Evolution of Guided Torpedoes

Dr Carlo Kopp

Torpedoes are a mature weapons technology with well over a century of operational use, both successful and unsuccessful. What is less often appreciated is the enormous diversity in torpedo design, be it propulsion or guidance and fusing, and as a result, the genuine challenges faced in defeating these weapons.

Drop of a Mk-46 lightweight ASW torpedo from a Seahawk ASW helicopter.

Since the 1940s Torpedoes have been delivered by a diverse range of systems, including surface combatants, fast surface boats, submarines, fixed harbour defences, as well as a wide range of aircraft, including maritime patrol aircraft, helicopters, and specialised high performance torpedo bombers. The size and weight of torpedo designs more than often reflects the capabilities of the delivery platform.

Torpedoes have also been equipped with guidance and sophisticated fusing, with guidance systems ranging across gyroscopic autopilots, remote control steering via cables, terminal homing using a range of techniques, and pre-programmed blind pattern searches.

Torpedo propulsion has also been and remains diverse, with designs using screws or water jet propulsors, driven by chemical batteries, single and multiple component propellants, or compressed gasses, with some torpedoes past and current propelled by rocket engines.

The size of a torpedo and its intended target often results in large designs with large warheads, but importantly, the volume permits often very sophisticated guidance and control systems to be fitted, for period basic technology. An air launched guided missile or bomb has much less volume for guidance hardware compared to its contemporary torpedo designs.

Torpedo Propulsion

As with most military technologies, torpedo propulsion system evolution reflects mostly the state of the art in available basic technology at that time. Imperatives for designers were initially range, then speed, and more recently noise has become a key consideration, to avoid exposing the launch platform or warning the target.

The earliest torpedoes of the modern era used simple three or four bladed screws. These had the disadvantage of imparting a torque reaction into the body of the torpedo, which had to be compensated for by its control system or fin design. By the 1940s, state of the art torpedo designs used counter-rotating screw designs which balanced the torque reaction, but were also often more efficient at converting shaft torque into propulsive force. Counter-rotating designs remain in use today.

The favoured technology in many contemporary designs is the pump-jet, which is usually constructed as a shrouded propeller. The pump-jet produces much less noise in the forward hemisphere of the torpedo, and if well designed, less cavitation noise compared to an unshrouded conventional screw design.

Powerplant designs employed to drive the screws or pump-jet vary widely, both in contemporary and historical torpedo designs.

The earliest viable torpedo designs used stored compressed air at hundreds of pounds per square inch (PSI) to drive a propeller using a reciprocating piston engine arrangement. This simple strategy evolved over time to encompass a wide range

The Mk-48 ADVCAP is a heavyweight torpedo powered by an Otto fuel gas generator driving a shrouded propulsor. A cable tether is used to transmit midcourse guidance commands.

The Alliant-Techsystems Mk.50 Barracuda or Advanced Lightweight Torpedo torpedo uses an unusual propulsion scheme, where steam is generated using a chemical heat source, to drive a pump-jet.

The Marconi (BAe) Spearfish uses Otto fuel to power a gas turbine, which drives the pumpjet.

of gas generating power sources, and in later designs, much more efficient turbine designs to convert the gas pressure into torque to drive the screws or later the pump-jet.

The favoured approach until the 1940s was the use of compressed air and a combustible fuel such as kerosene, initially in an uncooled and later cooled combustion chamber. The exhaust gas generated by the combustion system was employed to drive the propellers, later augmented by steam produced in cooling the combustor.

The Japanese extended this scheme during the 1930s by replacing compressed air with compressed oxygen in the (in)famous Type 93 heavyweight 610 mm torpedo, almost tripling its range in comparison with US equivalents at that time. Japanese warships carrying the Type 93 were often disabled by damage to stored torpedoes, as the oxygen supply would accelerate combustion during onboard fires.

Many alternatives to conventional fuels and compressed oxygen or air have been employed since.

Concentrated hydrogen peroxide has been employed in a number of designs, usually as an oxidiser and steam source, augmented by combustion of a fuel, often hypergolic. The high pressure gas flow would be typically used to drive a turbine. Hydrogen peroxide torpedoes were deployed by Germany, the US, Britain and the Soviets, but later abandoned following accidents. The explosion which sank the Oscar class boat Kursk in 2000 is officially blamed on the malfunction of a hydrogen peroxide powered 65-76 heavyweight anti-ship torpedo, an event not unlike that which sank the Royal Navy's S-class HMS Sidon in 1955, when a Mk.12 torpedo failed.

