 2.71828^(18.416 x 66^0.05), or 0.948

"A" figure for 85 hit score = 2.71828^0.19309 x 2.71828^(2.665 x 10^-21 x 85^10.25), or 1.38

The ratio of the dice and hit scores equals 0.948/1.38, or 0.7m. The shot placement table prediction for 85 hit score and 66 dice score is 0.7m.

APPENDIX 16 : PRECISE SLOPE MULTIPLIER EQUATIONS

Slope effect curve analysis indicates that the multiplier may be modeled as function of T/D ratio using this equation form:

Slope Effect at Angle = $a \times (T/D)^b$

For 122mm APBC against 85mm plate at 55° from vertical, a equals 2.110, b is 0.56444 and T/D is 0.70. Using the above-noted equation, the slope multiplier will be 1.69, so 85mm at 55° is equivalent to 144mm at 0° under attack by 122mm APBC. If the projectile were 128mm APC, a would be 2.5368, b would equal 0.24266 and the slope multiplier is 2.30, resulting in 196mm resistance at 0°.

The preceding example shows flat-nose APBC superiority on angled hits.

The a and b factors for APCBC/APC, AP and APBC are:

IMPACT ANGLE	APCBC/APC a/b	APBC a/b	AP a/b
10	1.0243/0.0225	1.039/0.01555	0.98297/0.0637
15	1.0532/0.0327	1.055/0.02315	1.00066/0.0969
20	1.1039/0.0454	1.077/0.03448	1.0361/0.13561
25	1.1741/0.0549	1.108/0.05134	1.1116/0.16164
30	1.2667/0.0655	1.155/0.07710	1.2195/0.19702
35	1.3925/0.0993	1.217/0.11384	1.3771/0.22546
40	1.5642/0.1388	1.313/0.16952	1.6263/0.26313
45	1.7933/0.1655	1.441/0.24604	2.0033/0.34717
50	2.1053/0.2035	1.682/0.37910	2.6447/0.57353
55	2.5368/0.2427	2.110/0.56444	3.2310/0.69075
60	3.0796/0.2450	3.497/1.07411	4.0708/0.81826
65	4.0041/0.3354	5.335/1.46188	6.2655/0.91920
70	5.0803/0.3478	9.477/1.81520	8.6492/1.00539
75	6.7445/0.3831	20.22/2.19155	13.7512/1.074
80	9.0598/0.4131	56.20/2.56210	21.8713/1.17973
85	12.8207/0.4550	221.3/2.93265	34.4862/1.28631

When hits take place at angles between listed figures, interpolation should be used. Say that 85mm is hit at 57° by 122mm APBC, and we just determined that 55° hits would be resisted by 144mm at 0°. For 60° hits the equivalent resistance equals 2.38 x 85mm, or 202mm at 0°. Resistance at 57° would equal 144mm + 2 x (202 - 144)/5, or 167mm at 0°, resulting in a 1.96 slope multiplier to convert 85mm at 57° to 0° equivalent.

Following equations relate slope multipliers for tungsten projectiles as function of angle, since T/D does not appear to influence the slope effects:

<u>90mm HVAP</u>

Compound angle equals 0° through 30°

$1.0000 \times 2.71828^{(A \times 0.000662)}$, where $A = (\text{compound angle})^{1.75}$

Compound angle greater than 30°

$0.9043 \times 2.71828^{(A \times 0.0001987)}$, where $A = (\text{compound angle})^{2.20}$

<u>76mm HVAP</u>

Compound angle equals 0° through 25°

$1.0000 \times 2.71828^{(A \times 0.0001727)}$, where $A = (\text{compound angle})^{2.20}$

Compound angle greater than 25°

$0.7277 \times 2.71828^{(A \times 0.003787)}$, where $A = (\text{compound angle})^{1.50}$

<u>APDS</u>

All compound angles

$1.0000 \times 2.71828^{(A \times 0.00003011)}$, where $A = (\text{compound angle})^{2.60}$

APPENDIX 17 : <u>ACCURACY AGAINST MOVING TARGETS</u>

British O.B. Investigation No. 659, Dated 28 Dec.'44, which is currently held by the Bovington Tank Museum, provides several valuable insights into the factors that influence hit probability against moving targets:

1. Vertical range estimation error and vertical dispersion not effected by target movement
2. Error in estimating target speed across line of sight is about 33% of speed
3. Error in laying gun onto horizontal center of target equals about 0.5 minute for each mile-per-hour across line of sight

4. Normal lateral dispersion would be added to factors 2. and 3.

Assume that a 2m high x 5.8m wide target is moving directly across the line of sight of a Sherman tank at 738m (800 yards), with 6.7 m/s crossing speed (15 mph speed). 75mm APCBC flight time to 738m is 1.26 seconds.

Following error analysis calculates standard deviation of bell-shaped distributions, where 68.26% of distribution within stated distance of aim point, or center of mass.

Error associated with crossing speed estimate is product of flight time and error in speed, or 1.26 seconds x 2.23 m/s, or 2.81m.

Error associated with gun laying onto target center is tangent (7.5/60) x 738m, or 1.61m.

Lateral dispersion at 738m is 0.95m.

Combined standard deviation is square root of the sum of the squares, or:

$(2.81^2 + 1.61^2 + 0.95^2)^{0.5}$, or 3.38m. Since the target width is 5.8m, there will be 0.86 standard deviations within the half width, for a lateral hit probability of 61%. Based on the above analysis, 61% of the initial shots against a 15 mph crosser at 738m will be within 2.9m of the horizontal target center. The lateral hit probability of 61% would then be multiplied by the vertical hit percentage, 50%, for an overall hit chance of 30% on the first shot (British estimate is 24%).

