RP-24: How to Knock Out a Tank

Researched and Written by: Cdr (Ret'd) Mark Tunnicliffe

Introduction
When the tank made its first appearance in battle at Flers-Courcelette in September 1916, its main obstacle was not enemy action so much as mechanical break-down and getting stuck in the tormented terrain of the Somme battlefield. The armour of First World War tanks was intended to provide protection from infantry small arms, machine guns and spent artillery fragments. As the field artillery of the day had been driven back from the forward edge of the battlefield by machine guns, it was not initially well placed to counter the new threat. Nevertheless, the Germans quickly learned to hide a number of small (37mm calibre) field pieces to cover areas where they could channel tank attacks and to provide their infantry with improvised grenades to lob onto the top of the slow-moving vehicles. By 1918 they had developed a 13mm Mauser rifle with a 13mm hard steel core bullet which was capable of piercing the 8 – 22mm of armor on tanks like the museum's M1918 (a US copy of the Renault FT).

Wartime experience coupled with the increasing armor thickness of vehicles developed in the inter-war years brought with it the realization that the extemporaneous use of field artillery in the anti-tank role was, except in an emergency, not very efficient or effective. Furthermore, modified rifles were not likely to be of much use either (though these, like the British Boys rifle continued to be produced into the early years of WW2). Once tank armor increased beyond an inch or two in thickness, gunners discovered what the navy had learned some 80 years earlier: standard high-explosive shells are not very effective in penetrating armor – they tend to break up outside it. Additionally, to attack a moving armored vehicle, guns needed to be traversed rapidly, and, in a fluid tactical environment, be easily concealed. The design of a typical field gun and its ammunition (with at least one notable exception) did not easily lend itself to such a role and in the '20s and '30s armies started looking for purpose built weapons.

There are several ways of defeating armour which, for the purposes of this article, will be broken down into three categories; kinetic energy systems, explosive energy techniques and armor avoidance.

Kinetic Energy

The most obvious (and still the most effective) technique is brute force – essentially the application of the kinetic energy provided by the launch of a round from a gun onto the defending armour of the target. In other words, a projectile is fired at the armor plate at sufficient speed to force its way through with the intent of causing fatal damage to the tender bits behind (crew, ammunition, equipment and the like). This is not a trivial task. Tank armour typically used a cemented type steel in which steel is heated with carbon rich gas and quickly quenched in water or oil to produce a plate that was very hard on its face but rather more flexible (tough) in the rear portion of the plate. This allows the plate to resist a high velocity shot and not shatter from the impact. A kinetic energy anti- tank system therefore has implications for two parts of the system; the round itself and the gun that fires it. Kinetic energy[1] is a function of mass (provided by the projectile) and its velocity (provided by the gun).

The Round

Anti-tank (AT) shot (solid rounds) and shell (a round with some explosive filling) have to be developed to a similar metallurgical standard as the armour it is intended to penetrate. A solid shot is mechanically more robust than a shell. Fired at sufficiently high speed (which usually implies a flat trajectory/direct fire engagement) it will punch a hole in armour plate pushing fragments into the tank with potentially lethal effect. However, given the relatively simple mechanical tank designs of the late '30's, a solid shot could just as easily pass through both sides of a tank hull and, if it did not hit a crew member or critical component, result in no critical damage at all. Consequently, many armies (essentially everyone but Britain) looked to develop an armor piercing shell to break up the round after it penetrated the initial plate and increase the behind armour damage. This is not easy to do. Such a round is both lighter and more fragile than a shot of the same calibre, and it needs an explosive (like picric acid) insensitive to extreme shock and a fuse that will not detonate prematurely.

Whether shot or shell is selected, the round has to be able to absorb a high-speed impact with face hardened steel at an angle without deflecting or shattering. This means that the round has to be tempered to a high degree of hardness to absorb the compression shock of impact but also have to withstand the inevitable shear stresses that can break it up in the usual case of an impact at an angle (lower tempering on the back part of the round to provide some flexibility or toughness). The optimum shape for such a round is a rather fat round cone which results in a very high shock on the point at initial impact. For this reason, a cap (called a Makarov cap after the inventor) of soft steel was added to spread the initial shock of impact to the shoulders of the penetrator and to resist deflection of the round in the case of an oblique impact. This was termed an armour piercing, capped round. The best shape for such a cap though, proved to be a poor one for ballistic flight so an even thinner ballistic cap was added to provide a better aerodynamic shape resulting in an armour piercing, capped, ballistic capped round. Early armour piercing rounds could penetrate about twice their diameter worth of plate at short ranges but this dropped off to about than their own calibre at ranges of 1000m or so. With the ballistic cap fitted the long-range performance roughly doubled.