Other propellant types have been used for torpedo powerplant gas generators. A very popular propellant is "Otto fuel", or stabilised Propylene Diglycol Nitrate, which is much less volatile than peroxide oxidiser, but also highly toxic. Otto fuel is ignited to generate gas to drive a turbine. The widely used contemporary US Mk.48 series uses an Otto fuel gas generator to drive a swashplate engine, which powers a propulsor, whereas the British Marconi Spearfish uses an Otto fuel gas generator to drive a gas turbine, which powers a pumpjet.

An interesting variation on the gas generator theme is the Stored Chemical Energy Propulsion System used in the US Alliant-Techsystems Mk.50 Barracuda or Advanced Lightweight Torpedo torpedo. This design uses steam to drive a pump-jet, with heat for steam generation supplied by the reaction of sulphur hexafluoride gas with lithium metal.

One drawback of all gas generator designs is that they typically produce a visible bubble wake as the expended gas is vented from the powerplant.

Electrical batteries driving electrical motors were introduced as an alternative to gas generator powerplants, in part to produce a 'wakeless' torpedo. During the Second World War, the Kriegsmarine deployed the battery powered G7e/T2/T3/T4 and T5 series torpedoes, the US Navy the battery powered Mk.18 and Mk.27, and air dropped Mk.24, and the Royal Navy the battery powered Mk.XI. More recent battery powered designs include the Royal Navy Marconi Mk.24 Tigerfish and Stingray series, the Bundesmarine Atlas DM2A4 Seehecht and Eurotorp MU90, and a number of Russian designs.

Battery types have varied widely since the 1930s, reflecting advances in battery technology. With the current commercial imperative for battery powered automobiles, it is reasonable to expect ongoing growth in battery technology for torpedoes.

Conventional torpedo propulsion schemes with screws or pump-jets typically achieve speeds of 40 to 80 knots. The alternative propulsion technology to provide higher speeds has been the use of rocket engines, to directly generate thrust.

Early experimentation by British engineers, and the Soviets, aimed to exploit solid rocket powerplants to produce low cost yet fast torpedo designs. This effort resulted in numerous spectacular failures, including torpedoes leaving the water on airborne ballistic trajectories.

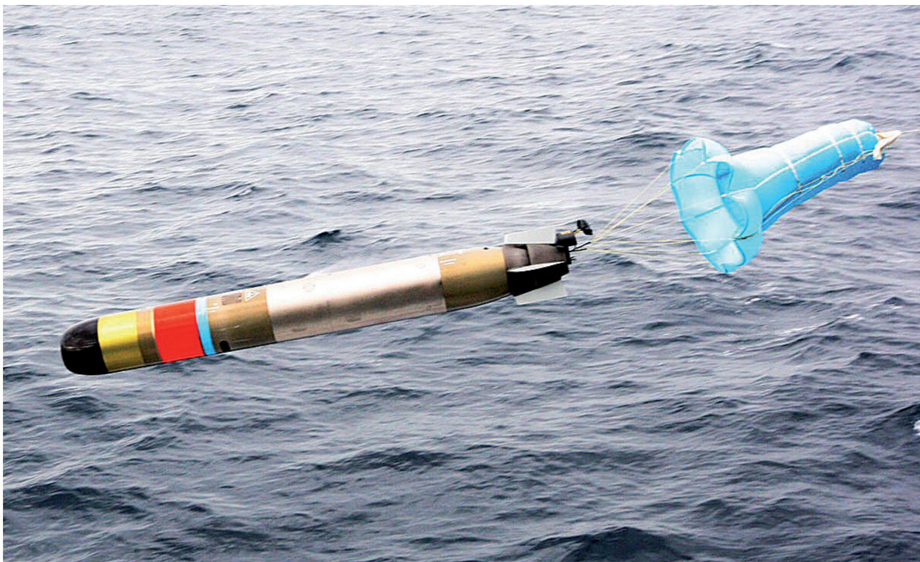
The only known rocket propelled torpedo in current production is the Russian GNPP APR-2/2E/3/3E series, a largely conventional lightweight airdropped design, using a solid rocket motor powerplant. The APR-3 is incorporated as the torpedo payload in the 91RE1 Beryoza rocket boosted ASW weapon, a Russian equivalent to the US RUR-5 ASROC system.

Much more interesting variations on the theme of rocket propulsion are supercavitating torpedoes, such as the Russian liquid rocket propelled GNPP VA-111 Shkval series, or the German Diehl-BGT Barracuda.