The following tables from the abovementioned O.B. Investigation present report estimates on hit probability against moving targets: tank moving directly towards firer and 15 mph direct crosser:

ESTIMATED HIT PROBABILITIES AGAINST MOVING TARGET

75mm APCBC

	FIRST SHOT		FOLLOW-UP SHOTS	
Range (yards)	Head-On	Direct Crosser	Head-On	Direct Crosser
400	97%	82%	100%	99%
800	50%	24%	99%	79%
1200	18%	7%	87%	53%
1600	8%	2%	69%	36%
2000	4%	1%	54%	25%

17 Pdr APCBC

	FIRST SHOT		FOLLOW-UP SHOTS	
Range (yards)	Head-On	Direct Crosser	Head-On	Direct Crosser
400	100%	95%	100%	99%
800	73%	46%	98%	79%
1200	34%	17%	86%	52%
1600	17%	7%	67%	35%
2000	9%	4%	51%	24%

6 Pdr APCBC

	FIRST SHOT		FOLLOW-UP SHOTS	
Range (yards)	Head-On	Direct Crosser	Head-On	Direct Crosser
400	100%	94%	100%	99%
800	66%	39%	95%	75%
1200	29%	14%	76%	47%
1600	13%	6%	56%	31%
2000	7%	3%	41%	21%

NOTES: Hit probabilities against stationary target are approximately equal to percentages against tank moving directly at firer.

Follow-up Shots probability appears to be maximum obtainable accuracy after several shots at target, with errors in range estimation and target speed reduced to zero, mean jump and throw-off adjusted for.

Direct crosser presents 2m high x 5.8m wide target

Head-on target presents 2.43m high x 2.74m wide target

If the accuracy against a head-on moving target is compared to the 15 mph direct crosser, following table presents the aeverage impact on accuracy of a target moving across the line of fire:

Range (yards)	FIRST SHOT Ratio of Direct Crosser %/ Head-On %	FOLLOW-UP SHOTS Ratio of Direct Crosser %/ Head-On %
400	0.91	0.99
800	0.57	0.80
1200	0.46	0.61
1600	0.37	0.53
2000	0.37	0.48

At 400 yards, which might be considered as the outer reaches of close range, target movement across the line of fire has a limited impact on accuracy due to the short flight time to target. Somewhere between 400 and 800 yards, the impact of target crossing movement significantly decreases accuracy compared to a stationary target.

The inability of guns to attain the stationary hit percentage on follow-up shots against direct crossers is consistent with other British analyses and firing tests, where it is difficult to consistently observe needed lead corrections and the attain the proper lead.

APPENDIX 18 : GERMAN CURVES FOR SLOPE EFFECT

The Germans estimated slope multipliers on the same table in the BIOS report where 30° penetration data is presented, and it is interesting to see how they approached the construction of an armor basis curve.

The Germans compared all slope multipliers to the assumed value at 30°, giving 30° a value of 1.00. Slope effects from 30° to 60° were then related to the impact velocity in the following manner;

GERMAN ARMOR BASIS CURVE
SLOPE EFFECTS KEYED TO 30° MULTIPLIER

45° IMPACT			60° IMPACT		
500 m/s	800 m/s	1100 m/s	500 m/s	800 m/s	1100 m/s
0.74	0.66	0.56	0.50	0.44	0.40

Use of the above table to determine slope effects is not straightforward, and an example will be presented. If the 30° slope effect equals 1.00, the 60° slope effect at 800 m/s impact would equal 1.00 divided by 0.44, or 2.27. Based on review of various German documents including the Tiger and Panther Fibels, it appears that a 30° slope multiplier of 1.25 was often used as a standard.

If 1.25 is assumed as the standard 30° slope multiplier, German and American slope effect estimates for APCBC and APC ammunition can be compared:

IMPACT ANGLE	m/s	GERMAN SLOPE MULTIPLIER	U.S. SLOPE MULTIPLIER	PERCENT VARIANCE
40	500	1.48	1.42	+4.2%
40	800	1.58	1.60	-1.2%
40	1100	1.76		
45	500	1.62	1.66	-2.4%
45	800	1.89	1.91	-1.0%
45	1100	2.23		
50	500	1.92	1.90	+1.1%
50	800	2.23	2.16	+3.2%
50	1100	2.55		
55	500	2.19	2.10	+4.3%
55	800	2.55	2.43	+4.9%
55	1100	2.93		
60	500	2.50	2.30	+8.7%
60	800	2.84	2.85	-0.4%
60	1100	3.13		

NOTES:

Slope multipliers from German curve.
U.S. slope multipliers from TM9-1907 for APCBC-HE projectiles.
PERCENT VARIANCE keyed to difference from U.S. figures.

The comparison of German and U.S. slope multipliers at various impact velocities and angles shows remarkable consistency between the two results, which supports the use of a single set of curves for all WW II APCBC and APC (projectile nose shape is roughly the same for all rounds with armor piercing caps, and nose shape determines slope effect). The consistency of German and U.S. slope multipliers is interesting since German projectiles had considerably harder noses, which implies that the percent reduction in U.S. penetration

(compared to what a German round would do at the same weight, diameter and velocity) was similar at all angles.

The Panther Fibel presents 45° and 60° slope multipliers of 2.00 and 3.00 for Panther APCBC. At 935 m/s (Panther muzzle velocity), interpolation from the above table results in estimated German slope multipliers of 2.04 at 45° and 2.97 at 60°, which round to the Panther Fibel listing.

Since penetration of 60° armor is obtained when a plug is driven down through the armor, and the projectile changes direction and follows the plug, there may be some logic to a slope effect curve based on impact velocity. At high velocities there may be a reduced tendency to follow the plug, requiring that the projectile directly push its way through armor and expend additional energy, thus a high slope multiplier.

The same logic would also predict that 75mm L24 hits on T34 armor would result in lower slope effects than Panther hits, since it is easier to change the course of low velocity rounds. Based on the German curves, when 75L70 and 75L24 APCBC rounds hit 45mm at 40° T34 side armor at 500m, the slope multipliers would be 1.61 on Panther hits and 1.41 versus the StuG IIIB 75L24.

While there may be accuracy advantages to a slope effect system based on impact velocity, mathematical modeling difficulties would arise during wargame and combat research efforts. Use of T/D based equations for slope effect estimation appears to produce reasonable results, although effective armor resistance may be overestimated against low velocity rounds.

APPENDIX 19 : FIRING TEST VALIDITY

The validity of firing test data on penetration ranges is often questioned on the basis of variations in armor and projectile performance. If the standard deviation of penetration data is 6%, 16% of hits will exceed average penetration by at least 6% and 16% will fall below average by 6% or more. Given these statistics, it appears that a small number of guns firing on a limited collection of captured tanks would have a difficult time reproducing the average penetration range.