As armour thickened in response to the mew AP threat, gun manufacturers responded by increasing AT round speed resulting in an impact shock that no steel alloy could withstand without shattering so other materials were examined for their potential. By the middle of the Second World War, both the allies and Germany started using tungsten

[1] K.E. = $1/2mv^2$ where m is mass and v is velocity (or more properly, speed).

carbide in their armour piercing shot not only for its stiffness but also because it is quite dense (about twice that of iron). While increased mass of a shot is an advantage (more "m" in the kinetic energy) making the entire shot out of tungsten would have made it too dense for a given gun calibre to accelerate to the necessary speed. Consequently, shot would be made with a tungsten core surrounded by a softer steel jacket of the required shape and calibre to produce a "composite rigid shot". This worked well at short ranges but still tended to slow down at longer ones demanding a different solution.

A heavy shot clearly delivers more mass than a smaller one onto its target and therefore more kinetic energy. It will also maintain its speed longer in flight than a smaller round of similar shape. However, a bigger round has to punch through much more armour than a smaller one (doubling the diameter quadruples the armour that must be defeated). A design was needed that would take the impulse from a large diameter gun, provide it to a hard, dense stiff shot which only needed to bore a small diameter hole in the defending armour plate.

One approach involved developing a round with flanges that fit into a larger bore at the breech of the gun which were swaged down in a decreasing diameter barrel accelerating the shot (in a 28 – 20 mm version) to 4000 ft/sec – a speed that no steel shot could withstand. This so-called Gerlich principle was implemented by Germany in their 28mm Schweres Panserbussh Model 41 which delivered a 20mm tungsten core shot once the light steel jacket had been swaged down in the barrel. (The museum apparently has a copy but it is currently not on display). The Allies copied the idea in a modified form using a special flanged shot for their 2 pounder guns (and the 37 mm US weapon used in armoured cars) with a tapered bore adapter fitted to the end of the gun, called a Littlejohn attachment, to provide a significant boost in initial muzzle velocity to these small-bore AT guns. For the Germans, the use of tungsten in ammunition became impractical as supplies were interdicted by the Allied blockade – they had to reserve all of their stocks for machine tool production.

A more practical solution, especially for larger calibre guns, developed towards the end of WW2, and still very much in use today, is the discarding sabot round. The sabot, made of a light metal allows for the impulse of a large calibre gun to be provided to a small encapsulated shot to accelerate it to very high speed (over 1000m/s). The sabot, made up of "petals", breaks away from the shot as it leaves the gun (at some hazard to nearby troops) allowing the shot to continue to the target as a sub-calibre round.

The museum's cut-away example shows the construction of such a round. The sabot (which appears to be from a 90-mm munition) encases a composite round consisting of a hard core with a cap encased in a ballistic jacket. This would be an armour piercing capped ballistic capped discarding sabot round (APCPBDS-T) with a tracer flare in the base.

Figure 1: An armour piercing shot with a disposable sabot cut away to show its construction. The rigid shot has an armour piercing cap and then is encased in a soft metal outer layer with a ballistic nose cap. A 105mm version is to the left of it with its Armor Piercing Disposable Sabot – Tracer marking clearly visible.

A further technique to increase the mass of a high speed but small diameter armour piercing round is to change its fundamental shape. To increase the mass of the projectile without increasing the diameter it can simply be made longer. Doubling or tripling the length of the armor penetrator at a given speed will double or triple the kinetic energy imposed on a given area of defending plate. However once the length to diameter ratio of a projectile exceeds about 6 or 7 to 1, it can no longer be stabilized in flight by spinning it and consequently metal fins are used instead. The result is what is called a long rod penetrator or armor piercing fin stabilized round fired (usually) from a smooth bore gun using sabots for stabilization in the barrel. Most modern tanks use these armor piercing, fin stabilized discarding sabot rounds (APFSDS)[2] as their primary anti-tank munition. The main exception is the UK which still prefers to use a rifled main gun on tanks like the museum's Chieftain and their more modern

[2] *Pace* Napoleon, a modern army does not march on its stomach – it can get nowhere without acronyms.

Challenger 1 and 2 tanks (they had to develop a technique for "de-spinning" APFSDS rounds fired from it)[3]. The penetrator itself must be dense and very stiff (to avoid shearing off on oblique hits) and is typically made of tungsten carbide or depleted uranium (which has the added benefit of being pyrophoric or igniting during the penetration process).

