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THE 76-MM GUN M1A1 AND M1A2: AN ANALYSIS OF U.S. ANTI-TANK CAPABILITIES DURING WORLD WAR II

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14. ABSTRACT

This report provides an analysis of the U.S. anti-tank technology during World War II. A ballistic analysis is used to corroborate the battlefield history and gain an understanding of the physical and technological factors that spurred the development of the M1 series 76-mm Gun and family of ammunition.

The technical manual (TM) 9-1907 was published 23 September 1944, but it was missing performance data for the 76-mm hyper-velocity, armor-piercing (HVAP) shell and any information for performance of the U.S. anti-tank capabilities against the German Panther tank. Battle history indicates there was a technological capability gap against upgraded Panzer armor. This report attempts to use hand calculations and modeling and simulation (PRODAS) to fill in the information that is missing in TM 9-1907. The analysis offers the reader a greater engineering comprehension of the challenges faced between June 1944 and May 1945 and the circumstances necessitating the rapid fielding of the 76-mm HVAP shell after German capability upgrades were encountered in the European Theater of Operations from Normandy to the Battle of the Bulge (June to December 1944).

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PRODAS   76-mm gun   M62A1 76-mm armor piercing capped (APC)
M93 76-mm hyper-velocity, armor-piercing tracer (HVAP-T)   TM 9-1907   Tank Destroyer
Armor penetration   Panzer IV   Panther   M4A3E8 Sherman tank   M4A3 (76) Sherman tank
M4A1 (76) Sherman tank   M18 Hellcat Tank Destroyer   Limit velocity V_{50}

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Most of all, the authors wish to thank Dr. Donald Carlucci for providing guidance in ballistics methodology and the inspiration to conduct this research.

INTRODUCTION

> "The tank forces are at once the youngest of all the arms, and the one with the highest degree of striking power… The more effective the developments in anti-tank defense, the more difficult will be the armored attack, and the more forcibly and loudly the tankmen must press their demands," Heinz Guderian, 1937 (ref. 1).

The German offensive of 1939 changed the perception of the threat assault by armored vehicles. The early German success can be attributed to both technological advancements since the First World War and the use of combined arms tactics with the Panzer. Guderian's refinements in combined arms tactics focused on using the armored force as the primary means of projecting striking power, providing shock effect en masse. The general fostered the perception that the Panzer was the master of the battlefield. Initial allied assessments of the rapid collapse of France attributed the success of the German army entirely to the tank, not truly grasping the impact of the supporting arms in exploiting the breakthrough and facilitating the advance. The result was a scramble to develop an effective means to defeat the German Panzer.

Infantry based anti-tank weaponry and fixed fortifications proved inadequate to stop the rapid movement of the German Panzer forces in France. Initial perception often dictates subsequent reaction; combined with Guderian's pro-Panzer propaganda, the Panzer was perceived as invincible. The pursuit of effective anti-tank measures was the logical course of action, resulting in the concept of the Tank Destroyer. This was a rapidly deployable, speedy, and heavily armed vehicle solely responsible for defeating enemy tanks. Doctrine emphasized employment of tanks in an infantry support role, and there was a call to develop units specifically with an anti-tank mission. The pursuit of a tank killer was born.

Anti-tank doctrine dictated the new vehicle needed armament powerful enough to defeat the German armor while remaining light enough to be fast moving to engage and withdraw. The development of improved weaponry and the development of this new armored vehicle was linked together for better or worse. To give this vehicle its striking ability, the U.S. developed the 76-mm Gun M1. The vehicle designed to carry out the mission would be the M18 "Hellcat" Tank Destroyer.

EARLY WORLD WAR II ANTI-TANK EFFORTS

The nemesis of the Tank Destroyer would be the two types of tanks the Germans had employed to enact Guderian's doctrine. The Panzer IV (Pz IV) tank was the primary means to carry out Guderian's doctrine of shock, while the lighter Pz III was tasked with quickly exploiting the breakthrough the heavier Pz IV made and then cause disruption behind the enemy's front lines.

The Pz IV was not without shortcomings. The model of the Pz IV used in The Battle of France in 1940 was equipped with a low velocity short barrel 75-mm gun. It could not penetrate the armor of heavy tanks such as the British Matilda. Many of the allied tanks in France, such as the Renault R35, were equipped with a 37-mm anti-tank gun that also could not penetrate the Pz IV armor. What the Germans could not destroy, they simply flanked and outpaced.

These shortcomings drove continual upgrades throughout the war. Eventually the Pz IV became the workhorse of the Panzer forces. Improvements in turn fueled the development of the dreaded Tiger and Panther tanks.

The total number of the Pz IV tanks in service as of December 1941 was only 480, but the impact had left its mark (ref. 2). The Pz IV was the tank set as the benchmark to defeat, given its relatively heavy armor compared to allied anti-armor capability in 1940.

The U.S. Army initially employed truck drawn anti-tank guns as a stopgap. This had serious drawbacks since the weapons still needed emplacement and the trucks had difficulty with rough terrain. The U.S. Army employed an interim solution of emplacing anti-tank guns in half-tracks to offer better cross-country mobility than the truck transported options. The field of fire was limited in the half-track and the bulky vehicle was not as fast as Tank Destroyer proponents desired. Initial response was, at best, an attempt to deploy countermeasures using inadequate equipment. Major Brian Denny has assessed the situation,

> “Although they possessed a combination of both light and heavy tanks, these weapons were built in accordance with French doctrine as infantry support weapons. To defeat enemy armor they relied on antitank guns of which they had neither the numbers nor the doctrine to effectively stop German armor” (ref. 3).

U.S. ANTI-TANK OPTIONS CIRCA 1940 VERSUS THE GERMAN THREAT

The effectiveness of U.S. Army weapons and ammunition during World War II was compiled in technical manual (TM) 9-1907, Ballistic Data, Performance of Ammunition (ref. 4). It is an informative snapshot of the capabilities of technology available to the U.S. Army at the time. The performance of each of the U.S. anti-tank guns is evaluated against plate armor and concrete.

The Pz III, Pz IV, and Tiger tanks are all included in the analysis published in the TMs. The TM 9-1907 paints a bleak picture for the crews that relied on the 37-mm anti-tank gun against any of the German Panzers. The Pz IV turret and hull frontal armor was invulnerable to the 37-mm at point blank range (ref. 4). Striking on the flank fared better, piercing the sides of the hull at a maximum range of 1,730 yd (1,582 m).

The rear of the Pz IV was the best aim point for a successful attack and was vulnerable at 3,940 yd (3,603 m). A 37-mm gun crew had to both be patient and allow the Pz IV to pass, or move rapidly enough, to a position in the rear and quickly set up their weapon. It is not difficult to see how the crew of an M6 37-mm Gun Motor Carriage (a Jeep with a rear facing 37-mm gun mounted in the bed) or an M3 Stuart Light tank would be at a severe disadvantage.

The 75-mm option showed more promise than predecessors but was still marginal. The hull frontal armor of the Pz IV could not be penetrated at point blank range using the M61 armor piercing capped (APC), the best anti-tank round available in this caliber. The front turret of the early Pz IV proved vulnerable at distances less than 1,280 yd (1,170 m) (ref. 4). The 75-mm weapons fared much better on the flank, defeating hull armor at 4,960 yd (4,535 m) and the turret armor at 4,700 yd (4,298 m). In a head-to-head contest, the Pz IV still held an advantage over an armored vehicle equipped with the M3 75-mm gun, which included the half-track, the M3 Lee/Grant tanks, and the M4 series of Sherman tanks.

The 3-in. gun was the only option available to the U.S. Army at the onset of World War II that could defeat the frontal armor of the Pz IV. This weapon used the M62 APC Shell, which TM-9-1907 predicted defeated the Pz IV frontal armor at ranges within 1,600 yd (1,463 m). It initially saw service as an anti-aircraft gun, but its higher muzzle velocity imparted enough energy to be effective defeating armor. The 3-in. gun was also similarly mounted on trailers and half-tracks but was the first weapon system utilized by a dedicated Tank Destroyer, the M10 Wolverine.

The M10 was based on the chassis of a Sherman tank, but its armor was reduced significantly to allow for greater speed and an open top turret was designed to accommodate the 3-in. gun. The M10 was still considered too slow and too large to effectively employ Tank Destroyer doctrine to its fullest capability. The result was the further development of a lighter and faster vehicle to fill the capability gap.

THE 76-MM GUN M1A1 AND M1A2

The T70 Tank Destroyer with the 76-mm M1 Gun was designed to replace the M10 Tank Destroyer and 3-in. M7 Gun. The M1 was designed to be a match for the M7 in performance but would be reduced in weight and size due to the smaller turret of the T70 Gun Motor Carriage. The T70 would be Classified Standard as the M18 Gun Motor Carriage on 17 February 1944 (ref. 5). The later produced M10s would also mount the 76-mm as the 3-in. Gun was phased out, but this variant did not see widespread use.

It was not until after Normandy that the 76-mm Gun saw use in both Tank Destroyers and late model M4A3 Sherman tanks. This was possible only when a shift in perception took root that a tank would certainly need to defeat other tanks encountered during combat.

Doctrine stated that the role of a tank was for infantry support, not fighting other tanks. Armored Forces Field Manual: Tactics and Techniques (FM 17-10) listed tank versus tank combat as “special operations” with less than a page devoted to the subject (ref. 6). The 75-mm Gun was retained for use in tanks because of the performance of its High Explosive Shell. The M61 75-mm APC was the anti-tank armament used in U.S. medium tanks, in spite of the inability to defeat the frontal armor of a Pz IV.

The omission of the Panther tank in the content of TM 9-1907 is telling and the M93 hyper-velocity, armor-piercing tracer (HVAP-T) shell is not included either. The HVAP-T round was fielded just prior to publication of the TM, so the performance data was likely available too late for printing. This becomes significant for the M1 76-mm Gun, both in its wider use and the development of more effective ammunition.

The total displacement of the M1 series 76-mm Gun was 11.82 ft^3. This contrasts with the 34.24 ft^3 of the 3-in. M7. The Tank Destroyer was intended to be smaller and faster than a tank, so the significant reduction in displacement supported this doctrine. The total weight of the breech and cannon tube was 1,193 and 797 lb, respectively, which are less than its 3-in. predecessor. The length of the cannon was 5 in. greater than the 3-in. M7, totaling 13 ft and 7-3/4 in. long. The 76-mm Gun was originally intended to be 15 in. longer, but the added weight of the original length lead to balancing issues that impeded turret traverse in the M18 Tank Destroyer. Instead of balancing the turret by adding weight to the rear as a counterbalance, the decision was made to reduce the total length of the cannon (ref. 7). This had a detrimental effect on muzzle velocity and subsequently armor penetration. A “what if” comparison analysis is included later in this report that predicts the performance reduction resulting from this reduction in cannon length. Figure 1 shows an M1 test gun (middle rack) at the Aberdeen Proving Ground (APG) Ordnance Museum, and figure 2 shows the measuring the M1 test gun breech at the APG Ordnance Museum.

Figure 1
M1 Test Gun (middle rack) at APG Ordnance Museum

Figure 2
Measuring the M1 Test Gun breech (Aberdeen Ordnance Museum)

Space was cramped inside the turret of the M18 Tank Destroyer and the M4 Sherman. The T1 Mount oriented the breech of the 76-mm gun at a 45-deg angle to compensate for the tight space in the M18 Tank Destroyer. The odd orientation ensured proper functioning of the recoil mechanism and facilitated loading of ammunition. Late model Sherman tanks also included the 76-mm gun in the T80 Mount, but the orientation was completely horizontal (ref. 8).

There were few differences between the 76-mm M1A1 and M1A2 variants. The easiest identifiable distinction was the addition of a muzzle brake on the M1A2. The rifling was also changed from a one in forty (1:40) calibers to a one in thirty two (1:32) twist. Figure 3 shows an image of the rifling in the test M1 gun.

Figure 3
Rifling in the Test M1 Gun (Aberdeen Ordnance Museum)

PERFORMANCE ASSESSMENT AT ABERDEEN PROVING GROUND

The Chief of Ordnance ordered determination of pressure and velocity data for the M1E1 76-mm Gun in March 1943 using piezo-electric pressure gages. The pressure was measured and curves were generated for muzzle velocities between 2500 and 2600 fps (ref. 9). The piezo gage results were compared to copper crusher gage measurements taken for the same firing, and a correlation was established. Both tank ammunition powder (87-10-3) and 155-mm and 8-in. howitzer powder (85-10-5) were tested in both the M28A1 and M28A2 Primer Assemblies. The report states that the data collection was specifically for the generation of interior ballistics calculations. These calculations were not included in the report due to time constraints.

Six “Pilot” T70 (M18) Tank Destroyers underwent testing starting in June 1943. First production started by order of General McNair in July 1943, prior to completing the qualification tests. The need to have vehicles available for the Tank Destroyer Battalions at the beginning of 1944 drove this decision (ref. 10). The “Number 3 Pilot” T70 (M18) Tank Destroyer underwent a series of endurance tests at APG, Maryland. Testing for the 76-mm gun resumed from June 1943 to January 1944. Daily logs record the results of driving over concrete, gravel, and rough terrain.

Several issues were uncovered during the June 2 through June 8 testing. The placement of the balance plate on the rear recoil guard forced the loading of a round into the breech at an angle awkward for the loader, increasing the risk of injury. The correction for this shortcoming was removing part of the balance plate. This allowed for greater clearance and easier loading. Nine hundred rounds were fired without failure during the first week of testing. An additional 800 rounds were fired the following week on gun no. 1019. Firing the 76-mm gun at service pressure (0, 10, and 20-deg elevation) generated muzzle velocities of 2564 to 2615 fps. The observed pressures for the service rounds were 45000 psi on average and followed by an additional 100 of these rounds at 115% of this service pressure (ref. 11).

The remainder of the testing conducted until January 1944 seems to be vehicle related as opposed to weapon. Endurance testing continued for the M18 after this date and continued from April to December of 1944. This test was a continuation of the engine endurance test started the previous year (ref. 12). The approval for the T70 to be Type Classified Standard as the M18 Gun Motor Carriage followed after successful completion of this test.

The assessment of the vulnerabilities of the German tanks, specifically the Pz III, Pz IV, and Tiger I, were published in TM 9-1907 and based on observations and data collected at both U.S. Army and U.S. Navy proving grounds (ref. 4). The kill zones were related to specific areas of the enemy tank based on known armor thicknesses versus demonstrated penetration capabilities of the weapon.