Examination of the penetration test data presented in this book indicates that 50% penetration often occurs at or close to the predicted range. When the British tested 2 pdr AP, 37mm APCBC, 6 pdr AP and 75mm AP and APCBC from the Grant tank against the PzKpfw IIIH front hull, the range of effective resistance figures for the "32 over 30" armor was less than 2mm.

The relatively consistent results between firing tests and predicted ranges for 50% success can be explained on the basis of statistical probability.

If the standard deviation for penetration is 6% among all the guns, ammo and tank armor that might be faced, a round with 90mm average penetration that hits 100mm armor will succeed on one hit in twenty. Rounds with 94mm average penetration will succeed once every seven hits, and 97mm average penetration will be successful on one hit in three. As the average penetration varies from the average armor resistance, the probability that a firing test will signficantly differ from the 50% success range decreases.

The statistical analysis that was just presented does not apply to firing tests against armor that has flaw problems, such as Sherman and Panther. Since about half of the Panthers might have significant glacis flaws, one firing test with one gun would probably result in an atypical result.

As noted above, the consistency with which the predicted penetration figures match the effective armor resistance suggests that the calculated 50% success range is usually close to the actual average distance.

ANNOTATED BIBLIOGRAPHY

Note on Sources

The following includes the main sources of technical information consulted in writing this book. However, numerous partial reports were consulted, sometimes consisting of only a data table without supporting information regarding origin, specific agency, or date. Minor detective work has resulted in fairly reliable conclusions about the origin and validity of such data, yet precludes its inclusion in a formal bibliography. Some sources contain errors, but also contain unique information unavailable elsewhere. Where known, the archive which held the document when the authors acquired it is listed, although some reports are available elsewhere. Documents from the National Technical Information Service (NTIS) include the call number under which the document may be retrieved.

I. TECHNICAL REPORTS

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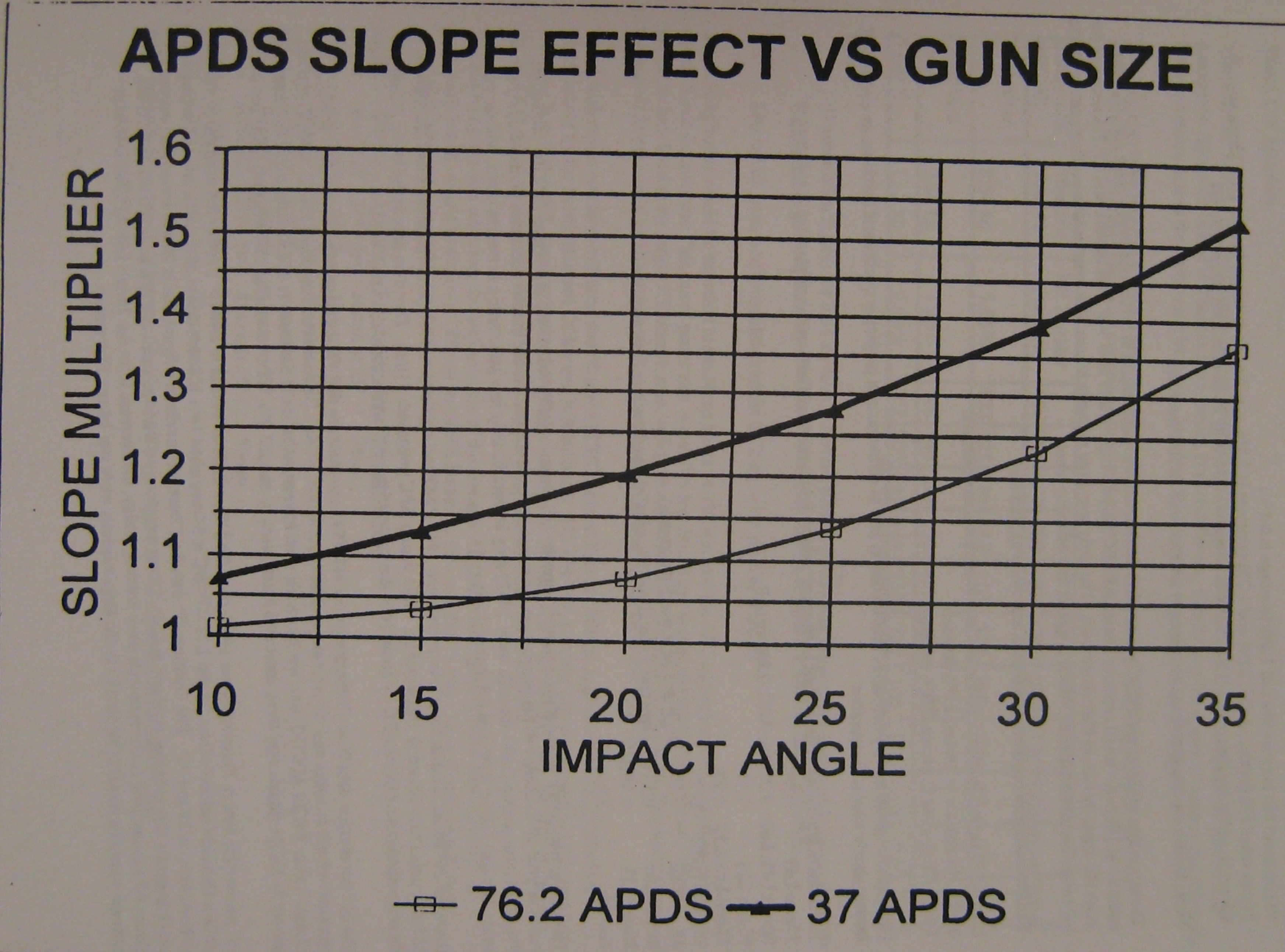

APDS SLOPE EFFECT VS GUN SIZE
SLOPE MULTIPLIER
1.6
1.5
1.4
1.3
1.2
1.1
1
10
15
20
25
30
35
IMPACT ANGLE
76.2 APDS
37 APDS

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ERRATA SHEETS

The following pages present errata sheets.

