THE DEVELOPMENT OF ROCKET-PROPELLED TORPEDOES

Geoff Kirby

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ABSTRACT

The torpedo is the essential weapon of underwater warfare. Many attempts have been made at using rocket propulsion to provide high speed and so catch the intended victim unprepared. The author describes the history of rocket-propelled torpedoes from early designs in the nineteenth century to the present day, where a single example is known to be being marketed. Rocket propulsion is necessarily violent and noisy; it provides little finesse and short ranges; the stealth and endurance of other propulsion systems in common use cannot be matched. But the evidence from the many developments that have been carried out, some almost to the point of providing in-service weapons such as those shortly after World War II in the UK, points to the advantages of cheapness, and minimal preparation and maintenance. Long range may not be an issue if weapons are launched close to their targets.

1 INTRODUCTION

Underwater warfare has long depended heavily on the torpedo for delivering the destructive charge. But a successful attack from the air, a ship or submarine, is not achieved easily. A modern torpedo couples a modest speed with stealth and a homing capability to provide a reliable method of attack. However, for much of its long history, the torpedo has been unguided and intended to be straight-running. To limit the time and scope for evasion, there has thus been a premium on speed. Many methods of propulsion have been investigated; the purpose of this paper is to review rocket propulsion in the context of torpedo evolution.

The automobile torpedo was invented by Robert Whitehead, who tested his first crude prototype, powered by compressed air, in 1866 [1, 2]. This weapon, with a top speed of six knots and range of two hundred metres, was the ancestor of the torpedoes in world-wide service a century later.

Figure 1. A very early Whitehead compressed-air torpedo

Increasing the pressure at which air was stored in the weapons resulted by 1906 in a torpedo capable of travelling at 35 knots to a range of 1,000 metres. However, as it expanded, the compressed air froze the engine, so paraffin was sprayed into the pressure vessel and ignited immediately before launch. Not only did this solve the problem of frozen engines but the energy released by the burning fuel doubled the running range - apparently to the surprise of the engineers involved.

A further development involved partially burning the fuel in compressed air and then feeding the hot, fuel-rich gas into a reciprocating engine, where combustion was completed. This was refined into the propulsion system of the British Mk 8 weapons (Mk 8 torpedoes were used to sink the General Belgrano on 2nd May 1982).

A disadvantage of using compressed air as oxidant is that the nitrogen is an unwanted passenger. This leaves a visible wake, which not only allows ships to take evasive action on the approach of a torpedo but also gives away the position of the attacking submarine. Solutions to this limitation were the use of oxygen-enriched air, hydrogen peroxide or pure high-pressure oxygen. Enriched-air weapons were developed and issued to the Royal Navy in 1924 but few were produced. However, two of these weapons were fired at the Bismarck. The Japanese developed the use of oxygen, resulting in the incredible Long Lance torpedoes used very effectively in World War 2. These travelled at 48 knots for 44 kilometres and left no wake. Hydrogen peroxide has become an oxidant for a wide range of modern Swedish and Russian torpedoes, although the British abandoned this approach soon after the explosion of an experimental hydrogen peroxide weapon in the submarine HMS Sidon in Portland harbour in 1955 with the loss of thirteen lives.

Many alternatives to the hot gas propulsion system have been developed. Some have been successful, such as those driven by electric batteries (e.g., TIGERFISH, STING RAY), OTTO fuel monopropellant (e.g., SPEARFISH, US Mk 48), flywheels (US Howell torpedo), and a lithium/sulphur hexafluoride closed-cycle system (Japanese GRX-4 and US Mk 50).

This article will concentrate on the somewhat sporadic development of rocket propulsion for torpedoes. First tried in about 1873, interest had lapsed by the end of the nineteenth century but was revived in the UK during World War 2 and abandoned in 1955. Later developments in the Soviet Union during the cold war resulted in the air-dropped APR-2E rocket-propelled homing torpedo, which is now a widely available weapon for the Russian armed forces.

2 NINETEENTH CENTURY DEVELOPMENTS

Many attempts were made to develop a rocket propelled torpedo between the 1870s and the end of the nineteenth century. These were inspired by the US Navy's reluctance to buy from Robert Whitehead - entrepreneurs were actively encouraged to invent weapons that circumvented Whitehead's patents for the compressed-air propulsion system.

In the early 1880s, the prolific inventor John Ericson invited the US Navy Torpedo Station (NTS) at Rhode Island to try his rocket torpedo. It ran at about 60 knots but suffered from a short range - scarcely 100 metres - and an unpredictable trajectory owing to its dynamic instability. Indeed, the NTS reported that Ericson's weapon was more of a liability to the launching ship than a threat to the target!

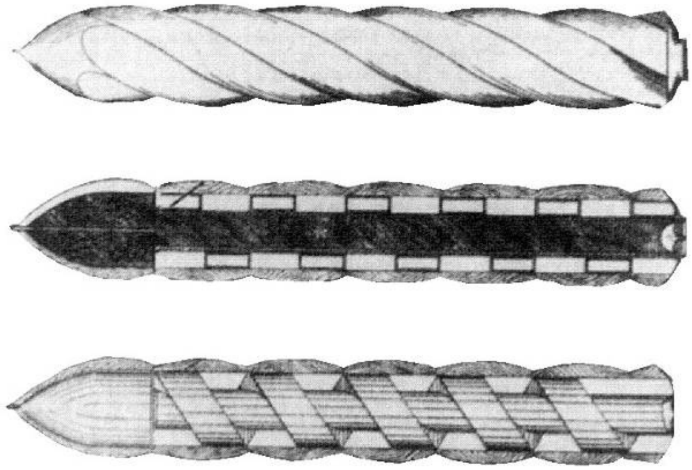

Figure 2. Lt Barber's rocket torpedo.