The performance is equivalent for both the 3-in. M7 and 76-mm M1 in TM 9-1907 with the M1 added on as an asterisk and footnote almost as an afterthought. At the date of publication, the manual lists 76-mm as mounted on both the M18 Tank Destroyer and the M4 Medium Tank Series (ref. 4). This publication only includes an assessment for the M62 APC and not the M93 HVAP-T since it was still very new at the time of publication.

AMMUNITION ISSUED FOR 76-MM IN 1943

Commonality of components between the 3-in. and 76-mm ammunition was utilized in order to maintain efficiency of manufacturing. The same projectiles [M62 APC and M42A1 high explosive (HE)] were used for both the 3-in. M7 and the 76-mm M1 Guns. The intent was to replace the 3-in. guns with the 76-mm through attrition but still be able to use the projectiles (ref. 10). Using common ammunition components ensured that inventories of 3-in. components could circulate in use after the 76-mm took its place. Even if some minor rework was necessary, e.g., change out of cartridge case and propellant loading weight, salvage was still possible and the cost was kept down.

The 76-mm used the M42 HE shell for anti-personnel missions. It originated in 1932 as the 3-in. Anti-Aircraft HE shell, 3AA Shell M42. The “AA” designation is a testament to the Anti-Aircraft origin of the 3-in. system, similar to the dual use of the German Krupp 88-mm AA by Rommel in North Africa.

The M62 APC first appears in technical data in August of 1942. Similar to the M42, this round has its origins with the 3-in. gun. Unlike the HE cartridge, this cartridge has no application for anti-aircraft missions. The M62 APC is specifically for defeating armor. The design is nearly identical to the 75-mm M61 except it is slightly larger in diameter and the propellant/gun combination ensures a higher muzzle velocity. Figure 4 shows an exploded view of the M62A1 APC.

Figure 4
M62A1 APC - exploded view

INITIAL FIELDING – ANZIO

The first T70 (M18) Tank Destroyers arrived at the Anzio beachhead in Italy in May 1944. Two were deployed with the 601st and three with the 894th Tank Destroyer battalions (ref. 10). The Tank Destroyer battalions provided the Tank Destroyer Center a report of their combat performance during the breakout operations that started 23 May. According to Major Bryan Denny, the Tank Destroyers seldom performed their primary function in Italy. The nature of the terrain and the layering of the German defenses meant that the M1 76-mm Gun was being used for indirect fire against concrete fortifications (ref. 3). There were limited opportunities to truly assess the effectiveness of the gun against German armor. The commander of the 894th issued T70 (M18) to his reconnaissance company because the vehicle could reach speeds of 60 mph. Since it would be in the open less time moving from one position to the next, the belief was that the Germans would be less likely to destroy it.

The units were impressed with the 76-mm performance but disliked the cramped space inside the turret of the M18 (ref. 10). The greatest concern was the lack of armor on the M18, which lead the crews to state that they would prefer the M10 since they offered more protection at the cost of speed. The alternating muddy and mountainous terrain in Italy offered little chance for mobility to play a large role. The M1 76-mm Gun seemed to be performing beyond expectations, so the project proceeded unaltered.

THE PANTHER PROBLEM – TANK TROUBLES IN FRANCE

The U.S. Army got a first look at the Panther tank in 1943 after the Russians captured some on the Eastern front. Liaison officers were offered an opportunity to examine the new tank and report back. The improvements were noted, but the Panther was not considered a tremendous threat since there were not great numbers produced in at the time (ref. 7). The new information did not alter development programs to compensate for the improvements. The M1 76-mm Gun and its ammunition were not upgraded as a result.

Given successful performance of the 76-mm guns near Anzio, some of the towed Tank Destroyer battalions converted to the M18 Tank Destroyer. A limited number of Sherman tanks including the M1A1 76-mm arrived in European Theater of Operations (ETO) in April 1944. The perception of the tank as an infantry support tool had not changed, so commanders were reluctant to accept them, given that the predecessor 75-mm HE was loaded with twice as much explosive as its 76-mm counterpart.

Initiation of Operation Overlord was at the beaches of Normandy on 6 June 1944. No 76-mm Sherman tanks were in the invasion because of the reluctance to trade HE anti-personnel lethality for armor penetration performance. This error would become apparent as the U.S. Army pushed inland from the beaches. The 75-mm was completely inadequate against improved German armor. The Sherman tanks were involved in tank versus tank combat in greater frequency than Italy, compounding the issue further.

The 4th Armored Division overcame many challenges in breaking out from Normandy. The Commander of F Co. 25th Cavalry Reconnaissance Squadron, Captain Murray W. Farmer, records his experience on the streets of Avranches. Farmer's Sherman tank contacted a Panther upon turning a corner. He ordered his driver to close the 30-yd distance separating the tanks at top speed to prevent the Panther from bringing its gun to bear and ram it in the flank. This was a solid strategy, since the Panther could not traverse with its barrel hung up on the turret of the Sherman. The Sherman opened fire on the Panther turret with its 75-mm gun at point blank range with no effect. Farmer resorted to shooting the dazed Germans with his submachine gun as they attempted to exit their Panther. Farmer then ordered his driver to push Panther off the road so it couldn't be retrieved by the enemy. They succeeded in flipping their Sherman into a ditch along with the offending Panther (ref. 13).

Situations like Captain Farmer's created a scramble to obtain upgraded 76-mm tanks. Some started to make their way into service by September, but they were still relatively scarce with only 250 of the 1,913 tanks in the 12th Army Group equipped with 76-mm guns (ref. 14). The Tank Destroyers were the only American vehicles equipped to defeat the German armor while upgraded Shermans slowly trickled in. They fared better but still were not as successful as anticipated. The only way the Panther could be defeated from the front was to deflect a shot off of the mantlet downward onto the armor above the driver's head (ref. 10). This was the fabled "lucky shot," and the odds of achieving this effect are extremely unfavorable.

It seems inconceivable that a 75-mm projectile would fail to penetrate a target at point blank range. The picture makes sense when taking a look at the physics behind armor penetration. The following formula is the Lambert-Zukas formula for deriving the limit velocity (V_l), commonly referred to as the V_{50} (ref. 15).

$$V_l = \left(\frac{L}{dproj}\right)^{.15} * \alpha * \sqrt{\left(\frac{dproj^3}{massproj}\right) * \left[\left[\left(\frac{t}{dproj}\right) * \sec(\theta)^{.75}\right] + e^{\left[-\left(\frac{t}{dproj}\right)*\sec(\theta)^{.75}\right]} - 1\right]} \quad (1)$$

V_l	*Limit velocity or* V_{50}
t	*Armor plate thickness*
θ	*Slope of armor*
L	*Length of penetrator*
$massproj$	*Mass of penetrator*
$dproj$	*Diameter of penetrator*
$\alpha = 4000$	*RHA constant*

The V_l is the velocity that penetration occurs 50% of the time for a specific combination of a given projectile against a specific target thickness and obliquity angle. A striking velocity below this V_l or V_{50} can be considered the point the projectile will not penetrate the target.

The TM 9-1907 lacks any data regarding the Panther, but the Lambert-Zukas V_l calculation for the M61 75-mm APC against the frontal hull armor of the Panther is calculated as approximately 3700 fps. The front turret does not fare much better at 3200 fps. This is well over the 2030-fps muzzle velocity of the 75-mm gun; failure at point blank is a given.

The M10 Tank Destroyer crews discovered in July 1944 that the 3-in. APC shell bounced off of the front glacis plate of the Panther tank at all ranges (ref. 16). The M62A1 was also the primary anti-tank round for the 76-mm M1 Guns, which proved unfortunate for the M18 Tank Destroyer crews. The inability of the 3 in. and 76-mm to penetrate the frontal armor of the Panther sent a shockwave through allied command.

FINDING A SOLUTION WITH SUB-CALIBER PENETRATORS

The U.S. Army Ballistic Research Laboratory (BRL) at APG performed a study of the effectiveness of using sub-caliber penetrators. Five types of rounds were fitted to sabots and fired, and two were fitted for the 76-mm gun. One was a 57-mm APC round modified to be fitted to a 76-mm base plug, and the other was a 38-mm solid tungsten carbide shot (ref. 17). These were not constructed, but only ballistic coefficients and velocities were calculated.

The flight stability of the 57-mm APC increased by cutting 0.25 in. from the base and reducing the windshield by 0.4 in. in length. Calculated muzzle velocity was 3400 fps; it was 2600 fps at 2,000 yd and 1,800 fps at 4,000 yd (ref. 17). The recommendation was made to increase the amount of propellant used to ramp up the projectile muzzle velocity. This is a similar approach the British took with the 17-pounder, which was 76-mm but was loaded with nearly three times the propellant of its American counterpart (ref. 7).

The muzzle velocity of the 38-mm tungsten carbide HVAP-T shot was calculated to be 3800 fps. This is based on an assumed mass of sabot and shot being 7.7 lb, half as much as the M62 APC (ref. 16). The size of the shot was recommended to be 1.5 in. and weighing 3.10 lb. The BRL calculations predicted the HVAP-T shot would retain a velocity over 3000 fps at 2,000 yd, then drop off to 2700 fps at 3,000 yd. The muzzle velocity for the HVAP-T round was dropped to 3400 fps because the cannon muzzle length was reduced by 15 in. The Ordnance Department ordered reduction of the cannon length to compensate for turret binding rather than rebalancing the turret and adding weight to the vehicle (ref. 7). The effect of this modification will be discussed later in this report.

HYPER-VELOCITY, ARMOR-PIERCING TRACER 76-MM M93

The first appearance in technical data of the top assembly for the 76-mm HVAP-T round was dated January 31, 1945, as the T40E20 (75-1-220), though its individual components are accounted for earlier. The shot, HVAP-T, 76-mm or 3 in., M93 metal parts assembly (75-2-361) was official and approved November 11, 1944. The initial limited fielding in September 1944 carried the T40 designation since the 76-mm HVAP-T round would be designated the M93 only after February 1, 1945. Figure 5 shows an exploded view of the M93 HVAP-T.

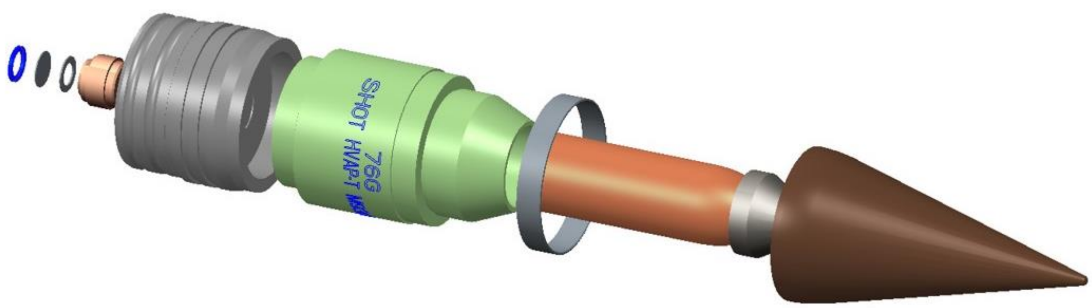

Figure 5
M93 HVAP-T exploded view

The T40E20 (M93) projectile, or “Shot,” consisted of a steel base, aluminum body, tungsten carbide core, nose, windshield, and bourrelet ring. The tungsten carbide core was assembled to the cylindrical opening through the center of the aluminum body. The aluminum nose threads into the mouth of the body, covering the nose end of the tungsten carbide penetrator and holding it in place. The steel base assembles onto the back end of the body, preventing the core from slipping out of the body rearward.

The bourrelet ring rests in a recess near the forward end of the body, positioned flush with the circumference of the body. The windshield was threaded onto the forward end of the body, in front of the bourrelet band. This process encapsulates the nose and core and holds the band in place. A tracer in the base of the projectile, ignited by the propellant combustion product, reduces drag. In a similar fashion as the M62A1, this “Shot” assembly uses the M26 case, loaded with 3.9 lb of M2 powder and an M28A2 percussion primer. The total weight of the 76-mm HVAP-T round was approximately 18.91 lb with an as-fired weight of the projectile of 9.4 lb.

WHAT HAPPENED IN NORMANDY?

The vulnerability values posted in TM 9-1907 indicate that the Pz IV should have been defeated without issue at combat ranges in the ETO. The Tiger would be difficult to defeat, but the low probability of an encounter and defeat via attrition negated the threat. The Panther is ominously not present in TM 9-1907 as late as September 1944, several months after the troubles in Normandy appear in the historic record. The question begs asking, “What happened?”

The necessary performance in order to defeat the given target needs to be established and, in this case, each German tank encountered in the ETO. Then, specific weapon and ammunition combinations against the German armor will be assessed to determine if they can defeat it. The ballistic limit will be calculated for each of our targets for this purpose. The ballistic limit, or limit velocity (V_l), is defined as the velocity required for a projectile to penetrate a given material at least 50% of the time, below which a target will not be defeated (ref. 15). This is analogous to what is typically called V_{50} velocity.

Three targets are considered for this analysis: the Pz IV E, the upgraded Pz IV H, and the Panther. The Pz IV was produced by the Germans in the greatest number and for the longest duration over the course of the Second World War and was modified and continuously upgraded. Allied armor had the greatest probability of encountering a Pz IV than any other German Panzer on the battlefield. There is a substantial amount of historic data for anti-tank performance against the Pz IV E, so this will be used as the baseline for comparison. Data for the Panther and 76-mm HVAP-T is less abundant and is not available in TM 9-1907 for comparison. The generic procedure that was developed for filling in the gaps in the data set is given in figures 6 and 7. The generic case was used as a framework to develop our specific process to assess the performance of the 76-mm gun and its ammunition against the German armor.