U. S. USE OF BRITISH APDS ROUNDS BY 57mm ATG

Claus Bonnesen posted the following on Yahoo! Tankers Site:

One important point - the US did not produce APDS, they used British APDS and apparently in limited quantities as well. So you won't find any Txx or Mxx numbers for those.

Rich Anderson posted a number of references to US Army 57mm APDS use on Tankers Net a while back, but that thread seem to have vanished into cyberheaven. I have some of the references copied though:

2nd U.S. Infantry in the (German) Breakthrough, 38th Infantry:

"During the course of the action a few noteworthy lessons were learned. Firstly, determined infantry armed with its organic weapons will stop German armor, principally by use of the rocket launcher (Bzooka) and by destroying the attack of the accompanying enemy infantry. Secondly, the 57mm AT gun with normal AP amunition was found to be of such little value that I regard it as a practically useless weapon. With the special "sabot" ammunition in abundance the weapon could be of great assistance in repelling enemy armor. I am, nevertheless, convinced it should be replaced by a self-propelled weapon of greater anti-tank possibilities..." F. H. Boos, Col., Inf., Commanding.

Also, appended to the 38th Infantry AAR was this "Report of Towed 57mm Guns (AT) in Rocherath-Krinkelt Action:

"...57mm guns knocked out two Panther....The first round (regular A.P.C.), fired at the side of the turret at about 175 yards riccochetted and had no effect. The second round was a hyper-velocity "Sabot" round and penetrated...I recommend the following changes in basic load:

Type	Present	Recommended
AP or APC	60	10
"Sabot"	6	30
HE	13	20

...I also recommend the development of canister ammunition..we have found the present issue of HE effective...butconsidering the reports on 37mm canister, 57mm canister would be more effective than HE. /s/ J. W. Love, Captain, 38th Infantry, Comdg, AT Company."

It is also noted that the 13 HE rounds was in excess of the prescribed load and was a "kitty" built up in Normandy.

And....

I have found more references to both 57mm HE and 57mm Sabot in wartime US unit reports. The 90th Division AAR for August 1944 has a G-4 Summary which mentions 57mm HE (Br.) and 57mm Sabot as being "continually desired" (I imagine for the Sabot!) while "limited quantaties" only were available. So, it appears that the issue HE round was in fact British.

Still, it is interesting that I have yet to see any mention of the official nomenclature for the HE and Sabot round, nor have I been able to find any specific table of allowance for the rounds. It is also obvious that the standard AP shot was in plentiful supply (go figure).

Regarding the HE, the US did apparently produce some, according to Kurt Laughlin who referred to:

An order in March, 1944 authorized production of 100,000 T18 (M303) 57mm HE rounds.

Hope this helps!

Claus B

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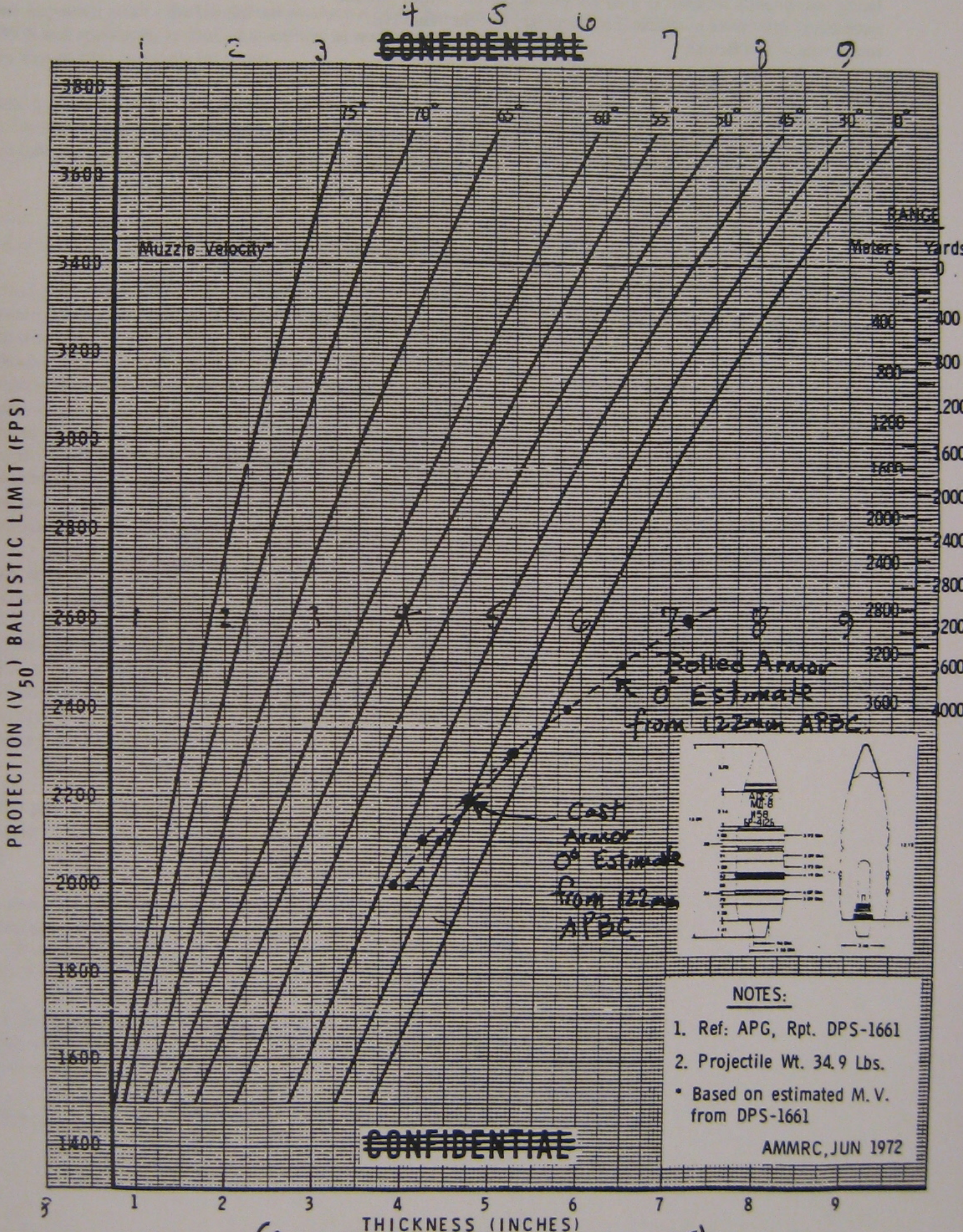