The museum has an example of a 105-mm long rod penetrator. Most of the round is buried in the cartridge case behind the sabot with only the tip visible.

Figure 2: A 105mm APFSDS round. The sabot is the black cone surrounding the rod which itself extends back to the ogive in the cartridge.

The Gun

The shell or shot provides the mass component in a kinetic energy round; the propellant cartridge ignited in the anti-tank gun provides the velocity. To this end, anti-tank guns tend to have larger propellant cartridges than field guns of the same calibre. This in turn, means that the recoil for the weapon will be relatively severe and will have to be managed by the carriage design or the vehicle if mounted as a mobile weapon. Furthermore, to gain maximum advantage of the impulse provided by the cartridge, the gun barrel needs to be relatively longer than a similar sized field gun to enable the shot (or shell) to attain the speed necessary to defeat armour plate. The British 17 pounder anti-tank gun (with a bore of 76.2mm) had a muzzle velocity 50% greater than their 75mm weapon with a kinetic energy three times as much despite firing a slightly heavier shell.

This means that some allowance for absorbing the recoil generated by such an expenditure of energy must be made – usually by permitting a long recoil stroke mitigated to some extent by the use of a muzzle brake where needed. For a towed artillery piece this usually is not a big problem but in the closer quarters of an armoured fighting vehicle it can be quite a design challenge. The KwK 42/L70 75mm gun used in the Panther tank was probably one of the most effective anti-armour weapons of WW2 with a penetration capability somewhat better than that of the feared "88". With its 42-cm recoil stroke and space required to load its 90 cm long shells it demanded (in a tank) a turret big enough to accommodate it. This in turn, required a large turret ring and consequently a wider tank chassis with knock-on consequences for the bridges, transporter trucks, railway transport cars and even railway tunnels necessary to get the

[3] See the museum's T-72 for a 120mm smooth bore gun armed tank example.

vehicle to the front.[4] Another approach to managing such a large gun in a vehicle is not to put it in a turret at all but rather mount it directly in the chassis and permit it the full length of that as a fighting compartment for recoil and loading. This is seen in the museum's Jagdpanzer IV which mounts essentially the same weapon as the Panther (in this use the gun was called the PaK 42/L70) on the rather smaller Mk IV tank chassis[5]. The chassis-based fighting compartment of this vehicle was roomy enough that a muzzle brake was found not to be necessary[6]. However, without a turret, the gun can only traverse several degrees in either direction, which means it essentially has to be aimed by the driver before the gunner can lock on to the target. The tactical implications are that even a minor mobility kill, such as blowing off a track, will leave the Jagdpanzer vulnerable to being quickly outflanked and hit from the side, unable to shoot back.

Figure 3: The KwK 42/L70 mounted in the Museum's Mk V "Panther" tank. The large turret permitted 360 degree firing at a cost of a large chassis and weight.

Figure 4: The same gun mounted in a tank destroyer. The extra weight of the gun and additional armour made the vehicle nose- heavy forcing reinforcement of the front road wheels

[4] Some sources suggest that the dimensions of the US Sherman were in part dictated by the capacity of the American railway system.

[5] As a tank, the Mk IV also mounted a 75mm gun but this was the much shorter, and less powerful KwK 40/L48.

[6] The low mounting of the gun in the Jagdpanzer when fitted with a muzzle brake tended to kick up a lot of dust, revealing its ambush position.

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The British were able to mount a weapon of similar capability on an even smaller chassis when they married their 17-pounder anti-tank gun to a Valentine tank chassis. The only way that this would fit was if the weapon was mounted backwards (where the gun recoil would hit an unwary driver) but this turned out to be a tactical advantage. The vehicle (called 'Archer') was perfectly positioned for a quick get-away if its shot missed. The 17-pounder was also mounted in a Sherman turret to provide Commonwealth forces with their own tank destroyer (the Sherman 'Firefly') at a cost of completely redesigning the recoil mechanism and turret.

For towed artillery application, other restrictions apply. Being much less mobile than its target, an anti-tank gun is usually operated from an ambush or concealed position necessitating as small a profile as possible. Also, as its target can appear relatively suddenly from any position, the gun must be capable of traversing quickly. This means that a towed AT gun has practical size limitations particularly when it becomes too heavy for its crew to manhandle in a fluid tactical situation as was the case with the 17-pounder.

Figure 5: The museum's British 6-pounder AT gun. Its 90-degree traverse and 1000 lb weight made it easily manageable by its crew. Even when it was outclassed by German armour late in the war it still provided good service as an infantry support weapon.