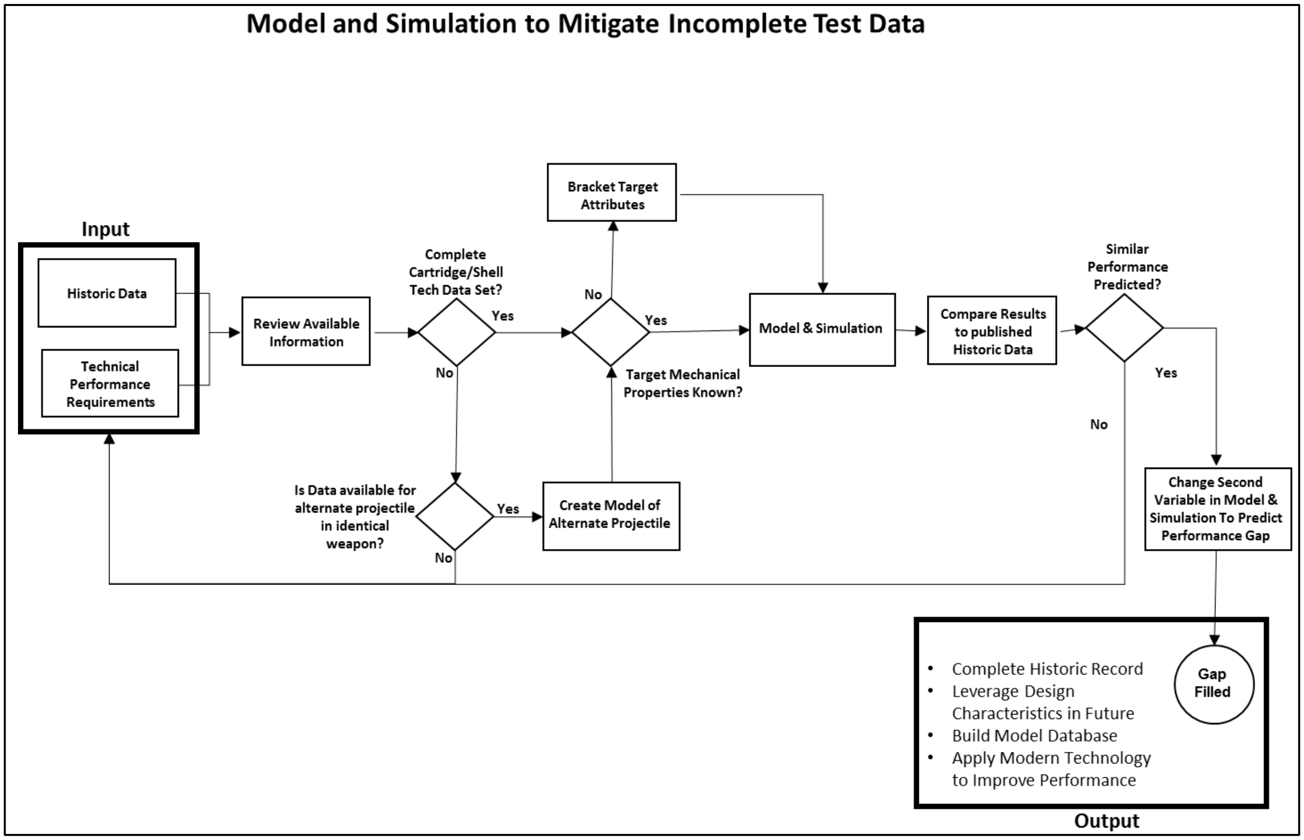

Figure 6
Model and simulation mitigation for incomplete historic data

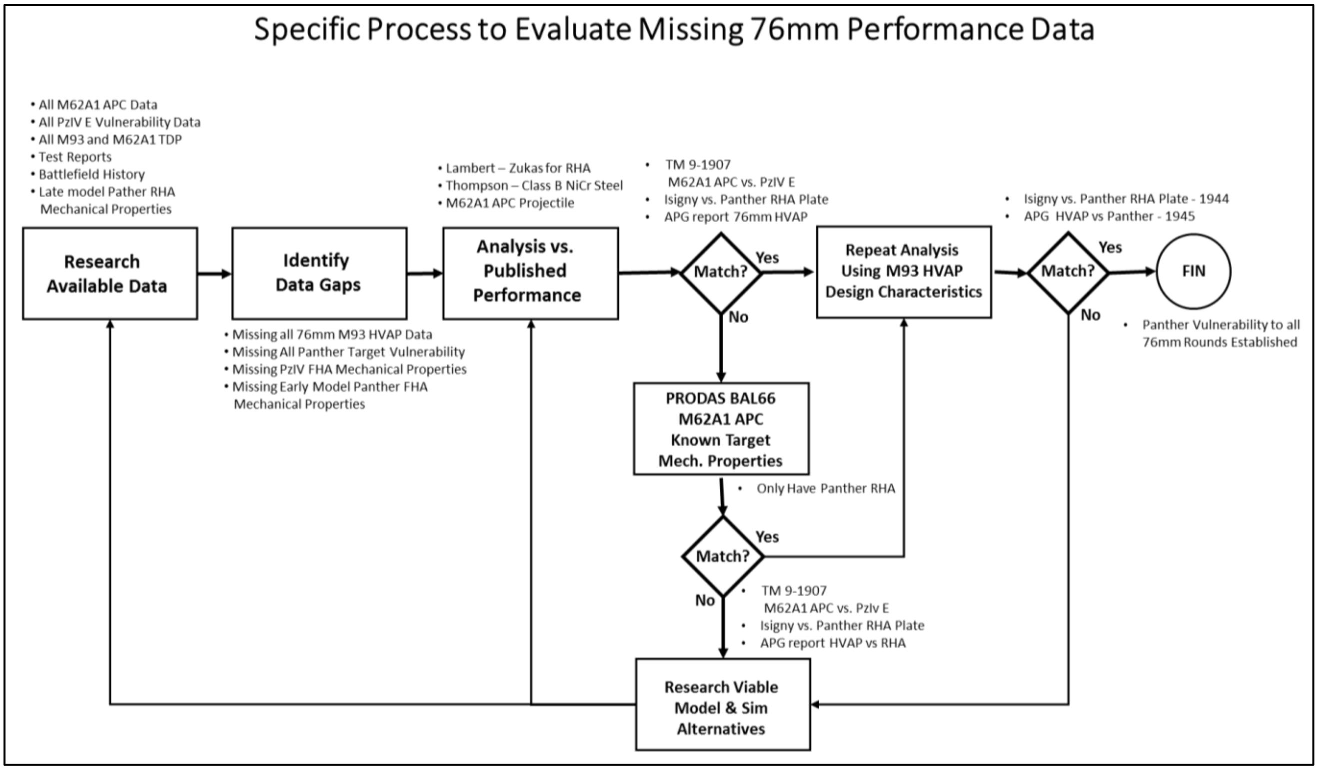

Figure 7
Process for filling gaps in 76-mm performance data

The physical characteristics and mechanical properties of the armor of the Pz IV and the Panther must be considered for our calculations. The Pz IV used face hardened armor (FHA) exclusively at first but switched to rolled homogenous armor (RHA) later in the war. The Lambert-Zukas and Thompson models that are being used in our hand calculations are based on empirical data for penetrating specific target materials. Lambert-Zukas is based on RHA and Thompson is based on Class B chrome nickel steel. The calculations using these methods can only be considered approximate since it is known that the FHA performance will differ to RHA or Class B armor plate. This can be used to see how the M62A1 APC historical data published in the September 1944 publication of TM 9-1907 against the Pz IV with FHA compares.

The Ballistic Analysis Laboratory Technical Report No. 66 (BAL66) model used in the PRODAS software will also be used in comparison to the hand calculations. There is information about the metallurgy of the Panther armor, which can be inputted into the PRODAS model. Then, similar methodology as with the Pz IV evaluation will be used to predict the HVAP-T performance omitted from TM 9-1907. Field test results from August 1944 and APG test results from March 1945 will provide a means to validate the PRODAS model for the HVAP-T against the Panther.

Plate thickness and slope will vary depending on the part of the tank impacted (front hull, side turret, etc.). The slope (angle of obliquity) effect must be taken into account for each target in order to ensure any degree of accuracy. Actual plate thickness and slope measurements for the hull and turret armor published for the Pz IV E, Pz IV H, and Panther tanks provide the basis for our target characteristics.

The V_l is calculated based on specific target versus weapon/projectile pairing. The physical characteristics of each individual projectile must be incorporated for our calculations to be valid in determination of ballistic performance. The anti-tank projectiles available to the U.S. Tank Destroyer and tank crews during operations in the ETO will be evaluated. These options consist of the 76-mm M62APC and M93 HVAP-T shells as well as the 75-mm M61 APC shell that they were replacing.

This V_l for each target versus projectile combination can then be compared to the velocity degradation over distance from muzzle exit in order to determine the effective range against the specific target. This will depend on the facing of the target under attack, i.e., front/side/rear. The armor plate thickness and obliquity will vary depending on each facing. Turret and hull armor thickness differences are also accounted for and will be factored into effective range determination.

BALLISTICS MODELING AND CALCULATIONS

Velocity Degradation versus Range

The first method that was considered for the expected degradation of velocity from muzzle exit over a given range is via hand calculation. This can be represented as a function of the muzzle velocity, or initial velocity (Vo), and the physical properties of the projectile and air.

Following this reasoning, the velocity at a given horizontal range (x) can be calculated via the following simplified formula (linear velocity decay formula):

$$V_X = V_0 - (k2 * x) \tag{2}$$

The Constant k2 is derived via the interaction of the projectile cross section and mass with the surrounding air (ref. 15). This constant was chosen because the velocity of the projectile is expected to be 0.8M <Vx< 2.5M for much of its effective range.

This is likely a better approximation for the M62A1 APC since its muzzle velocity is in the Mach 2.3 range. The HVAP-T is also within this Mach number range over much of its trajectory, but with a muzzle velocity of 3400 fps, the close ranges exceed Mach 2.5. This introduces error into the assumed linear velocity decay. The validity of this method is also suspect at longer ranges when the striking velocity drops below Mach 0.8. The effect of Mach number/K constant after evaluating just k2 first will be examined as well as the shift in striking velocity decay when accounting for the subsonic and above Mach 2.5 portions of the trajectory.

$$k2 = \left[\frac{(\rho * S)}{(2 * mass)}\right] * K2 * a \tag{3}$$

$S = Cross\ sectional\ area\ of\ projectile$
$Derived\ constant \quad K2 = 0.841$
$Cd = Drag\ coefficient \quad K2 = Cd * MM = Mach\ number$
$Speed\ of\ sound\ in\ air \quad a = 1120\ fps$
$Mass\ of\ Projectile \quad mass = 11.09\ lb$ for (M62A1 APC)
$Air\ density \quad \rho = 0.0751\ lb/ft3$

Attempting to find the velocity at a range of 500 yd, 1,500 ft is inserted for x in the equation. Given that the muzzle velocity for the M62A1 is 2600 fps, the expected velocity at 500 yd is calculated to be 2433 fps. In order to determine the rate of degradation, a series of ranges are evaluated similarly.

The predicted velocity degradation over range can now be predicted using the previous equation. Given the velocity curves for each shell, it is determined how each should retain its velocity. Figure 8 contains the two 76-mm (M62A1 and M93) and one 75-mm (M61) anti-tank shells. This plot indicates velocity from muzzle exit to a range of 5,000 yd. The HVAP-T is expected to retain a higher velocity over the same given range as its counterparts, except for over a range of 4,200 m. This is not surprising given that it starts out with a much higher muzzle velocity. What is surprising is that the M61 75-mm APC seems to retain its velocity on par with the M62A1 76-mm APC. The lower performance of the 75-mm is likely related to its lower muzzle velocity rather than an issue with the projectile design. The “Y intercept” has also been adjusted to 3800 fps for the fourth case, which is the M93 HVAP-T in an uncut original longer barrel 76-mm gun.

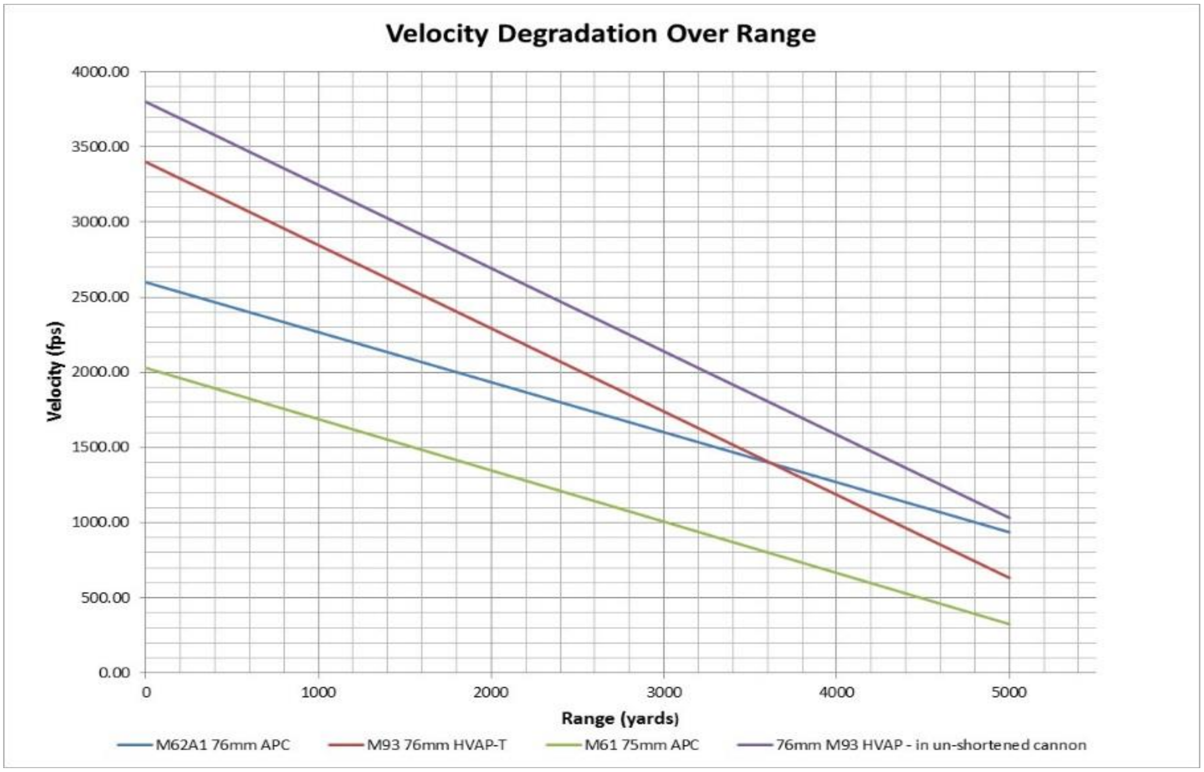

Figure 8
Velocity degradation over range

Shown previously in equation 2, the velocity decay is linear when only taking into account k2 over the entire range. The HVAP-T cartridge dips below the APC at 3,600 yd according to this calculation. The transition point to below APC performance also coincides with 1400 fps, just above Mach 1. The equation seems to break down just about the speed of sound. The subsonic (K1) and high Mach number at muzzle exit (K3) also need to be accounted for to present an accurate velocity degradation curve.