Lt F M Barber was a US Navy officer who spend much of his time inventing novel weapons of war. His rocket torpedo, illustrated in three cutaway views in figure 2, was demonstrated in 1873. This carried an explosive charge of 26 kg inside an iron tube wrapped in asbestos and lined externally in oak [3]. It was intended to be fired from an underwater tube but its performance, like that of the Ericson rocket torpedo, was very poor and unreliable.

The Berdan weapon floated with its deck awash to reduce visibility. It had a sighting mast that allowed a shore-based operator to steer it to a moored ship target by means of two ropes attached to the tiller.

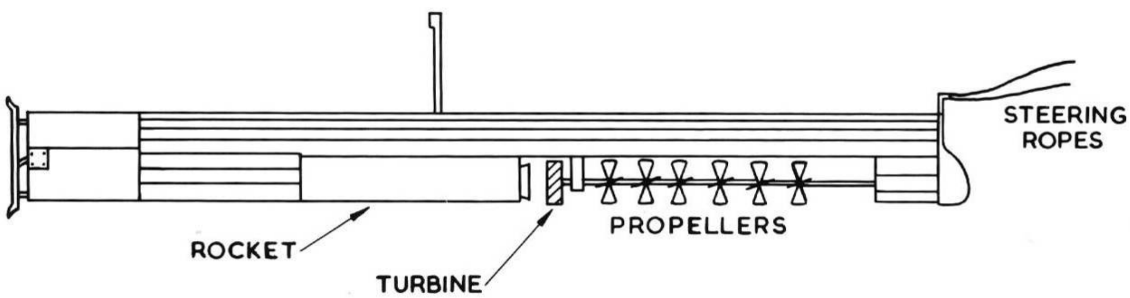

Figure 3. The Berdan Rocket Torpedo, c1885

The efflux from an underwater rocket drove a turbine, which then drove a set of propellers. This imaginative but hopelessly inefficient propulsion system failed to drive the weapon forward because the drag of the steering ropes exceeded the forward thrust of the weapon.

Another unsuccessful rocket torpedo inventor was Patrick Cunningham, an Irish immigrant who earned his living as a shoe maker and repairer in New Bedford, Massachusetts.

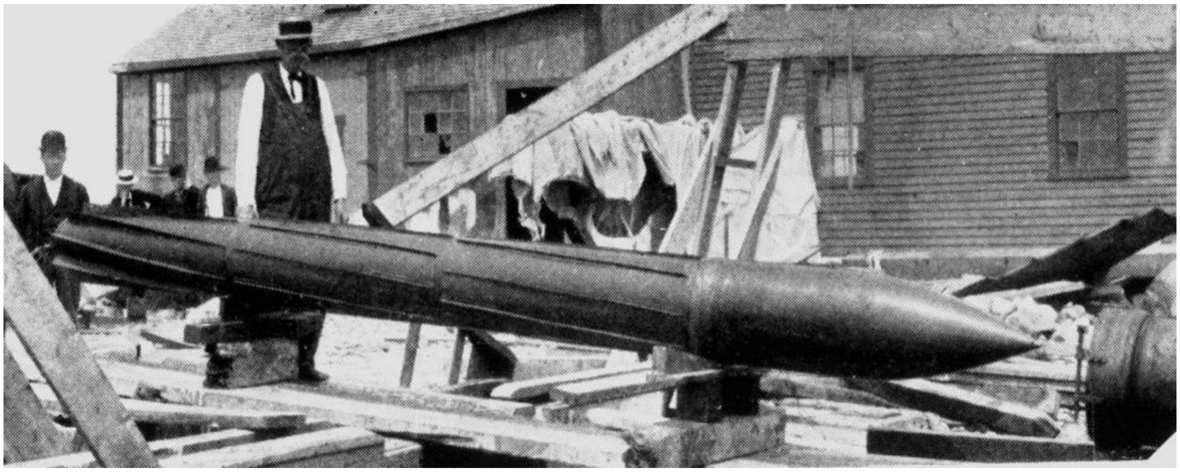

Figure 4 Cunningham with his rocket torpedo

Samples were tested for several years at NTS but the short range and wholly unpredictable trajectory destined this weapon for the scrap heap. However, in one last fling of exuberance, Cunningham fired his torpedo down the main street of his home town; it roared along at very high speed before coming to rest in the butcher's shop where it burned down the ice room. [1, 4]

3 UK INVESTIGATIONS IN WORLD WAR II

A problem with pre-World War 2 torpedo development that had plagued the UK, Germany and United States alike was the high cost and complexity of torpedoes. Between the world wars, weapons had been manufactured slowly and in small numbers using expensive materials. This was wholly inappropriate for wartime requirements and torpedoes were in short supply soon after World War II started. All the warring nations looked urgently for ways to speed up production, simplify construction so that relatively unskilled workers could be employed, reduce costs, reduce demands for metals in short supply, increase reliability and reduce preparation time before launch. Table 1 shows the achievements of the German Navy in some of these requirements.

	1939	**1943**
Weight of copper (kg)	370	169
Weight of tin (kg)	61	22
Weight of nickel (kg)	46	2
Man-hours per weapon	3,730	1,707
Cost (Reichmark)	24,000	13,500

Table 1. Simplification of the German G7A Torpedo

It was with the same aims that the Torpedo Experimental Establishment in Greenock experimented with a jet propelled torpedo between 1938 and 1942 [5]. The plan was to use a standard compressed air/paraffin burner weapon with the reciprocating engine removed and the number of burners increased from one to four; the hot air, steam and combustion products would be released through a convergent/divergent nozzle where the propellers would have been. It was estimated that this weapon would be very much cheaper and simpler to manufacturer and be more reliable. The disadvantage would have been the inefficient propulsion performance, which, in certain circumstances, could have been acceptable in view of the potential logistic gains. Tests were carried out in Scotland in 1942 and a weapon travelled for 800 yards at 23 knots.