Figure 6: The 17-pounder AT gun. This had a similar and arguably better performance against armour than the German "88" but at 3 tons weight was not easily maneuvered on the battlefield.

These two constraints are usually not major considerations for regular field artillery operating in an indirect fire role. However, the fluid conditions that marked the battlefields of the eastern front and the North African desert frequently forced field artillery into the AT role. When the 2-pounder AT gun proved inadequate against Rommel's Mk III and Mk IV tanks, the 25-pounder gun howitzer was pressed into that role - performing quite well though its ammunition had to rely only on its high explosive capability to defeat tanks. It proved reasonably well suited to this impromptu function largely because of its unique circular firing table which permitted its crew to traverse it rapidly as required[7]. Subsequent revisions to the weapon provided it with a dedicated AT round complete with a supercharged cartridge (or No. 3 "charge super"), a 20 lb solid shot, and a muzzle brake to provide it with a better anti armour role in future engagements. The museum's ZiS-3 field gun had a similar history. An improvised design, it was light enough to be quite effective in the anti-tank role against earlier German tanks, especially when supplied with AT shot and composite ammunition.

Figure 7: The ZiS-3. The improvised 75mm field gun was married to a light 57mm AT gun carriage necessitating the use of a muzzle brake. This resulted in a low-profile light gun that worked well in the AT role.

[7] Indeed, the first 17-pounder AT guns that the British fielded were mounted on 25 pounder carriages as a stop gap measure.

Explosive Energy Systems

Kinetic energy anti-tank systems rely on large launch platforms impractical for use by individual soldiers. However, instead of relying on energy expended at the launch platform (i.e. in the propellant cartridge), the high explosive content of the round itself can be used to defeat armour – if it is designed properly. There are two common techniques for doing this: High Explosive Anti-Tank (HEAT) and High Explosive Squash Head (HESH). Both of these techniques use a relatively slow moving round and the former is quite amenable to launch by infantry portable weapons.

HEAT

The principle of operation of a HEAT round was not understood until after the Second World War but it had its origins in the "Munroe effect" of 1880 when a US engineer noted that letters impressed in explosive tended to "burn" themselves into plate when the explosive was detonated against it. The concept received rapid, if empirical, development during WWII and it was not until afterwards that the concept was fully understood and better implemented. A warhead surrounding a metal-lined conical cavity detonated from the back of the explosive at a small stand-off distance from a target will set up a detonation wave that collapses the cone and its lining which is deformed into a metallic jet focused on the plate at speeds of 6 – 8000 m/s. Executed under optimal conditions, this jet is capable of penetrating 3 or 4 cone diameters of armour thickness. Ideally, the round should not be spinning, should impact the plate at relatively slow speed, as perpendicular to the plate as possible and should be detonated about 4 cone diameters from the target plate. This lends itself to relatively low velocity launch systems like grenades, rockets, mortars or low velocity guns.

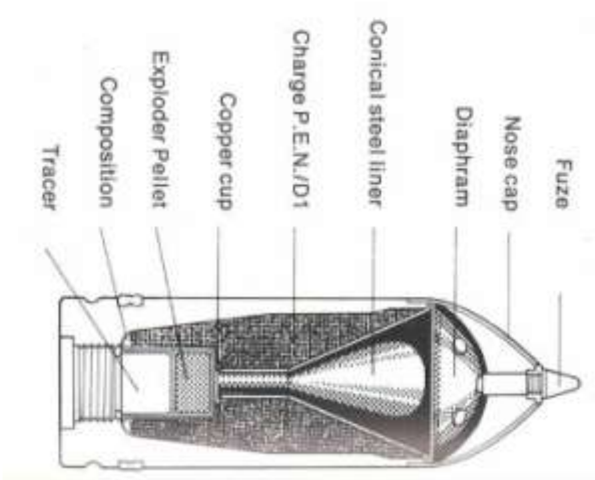

Figure 8: An early British 95mm HEAT round. Modern rounds use a copper liner or even more exotic materials and have a longer stand off nose cap. (Taken from Ref 1)