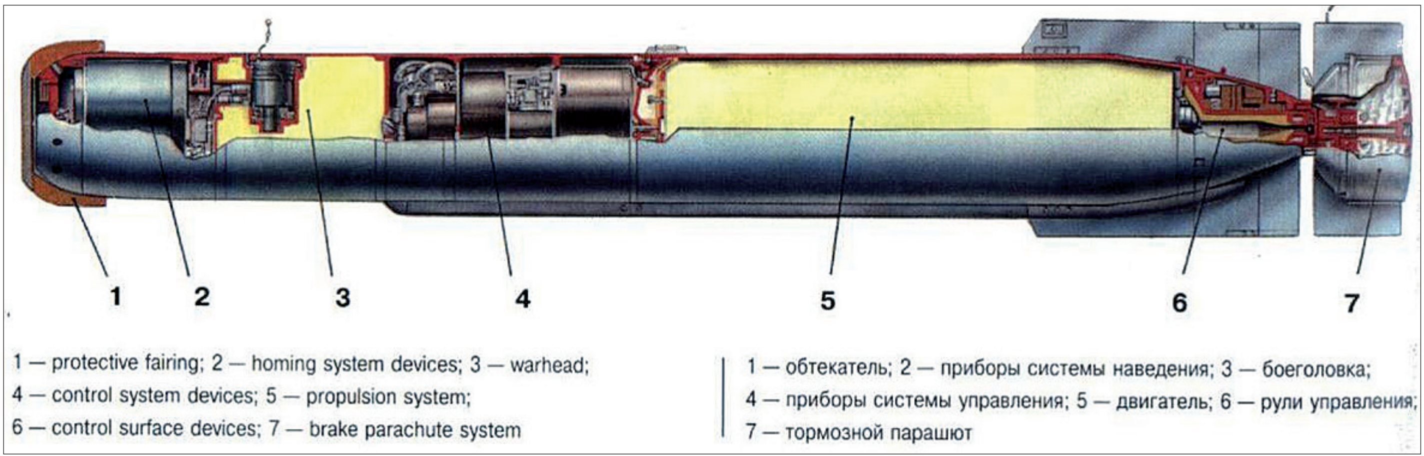
Supercavitating torpedoes employ an internal gas generator with exhaust ports in the nose of the torpedo. The hull of the torpedo is thus travelling in a bubble of high pressure gas, which keeps the hull from contact with the surrounding mass of water. As a result of the supercavitation bubble, drag is dramatically reduced, and speeds are cited at 200 knots, or higher if some sources can be believed.

The high speed of supercavitating torpedos makes them nearly impossible to evade by manoeuvre or high speed dash, the latter tactic often feasible for nuclear powered subs under attack by slower torpedoes. The weakness of supercavitating torpedoes is that they are much noisier than conventional designs and will betray the position of the launch platform.

In conclusion, torpedo propulsion techniques are diverse and are likely to further diversify over time, as different capability niches are occupied.



The MU90 is an electrically powered lightweight torpedo.



The GNPP APR-2E is a rocket propelled lightweight ASW torpedo.

Torpedo Guidance and Control

The diversity observed in torpedo propulsion schemes used over more than a century is paralleled by no less diversity observed in guidance and control schemes. Guided torpedoes appeared as operational weapons during the Second World War and have wholly displaced unguided weapons since then.

The earliest guidance and control systems fitted to torpedoes were simple gyroscopic designs intended to maintain the torpedo's heading, and later its depth. Torpedoes drifting off course or passing under targets without making contact to set off the impact fuse were frequent and unwanted occurrences before the advent of proper guidance systems.

By the early 1940s most newer torpedo designs have reasonably good gyroscopic autopilots, which permitted the torpedo to be launched from a tube not pointing at the intended target, the torpedo taking up its prelaunch heading and running depth once clear of the tube.

The choice of heading to effect an intercept was initially computed on a slide rule, and later by electromechanical analogue fire control computers. If the target did not change speed or heading, and there were no cross currents strong enough to impair accuracy, a hit could often be achieved from many miles away. In practice, multiple torpedoes were often salvoed on slightly divergent headings to improve the probability of a kill.

A simple improvement introduced by the Kriegsmarine to attack convoys were pattern-running guidance systems, which would steer the torpedo through a 180 degree turn after a programmed distance. This meandering pattern would be repeated until propellant was expended, or a target was hit. In a closely spaced convoy such a weapon could be devastating. The FAT and LUT equipments were fitted to G7a and G7e torpedoes carried by U-boats.