Although the weapon was not suitable for in-service use, it was estimated that using high pressure oxygen in place of compressed air would have led to a useful speed and range. However, the project was cancelled.

4 CAMROSE AND BOOTLEG

CAMROSE was conceived soon after World War II as a rocket-propelled torpedo to be fired from the decks of anti-submarine frigates and merchant ships to attack oncoming torpedoes. It was to be a simple device, requiring no maintenance or preparation, which could be fired with the minimum of delay when a torpedo had been detected heading for a ship. There were to be two types: a 50 knot weapon for use from frigates and a 35 knot weapon for use from merchant ships. Studies subsequently showed that severe space limitations on frigates meant that only a 35 knot version having a running range of 1,200 yards could be fitted. Although this lower speed could easily have been achieved with conventional torpedo propulsion systems at that time, rocket propulsion was chosen for simplicity, lack of maintenance and reliability.

Oncoming torpedoes would have been detected by a modified Type 176 sonar, and a salvo of CAMROSE weapons would then have been fired at the oncoming torpedo once the range was indicated to be 1,200 yards or less. CAMROSE would have been fitted with an acoustic influence fuse that would have detonated its warhead when within 45 feet of an enemy torpedo either to destroy it or disable it to the extent that it would no longer be a threat to the ship.

Research started on the project in July 1951 when a study was published suggesting that anti-torpedo torpedoes could be a feasible method of protecting ships. On 21st November 1951, a working party was set up to co-ordinate research activities between the six research establishments involved, these being:

Underwater Countermeasures and Weapons Establishment (UCWE), Havant;
Underwater Detection Establishment (UDE), HM Naval Base, Portland, Dorset;
Underwater Launching Establishment (ULE), Bournemouth, Dorset;
Admiralty Gunnery Establishment (AGE), Southwell, Portland, Dorset;
Admiralty Research Laboratories (ARL), Teddington, Middlesex;
Torpedo Experimental Establishment (TEE), Greenock, Scotland.

(All these establishments were merged as the Admiralty Underwater Research Establishment on Portland, Dorset in the early 1960s.)

Concept development

Concepts were developed for the production weapons, which would be of three types:

CAMROSE M — A 16 inch diameter weapon weighing 750 lb and having a speed of 30 knots;

CAMROSE W — Also a 16 inch diameter weapons but weighing 850 lb and having a speed of 50 knots;

CAMROSE 15 A 15 inch diameter weapon weighing 725 lb and capable of running for 1,200 yards at 35 knots.

Because of the difficulty of fitting the larger diameter weapons into anti-submarine frigates, it was decided to proceed with the development of the CAMROSE 15 weapon.

Influence fuse development

The greatest risk to successful development was assessed to be the acoustic proximity fuse, and practical work to prove its feasibility was immediately started. Measurements of the noise of running torpedoes were made on the Arrochar range using Mk 8, Mk 9, Mk 11 and DEALER weapons together with some Soviet weapons that had fallen into British hands during World War II. As a result of these measurements and preliminary development work on high-frequency acoustic fusing, it was demonstrated that development of a successful fuse would be possible. In July 1954, a report was presented to the programme manager showing that the fusing problems had been essentially solved.

Dynamic test vehicle trials

A decision had been taken at a CAMROSE Working Party meeting on 5th February 1952 to proceed with the conversion of existing Mk 15 (18 inch diameter) torpedoes to rocket power. These would be used for testing rocket propulsion in torpedoes - a new concept for the British. These conversions were expected to take about a year. However, in March 1952 the priority for the CAMROSE programme was downgraded to Class 3 and this was a severe blow to the project. In effect, no additional staff could be allocated so that much of the subsequent research and development was carried out on a part-time basis. It meant that no resources were available to modify the Mk 15 torpedoes.

In parallel, the BOOTLEG programme had been under way at the Vickers Armstrong factory in Weymouth to develop a rocket-propelled, air-dropped, anti-ship torpedo of 18 inches diameter. Trials in Weymouth Bay of a torpedo that was expected to run at 65 knots were imminent. However, the programme was not expected to survive after these trials. The CAMROSE Steering Group decided that the optimum way forward was to take over the BOOTLEG programme and acquire the BOOTLEG test vehicles from Vickers Armstrong.

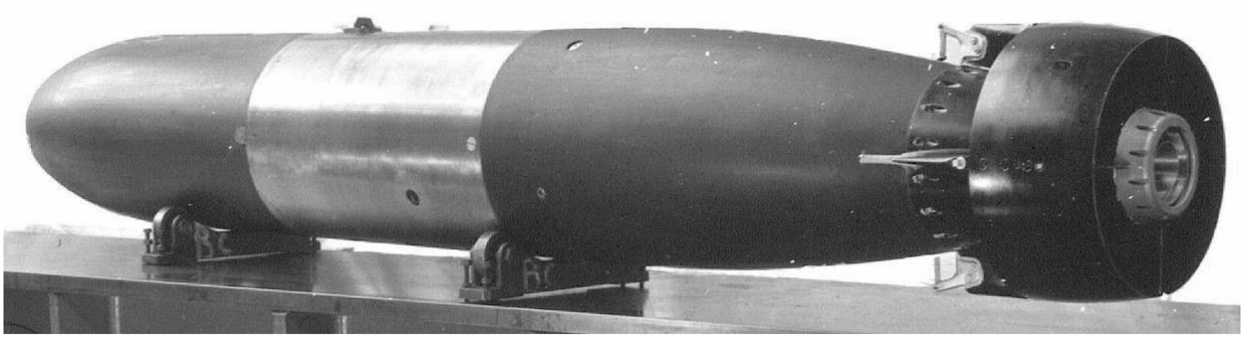

Figure 5. BOOTLEG at Vickers Armstrong c1952

BOOTLEG was a single-shot weapon. The rocket propellant was pressed into the hull and a central exhaust core was then machined out. Vickers set about modifying the three BOOTLEG vehicles to take replaceable rocket charges so that each test torpedo could be run many times.