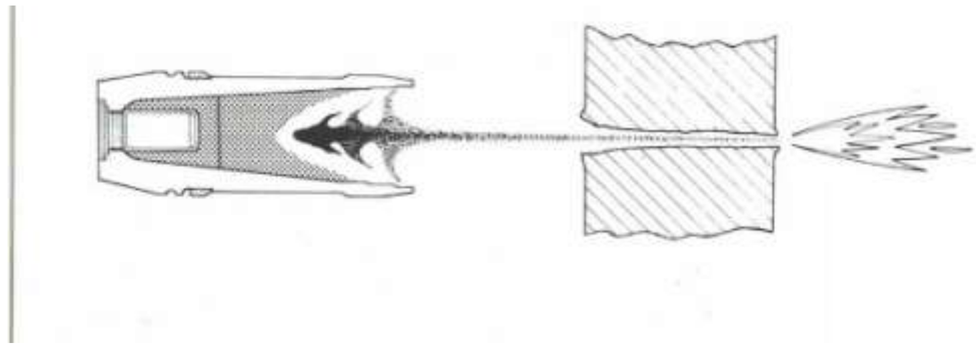

Figure 9: The HEAT Principle (Taken from Ref 1)

The museum has a number of examples of weapons which exploit the HEAT effect. The British developed a rifle grenade as an interim anti-tank round in the desperate days after the Dunkirk evacuation and a somewhat larger bomb fired from a spigot mortar called the Blacker Bombard. It was not particularly practical but the principle was pursued in an infantry portable weapon called the Projector Infantry Anti-Tank (PIAT). The device, normally served by a crew of two, consisted of a tray in which a fin stabilized 2.5-pound bomb was placed. On firing, a spring-loaded spigot entered the stem of the bomb setting off a small propellant charge that projected the bomb out to about 100 yards in direct fire mode (it could reach over 300 yards if employed as a mortar). The bomb rarely achieved its 100mm armour penetration potential and was less than perfectly reliable. The PIAT had a mixed reaction from the Commonwealth forces that used it, and given its short range, it is not surprising that at least 6 VC's were won using it (one by a Canadian).

Figure 10: The museum's PIAT, bomb and ammo carrier.

The US chose a different approach, using a 2.36-inch rocket fired from a shoulder held launcher, the M1 Rocket Launcher, otherwise known as the Bazooka. The weapon was capable of several hundred yards range and of penetrating 100mm of armour – when it worked. Unlike the PIAT, it had a very visible launch flash which rendered the user vulnerable to counter fire. Early versions did not work well but copies captured by the Germans in Tunisia allowed them to develop their much better *Panzerschreck* based on the bazooka design. Ironically, the US used their captured copies of the *Panzerschreck* to improve the bazooka design toward the end of the war producing the 3.5-inch rocket launcher known as the M20. Nominally capable of firing out to 900 yards, it had a practical range of 150 yards and was capable of penetrating 280 mm of armour. This upgraded bazooka was first used in Korea.

Figure 11 The Museum's M20B1 'Super Bazooka' and 3.5" rocket

The Germans pursued the tube launched grenade concept even further, producing a family of one- shot disposable recoilless projectile launcher weapons. The Panzer Faust fired a fin stabilized shaped charge grenade a short distance (most were only capable of a 30m range) from a tube held in the crook of the arm. There were a variety of these with bombs from 100mm to 149mm in diameter. Cheap to make, it was often the only weapon issued to the Volkssturm troops towards the end of the war.

Figure 12 The Museum's Panzerfaust

As the museum points out (but does not display), Canada also developed a 3.2 inch AT rocket launcher, the Heller, which was intended to replace the original Bazooka in Canadian Army use. It was deployed in the 1950's.

The shaped charge or HEAT round still plays an important role in today's anti-tank weapons. Artillery fired versions exist launched from conventional artillery tubes or from recoilless systems intended to dispense with the weight and infrastructure associated with recoil management systems associated with large guns. However, while a rifled HEAT round is more accurate particularly at long range, the spin tends to dissipate the metal jet on impact, reducing some of its effect.

Figure 13 A 90mm gun-launched HEAT round

A more common way of delivering a HEAT warhead today is by using either an unguided rocket or a guided missile, though the recoilless gun, either vehicle or shoulder mounted is also used. The Museum has a number of examples of these including a Jeep mounted 106 mm recoilless rifle (a BAT or Battalion Anti-Tank weapon). As it is a rifled weapon, enabling it to fire a variety of types of recoilless ammunition, its HEAT warhead needed to be "despun" using slipping driving bands to stabilize it in the barrel and deployable fins to steady it in flight.

The museum's B-11 recoilless gun is a Soviet piece using a smooth bore barrel to fire a fin-stabilized 107mm HEAT round capable of penetrating 380mm of steel at an effective range of about 450m. It is light enough to be towed by a relatively small 4X4 truck using the towing loop on the barrel.