The first acoustic homing seekers used in combat were by the Kriegsmarine. These were fitted to the G7e T4 Falke and T5 Zaunköning or GNAT torpedoes in 1943. These were passive acoustic homing seekers that used gyroscopic midcourse guidance, and once their hydrophones activated, homed in on the screw and hull noise signature of a target. Despite a 400 metre safety timer, there are reports of several U-boats which fell victim to their own torpedoes.

Shortly after the G7e T4 deployed, the US deployed its Mk.24 FIDO air dropped acoustic homing torpedo, which claimed 37 submarines by the end of the war. The Mk.24 employed four hydrophones evenly spaced around the body of the torpedo. The system activated once a 24 kiloHertz signal of sufficient strength was detected, upon which the vacuum tube electronic guidance system used a proportional navigation control law to effect terminal homing. The seeker design was later migrated into the Mk.27 for submarine tube launch.

In the post-war period and subsequent Cold War rapid advances in guidance technology resulted in a number of commonly used schemes.

Passive acoustic homing guidance tracks the target's noise signature, and has the advantage of not providing early warning to the target. Modern designs, unlike their predecessors will use sophisticated signal processing to reject noise generating decoys.

Active acoustic homing guidance uses a high frequency sonar system in the nose of the torpedo to produce range, angle and velocity measurements of the target. The characteristic acoustic signature will alert the target to the approaching torpedo.

A scheme described in some publications is semi-active acoustic homing, where the launch platform 'paints' the target with a sonar signal, which the torpedo seeker homes in on to impact.

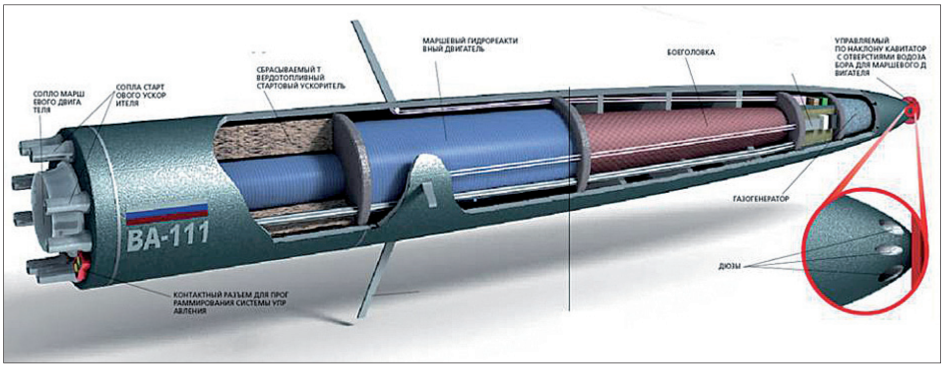
All these schemes can be combined in a modern guidance package design, as the volume of the guidance package is large enough to provide significant internal computing capacity.

Most modern submarine launched torpedos are 'wire guided', in the sense that the torpedo after launch is tethered to the launch platform by a cable which is used to transmit steering commands to the outbound torpedo. At some point the torpedo is commanded to switch over to its internal seeker, and the cable is cut. This approach permits the torpedo to be guided over a long distance using steering commands generated from a passive sonar in the launch platform. The "wire" may be a metal cable or in some designs, an optical fibre, the latter providing enormous bandwidth compared to metal cables.

An alternative to conventional homing guidance is that of wake homing guidance, employed especially in Soviet Type 53 series heavyweight torpedoes, intended for attacking capital ships and large transports. A wake-homing guidance system looks for the wake of its target, and when it crosses the wake, it will turn back toward the wake. Repeated zig-zag turns will eventually converge with the direction of the wake, and drive the torpedo into the stern of its target. Wake homing is considered to be especially difficult to defeat, since there are no easy ways of producing decoy wakes of comparable size to that produced by a large ship.

The long term outlook for torpedo guidance evolution is increasing sophistication and countermeasures resistance, as volume and power supply are not significant constraints for contemporary signal and data processing hardware, and the basic computing technologies involved follow exponential growth laws.

More interesting will be developments in propulsion technologies, especially battery driven systems, as that area of technology will see significant growth in coming years. Supercavitating torpedoes may also see significant growth, as China and Iran both appear to have gained access to Russian technology.



The supercavitating GNPP Shkval is the fastest torpedo in operational use at this time, capable of exceeding 200 knots. The gas generator in the nose produces a supercavitation bubble using the nose mounted exhaust port. The booster solid rocket exhausts through a circular array of nozzles, the sustainer solid rocket exhausts through the central nozzle. The technology has been acquired by China and Iran.