A contract was placed with Imperial Chemical Industries at Ardeer for the manufacture of solid rocket charges. These modified BOOTLEGs were named Dynamic Test Vehicles (DTVs) and were to be used to test the speed, range and control of rocket-propelled weapons.

The first DTV produced from a modified BOOTLEG vehicle was obtained from Vickers on 21st September 1953 and was delivered to the torpedo testing range at Arrochar, where the first firings were made on 5th November 1953.

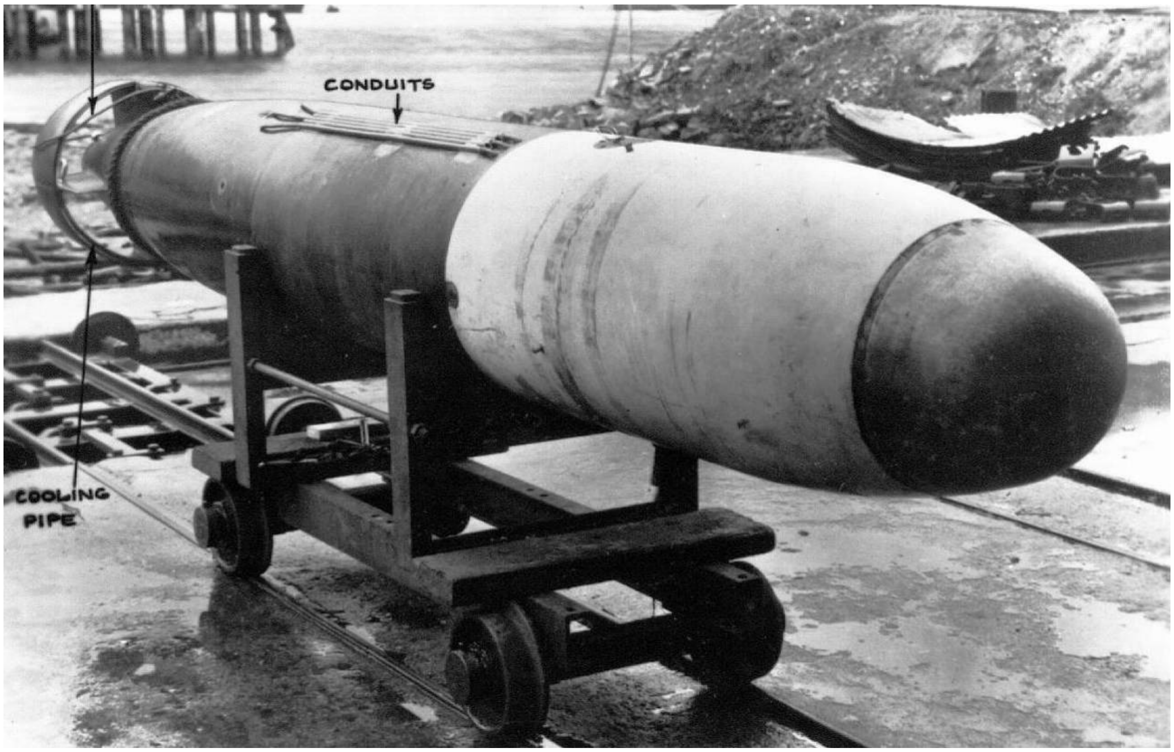

Figure 6. CAMROSE DTV c1954

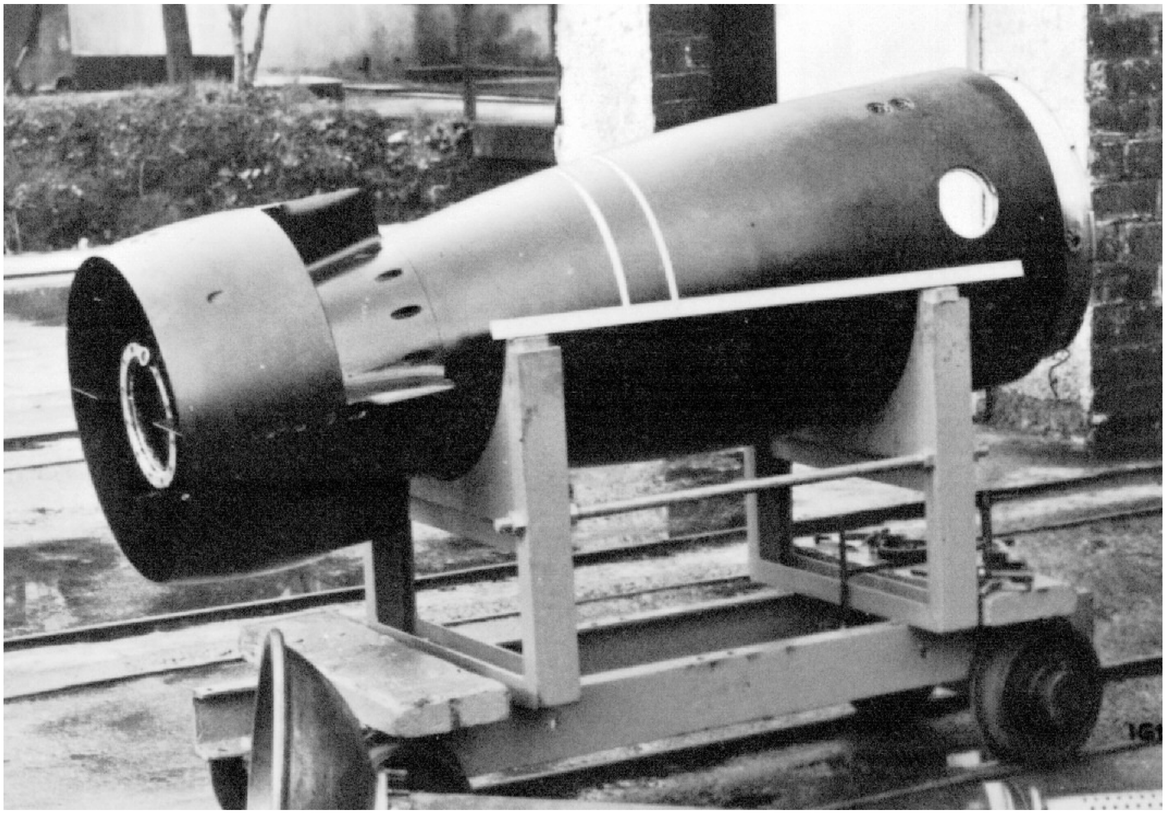

Figure 7. CAMROSE DTV c1954

The first results were somewhat disappointing, the speed achieved being significantly less than predicted. The table shows the speeds expected and what was achieved.

Planned speed (kts)	Measured speed (kts)
20	13.2
30	21.9
40	30.1
50	38.8

Table 2. Shortfall in DTV's speed

By the summer of 1954, more than 80 runs had been carried out in Scotland and in Portland Harbour. It was found that speeds were higher in Weymouth; this was attributed to the higher water temperature, which reduced the heat loss from the rocket hull, and to the shallower running depths and consequent lower back pressures on the rocket exhaust.

Some static runs were made with the DTVs harnessed on a platform in air. These were performed to investigate a problem with noise 'spikes' in the acoustic influence fuse system. It was thought that these transients might have been caused by the rocket charge 'spitting'. Another possibility was noise from the control system, which was powered by high pressure gas bled from the main rocket charge. However, these land-based trials, which must have been spectacular to watch, were inconclusive.

System development trials

The general success of the acoustic fusing and DTV running trials resulted in a new phase of the programme being approved late in 1954. The three DTVs were heavily modified and called Experimental Rocket Vehicles (ERVs). These vehicles were prototypes for a future anti-torpedo torpedo but without the warhead and acoustic proximity fuse.