Determination of Velocity versus Range using PRODAS

The models were built and physical properties of each of the shots were entered into PRODAS to generate the velocity decay versus range curve. Muzzle velocity and spin rates were also accounted for in the simulation. Creating the model is a time consuming portion of the analysis. PRODAS uses elements to represent feature geometry as either solids or voids. Components are made up of elements that can be assigned a density, weight, and a physical function.

The M93 HVAP-T shell is made up of seven components, in which the tungsten core serves as the penetrator (fig. 9). Conversely, the M62A1 APC-T round projectile steel body serves as the penetrator (fig. 10). Defining these functions is mandatory in order to execute the ballistics analysis. The convention for modeling is to build the representation of the round with the projectile base to the left hand side and the nose pointing to the right. Once the model is complete, the mass properties analysis is conducted to determine the mass, center of gravity, transverse, and axial moments to fall within the design limits.

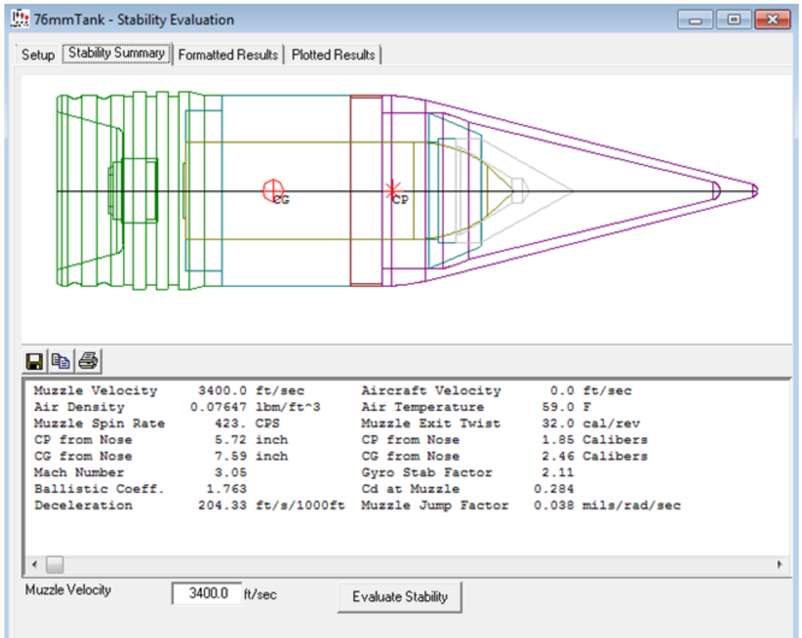

Figure 9
M93A1 HVAP-T - PRODAS model

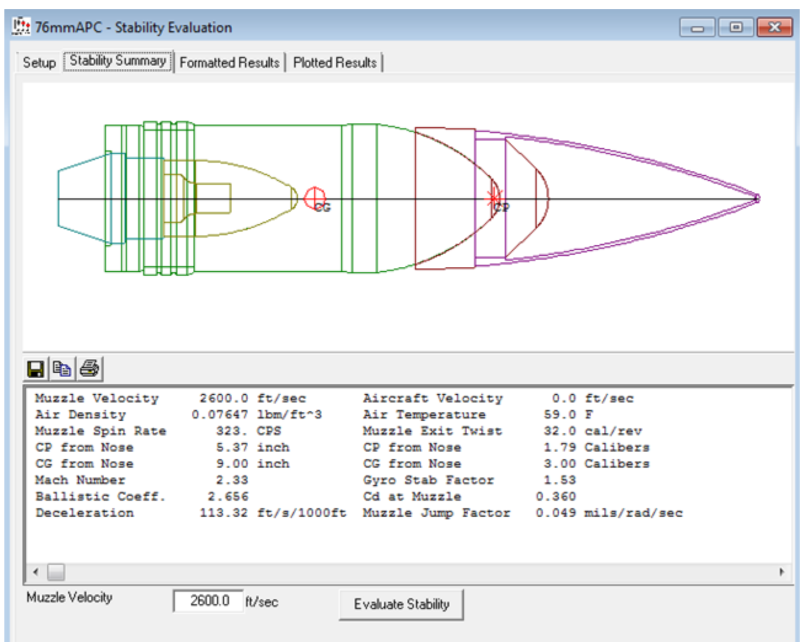

Figure 10
M62A1 APC - PRODAS model

Now, the velocity decay versus range results are compared, taking into account the transitions in Mach number for subsonic and high Mach scenarios along the projectile trajectory. The PRODAS software predicted the velocity degradation, and the resultant curve was plotted in Excel. The PRODAS software is capable of executing fixed plane 4-degrees of freedom (DOF), 6-DOF, and 6-DOF body fixed simulation codes trajectory analysis. A fourth order Runge-Kutta numerical integration is used to integrate the equations of motion in a time step for an accurate simulation. The simulation for this study used a fixed plane 4-DOF modified point mass and 6-DOF trajectory to obtain the projectile velocity at fixed intervals from muzzle exit to a maximum range of 15,000 ft. The results are nearly identical for 4-DOF and 6-DOF simulation. The quadrant elevation (QE) and muzzle exit spin rate (rpm) are entered as constants to calculate the trajectory and velocity. The muzzle spin for the M93 HVAP-T and M62A1 APC-T were 20,299 and 19,403 rpm, respectively, and the QE was 177.78 mils (10 deg) for both.

The aerodynamics stability analysis calculated the gyroscopic and dynamic stability factors of the projectile as a function of the Mach number. The muzzle velocity as well as the twist and gun barrel diameter are entered as constants into this analysis. A stability factor, S_g, value of over 1.1 indicates stable flight. The gyroscopic stability factors for the M62A1 APC-T and M93 HVAP-T rounds were 1.53 and 2.11, respectively.

The comparison of the M62A1 APC published in TM 9-1907 (green) using the hand calculation linear formula (blue) and the PRODAS data curve fit (red) for the multiple Mach regimes is displayed in figure 11.

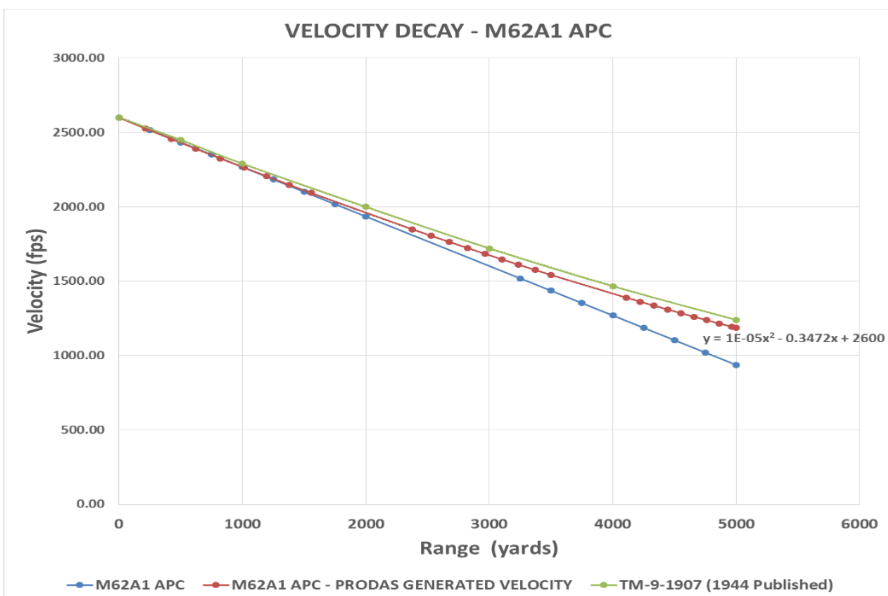

Figure 11
M62A1 APC adjusted velocity decay curve (PRODAS)

The adjusted velocity decay curve for the M62A1 (red) derived using the PRODAS trajectory data reflects the known data from TM 9-1907 published in 1944 (green) (ref. 4). The PRODAS and 1944 velocity curves are nearly identical.

The muzzle exit velocity decay is fairly close to the linear k2 assessment, but the decay rate diverges greatly after the transition to subsonic velocity. The slower the projectile moves, the greater the divergence is between the PRODAS data curve from the initial linear k2 calculation that is only truly applicable for the transonic velocity. The PRODAS decay curve accounts for both transonic and subsonic regimes, where the linear k2 plot does not adjust for the transition.

The equation of the velocity decay curve for the M93 HVAP-T accounting for the Mach transition is displayed in figure 12. This curve equation will be used to determine the range (x) corresponding to the calculated limit velocity (V_l), i.e., (y) in the next section to determine the effective ranges. Note that the y intercept for both figures 11 and 12 are the corresponding muzzle velocities for each shell (M62A1 APC and M93A1 HVAP-T).

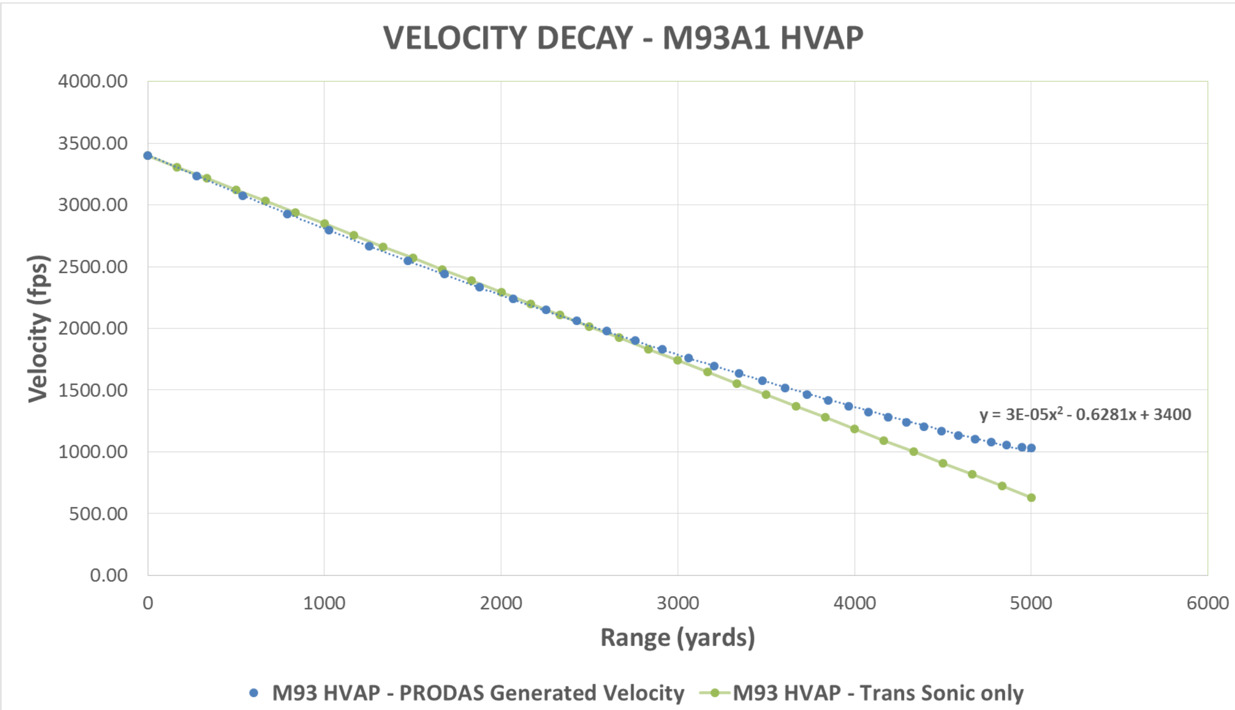

Figure 12
M93 HVAP-T – adjusted velocity decay curve (PRODAS)

The striking velocity curves are justified for use in determination of APC and HVAP-T effective ranges against German Panzers. The displayed equations based on the PRODAS generated velocity decay curve will be used to determine striking velocities for the M62A1 APC and M93 HVAP-T and will be used to validate the TM 9-1907 effective ranges against the Pz IV and fill in the missing HVAP-T and Panther performance.

Limit Velocity Calculation

Two formulas in hand calculation determination of V_l/V_{50} will be considered and compared to the results of the PRODAS BAL66 simulation. The BRL at APG developed the Lambert-Zukas model for calculating V_l, which was the primary U.S. Army method (ref. 15). The second is the Thompson formula developed by Dahlgren Naval Surface Warfare Center. The BAL66 method is the calculation of the V_{50} via computer simulation, specifically PRODAS ballistic simulation.

The following equations will be used to solve for V_l. The first assessment will be the Lambert-Zukas method previously discussed in this study. The second hand calculation formula is the Thompson method listed in the following equation developed by the U.S. Navy at Dahlgren (ref. 15).

$$F_{STD} = 6 * \left(\frac{t}{d} - 0.45\right)(\theta^2 + 2{,}000) + 40{,}000$$

$$V_l = \left(\frac{1}{41.57}\right) * F_{STD} * \sqrt{\frac{t}{d}}\sqrt{\frac{d^3}{m}\frac{1}{cos\theta}} \quad (4)$$

F_{STD}	*Armor penetration force*
V_l	*Limit velocity or* V_{50}
t	*Armor plate thickness*
θ	*Slope of armor*
l	*Length of penetrator*
m	*Mass of penetrator*
d	*Diameter of penetrator*

ARMOR PENETRATION PERFORMANCE

Limit Velocity Calculations for 76-mm M62A1 Armor Piercing Capped versus Panther

The 76-mm Sherman was introduced along with the M93 HVAP-T in small quantities during September 1944. The Tank Destroyer units were given priority issue; however, tank crews didn't start seeing it until late in the year.

We will start the evaluation of the 76-mm with the M62A1 APC, since it was the only 76-mm anti-tank shell available at the start of the Normandy campaign until September 1944. The specific physical characteristics of the M62A1 projectile and the frontal armor plate of the Panther are incorporated into the V_l equation. The effect of lateral obliquity will be visited later in this analysis but will consider normal impact

The Lambert-Zukas formula results in a limit velocity of 3383 fps for the frontal hull armor when paired against the M62A1 APC. This is a pretty good indicator why it didn't kill the Panther because this is above the muzzle velocity of this round. Test data obtained for the qualification of the M1 76-mm Gun recorded a muzzle velocity of 2600 fps for the M62A1 APC. This is severely inadequate against the Panther frontal armor as it would fail at point blank range. Table 1 shows the Lambert-Zukas M62A1 APC versus the Panther.