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(RUSSIAN WW II APHE PROJECTILE)

FIGURE 356 (C) PROTECTION PROVIDED BY CAST HOMOGENEOUS STEEL ARMOR AGAINST SOVIET 100MM APHE-T BR-412B PROJECTILES (U)

Xtra copy

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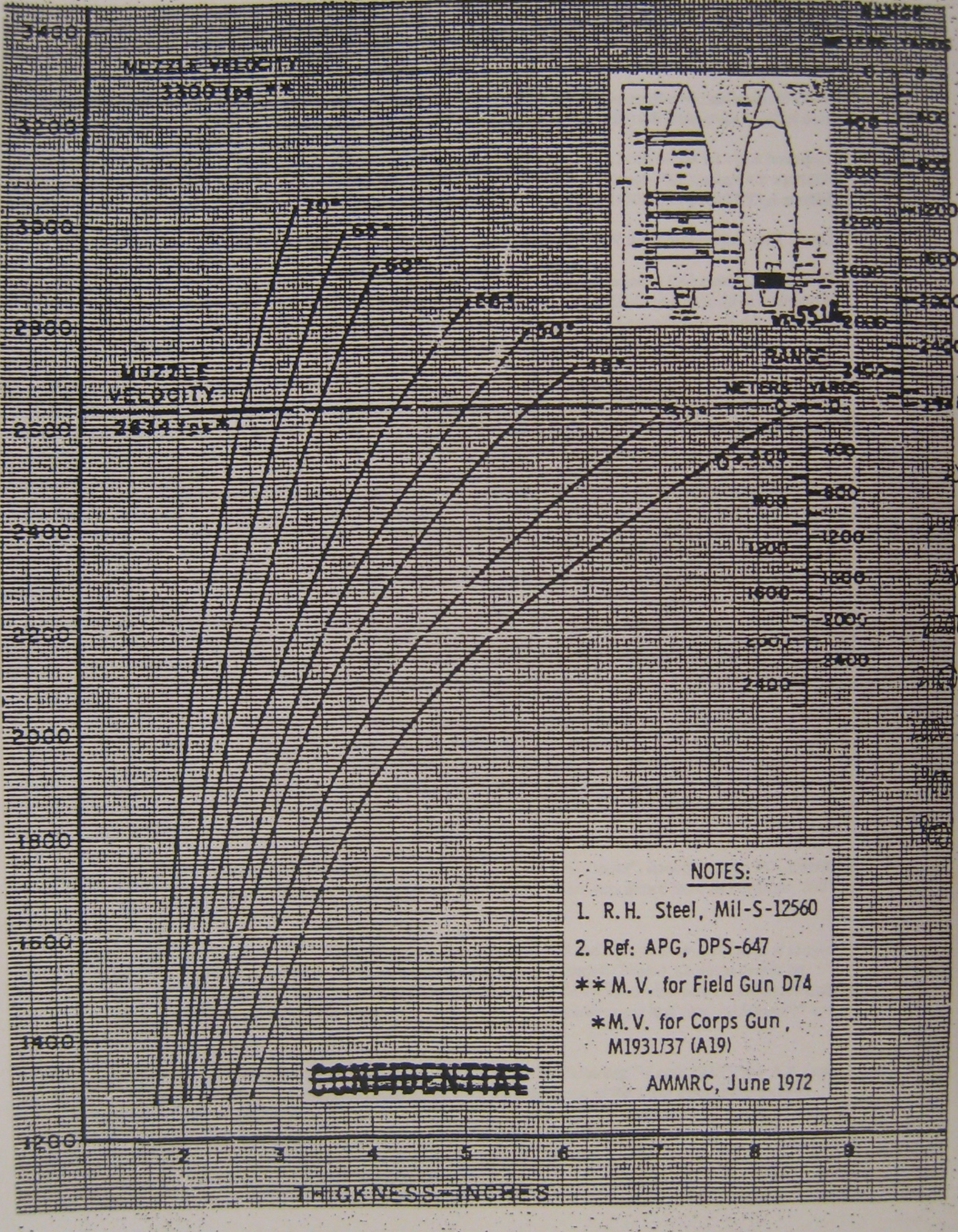


FIGURE 286 (C). PROTECTION PROVIDED BY ROLLED HOMOGENEOUS STEEL ARMOR AGAINST SOVIET 122MM AP-T BR471B PROJECTILES (U)

75mm L43 VERSUS T34 ARMOR

Valera Potapov has posted material on Combat Mission site where Russian tests result in 1000m penetration of T34 glacis by 75mm L43 APCBC (30° lateral or horizontal angle).

Compound angle for 60° vertical slope hit at 30° side angle would be 64.34°, resulting in armor resistance of 45mm x 3.13 slope multiplier x 0.76 high hardness factor, or 107mm of good quality armor at 0° impact. Estimated penetration of 75mm L43 APCBC at 1000m is 107mm, which matches up well against computed armor resistance.

Thomas Jentz in Panzertruppen Volume I, 1939-1942, presents two combat descriptions for 75mm L43 against T34.

In first report, 75mm L43 penetrates T34 out to 1200m at any angle, and has maximum penetration range of 1600m. If T34 glacis is hit at 0° lateral angle, the armor resistance will equal 122mm vertical on level ground times a high hardness multiplier of 0.76, for 93mm of good quality armor at 0°. 75mm L43 APCBC penetration at 1600m is estimated at 93mm.

At 1200m and 30° lateral angle, T34 glacis presents 107mm resistance and 75mm L43 APCBC penetrates 102mm, which will succeed on 11% of hits against 45mm armor. T34 advancing over downward sloping terrain, or with glacis thickness below 45mm (42mm to 50mm was usual thickness range), would allow high percentage of hits at 1200m with 30° horizontal angle.

The second report given by Jentz states that 1000m penetration range is maximum for 75mm L43 against T34. The difference between the two reports in Jentz' book could be due to thicknesses at high end of range, upward sloping terrain, subpar ammunition or unusual quality armor (some references suggest that U.S. provided armor plate to Russians which could have been in machineable quality hardness range with improved resistance characteristics).