Although the ERVs were used mainly for development of components for the final CAMROSE weapon, one special run has become famous in the archives of British torpedo development. An ERV was fitted with a special rocket charge designed to give a thrust of 2,600 lb, which was expected to provide 60 knots underwater. This ERV was fired at a depth of 15 feet at the Arrochar Torpedo Range.

The torpedo was successfully launched and accelerated to 60 knots within two seconds. It dived to 50 feet but then shot to the surface, where it emerged 150 yards from the firing point after six seconds. It then climbed to an altitude of 150 feet and flew steadily at an angle of 30 degrees to the vertical. As the rocket charge was burnt away, the torpedo rose to about 200 feet and headed off down Loch Long towards a local hotel. After 14 seconds in the air, the charge burnt out and the weapon fell nose-first into the water some 900 yards from the point at which it had broken surface. It plunged to the bed of the loch, where it was found almost totally submerged in mud. This flight was recorded on film but this was destroyed in the mid-1970s during a purge of archival material held at AUWE Southwell. Only the three still shots shown below survive.

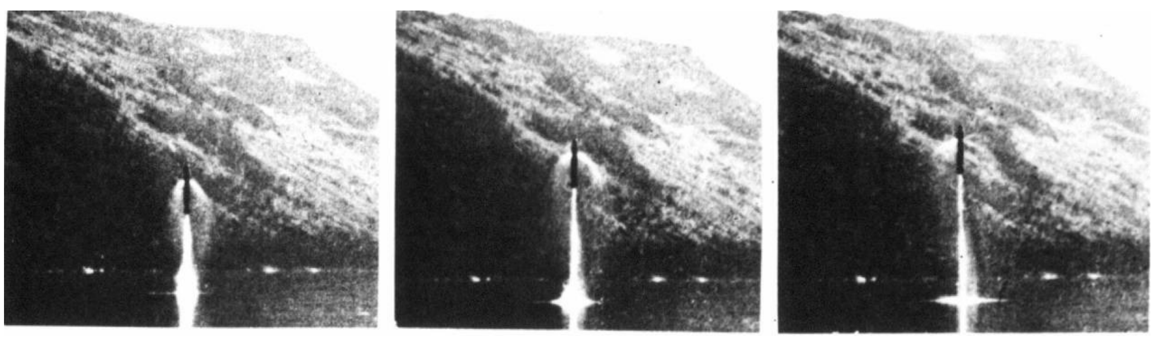

Figure 8 Sequence of still shots showing torpedo breaking surface

The cause of the mis-fire was found to be a small hysteresis in the floor depth switch, which resulted in the control surfaces not bringing the weapon under adequate control until it had left the water.

CAMROSE system design

By end of the test programme, 83 DTV and 18 ERV runs had been carried out. As a result of the experience gained, a design for the in-service CAMROSE weapon was finalised. The weapon was to be 120 inches long by 15 inches diameter, with a total weight of 725 lb. A speed of 35 knots would be achieved to a range of 1,150 yards and the weapon would run at 50 feet depth. An acoustic proximity fuse would be used to explode a warhead close to an enemy weapon and disable it.