Figure 14: A US 106mm BAT mounted on a jeep. A recoilless rifle (with its perforated cartridge visible), its back-blast would be highly visible to its intended victim - making a first-round hit and a "shoot and scoot" capability highly desirable. The museum also has a similar Soviet designed weapon used by Syria.

The most ubiquitous HEAT round today is probably that in the widely disseminated Soviet/Russian RPG series of shoulder fired weapons. The Ruchnoy Protivotankoviy Granatomyot – 7 launcher and its variety of ammunition has been in service since 1961 and is in service in more than 40 nations. The warhead (varying in size from 4 to 10 lbs) is propelled by a two-stage rocket out to around 1000 yards though the most effective range is about 250 yards and is capable of penetrating over 500mm of armor. The museum has an example in the hands of a Warsaw Pact soldier.

Figure 15: An RPG-7 and grenade. The rocket consists of a boost motor to propel the round out of the tube and a sustain motor that ignites about 10m after leaving the tube.

For more accurate delivery of a large HEAT round at long ranges, a slow-moving warhead needs mid-course guidance and modern infantry are typically supplied with guided weapons. The museum's ENTAC (Engine Télèguidé Anti-Char) is an early example of a manually guided command-to-line-of-sight (MCLOS) missile. In this instance the weapon is guided through fine trailing copper wires from the launch post by an operator with a joystick. Used briefly by Canada in the early 1960's, the missile delivered a 4-kg shaped charge warhead capable of penetrating 650mm of armour at ranges from 400 to 2000m. Its guidance system demanded a steady hand as the operator had to manually keep the missile heading towards its target during its relatively slow flight. The flash of the initial launch would attract the attention of an alert target which would respond by firing a barrage of smoke grenades and a burst of machine gun fire down the threat bearing. Nonetheless, the Soviet copy of this weapon, the AT-3 Sagger, proved to be a nasty surprise when used by the Egyptian army against unsupported Israeli armour in the Yom Kippur war.

Figure 16: An early guided AT missile, the French ENTAC. The fine copper guidance wire can be seen emerging from the back of the body. The operator's joystick signals would be implemented in the missile's pitch and yaw signals by the light coloured trim tabs.

High Explosive Squash Head (HESH)

The second significant way of using explosive force against armour is not to penetrate it at all but rather to use it against itself. Developed in the Second World War largely for use in low velocity (recoilless) guns, the high explosive squash head (HESH) consisted of a base-fused thin-walled projectile that smashed its explosive charge against the target armour plate before detonating. The detonation sends a shock wave through the plate and breaks off a fragment or "spall" which then flies around the fighting compartment.

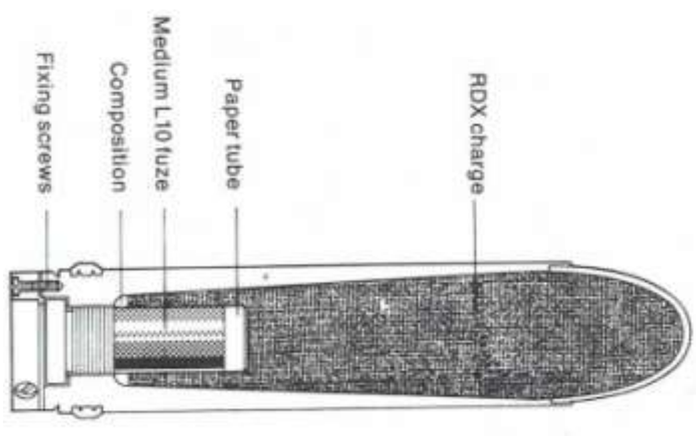

Figure 17: A HESH warhead (Taken from Ref 1)

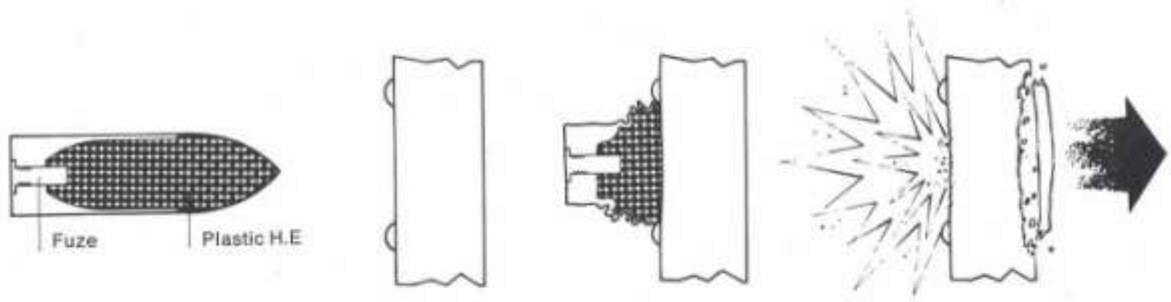

Figure 18: The HESH concept. (taken from Ref 1)

The explosives used in WW2 were only suitable for slow moving artillery rounds but the application of plastic explosive after the war meant that HESH technology could be applied to just about any gun. A HESH type shell as developed for a 105mm tank gun is part of the museum's display.