German APCBC nose hardness variations of 57 to 69 Rockwell C were reported by Miles Krogfus, and projectiles at the lower end of the range could have 13.3% less penetration than the average round. If the 75L43 APCBC penetration at 1000m is reduced by 13.3% (from 107mm to 93mm), the revised figure at 1000m matches the estimated resistance of a the T34 hull front after high hardness modification.

RUSSIAN 76.2mm PENETRATION AND COMBAT AGAINST TIGERS AND FERDINAND

Thomas Jentz has provided Russian firing test results against Tiger II where ranges are indicated but the horizontal or lateral firer angle is not specified. The following ranges represent the distance at which the turret side (80mm/20°) and superstructure side (80mm/25°) were defeated:

45mm solid shot AP type	300m	45mm APCR	300m	85mm APHE type	500m
57mm APHE type	400m	57mm APCR	600m	122mm M-30 APHE type	400m
76.2mm APHE type	300m	76.2mm APCR	400m		

AP solid shot and APHE types appear to be APBC rounds.

The 45mm results appear to be from M42 L66 gun, as that weapon's APCR is capable of penetrating 80mm/25° at 300m with 0° lateral angle. Solid 45mm AP or APBC would penetrate less than 75mm at 0° and 300m, suggesting test for that round was against vertical 80mm side hull or obtained very low probability success against 80mm at 20° and 25°.

Russian Battlefield presents official firing trial results from late 1943 where 76.2mm BR-350B round (fired by T34) defeats about 85mm at 300m and 0° on half the hits. T34 APBC round would penetrate 80mm/25° on a fair proportion of hits at 300m, based on test results, if there was no lateral angle from firer to armor facing.

If Russian Battlefield penetration statistics are applied to combat against Tiger E, T34 APBC would defeat 82mm side armor on about 42% of hits at 500m with no lateral angle (81mm penetration for BR-350B at 500m and 0°), and succeed on 42% of hits at 300m with 20° horizontal side angle and 10% at 25°.

In contrast to above results, following factors suggest that 76.2mm performance may be less than 1943 firing trial penetration on Russian Battlefield suggests:

> 76.2mm gun firing APBC at Kubinka testing grounds during 1944 failed to penetrate Tiger II turret and superstructure side (point brought up by Ricord_88 on Tankers site after review of report at http://www.battlefield.ru/library/bookshelf/weapons/weapons7.html).
>
> German design and testing of Tiger 82mm side armor at Kummersdorf has armor resistant to standard 76.2mm gun ammo (APBC) at all angles after "breakthrough" of Russian lines, Russian tankers advised to aim for 62mm armor between wheels and 82mm plate, and German experience with Tiger identifies side penetrations through 62mm armor (points brought up by Ricord_88 after reviewing Wolfgang Fleischer's book on Heer Weapons Testing at Kummersdorf). Minimum range for hull side safety against 76.2mm hits is not indicated.
>
> Valera Potapov references "Instructions to combat with German heavy tanks", issued during 1943, where there is a recommendation that all 76mm guns and tanks fire at Tiger 82mm side armor from short ranges, 200 meters and closer.
>
> Ferdinand tank destroyer 602 at Kursk was fired upon by seven T34 and four 76.2mm field guns at ranges from 200m to 400m, at a variety of angles, with only one side penetration (Ricord_88 noted details on Ferdinand 602 penetration from review of following site: http://www.uw.ru/msvirin/ferdinand/fertabl-e.html). Tank destroyer side armor presents 80mm/30° superstructure, 80mm/0° upper hull side and 60mm/0° lower hull side.
>
> Sonny19412002 wrote on Tankers site: "Page 70 footnote 7 of N. Zetterling "Kursk 1943" :the A.P. "round of the 76 mm F-34 tank gun had difficulties penetrating the side armor of the Tiger even at distances of 200m." Tests happened on 24-30 April 1943 and a photo reveals that the Tiger had a 82 mm upper side hull with one hole in it showing in the photo (only part of the hull is visible).

GERMAN 88mm APCBC AMMUNITION NOTES

88mm L56 Additions

The early war 88mm Flak units fired a projectile which appears to be inferior to later war ammunition, based on 30° penetration figures contained in Thomas Jentz' book, *Dreaded Threat*. Combat reports appear to support the relatively low penetration figures for early war Flak ammo based on shattered hits against KV and T34 tanks.

The following table presents 0° penetration figures for three versions of the 88L56 APCBC projectile, with the improved Flak ammunition becoming available during mid-1942.

88mm L56 APCBC	Projectile Weight	HE Burster Percent	100	250	500	750	1000	1250	1500	1750	2000	2500	3000
Early War Flak	9.54 kg	1.65%	123	121	116	112	108	104	100	97	93	87	81
Later War Flak	9.54 kg	1.65%	149	145	139	133	127	122	116	111	106	97	89
Tiger E	10.2 kg	0.59%	162	158	151	144	138	132	126	121	116	106	97

Notes:

0° penetration figures for 9.54 kg rounds derived from application of slope effect equations in our book to 30° penetration data found in Jentz' *Dreaded Threat* and American report on 88mm Flak penetration.

88mm Flak units may have also used the 10.2 kg round fired by Tiger E.

The 9.54 kg round would be expected to penetrate about -4.7% less than the 10.2 kg projectile if everything else were equal. Since the later war Flak round penetrates about -7% less than Tiger ammo, the additional difference would appear to be related to the larger HE burster area, which would weaken the overall structure of the ammunition (more of the impact forces would be absorbed by the projectile, offering less energy for armor penetration).

The British report on German 75mm and 88mm APCBC Ammunition at Oblique Angle, Report No. N.69144/4 No. 1, which is held by the Public Records Office and is listed under WO 194 749, provides armor penetration firing test data at angles from 45° to 55°. Comparison of 55° penetration results for later war Flak APCBC with the expected results for the Tiger round resulted in a -8% inferiority, which compares well with the above data.