One concern was the visibility of the rocket flame as CAMROSE left a ship's deck torpedo tube – the event was easily visible to the eye, and petrol soaked rags were ignited three feet from the launch tube mouth by the heat of the rocket flame. Thus, it was decided that CAMROSE would not be ignited until it was underwater.

The rocket propellant would be ammonium nitrate-guanidine nitrate RC pressed charge. Two charges would be used, with a combined weight of 435 lb. The burning time would be 60 seconds.

Utility torpedoes

In parallel with the design study for CAMROSE, a study was made for a 'Utility' torpedo. This would be used against small, low-value targets that did not justify the use of a large and a very expensive homing torpedo. Such targets had been dispatched by gunfire in World War II but post-war submarines were no longer to carry guns. Such low-value targets could be trawlers, Chinese junks, etc. One argument used in favour of this cheap, reliable and small weapon was that it would not be necessary to fire and compromise intelligence on the existence of sophisticated weapons in minor third-world skirmishes.

The utility weapon would be half the length of a normal weapon so that two could be stored in each torpedo rack on a ship or submarine. Consideration was also given to a weapon only 87 inches long, allowing three to stored in the space of a single Mk 8 torpedo. However, the range of such a weapon was considered to be inadequate and this version was not pursued.

These utility weapons would be rocket propelled using CAMROSE expertise. They would thus be fast (60 knots), reliable, cheap, quick-reaction and would require no maintenance.

The end of CAMROSE

On 25th September 1955, the requirement for CAMROSE was cancelled and all work immediately stopped. Operational studies had indicated that frigates would not be able to carry sufficient CAMROSE weapons to protect themselves throughout a protracted mission in enemy waters.

A CAMROSE/BOOTLEG test vehicle has survived and was discovered by the writer at Priddy's Hard Museum, Gosport during a visit in September 1999.

5 HEYDAY

HEYDAY was designed and tested by Dr Barnes Wallis for Vickers Armstrong, Weybridge, who were funded by the government. The aim was to produce a laminar-flow body that would have a very low hydrodynamic drag coefficient.

The reasons for the building of HEYDAY are disputed. Its development appears to have been to meet the requirements for a super-fast torpedo. However, Norman Boorer and Ted Way, who were development engineers working for Barnes Wallis, have told the writer that Wallis built HEYDAY to test theories for the aerodynamic design of laminar-flow aircraft fuselages and wings. He had no interest in torpedo development but he found it easier to get funding from the Royal Navy for his research than from the Air Ministry.