Figure 19: This is a dummy 105mm round which emulates the basic shape of a HESH round. This type of ammunition is particularly useful against concrete emplacements.

Avoidance

The weight of armour on a typical tank means that it cannot be applied in equal thickness everywhere on the vehicle – it would be too heavy to move. Consequently, the thickest protection has to be applied to the parts of a tank most likely to be hit. A quick look at the museum's cut-away Sherman illustrates very well how it is distributed. Given the weight of steel, it is impossible to provide thick all round protection to a vehicle. Even if the engine and drive train could withstand the strain, the ground, bridges and transporters that it must travel on could not. Consequently, a tank is most thickly armoured in the direction of the enemy (which is expected to be toward the front). The turret front, gun mantle and front glacis plate are thickly armoured and (generally) sloped to provide maximum protection in this direction – as the museum's Chieftain tank well illustrates. Hull and turret sides are provided some protection against flanking attack and the rear even less. However, it is the tops and bottoms of a tank that generally receive the least amount of armour. Consequently, weapons designed to attack the top or bottom of a tank will have the smallest challenge – at least in terms of penetrating the plate – though solving the problem of getting the warhead there in the first place is quite a different issue.

Figure 20: Massive frontal armour - the museum's Chieftain tank. Smoke grenade launchers for defense against missile attack are attached to the turret.

Top Attack

One early technique, born of desperation, was developed by the Germans in WW1: strapping several grenades together and hurling them from ambush onto the top of oncoming tanks. The idea continued in WW2 using specially designed (shaped charge) grenades which were stabilized in flight by canvas wings (in the case of the German *Panzerwerfmine*) or strips of cloth as in the Soviet RPG 40/43 series grenades. The shaped charge warheads of these grenades could penetrate quite a lot of armour but to be effective they had to hit close to 90 degrees to the plate suggesting that a top attack would be most likely to succeed. One German solution to the issue of getting a grenade to stick in the right orientation before detonating was to develop a magnetic hand delivered mine – the *Hafthohlladung*. Fitted with three strong magnets, the weapon had to be hand placed from ambush but its construction meant that its orientation and displacement from the armour was optimum penetrating up to 140 mm of armour. Fearing their own technology it seems, the Germans developed a defence against such a weapon in the anti-magnetic Zimmerit coating they applied to some of their vehicles such as the museum's Panther tank[8].

Another approach to attacking a tank from the top, is to do it using an aircraft. While the German small bore anti-tank guns were quite incapable of confronting a T-34 tank, mounting a similar calibre weapon, like the BK 3.7 (a 37mm autocannon) on an aircraft optimized for dive attack like the JU- 87G ('Stuka') could, in the hands of a skilled pilot, defeat the top armour of the vehicle. The top anti-tank ace of the Luftwaffe, Hans-Ulrich Rudel, destroyed over 100 tanks using cannon and bombs from his aircraft. The Allies were also using aircraft against tanks. The Soviet Il-2 (Sturmovik) ground attack aircraft primarily used its 23mm high velocity cannon and shaped charge bomblets very successfully in the anti-armour role. On the western front, aircraft like the Hawker Typhoon were employed in the ground attack role – most famously equipped with the RP-3 3" rocket. Either armed with a 60-lb high explosive or 25-lb solid shot armour piercing warhead, the weapon was used not only against armour but also against transport, trains and ships. It was quite inaccurate. It's most notable success was at the Battle of the Falaise Gap in which retreating German forces lost most of their vehicles – many to air attack.[9]

Figure 21: The museum's 3" armour piercing rockets. Quite inaccurate, they were more useful against shipping and transports

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[8] A very expensive process. The Allied approach to the problem of magnetic mines was tactics – in close quarters situations where tanks might be ambushed, they went in with close infantry support.

[9] Though only 17 of them were positively identified to have been knocked out by rockets. Most of the lost vehicles were simply abandoned often after minor damage – the impact of the rocket was often severely psychological.