The following analysis examines the performance of the German APCBC rounds in the British tests compared to predictions based on data in our book (88mm small HE burster is later war 88L71 Flak, Tiger II and Tiger E round, large HE burster is later war 88L56 Flak ammunition) :

Round	Burster	Velocity	Test Penetration	Book Prediction
75mm	small HE	2440 fps	58mm at 55°	58mm
75mm	small HE	2060 fps	62mm at 45°	63mm
88mm	large HE	2310 fps	58mm at 55°	59mm
88mm	large HE	2060 fps	62mm at 45°	68mm
88mm	large HE	2750 fps	65mm at 55°	72mm
88mm	small HE	2230 fps	57mm at 55°	59mm
88mm	small HE	2882 fps	76mm at 55°	79mm
88mm	small HE	2965 fps	81mm at 55°	82mm

Note: book predictions include impact of 9.54 and 10.2 kg weights but do not consider HE burster size.

In terms of differences from book estimates, the following "error" analysis was obtained:

75mm small HE burster: 0% and 1.6% (average is 0.8%)
88mm small HE burster: 3.4%, 3.8% and 1.2% (average is 2.8%, may be due to larger burster than 75mm ammo)
88mm large HE burster: 1.7%, 9.8%, 9.7% (average is 7.1%, may be due to much larger burster)

Note: British report notes great variations in resistance of British test plate

The tabulation of German APCBC penetration data on the first page results in no change from 75mm APCBC based estimate at 100m for small capacity 88mm APCBC (Tiger, Tiger II and later war Flak round), and a 2.7% decrease for large HE capacity 88mm Flak (later war). The early war large capacity 88mm Flak ammunition performance is 21.2% below the DeMarre estimate, which suggests less effective steel.

The limited ammunition sample British test data suggests that:

0.20% HE burster in 75mm, 0.8% decrease to penetration estimates
0.59% HE burster in 88mm, 2.8% decrease
1.65% HE burster in 88mm, 7.1% decrease

Note: above variations in penetration may be due in part to differences in projectile quality and hardness as well as HE burster size in 88mm ammunition

The following table summarizes HE burster percentage for a variety of German armor piercing ammunition:

37mm L45	1.9%
50mm L42, L60	1.2% for APC, 0.8% for AP
75mm L24	1.7%
75mm L43-L70	0.2%
76.2mm L51.5	0.2%
88mm L56	1.65% (early and later war Flak rounds)
88mm L56	0.59% (Tiger and Tiger II rounds, possible for later war Flak ammo)
88mm L71	0.59%
128mm	2.0%

The data presented above suggests that small capacity HE bursters (0.2% to 0.59%) in German APCBC projectiles result in little or no change to the penetration estimates in this book, and 1.65% bursters decrease penetration by about 3%. Early war ammo (1941 through early 1942) may be significantly less penetrating in certain cases, with an example being German 50mm APC and AP ammunition.

Based on 30° penetration in Jentz' *Panzertruppen 1943-1945* and application of slope multipliers, 50mm AP fired at 835 m/s penetrates 88mm at 100m and 0°, while 50mm APC penetrates 91mm. Based on data in the book, 50mm AP should outpenetrate 50mm APC by about 14% due to the absence of armor piercing caps.

The 30° penetration data from *Panzertruppen 1943-1945* also predicts that 75L24 large capacity APCBC would penetrate 49mm at 100m and 0° after slope effect conversion, while a DeMarre estimate from 75L43 APCBC predicts 52mm. In the 75L24 APCBC case, the projectile steel appears to be about the same as 75L43 ammo and the large HE burster in 75L24 rounds may have decreased penetration by about 5.8%, which is similar to the British firing test result.

30° penetration data in *Panzertruppen 1943-1945* for 37mm L45 AP results in a 0m/0° penetration estimate of 46mm, while a DeMarre estimate from 75mm L48 APCBC is 64mm when 14% is added due to absence of armor piercing and ballistic caps on 37mm AP. The German 30° data for 37mm AP results in a figure that is 28.1% lower than expected, which suggests less effective steel use in early 37mm rounds as well as decreases due to a large HE burster. If the 37mm AP rounds used in German tests were combat quality, the decrease from the 75mm L48 APCBC DeMarre estimate would be about 21%, similar to the large capacity early war 88mm Flak ammo.

SHATTER GAP ADDITION: DEPENDENCE OF T/D RATIO UPON IMPACT ANGLE

Published research by W. Goldsmith in the Journal of Impact Engineering 22 presents results for the angle at which project damage occurs as a function of T/D ratio (termed "h/D normalized plate thickness" in article).

When projectile strikes at a certain angle and T/D ratio, damage may occur if projectile nose hardness is in certain range, which may increase the velocity required for penetration. This is the basis for the shatter gap, which projectile damage causes failure at ranges where penetration would normally be expected.

On the following graph, solid circles represent damaged projectiles, open circles represent intact hits and the line is predicted performance based on a theoretical relationship. From 70° through 30° the predicted line for projectile damage is consistent with experimental results using 20mm projectiles, and continuation of the line below 15° impact appears to rule out projectile damage on hits with close to 0° impact angle.