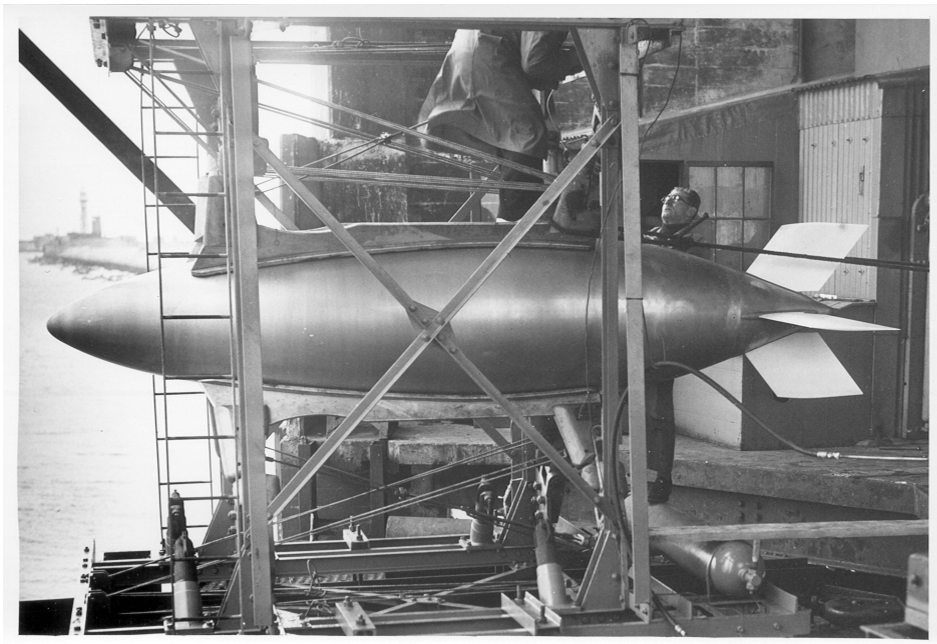

Figure 9 HEYDAY prepared for launching from Portland Breakwater

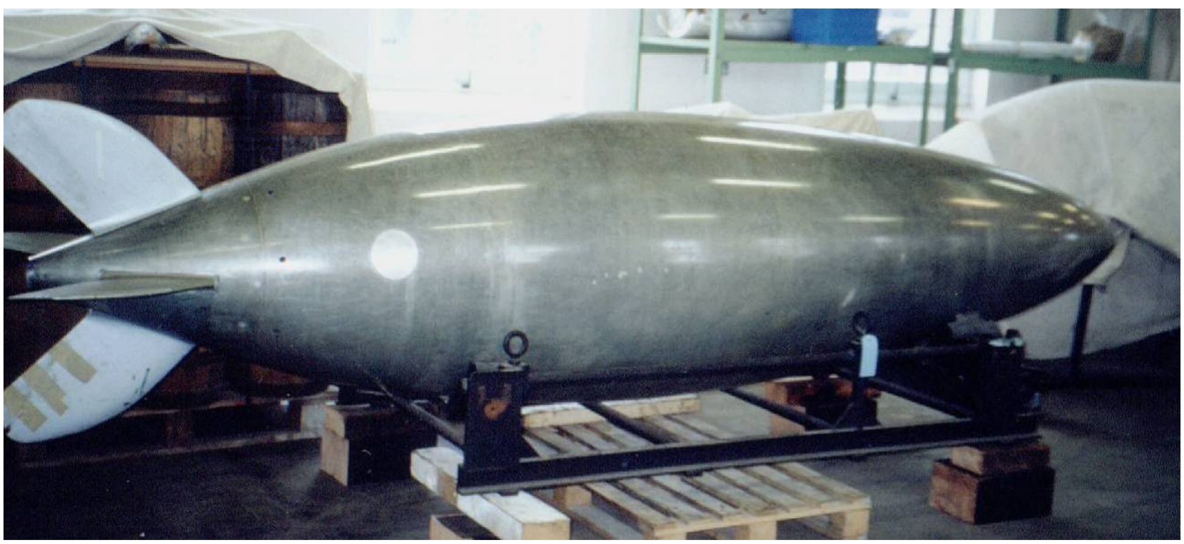

Figure 10. The Barnes Wallis 'HEYDAY' vehicle at Priddy's Hard Museum, 1999 [1]

The propulsion of HEYDAY was by HTP (High Test Peroxide) and compressed air. The HTP was forced by the compressed air over a fine silver mesh and catalytically decomposed into high-pressure air, oxygen and steam. The design was carried out by a German scientist working at the Naval Research Establishment of Vickers Armstrong at Welwyn Garden City. (The same rockets were used in the development of the SWALLOW prototype swing-wing aircraft.) The rocket nozzle was spring-mounted so that the thrust on the vehicle could be measured directly and the drag calculated.

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1 Now (2010) on display at the EXPLOSION! Museum, Gosport, Hampshire, UK - see http://explosion.kgbinternet.com/collection/results.do?view=detail&db=object&id=3843

Although the use of a rocket was unusual, it was not unique as we have seen from the contemporary developments of CAMROSE and BOOTLEG. What was unusual was the attempt to develop a low-drag body by breaking away from the traditional pencil shape for torpedoes (figure 11).

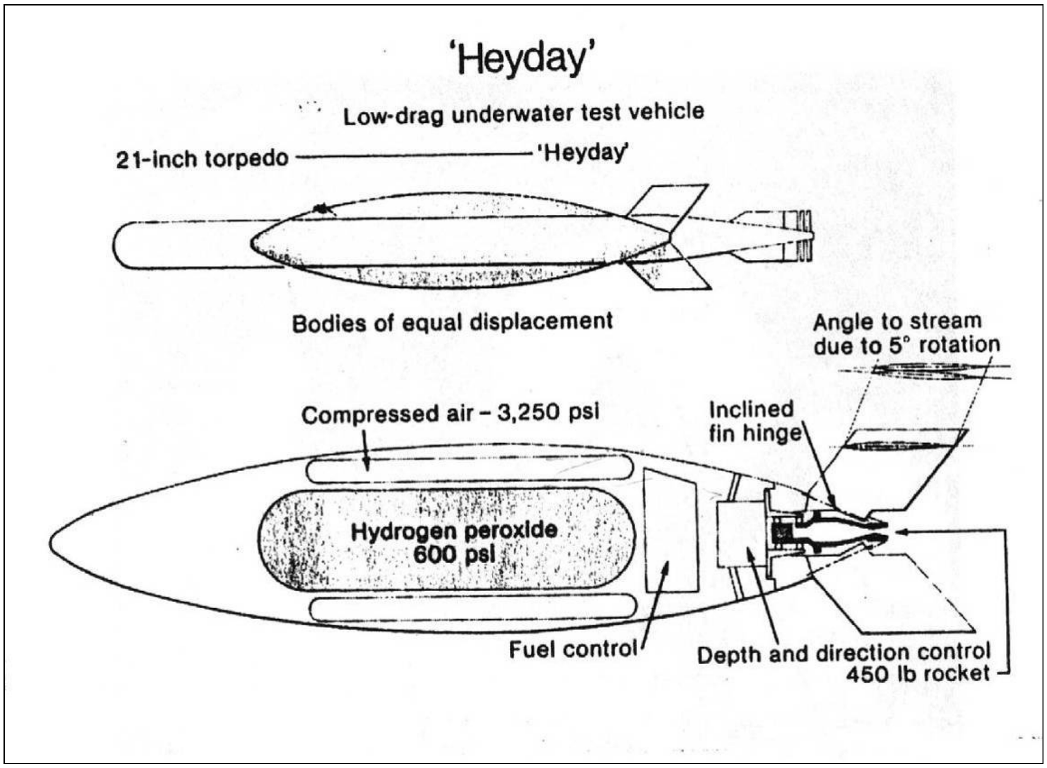

Figure 11. HEYDAY propulsion system

Laminar-flow torpedoes

The flow over any body moving through a fluid - whether air or water - can be described as laminar or turbulent. In laminar flow there is no random motion in the fluid and it moves in a predicable, smooth and orderly manner around a vehicle's hull. However, under circumstances related to the speed and viscosity of the fluid, this orderly motion can break down and become highly chaotic and unpredictable. Laminar flow then becomes turbulent flow. The force needed to push an object through a fluid is normally much higher if the flow is turbulent, increasing as the square of speed, than if it is laminar, when drag increases linearly with speed. Thus, the greater proportion of surface covered with laminar flow, the lower the overall drag and the faster the vehicle will travel with a given power unit. For most objects moving through water and air, the flow is overwhelmingly turbulent - for example, the drag forces on submarines and aircraft are predominantly caused by the turbulent flow over their hulls. However, for torpedoes, there is an almost unique opportunity to design shapes that significantly increase the proportion of the hull covered by laminar flow.