Table 1
Lambert-Zukas M62A1 APC versus Panther

LAMBERT - ZUKAS		Facing - 0 degrees				
LAMBERT - M62A1 APC vs. Panther						
76mm	Front Hull	Front Turret	Side Hull	Side Turret	Rear Hull	Rear Turret
QE	0	0	0	0	0	0
Armor Slope	55	12	30	25	30	25
tplate (cm)	8	10	5	4.5	4	4.5
Vl (m/s)	1031.29	893.76	533.30	470.57	436.17	470.57
Vl (fps)	3383.68	2932.41	1749.77	1543.93	1431.06	1543.93

Once again, the V_l is above the muzzle velocity for the APC shell for the front of the Panther's turret. A 10-cm cylindrical mantlet protected the front of the Panther's turret. Impact angles could vary widely as a result of the curved surface. A 12-deg impact is assumed for simplicity, given this is the slope of the turret. The M62A1 could not pierce this mantlet, so the 76-mm APC could not have defeated the Panther in front attacks even at point blank range. Attack from the flank and rear fared much better, since the thickness of the side hull reduces to 5 cm at a 30-deg slope and the side turret reduces to 4.5 cm at a 25-deg slope (ref. 7). Lambert seems bleak for a frontal attack, but table 2 compares it to the Thompson and BAL66 (PRODAS) equations.

Table 2
M62A1 APC versus Panther – V_{50} comparisons

	M62A1 APC vs. Panther - Vl (V50) Comparison (fps)			
76mm	Front Hull	Front Turret	Side Hull	Side Turret
Lambert-Zukas	3383.68	2932.41	1749.77	1543.93
Thompson	3290.84	1895.03	1819.24	1132.72
BAL 66	3536.00	2808.00	2315.00	1664.00

The front hull V_l(V_{50}) is above the muzzle velocity of the M62A1 APC shell for all methods used. This indicates that the M62A1 will fail at point blank range against the frontal armor of the Panther since the ballistic limit is above the muzzle velocity. Striking the turret from the front is only slightly better. Since Thompson is the only V_{50} calculation below the M62A1 muzzle velocity, the performance is assumed to be marginal.

All methods indicate that the frontal armor could withstand a point blank shot from the M62A1, so why was it believed that this shell would defeat the Panther in all facings? The U.S. forces captured Tigers during combat in Sicily and Italy, but this was not true of the Panther, so no assessment could be conducted prior to the Normandy campaign (ref. 14). The degree of the slope and condition of the armor remained unknown until combat trials.

The slope of the hull armor appears to be the defining characteristic that prevents penetration of the front hull. The front turret is actually 2 cm thicker than the front hull but is nearly vertical compared to the hull. Assuming normal impact greatly reduces the striking velocity needed to penetrate the frontal armor of the Panther, dropping the V_l down to just around 2800 fps. This is still above the muzzle velocity of the M62APC but is closer. This demonstrates the tremendous effect the 55-deg slope of the 8-cm armor had in protecting the Panther from its adversaries (ref. 7).

The Thompson V_{50} of the side hull and front turret are roughly equivalent, in spite of the armor thickness of the front turret being nearly double that of the side hull plate. The difference, again, is the 50-deg slope of the hull armor as opposed to the nearly vertical.

Lambert-Zukas consistently has a higher V_l than Thompson. The question remains: which is more accurate? The Lambert-Zukas equation was derived via test data against RHA targets. Similarly, the Thompson equation was derived based on Class B chrome nickel steel. Differences in mechanical properties of the steel likely affect the end result of the calculation. The BAL66 PRODAS model allows for specific mechanical properties (e.g., hardness) of the target to be inputted.

The Panther initially had face hardened steel frontal armor, but later production switched to a homogeneous steel plate. Further complicating the matter was the loss of a reliable source of molybdenum for the Germans as the war progressed, leading to a brittle plate that was prone to cracking on impact (ref. 7). A metallurgical analysis of the Panther armor plate was conducted in July 1944, which indicated a hardness of 262 to 269 Brinell Hardness Number (BHN). This input was used to determine the V_{50} for the PRODAS model.

Limit Velocity Calculations for 76-mm M62A1 Armor Piercing Capped versus Panzer IV

Now that the issues the 76-mm M62 APC had with the Panther are seen, the Pz IV will be examined. The “E” variant was state of the art in September 1940 when it was first produced. Lambert-Zukas is the start point again for the 76-mm M1 Gun with M62A1 performed against the Pz IV E (table 3).

Table 3
Lambert-Zukas V_{50} for M62A1 APC versus Pz IV E

LAMBERT - M62A1 APC vs. PZ IV E						
76mm	Front Hull	Front Turret	Side Hull	Side Turret	Rear Hull	Rear Turret
Armor Slope	15.00	12.00	0.00	11.00	11.00	11.00
tplate (cm)	5.00	6.50	4.10	2.10	2.10	2.10
tplate (in)	1.97	2.56	1.61	0.83	0.83	0.83
Vl (m/s)	495.63	620.20	404.24	218.68	218.68	218.68
Vl (fps)	1626.15	2034.88	1326.30	717.49	717.49	717.49

The bow is the thickest part of the Pz IV hull. The 76-mm M62A1 APC with a muzzle velocity of 2600 fps would have no issue defeating the “E” variant at typical combat ranges in the ETO, which were within 890 yd (ref. 7). The turret is more stubborn but is still vulnerable. These results support the reasonable conclusion that the 76-mm gun with the M62A1 APC would have little difficulty defeating earlier model German Panzers. However, by the time the M1A2 76-mm arrived in the ETO in the summer of 1944, the Pz IV received several upgrades in armor and armament.

The Germans produced over 3,500 of the Ausführung (Ausf.) H by July 1944 and was the most numerous tank in the Panzer corps during this timeframe (ref. 2). Since the “H” variant was the most numerous tank in the German war machine, it was the probable adversary even after the introduction of the Panther. The armor thickness increased for the bow and side turret over the course of upgrading. Skirt armor strengthened the side of the hull and turret but tended to break off under combat conditions. Table 4 shows the Lambert-Zukas comparison for the M62A1 APC versus Pz IV H.

Table 4
Lambert-Zukas V_{50} - M62A1 APC versus Pz IV H

LAMBERT - M62A1 APC vs. PZ IV H						
76mm	Front Hull	Front Turret	Side Hull	Side Turret	Rear Hull	Rear Turret
Armor Slope	15.00	12.00	0.00	11.00	11.00	11.00
tplate (cm)	8.50	6.50	4.60	5.00	2.10	5.00
Vl (m/s)	787.01	620.20	449.00	490.27	218.68	490.27
Vl (fps)	2582.18	2034.88	1473.15	1608.57	717.49	1608.57

The effect of the armor upgrade is evident. The V_{50} is more than doubled for the side and rear strike on the turret, which is the result of add-on armor applied around the turret. The front hull increased to near muzzle velocity for the APC. This was a serious issue since the 76-mm armed with the APC would be marginal at best to penetrate the frontal hull armor of the “H” and was reduced significantly relative to the “E” model on a flank attack as well.

Limit Velocity Calculations for 76-mm M93 Hyper-velocity, Armor-piercing Tracer

The HVAP-T was developed specifically to give the 76-mm M1A2 Gun a boost to its lethality given the shortfall with the M62A1 APC against upgraded German Panzers encountered in the post-Normandy ETO. The Lambert-Zukas, Thompson, and BAL66 PRODAS will be used again to see how the HVAP-T V_{50} compares (table 5).

Table 5
M93 HVAP-T - V_{50} comparisons

	M93 HVAP vs. PZ IV E - Vl (V50) Comparison				M93 HVAP vs. Panther - Vl (V50) Comparison			
76mm	Front Hull	Front Turret	Side Hull	Side Turret	Front Hull	Front Turret	Side Hull	Side Turret
Lambert-Zukas	2176.41	2667.71	1803.37	1008.87	4176.45	3687.88	2327.01	2075.23
Thompson	1370.41	1681.01	1106.62	702.04	5060.99	2520.26	1338.22	1385.30
BAL 66	1873.00	2244.00	1582.00	987.00	3861.00	3067.00	2528.00	1818.57

Even the M93 HVAP-T would not be able to defeat the hull frontal armor of the Panther tank since the V_{50} is above the 3400-fps muzzle velocity of the round. Thompson is more forgiving for the turret and sides but is the worst case for the front hull of the Panther. The PRODAS and Thompson both predict the HVAP-T to penetrate the front of the turret, where Lambert indicates failure against the Panther under the same criteria.

EFFECTIVE RANGE DETERMINATION

The limit velocities only give us a part of the picture. In order to assess the true effectiveness, these values need to be compared with the velocity degradation calculation charts made previously. Relating the velocity degradation curve generated previously based on how the PRODAS curve fits to the V_l calculations yields the effective range for each weapon/ammunition pairing per target.

Lambert-Zukas appears to be the most conservative assessment in most of the cases, so research will start here to compare effective ranges of the 75-mm and 76-mm round types (table 6). This is possibly because RHA and Class B chrome nickel steel differ in hardness, making Thompson assessed targets more difficult to defeat. It has not been established which method is the more accurate to determine performance, but the prevalent trends in comparing the calculations across gun systems and round designs will be identified.

Table 6
Lambert-Zukas effective ranges

Filling in Gaps TM 9-1907				
LAMBERT - ZUKAS	**(ZERO DEGREE FACING)**			
Vulnerability of German Panzers To Allied Guns				
Gun Caliber	75mm	76mm	76mm	76mm
Ammunition	M61 APC	M62A1 APC	M93 HVAP-T	M93 HVAP-T (Long Barrel)
Muzzle Velocity (fps)	2030	2600	3400	3800
Vulnerability of German Tank Pz IV E To US Guns				
Maximum Effective Range (yards)				
Front Hull	725.00	3078.00	2173.76	3020.75
Front Turret	0.00	1712.00	1239.25	1992.35
Side Hull	1750.00	4170.00	2960.65	3908.00
Side Turret	4050.00	6722.50	5002.00	6400.00
Rear Hull	4050.00	6722.50	5002.00	6400.00
Rear Turret	4050.00	6722.50	5002.00	6400.00
Vulnerability of German Tank Pz IV H To US Guns				
Front Hull	0.00	**50.00**	**163.15**	832.00
Front Turret	0.00	1712.00	1239.25	1992.35
Side Hull	1238.00	3622.00	2562.50	3456.39
Side Turret	785.00	3140.00	2217.15	3069.25
Rear Hull	4050.00	6722.50	5001.90	6400.00
Rear Turret	785.00	3140.00	2217.15	3069.25
Vulnerability of German Tank Pz V "Panther" To US Guns				
Front Hull	0.00	0.00	0.00	0.00
Front Turret	0.00	0.00	0.00	249.00
Side Hull	320.00	2653.00	1876.50	2691.00
Side Turret	1000.00	3370.00	2379.63	3250.00
Rear Hull	1385.00	3777.50	2673.95	3582.40
Rear Turret	1000.00	3370.00	2397.63	3250.00

A hypothetical case is added for comparison to the fielded configuration in table 6 for the expected muzzle velocity resulting from firing in the original uncut M1 76-mm cannon length (orange). The performance differences resulting from this modification to the original design will be assessed using the apparent and most conservative Lambert-Zukas calculation. A red block indicates failure at point blank range. A green block indicates penetration up to and including the range posted. A yellow block indicates marginal performance with penetration occurring only within 100 yd.

The 75-mm gun is ineffective at point blank even against the front turret of the Pz IV E and is only effective at close ranges against the side hull armor of the Panther. Captain Farmer's predicament recounted previously in this report becomes painfully clear.

The introduction of the 76-mm M1 Gun and M62A1 APC shows a marked performance increase against the Pz IV E in respect to its 75-mm counterpart. The effective range increases from 725 yd to over 3,000 yd against the front hull and from point blank failure against the front turret to 1,700 yd for the 76-mm APC. The velocity drop-off is more drastic with the HVAP-T than APC, evidenced by the nearly 1,000-fps difference in V_{50} between the two against the frontal armor and a drop-off from 1,712 to 1239 yd, which is in the effective range in table 6. Given most tank engagements in the ETO were within 890 yd, this wasn't a horrible drop-off in performance (ref. 7). This is not the entire picture of the close-in performance increase with the HVAP-T, which is evident when evaluating the up-armored Pz IV H.

The benefit of the HVAP-T round is evidenced in the close range fight. Penetration of the frontal armor of the Pz IV H is increased from 50 yd with the M62A1 APC to 163 yd with the HVAP-T round (table 6). The detrimental effect Pz IV H upgrade on 76-mm APC performance is evident. The front armor was increased and is nearly invulnerable to the M62A1 APC shot. Side hull and turret armor upgrades cut the effective range significantly in flank attack. The performance improvement with the HVAP-T is evident at close range fight. A gun crew needed to know this distinction between their APC and HVAP-T performance to effectively engage the enemy based on range to target.

Ramping the M93 HVAP-T muzzle velocity up to 3800 fps to account for the lost cannon length yields some interesting results. The front hull of the Pz IV H would be vulnerable out to 832 yd, covering the full range of tank engagements in the ETO. The Panther is vulnerable at 249 yd, which is improved from the point blank failure. The Hellcat or Sherman armed with the unaltered 76-mm gun would have had a much better chance of defeating the front hull armor of the Panther. Cutting the muzzle length to save weight while reducing velocity on the muzzle exit was a costly mistake that hampered the Tank Destroyer's primary mission, which was destroying German Panzers.

The British had no doctrine imposed limits dictating cannon weight. They incorporated their own 76-mm gun, dubbed the 17 pounder. Three times the amount of propellant coupled with a longer barrel than the US M1 76-mm meant that the muzzle velocity obtained by their Sherman tank mounted weapon was significantly higher than their American counterparts. The armor piercing discarding sabot (APDS) round for the 17 pounder had a muzzle velocity of 3950 fps. Without conducting an analysis for the 17-pounder ammunition, a "what if" scenario can be conducted with the M93 HVAP-T design. Ramping up the M93 to the 3950 fps results in a weapon capable of defeating all German armor at ranges well beyond the average tank engagement in the ETO. Given the 17 pounder was mounted on the same Sherman tank chassis as the M1 76-mm, this is an entirely plausible and effective solution to the Panzer upgrade problem.

Now, the effective ranges are compared using each V_{50} method to each other and to the values for the Pz IV E published in TM 9-1907 (table 7). The Pz IV E is the only direct comparison to TM 9-1907 we can make for this study since the Panther is not published. Lambert-Zukas effective ranges tell one story, but differences in the V_{50} have been seen depending on methodology employed. This should also translate directly to the predicted effective range penetrations. The TM 9-1907 ranges were also compared to ranges using the Thompson and PRODAS V_{50}.