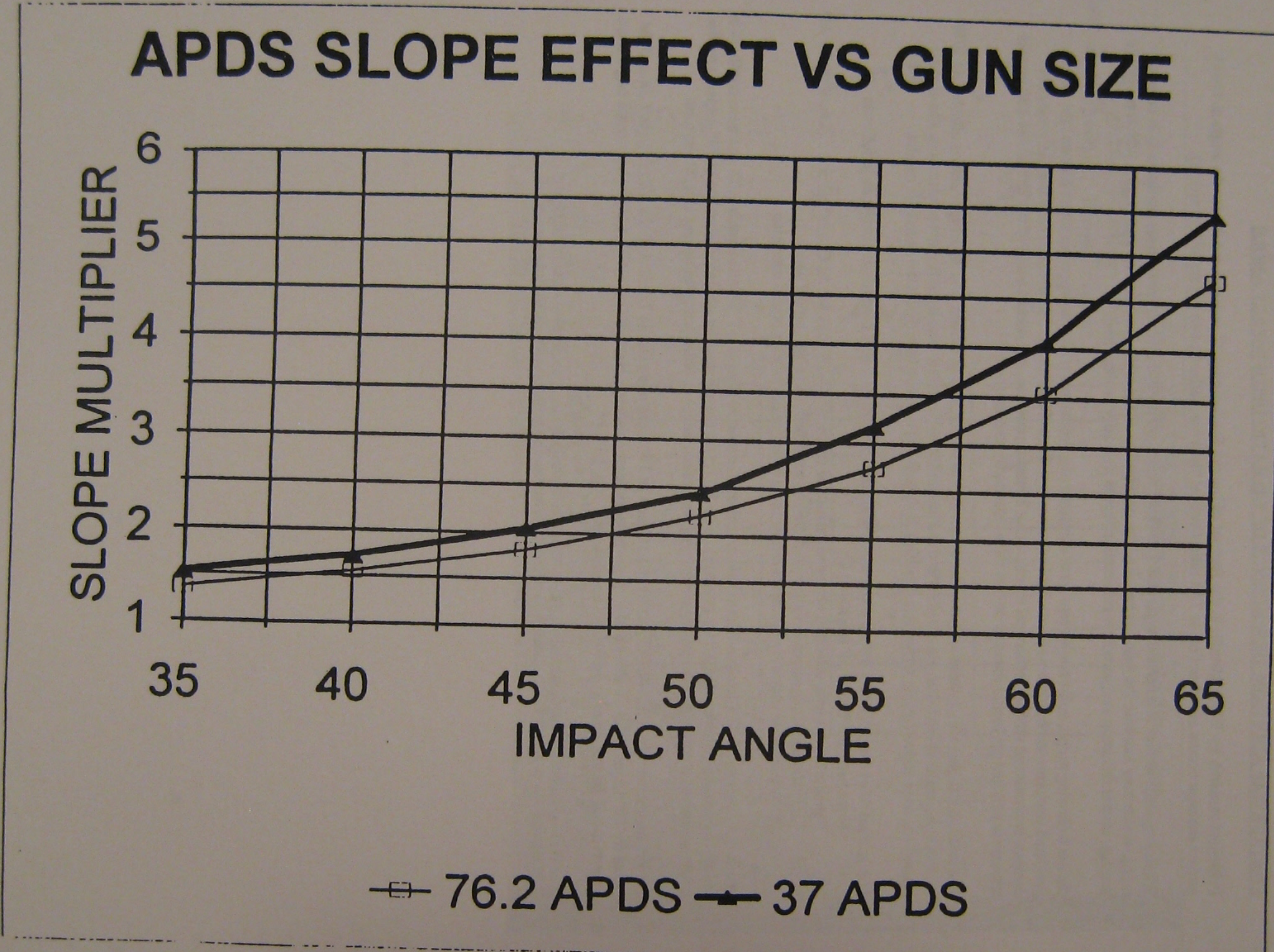
The solid rectangles, which were added to the graph by this writer, depict British and American test results during WW II where projectile shatter was experienced and the hits failed to penetrate despite sufficient penetration. The double dashed line was added by this writer and modifies the predicted curve to agree with the rectangle results.

The ground rules for projectile damage and ensuing shatter gap results could then be summarized as follows:

1. Nose hardness below 59 Rockwell C
2. Penetration exceeds effective armor resistance at angle by 5% to 25% for APC/APCBC and 5% to 40% for AP
3. T/D ratio equals or exceeds figure predicted by modified curve for impact angle
4. Projectilewould normally penetrate armor in an intact or slightly damaged condition

When U.S. 76mm APCBC strikes 82mm side armor on Tiger at 30° impact, T/D ratio equals 1.08 and nose hardness is usually less than 59 Rockwell C (54.5 average). The T/D ratio is sufficient for projectile damage at 30° impact and the other conditions are met, resulting in a shatter gap prediction, which is what occurred during U.S. Navy tests.

For the case where 76mm APCBC attacks the 102mm at 10° front plate on the Tiger hull, the T/D ratio is 1.34 and the result for 10° impact will be close to the area where projectile damage is predicted. With a slight horizontal angle from firer to armor facing, shatter gap would be expected.


APDS SLOPE EFFECT VS GUN SIZE
SLOPE MULTIPLIER
6
5
4
3
2
1
35
40
45
50
55
60
65
IMPACT ANGLE
76.2 APDS
37 APDS

Projectile Shatter
U.S. and British Firing Trials

	T/D RATIO
55°	0.32
30°	0.56
20°	1.11
5°	1.44
0°	1.60

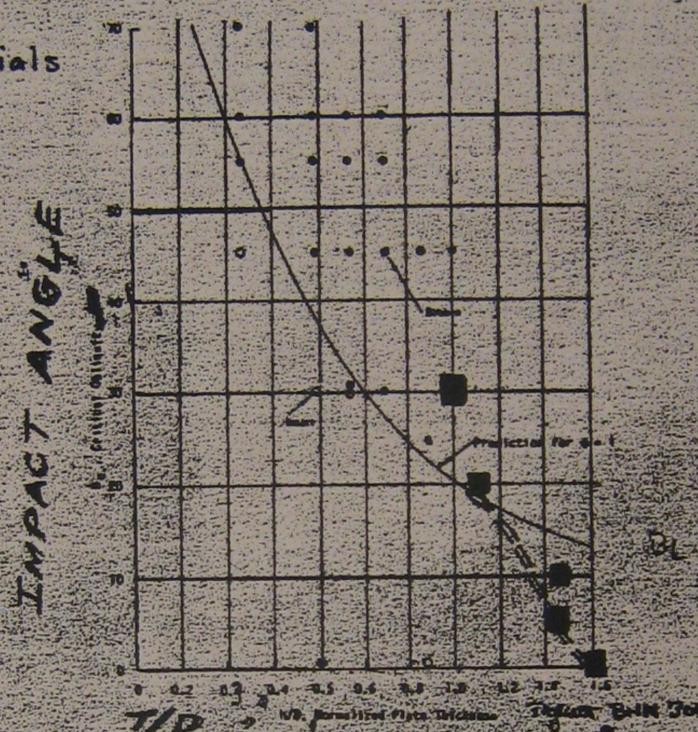


Fig. 57. Critical obliquity angle, β_{cr}, for projectile breakup. 20 mm armor piercing projectiles striking steel armor p... showing broken (solid) and intact (open) strikers. The solid line is the prediction of Eq. (3.38) for $\Phi = 1$ in Eq. (3.37)...