With the conventional 'pencil' shape for torpedoes, laminar flow exists only over the front curved part of the nose; all the parallel part of the body is under turbulent flow. However, by careful design, the laminar flow region can be extended to cover a significant proportion of a torpedo's hull. HEYDAY was so designed to cause laminar (low drag) flow to be maintained over at least half of the hull. There are severe penalties for such a scheme. The first, and obvious one, is that the shape of the laminar-flow torpedo is quite different from conventional weapons, so they cannot be launched from normal torpedo tubes or stored easily on a ship or submarine.

The second disadvantage is that the shape of the weapon and smoothness of the hull are absolutely critical: a blemish in the surface of the order of a micron can cause turbulence to be triggered and the laminar flow regime to break down. Even the heads of modern homing weapons have to be carefully machined and polished to avoid premature transition from laminar to turbulent flow; imagine achieving and maintaining this over the entire hull of a torpedo!

In the USA researchers were grappling with the same problem of creating torpedo-like bodies having a large area of the hull under laminar flow, and figure 12 shows one of the experimental bodies. Their performance was examined by dropping them in deep water and measuring their speed with different ballast weights inside. They would then be recovered to the surface. The picture shows a conceptual design with a propeller, although no tests where ever performed with self-propelled vehicles.

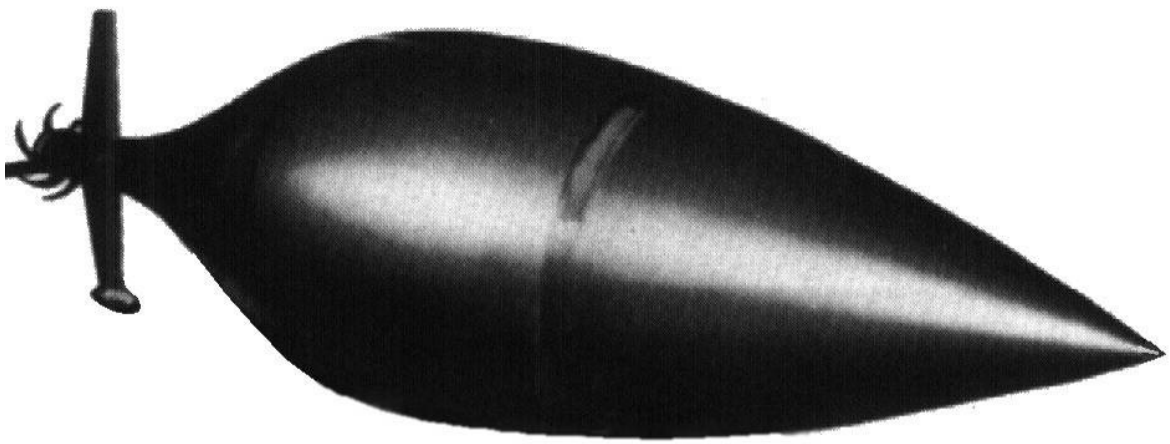

Figure 12. A US laminar-flow body

Whilst HEYDAY tests were being carried out from the Vickers Armstrong (ex-Whitehead) torpedo launching facilities on Portland Breakwater, news arrived from the USA that laminar flow was much more difficult to achieve and maintain than had been expected. By then, Wallis had shown that laminar flow was only being achieved over 28% of the body surface - still a remarkable achievement but not enough to justify continuing tests. HEYDAY would never be able to achieve the low drag figures required, and the trials were abandoned. However, the data collected were exchanged with the US researchers and were used in the design of the USS Albacore submarine, which had an experimental low-drag hull design.

Two HEYDAY test vehicles had been built. One was a small-scale model used for drag measurements in the towing tank of the National Physical Laboratory at Teddington. This was destroyed but the second, full-scale, model was passed to the Admiralty Research Laboratory, also at Teddington, for further drag measurements to be made. After these tests were completed, this HEYDAY test vehicle was moved to the Admiralty Underwater Weapons Establishment on Portland in about 1970, where it stood exposed to everything that the English Channel could throw at it. By then, it had acquired cosmetic wooden tail fins.

6 RECENT DEVELOPMENTS IN TORPEDO ROCKET PROPULSION

During the cold war, the Soviet Navy developed a rocket-propelled air-dropped homing torpedo. In the present climate, the Russians are anxious to sell this weapon and a few sparse details have now emerged in their armaments sales catalogue [6]. The APR-2E is designed to be dropped from helicopters or aircraft, and it searches for a submarine target whilst performing a downward spiral. On detecting the target, it attacks it at high speed under rocket power. No details of speed or range are yet available .

Figure 13. Russian APR-2E rocket torpedo

7 THE FUTURE

Is there a future for rocket-propelled torpedoes? They are fast, short range, reliable and require negligible pre-launch preparation and maintenance. They are unsuitable for use as submarine-launched weapons, where long range is mandatory for attacking enemy submarines and ships. However, the requirements for air-dropped torpedoes match the capabilities of rocket propulsion systems quite well since a high-speed torpedo is essential for pursuing an enemy submarine before it has time to react and deploy countermeasures. Long range may not be an issue if the weapons are dropped close to a submarine target.

Apart from the Russian APR-2E, current air-dropped weapons use either batteries or thermal propulsion systems. These can be expensive and complicated to manufacture; they need maintenance throughout their lives and sometimes require pre-launch heating and/or priming, which can be time-consuming when a rapid reaction time is paramount. The Russian rocket-propelled APR-2E torpedo may mark a revival of interest in a propulsion system that has been largely neglected for five decades elsewhere in the world.

ACKNOWLEDGEMENTS

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