Table 7
Effective range comparison Pz IV E to TM 9-1907

Effective Range - 76mm M62A1 APC vs. PzIV E				
V50 Calculation Method				
	Lambert-Zukas	Thompson	BAL 66 (265 BHN)	TM 9-1907 Published
Maximum Effective Range (yards)				
Front Hull	3078.00	4918.00	2769.00	3300.00
Front Turret	1712.00	4076.00	1586.00	4220.00
Side Hull	4170.00	5670.00	3575.00	5000+
Side Turret	6722.50	7100.00	5830.00	5000+

The Pz IV effective range values published for the 1944 edition of TM 9-1907 are close to the Lambert-Zukas predictions for the frontal and side hull armor of the Pz IV E (ref. 4). The performance against the front and side of the turret is significantly different for the M62A1 APC at range for the same target facing based on the Lambert-Zukas model. The front armor of the turret, per the TM, predicted a vulnerability 4,220 yd. In this case, it appears that the Thompson-based V_{50} effective range is closer to TM 9-1907 than Lambert at 4,076 versus 1,712 yd compared to 4,220 yd per the TM.

The Pz IV E and H used FHA; RHA was not introduced until the G variant. None of the methods used to predict penetration performance are based on FHA empirical data. The BAL66 simulation seems conservative and was based on the metallurgical analysis of the armor on a Panther. Late war production Panthers used RHA instead of FHA. The closer results between Lambert and BAL66 (PRODAS) are likely because both are RHA material; the empirical data for Lambert and mechanical properties of the Panther armor metallurgy were inputted into PRODAS.

A metallurgical analysis was conducted in January 1945 for the frontal armor of captured Panther tanks (ref. 18). The analysis concluded that there was significant variation in the quality of armor in the captured tanks. Improper temper caused some plates to be susceptible to shatter on impact. The good quality armor was much tougher, and re-tempering the defective plate corrected the inferiority observed.

The mechanical properties for the “good” quality armor for the Panther were able to be inputted into PRODAS for using the BAL66 calculation. The benefit of this model is that the intended target parameters were able to be tailored to match the Panther. The methods used in the hand calculations are truly only valid for a single specific target material and are at best an approximation. By using both Lambert-Zukas and Thompson, the actual performance can possibly be bracketed, understanding that it is only an approximate when the mechanical properties of the target are unknown.

The Lambert model is closer to the observed performance for RHA targets because it is based on test data for this particular armor type. Additional research into the specific material properties of the armor of the FHA on the Pz IV tanks is needed. The test data used to generate the published values in TM 9-1907 would be helpful in this cause, but that historic data has eluded us so far. Once the mechanical properties of the FHA used on the Pz IV are determined, a simulation for FHA can be run based on actual target properties, similar to the BAL66 Panther case.

The Pz IV E Thompson data seems to indicate that the mechanical properties were likely similar to Class B chrome nickel steel for the sides. The frontal armor FHA is probably treated differently. The effective range in TM 9-1907 is much closer to the RHA values predicted by Lambert-Zukas.

The unanticipated German improvements were certainly a source of major concern for allied command. One item of interest is the theoretical performance of the M93 HVAP-T if the muzzle velocity had not been reduced from the BRL recommended 3800 fps that resulted from cutting the barrel length rather than rebalancing the turret. Interestingly, the V_{50} for the HVAP-T becomes equivalent to the APC at long range while providing the improved close range performance the HVAP-T design was intended. The front armor of the Pz IV H is vulnerable out to 800+ yd, and the Panther turret mantlet would be vulnerable at close range (table 6).

Comparing Effective Ranges – PRODAS and Ballistic Analysis Laboratory Technical Report No. 66

Determination of the effective ranges of the weapon/ammunition pairings is based on the corresponding V_{50} calculation. Thompson and Lambert-Zukas was discussed earlier, but PRODAS also can calculate a V_{50} approximation using the BAL66 method proposed by BRL in BAL66 technical report published in 1968 (ref. 19).

A comparison of the three V_{50} calculations for the Pz IV H are given in the following paragraphs. Two separate charts are provided for the M62A1 APC (table 8) and the M93 HVAP-T (table 9).

Table 8
V_l (V_{50}) comparison - M62A1 APC versus Pz IV E

	M62A1 APC vs. PZ IV E - Vl (V50) (ft/sec) Comparison			
76mm	Front Hull	Front Turret	Side Hull	Side Turret
Lambert-Zukas	1626.15	2034.88	1326.30	1608.57
Thompson	1134.47	1350.34	952.64	638.85
BAL 66	1715	2074	1486	915

Table 9
V_l (V_{50}) comparison - M93 HVAP-T versus Pz IV E

M93 HVAP-T vs. PZ IV E - Vl (V50) (ft/sec) Comparison				
76mm	Front Hull	Front Turret	Side Hull	Side Turret
Lambert-Zukas	2176.41	2667.71	1803.37	1008.87
Thompson	1370.41	1681.01	1106.62	702.04
BAL 66	1032.96	1237.64	872.38	545.49

The gap between Lambert-Zukas and BAL66 is tighter for the M62A1 APC than the M93 HVAP-T against the frontal armor. The case is inverted comparing HVAP-T with Thompson being closer to BAL66. Interestingly, the BAL66 switched extreme positions (best prediction/worst prediction) for the frontal armor when evaluating the different shells. A larger discrepancy exists for Lambert-Zukas for the HVAP-T against the thicker frontal armor of the turret and hull, while the APC diverges for the thinner side armor. The Thompson V_{50} exhibits the least divergence APC versus HVAP-T.

The first factor likely influencing this discrepancy is the target material versus method used. Lambert-Zukas is specifically based on the use of RHA and Thompson on Class B chrome nickel steel. PRODAS allows for varying the selection of target material properties used with BAL66. German armor was face hardened steel, which is a source of variation and error when considering that Lambert-Zukas or Thompson are based on empirical data for targets made of specific materials. The BAL66 method in PRODAS allows for specifying the mechanical properties and hardness of your intended target prior to conducting the modeling.

The second factor is the geometry of the shell. The length/diameter (L/D) ratio of the penetrator comes into play. The M93 HVAP-T has a ratio of 3.4, and the APC has a ratio of 2.6. Lambert-Zukas is generally most accurate for penetrators with L/D between 4 and 30 (ref. 15). The HVAP-T is just shy of the lower end of that ratio range and the APC even is even shorter. PRODAS has the ability to perform the Lambert-Zukas analysis but recommended BAL66 because the L/D ratio of each shot is less than 4.

The BAL66 method recommended by PRODAS undoubtedly produces different effective range values. Table 10 compares the effective range determinations based on Lambert, Thompson, and BAL66 PRODAS VI calculations to the effective ranges of the M62A1 APC against the Pz IV H published in TM 9-1907.

Table 10
Effective range comparison versus Pz IV H

Effective Range - 76mm M62A1 APC vs. PzIV H				
V50 Calculation Method				
	Lambert-Zukas	Thompson	BAL 66 (265 BHN)	TM 9-1907 Published
Maximum Effective Range (yards)				
Front Hull	50.00	2848.00	230.00	3300.00
Front Turret	1712.00	4076.00	1645.00	4220.00
Side Hull	3622.00	5350.00	3260.00	5000+
Side Turret	3140.00	5005.00	2912.00	5000+

A discrepancy exists between all of the calculated effective ranges and the 1944 TM 9-1907 publication. The BAL66 PRODAS is between the Thompson and Lambert-Zukas effective range prediction. Thompson seems the closest to the TM 9-1907 values, which likely do not account for upgrades made to the Pz IV armor in the H model. Predictions of actual performance would likely be closer if the mechanical properties of the armor were able to be factored into the analysis. Thompson analysis seems to track well with published TM 9-1907 ranges, but combat performance seems to lean closer to BAL66 and Lambert-Zukas.

The Panther will now be evaluated to see how it fairs. While TM 9-1907 does not contain data for effective ranges against the Panther, field test data does exist from August 1944 in Isigny, Normandy. These tests were conducted against captured Panthers to evaluate American and British gun performance against this German tank that was causing headaches for the allies.

Testing conducted at Isigny evaluated the American 76-mm APC and HVAP-T along with the British 17 pounder APC ballistic cap and APDS against the frontal armor of the Panther. The performance was then compared to American RHA emplaced with a slope equivalent to the

Panther's armor with 2 deg removed to account for the ground slope (ref. 20). Table 11 shows the effective range against the Panther.

Table 11
Effective range against Panther

Effective Range - 76mm M62A1 APC vs. Panther				
V50 Calculation Method				
	Lambert-Zukas	Thompson	BAL 66 (265 BHN)	Isigny Test (August 1944)
Maximum Effective Range (yards)				
Front Hull	0.00	0.00	0.00	Fail 200yd
Front Turret	0.00	2165.00	0.00	Fail 200yd
Side Hull	2653.00	2415.00	840.00	Not Recorded
Side Turret	3370.00	4925.00	2945.00	Not Recorded

Effective Range - 76mm M93 HVAP vs. Panther				
V50 Calculation Method				
	Lambert-Zukas	Thompson	BAL 66 (265 BHN)	Isigny Test (August 1944)
Maximum Effective Range (yards)				
Front Hull	0.00	0.00	0.00	1 of 4 penetrate 200yd 1 of 2 penetrates 67mm (of 80mm) at 400 yd none penetrate at 600yd
Front Turret	0.00	1509.50	543.00	Unknown - Report Needed
Side Hull	1876.50	4075.00	1500.00	Unknown - Report Needed
Side Turret	2379.63	3955.00	2927.00	Unknown - Report Needed

According to the results of the Isigny test, one of four shots succeeded against the frontal armor of the Panther at 200 yd. One of two is listed as penetrating 67-mm of frontal armor and a 67-mm RHA plate. The secondary source is not clear if this 67-mm is a partial penetration of the frontal armor or if the section penetrated was measured to be 67-mm thick and penetration was complete. The confusion is compounded because the source lists no penetrations of Panther frontal armor RHA plate at 600 yd.

The original Isigny test report is needed to confirm the specifics of penetration depth reported. All calculation methods used indicate that the frontal armor of the Panther could not be penetrated by any of the 76-mm armor piercing shells based on calculated V_{50} values for each method. One of four penetrations at 200 yd observed in the Isigny test indicate a closer range is needed to obtain penetration 50% of the time.

A series of tests were conducted in March 1945 to evaluate the 76-mm and 90-mm HVAP-T shells against armor plate (ref. 21). The standard HVAP-T shells were evaluated in addition to ones containing tungsten penetrators of varying weight for the purpose of determining the optimal penetrator weight experimentally.

The test subject for the opening portion of the test was a 3.25-in. thick armor plate at a 55-deg slope, i.e., the frontal armor of the Panther. According to the test data, the ballistic limit of the 76-mm HVAP-T shell with the standard 4-lb tungsten carbide penetrator is roughly 3400 fps, which is the muzzle velocity of the HVAP-T shot in the fielded 76-mm M1 gun. The HVAP-T would fail at point blank against the frontal bow armor of the Panther because the V_{50} is equal to the muzzle velocity.

General Omar Bradley recalls of General Eisenhower's consternation in July of 1944, "Ordnance told me this 76mm would take care of anything the Germans had. Now I find you can't knock out a damn thing with it" (ref. 14). The actual battlefield performance corroborates the calculated values and the March 1945 test data that the M62APC could not defeat the frontal armor of the Panther tank.

The folly and consequences of cutting the barrel length of the 76-mm gun back to mitigate the need to re-balance the turret of the M18 Tank Destroyer is now clearly apparent. The close range ability to defeat the Panther was sacrificed to save weight, negating the primary function of a Tank Destroyer, which was to destroy enemy tanks.

The benefit of the 76-mm HVAP shot is that the front of the Panther Turret was now vulnerable at typical combat ranges in the ETO, which was validated via BAL66 calculation and the historic record. The Panther could be defeated from the front within 500 yd via penetrating the turret. While the bow remained impenetrable, a portion of the front face was better than no chance. This capability once again gave the Tank Destroyer and tank crews a fighting chance from front attack from a formidable enemy.

FIGHTING BACK – M1A2 76-MM SEPTEMBER 1944 TO JANUARY 1945

The first 2,000 rounds of 76-mm HVAP-T were air delivered to France in August 1944 and distributed on 11 September (ref. 10). The metal parts for both 76-mm and 3-in. gun variants were fabricated at Frankford Arsenal, PA, and the propellant was loaded and shells were assembled and packed at Picatinny Arsenal, NJ. The rounds were packed out per Picatinny Arsenal Order 1102-152, 17 August 1944 (ref. 22). This is the first recorded mass production of the HVAP shell. The rapid turnaround from July to September 1944 is a testament to the dedication in the Ordnance Department to supporting the war effort.

The M18 Tank Destroyers of the 704th and 603rd Tank Destroyer Battalions engaged German tanks soon after on 18 September near Lunéville, France. The M18s were able to destroy eight Panthers during the fight with no losses of their own. During the German counter attack at Arracourt, France, the M18s were positioned hull down with only their turrets exposed and arranged in a way to ensure mutual support. They forced the Panzers to expose their flank to the fire from supporting M18 sections during any attack. The 704th Tank Destroyer Battalion killed 79 Panzers with the new ammunition by the end of September, losing 14 Shermans (7 each), M5s, and one M18 (ref. 23).

The German offensive in the Ardennes put the American armor and the 76-mm gun to the test. On December 16, 1944, the 6th Schutzstaffel (SS) and 5th Panzer armies initiated an assault on allied positions. The Germans pushed into allied territory, forming a "bulge" in the lines and lending to the popular reference of "the Battle of the Bulge." The town of Bastogne, Belgium, was a hub of seven converging roads, so preventing German occupation of the town was critical to halt the German advance (ref. 24). The 101st Airborne Division received orders on December 1 to leave France and move toward Bastogne (ref. 24).

The next day, the M18s of Company C, 609th Tank Destroyer Battalion, received the same orders as their paratrooper counterparts (ref. 23). The third platoon, under command of Lt. David Hagen, arrived northeast of Bastogne, in the vicinity of Noville, early the morning of the 19th. His four M18s would support 15 Sherman tanks from Command Company B (CCB) 10th Armored Division and elements of the 506th Parachute Infantry Regiment (PIR).