The Underside

Finally, the most vulnerable part of a tank is its underside. This is not only due to the relative lack of armour protection there, but also because some of the tank's most complex parts, the track and suspension system, are almost completely unprotected. The most common method, albeit a passive one, for attacking the underside of a tank is the use of a purpose built anti-tank mine. Improvised mines developed from shells and bombs with an upright fuse were employed by the Germans in WW1 but purpose-built versions were far more common in the next war. Early versions were blast mines set off by the heavy weight of a tank tread but these had a good chance of missing the tank (only 20% of the bottom area is covered by track) and tended only to blow the track off, leaving the gun and crew intact. Later versions used a small stick fuse to set the mine off directly under the hull to produce a more devastating kill. These naturally engendered a more cautious approach by the Allies in deploying tanks in areas likely to be mined and advances had to be supported by mine clearing engineers or "funnies" like the flail and crab tank variants of the Sherman and Churchill tank which used rotating chains or rollers to clear armored advance routes.

Other approaches to attacking the underside of a tank include improvised systems as well. A common one used on the Asian front, initially by the Chinese and later by the Japanese, was the employment of suicide bombers, equipped with explosive vests, either to hide in concealment on a road or to dive under a tank and detonate. Finally, the war in Afghanistan has seen the large-scale employment of explosives under roads and remotely or automatically detonated under a passing vehicle. The museum's RG-31 Nyala mine resistant ambush protected (MRAP) vehicle is one of a family of designs intended to protect its crew from the blast of up to two standard anti-tank mines using its armoured V-shaped underside.

Indirect

The inaccuracy of the fighter-bomber fired rocket against armoured targets was reasonably well known by the Battle of Falaise Gap, but as previously mentioned, its psychological impact was nonetheless significant – German tank crews were well aware that their chances of escaping a vehicle which was successfully hit were very slim. Consequently, in an analysis of a representative number of German armoured vehicles found after the battle by the 21st Army Group's operational research section, over 71% were either destroyed by their own crew or abandoned in a fully operational state. Some were probably abandoned in a panic by their crews under the intense bombing and strafing conducted by the Allied tactical air forces. However most of them were left behind because they could simply no longer move. Some of this resulted from the Allies blocking the narrow lanes of retreat by concentrating on traffic at the head and tail of the retiring German forces. However, most of the combat vehicle losses fell afoul of the immutable laws of logistics. Over 7,000 German vehicles were found abandoned after Falaise Gap – most of them soft skinned platforms like trucks and lightly armoured vehicles which were either abandoned undamaged or shot up by machine gun fire. As Germany increasingly discovered for the remainder of the war, the surest way of knocking out a tank is to cut off its supplies of fuel and ammunition.

Summary

As in any development in military technology, none of the advances in anti-tank weapons went without a response from tank designers. The obvious response was to thicken armour and this is clear in simply viewing the display of tanks in the museum's collection. Almost as obvious is the arrangement of armour – sloping it makes the effective thickness of armour which must be defeated by a flat trajectory, solid-shot round much greater even if the shape of the projectile was designed to avoid ricochet. The Churchill with its vertical frontal armour had thicker plates than even a Tiger I but still had less effective protection than a Panther because of its geometry.

As anti-tank ammunition became more sophisticated, so did armour design and composition. HEAT rounds could be defeated by skirts and grids designed to set them off early, while ceramic layers within armour disperse its flame jet. Explosive reactive armour (ERA) with a thin plate that blows off on initial contact by a projectile not only will disperse a HEAT jet but tends to shear a long rod penetrator while gaps or rubber layers in plate and spall liners will defeat the shock wave induced by a HESH round. Composite armour comprising tiles of layered steel and highly compressed ceramic like the British developed (and still secret) Chobham armour has been combat proven against long rod penetrators and HEAT rounds.

One might argue that this constant one upmanship between defence and offence in armour development is nothing new. In British history at least, the long rod penetrator is an ancient weapon - just a reincarnation of the bodkin point used by English archers at Crecy and Poitiers in the 14th century. The narrow tapered point of the bodkin-tipped clothyard arrow, propelled by a 100+ pound pull longbow was probably quite capable of penetrating mail armour and possibly early plate though the wounds it inflicted were less devastating than the standard broadhead point. Whether the bodkin was made of tempered, hardened steel is not clear but by the end of the 14th century better made, pigeon breasted (sloped?) body armour was largely impenetrable. Until the invention of firearms. Is there nothing new under the sun?

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