Two M18s took up position of the Eastern edge of the town using the buildings for concealment and protection. The remaining two M18 Tank Destroyers acted as roving support, rapidly deploying from place to place as needed when German tanks appeared. Sergeant Richard

Beaster immediately opened fire on two Pz IVs approaching from Houffalize, Belgium, when his M18 arrived at the north edge of Noville, Switzerland. When the fog dispersed at 1,000 hr, the Americans spotted 30 German tanks from the 2nd Panzer Division. In rapid succession, Sergeant Beaster's M18 opened fire with its 76-mm gun and destroyed five Panthers with six shots fired (ref. 23). Unfortunately, the Germans returned fire and hit his M18, killing the driver and wounding the crew. The Germans then withdrew after losing nine tanks.

Major Desobry ordered CCB, C/609th, and 506th PIR to counterattack when a platoon of M10s from C/705th Tank Destroyer Battalion arrived as reinforcement. A German force met the American advance while advancing westward toward Noville. The Tank Destroyers attacked from the flank and destroyed five panzers at 1,500 yd. The Germans responded by shelling the American positions all night.

Panzers and infantry counterattacked the morning of 20 December 1944. The M18s knocked out five of the fifteen Pz IVs they spotted. The Americans withdrew only after completely depleting all of their armor piercing shells. The Americans fighting at Noville lost half of their men, 11 tanks, and five Tank Destroyers, but they succeeded in delaying the German encirclement of Bastogne for two days (ref. 23).

The German General Manteuffel sent a message to the American command to surrender after Bastogne was completely surrounded on 21 December. This was followed on the 22nd with 101st Airborne General McAuliffe's famous one word response, "Nuts." German messengers did not comprehend the message, and he clarified by saying, "It is the same as go to Hell. And I'll tell you something else, if you continue to attack we will kill every goddam German that tries to break into this city" (ref. 24).

Communication remained open even though Bastogne was surrounded, and General McAuliffe knew that General George S. Patton made a claim that he would be able to attack the Germans with three divisions on 22 December (ref. 23). True to his word, he ordered the 4th Armored Division to shift its line of attack from Eastward to Northward toward Bastogne. Reinforcement was on its way, and they needed to resist the Germans and buy time. The Command Company A of the 4th Armored Division attacked at dawn on 22 December in the middle of a snowstorm along the Arlon-Bastogne highway with CCB to their West on a parallel course (ref. 25).

The 4th Division leapfrogged town-to-town northward over five days, taking heavy losses, while ammunition supplies were running dangerously low in Bastogne. General Patton sent a message that was sent to Bastogne on Christmas Eve, "Xmas Eve present coming up. Hold on" (ref. 23). Heavy fighting erupted on Christmas Day when the 15th Panzergrenadier Division attacked at 0300 hr with two battalions supported by artillery and 18 tanks (ref. 24).

The Americans noticed that the Panzers preceded their supporting infantry by about 200 yd. The 101st Airborne allowed the Panzers to pass but sealed off entry for the infantry. The Tank Destroyers and the airborne engaged the Panzers from their rear while the Sherman tanks opened fire on the German infantry with HE shells in front (ref. 22). The M18s destroyed 27 Panzers at a loss of six of their own (ref. 10). The tactic rear attack confirms the result of our previous calculations. American soldiers were aware of the limitations of a frontal attack against German armor. Attacking the thinner armor in the rear would offer better odds. Tactics evolved along with technology.

The siege of Bastogne ended on December 26, 1944. The 37th Tank Battalion, commanded by Creighton Abrams, broke through the German lines along the Assenois Rd, Belgium, and entered Bastogne late in the day. The lead tank element, C/37th Tank Battalion, was commanded by Lt. Charles Boggess. His gunner, Cpl Milton Dickerman, recounted using his 75-mm "like a machine gun," pouring round after round into German targets as he pressed toward Bastogne (ref. 26). At 4:45 PM, Boggess made contact with Lt. Webster of the 36th Engineers, 101st Airborne.

This 76-mm ammunition continued to make a difference for the duration of the Second World War. Evidence of its use at the Remagen bridgehead was sent via a letter to Picatinny Arsenal from Lt. William Goldie. He returned the packing slip from his 76-mm ammunition packed by Sebastian Palma and inspected by Herman Olsher with a note saying, "When my outfit broke out of the Remagen Bridgehead this round was in the chamber of my gun and ten to fifteen minutes after crossing the L.D., I had the opportunity of slamming it into a Jerry A.T. gun" (ref. 27). The "A.T. gun" is an armored German self-propelled anti-tank gun Strumgeschutz built upon a Pz IV chassis.

CONCLUSIONS

Tank Destroyer vehicle requirements unintentionally lead to compromises that severely curtailed the primary function of the M1 76-mm Gun, which was defeating enemy tanks. All other characteristics should have been secondary to superior armor piercing capability. The British recognized this when developing the 17-pounder. With the same 76-mm diameter, they succeeded in developing the most effective allied anti-tank gun of the war by having a long barrel and three times as much propellant as their American counterparts. The result was a projectile moving 600-fps faster, which was all the advantage needed to decisively defeat any of the German Panzers. Unencumbered by tactical doctrine and special constraints, the British fit the 17-pounder to the Sherman tank well before the U.S. Army considered the 76-mm for a tank armament.

The British had sufficient numbers of "Firefly" variant Sherman tanks for the real-world tank versus tank combat in Normandy, France. American tankers were struggling with the inadequacy of their 75-mm gun in the meantime. The decision to cut barrel length of the M1 instead of rebalancing the M18 turret reduced the capability that would have ensured successful performance against heavier German armor. The muzzle velocity reflecting the recommendations of the Ballistic Research Laboratory report on sub caliber penetrators would have put the M1 76-mm closer to the 17-pounder in performance and given the U.S. tanks a chance of defeating the Panther from the front at close range.

The lack of data for the hyper-velocity, armor-piercing tracer (HVAP-T) or the Panther in the September 1944 publication of technical manual (TM) 9-1907 is a testament to the fluid nature of the armament versus armor upgrade race. The nearly identical velocity decay curves of M62A1 adjusted for transonic and subsonic flight matches the published test observation in TM 9-1907 closely. The values calculated for the M93 HVAP-T using the same methodology can be considered valid to fill the gap in the TM data. The Thompson and Lambert-Zukas models are both close in approximating the penetration performance of the shells and can be used in conjunction if the specific steel mechanical properties of the target are unknown.

The Ballistic Analysis Laboratory Technical Report No. 66 PRODAS simulation is clearly closer to the observed performance, due to the ability to input specific target mechanical properties. The Panther armor analysis was closer than either the Lambert-Zukas or the Thompson calculation because we were able to use the data from the historic metallurgical analysis to support the model.

It is not fair to completely discredit the M1 76-mm Gun and its accompanying ammunition. It was a solid designed weapon system and performed the task assigned. The development of the 76-mm M1 Gun was specifically to counter the Panzer IV (Pz IV) threat. It met the requirement it was designed to defeat admirably. The 76-mm gun proved to be superior to the 75-mm gun, but it was barely adequate to the task of defeating German armor in Normandy. The German Panther earned a reputation of invincibility as a result of the frontal armor resistance to the 76-mm shells. The Pz IV upgrades also took the Americans by surprise, leading to a scramble for the new HVAP-T shell.

The development of the HVAP-T round to supplement the 76-mm gun was successful in improving close range capability against Pz IV upgrades, but supplies were never adequate until nearly the end of the war in the spring of 1945. The M62A1 armor piercing capped was still superior in performance to the HVAP-T at longer ranges. Both rounds would be needed to achieve optimal performance. The true benefit of the HVAP shot was opening up the front of the Panther turret as a viable target, albeit at close range. The effective range was within typical tank engagement ranges in the European Theater of Operations, and even though the bow armor was still invulnerable, the HVAP gave the U.S. Tank Destroyer and tank crews a chance against the Panther front face via the turret. Given the data was not published in the TM at the time of fielding, the crews would have to learn this via trial and error.

The early war 76-mm development efforts was a missed opportunity to significantly improve upon the 3-in. gun. The lesson learned from this is to ensure that your capability exceeds the projected threat because just good enough now may not be in a few years' time. Anticipate improvements in enemy capability and be flexible enough to adapt when encountered. Even if a weapon system fully meets the design and performance requirements, it may not reflect the actual capability of the enemy. The success of the American tank and Tank Destroyer crews as well as the engineers in developing an effective new technology in a short time is a testament to the spirit and dedication of the World War II generation.

Our calculations have provided a clear picture of the armor defeating improvements the 76-mm system offered over the standard 75-mm U.S. tank armament. The M1 76-mm Gun and the HVAP shot played a significant part in evening the odds and ensuring victory during the Battle of the Bulge and the duration of the Second World War. The rapid fielding of the HVAP shot during the autumn and winter of 1944 gave crews a viable anti-armor capability against heavy German Panzers. During the 1940s, there was no accurate method of determining performance against an enemy until enemy equipment was engaged in combat and captured for evaluation. We have the benefit of modern modeling and simulation to predict weapon performance against a variety of targets that World War II-era engineers and scientists were not capable of conducting.

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APPENDIX A
76-MM AMMUNITION CONFIGURATION MANAGEMENT

Ammunition Configuration Management

M42 HE Shell:

The earliest revision of the M42 shell available changed nomenclature to “3AA SHELL M42” in the December 5, 1932. The 1932 revision also changed the energetic material main charge to an explosive as the bursting charge rather than black powder. This revision also allowed for the use of 50/50 Amatol or 50/50 Tridite in addition to straight TNT. The depth of the fuze well varied depending on the HE load. It varied from 2.25” for TNT to 2.3” for Tridite and Amatol. Amatol required facing to a depth of 2.55” and a layer of TNT poured on top. Drilling of mouth of the shell to a depth of 2.3” followed. The paint scheme was changed to Yellow with Black markings to indicate HE loading rather than Practice. The words, “Shell not for Service” was marked with vermilion ink. It is not immediately apparent what the original intent of this shell was if not for combat. Speculation is perhaps the spotting charge did not provide enough of a signature to be useful for training.

The December 4, 1940 revision changed the marking of the shell to read “3AAG SHELL M42.” The addition of the letter “G” in the marking is the first indication that M42 HE served a dual purpose as a 3” Anti Aircraft and 3” Gun munition. The fuze well cavities were decreased in depth by .03”for all HE loading options (TNT, 50/50 Amatol, 50/50 Tridite). The October 22, 1941 revision changed the designation from “3AAG” to “3G,” making the M42 solely designated for a 3” Gun. The explosive fill “Tridite” changed nomenclature to “Trimonite.” The depth of the Fuze well cavity was changed again for 50/50 Amatol to a 2.77” depth. It topped off with a minimum of .5” of TNT. This ensured a minimum of .08lbs of TNT surrounded the fuze booster when fully assembled.

The November 12, 1941 revision incorporates the addition of an “A1” suffix to the M42 Shell, changing the designation to M42A1. Removal of the requirement to coat the threads with grease after installation of the fuze well cup also is included. The weight of Amatol allowed for loading increases by .04lbs to .77lbs total. Recoating the base of the projectile with Yellow paint was no longer necessary, since touch up was now only required for the portion of the shell forward of the rotating band.

The September 23, 1942 revision added a diameter of 1.73” to the fuze well. The fuze well cup removed from the projectile drawing and replaced with its own drawing, 75-14-375. A statement stating that explosive chipped or broken during machining of the sidewall of the fuze cavity did not need to be replaced by topping off the explosive was also added via this revision.

The March 18, 1943 revision of the Loading Assembly removed Trimonite as an approved HE fill. The paint scheme of the shell was changed from Yellow with Black markings, to Olive Drab with Yellow markings. This is the first observed use on the M42 of the standard convention for paint and marking scheme in use at present time for all HE shells and munitions.

The initial release of the M42A1 Shell top-level assembly specifically for 76mm Guns (75-1-244) is recorded on April 5, 1945. This is well after the system was introduced into the field for combat. The 76mm designated shell uses the same 3” steel projectile body (75-14-

170) but designates TNT as the only allowed explosive fill. The Projectile is assembled with the M55A3 Superquick Time Fuze (75-3-156). This projectile assembly is crimped into an M26 brass casing. The brass casing is loaded with 3.75lbs of Powder Propellant (75-1-244A) and an M40 Percussion Primer assembly (74-2-68). The Primer consisted of a perforated tube loaded with black powder, initiated via a primer cap in the base. The total weight of the round was 22.58lbs, with a projectile in flight weight of 12.87lbs. The projectile is Olive Drab and marked “76G TNT SHELL M42A1” in 5/8” yellow lettering. Instruction to obliterate the “3G” designation with Olive Drab paint and to remark “76G” with Yellow ink is given. Approval of the final revisions of the Second World War M42A1 Shell and Loading Assembly are on August 15, 1945.

The M42A1 continued use in service in the post war period. Modifications to the configuration continued until 1956. A noteworthy change to the shell during the post war period was the incorporation of Composition B explosive as an alternate to TNT. Both explosives were considered acceptable for use in the same shell, though performance likely varied significantly between the two variants. For purposes of this study, we shall consider the April 15, 1945 TNT configuration as the World War 2 service configuration.

M62A1 76mm Armor Piercing Capped (APC):

Technical Data established the M62 APC (75-1-150) for use in the 76mm on August 28, 1942. Four revisions of the top assembly exist for the duration of the Second World War. Ironically, the final revision is dated to the day Emperor Hirohito announced the surrender of Japan via radio address, August 15, 1945. The M62A1 Projectile Assembly (75-14-269) consists of a steel projectile body loaded with a .144lb Ammonium Picrate bursting charge, M66A1 Fuze, steel ballistic cap, and steel windshield. A brass casing loaded with propellant is crimped to this assembly. The brass casing is loaded with 3.75lbs of Propellant (75-1-150A) and a Percussion Primer assembly in a similar manner as the M42A1. The total weight of the round was 22.15lbs, with the projectile weighing in at 15.44lbs as fired. The Projectile is painted Yellow with Black markings, “76G PROJAPCM62 WITH TRACER” in ½” lettering. The drawing instructs obliteration of the “3G” marking on existing M62 projectiles (75-14-269) with Yellow paint and remarking “76G” with Black ink in its place.

The first revision to the M62 76mm APC round was November 13, 1942. This changed in the M28A2 percussion primer drawing from “74-2-41” to “74-2-63”. Multiple percussion primer assemblies were consolidated in a single drawing, consisting of the M28A2, M1A2, M40, and M64.

A second revision, dated May 1, 1944, changed the coloring of the projectile from Yellow with Black markings, to the familiar Olive Drab with Yellow markings. Instruction for repairing damaged paint on the projectile with rust preventing compound was added. This revision also incorporated a steel M26B1 cartridge case as an alternate to the standard brass M26. The number of crimps securing the case to the projectile increased from four to eight. We can only speculate the reasoning, as this has been lost. Markings on the alternate case were specified black or silver nitrate. The revision also lists the M28B2 Percussion Primer as an acceptable alternative to the M28A2. The difference between the two primers appears to be that the “A2” had a brass body where the “B1” is steel. The “Restricted” category was also removed from the drawing at this time.

The April 3, 1945 revision added the suffix to the model designator, changing it from M62 to M62A1. The Markings on the projectile changed from “76G PROJAPCM62 WITH TRACER” to the simplified, “76G PROJAPCTM62A1” reflecting the new model suffix. This revision also replaced the M28 Percussion Primer assembly (both “A2” and “B1” variants) with the M40 Percussion Primer. The M40 contained a longer flash tube, extending further into the case than the M28A2. Reasoning is not given, but it is assumed that that the purpose was to ensure uniform ignition of the powder propellant. This is speculation, as no record has been uncovered to confirm this. The “B1” steel case is not an alternative after this revision.

The final revision, approved on August 15, 1945, obliterated the call out to repair damaged areas of the varnished steel projectile with rust preventing compound. The requirement for black or silver nitrate markings on the brass casing was also removed.

Hypervelocity Armor Piercing – Tracer 76mm M93 (HVAP-T-T):

The first revision to the 76mm HVAP-T Tech Data is February 2, 1945. It appears that the only change was a model designation change from T4E20 to M93. The Projectile is painted Black with White markings, “76G SHOT HVAP-T-T M93” in 5/16” lettering. The M26 case is marked “HYPERVELOCITY MV3400” with ½” black or silver nitrate lettering. The available copy of the initial release of the T4E20 is difficult to read, making verification of changes difficult to verify. Since there is a day separating the revision from the initial release, it is assumed that the Jan 31 was for record keeping to document the T4E20 HVAP-T shot fielded in September of 1944.

The second revision is the last that is relevant to the Second World War, approved on the day Japan surrendered, August 15, 1945. The revision changes the weight of the “shot” on the List of Components. Initial weight was given as 9.36lbs, which is the weight of the Metal Parts Assembly. This revision changed the weight listing to 3.95lbs, the actual weight of the tungsten carbide core. The “as fired” weight changed from 9.4lbs to 9.36lbs.

Changes to M93A1 HVAP-T continue post World War II until December 1954. The most significant update appears to be the incorporation of a threaded tracer into the base of the Loading Assembly. This replaced the press fit tracer that had been in use from 1944-1946. For purposes of this study we will consider the August 15, 1944 revision as the representative configuration for the timeframe encompassing fielding to the end of the war.

APPENDIX B
DRAWINGS

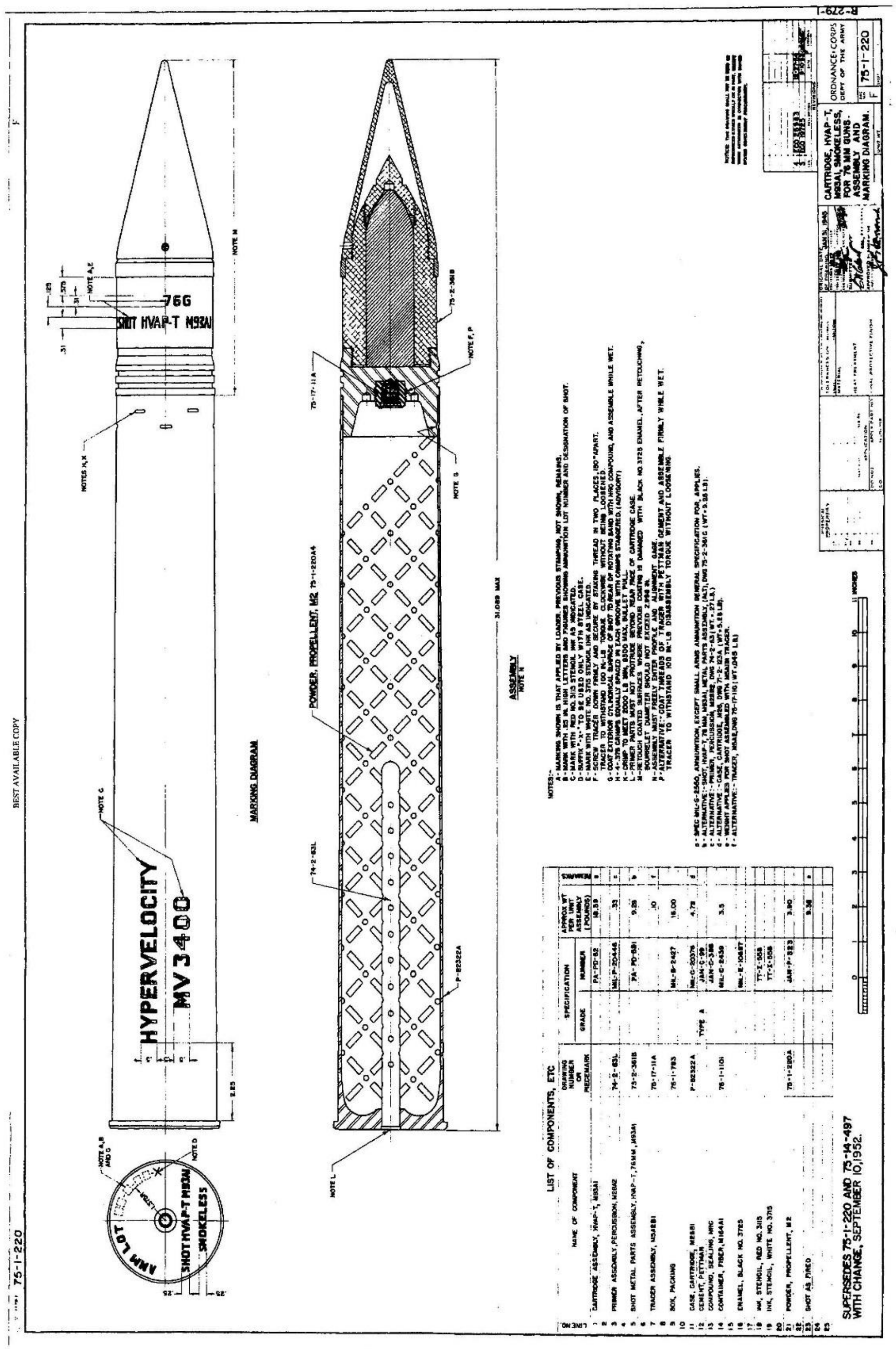

Figure B-1
76mm HVAP-T - Top Assembly Drawing

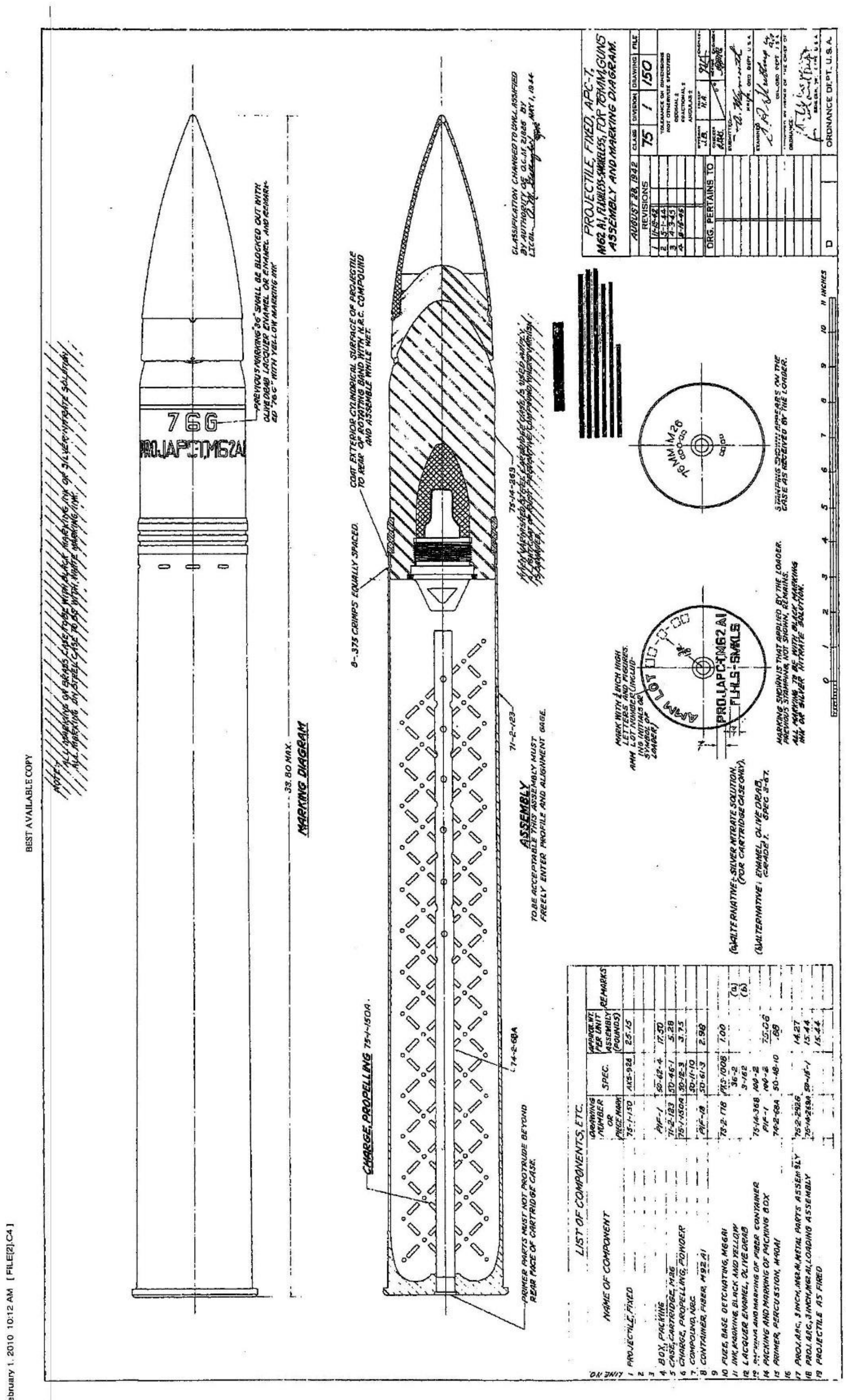

Figure B-2
M62A1 76mm APC Top Assembly Drawing

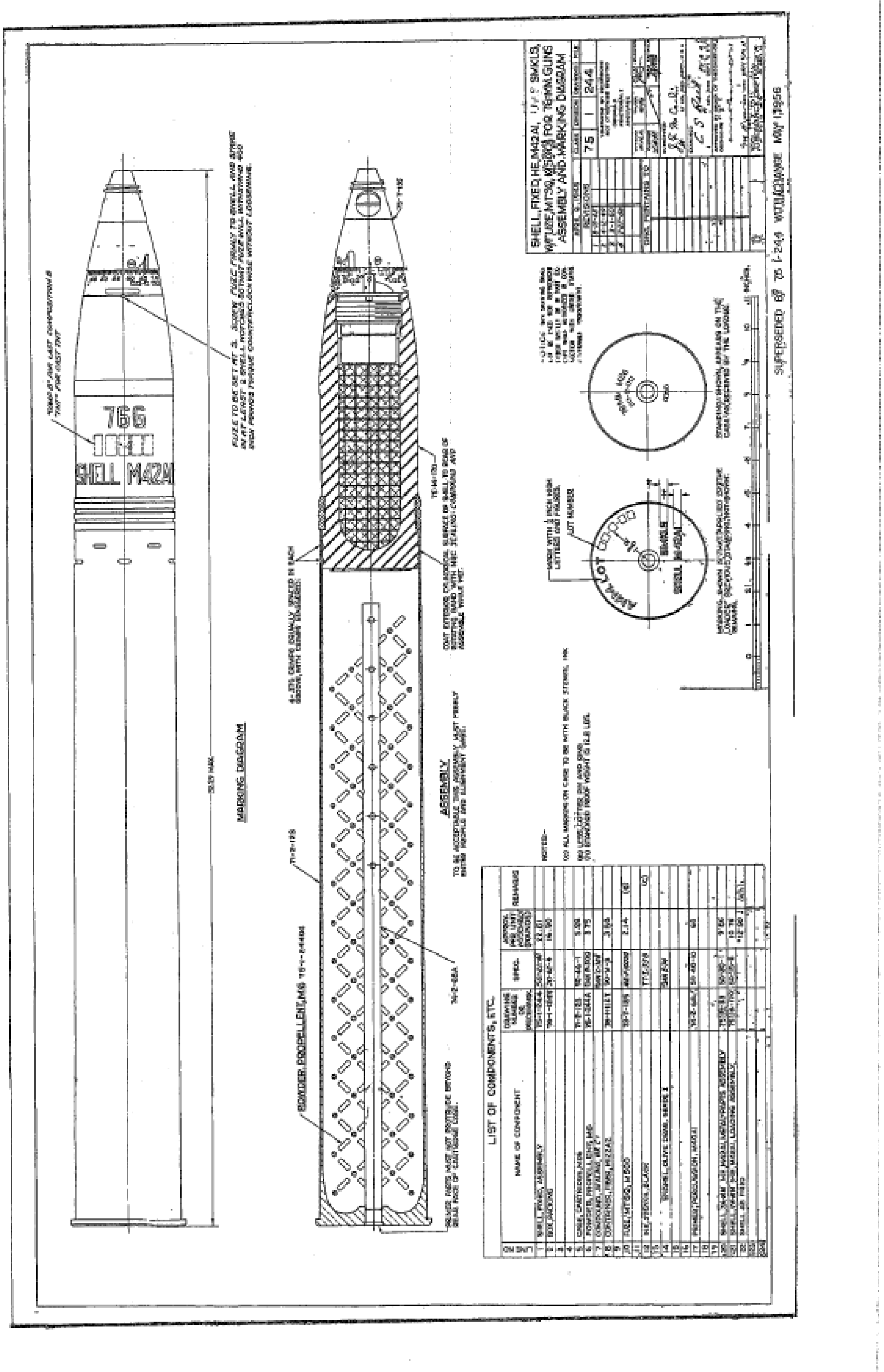

Figure B-3
M42A1 76mm HE Top Assembly Drawing

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