SPEARFISH THE WEAPON AND ITS DEVELOPMENT

BY

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ABSTRACT

The replacement for TIGERFISH, the current submarine launched heavyweight torpedo, is about to enter service. SPEARFISH is a fast, deep diving and highly manoeuvrable torpedo for use against ships and submarines. Its advanced homing system and good countermeasure resistance make it a most versatile and effective weapon. The article provides an overview of the weapon, a discussion of its development programme and highlights the procurement lessons that can be learned from the project.

Background

In the face of a rapidly developing Soviet submarine fleet, during the middle 1970s, the Naval Staff identified the need for a replacement for the submarine launched TIGERFISH torpedo. Following feasibility and project definition studies, Marconi Space and Defence Systems (MSDS) (now Marconi Underwater Systems Limited (MUSL)), were contracted to develop their proposed solution to Naval Staff Requirement (NSR) 7525; a significantly more capable weapon than TIGERFISH, with a projected In-Service Date (ISD) of late 1987. The development programme eventually achieved very high levels of performance. But during acceptance trials in 1988, severe problems were identified with weapon reliability. Design certification and fleet weapon acceptance had to be delayed, and a major programme to resolve the deficiencies was instigated in November 1990. That programme is now approaching successful completion and the Royal Navy is soon to take possession of a new, high performance heavyweight torpedo: SPEARFISH (FIG. 1).

Introduction

The development of complex weapon systems, such as SPEARFISH, is an inherently difficult and involved activity. Despite the MoD attempts to place the majority of programme risk on a prime contractor through a fixed price development contract and the adoption of a 'hands off, eyes on' approach to the procurement, the SPEARFISH programme has slipped by over 5 years compared, with hindsight, to the extremely ambitious ISD forecast in 1981. Any project that does not progress to schedule tends to focus attention on the problems causing the delays, rather than the overall achievement. Such a perspective may adversely colour the customer's perception of the end product.

With SPEARFISH shortly to enter service, it is a good time to review the project and provide a dispassionate assessment of the weapon and its development programme. It is hoped that some of the poor impressions, that may formerly have been associated with SPEARFISH, can be put into context and any associated misconceptions dispelled.

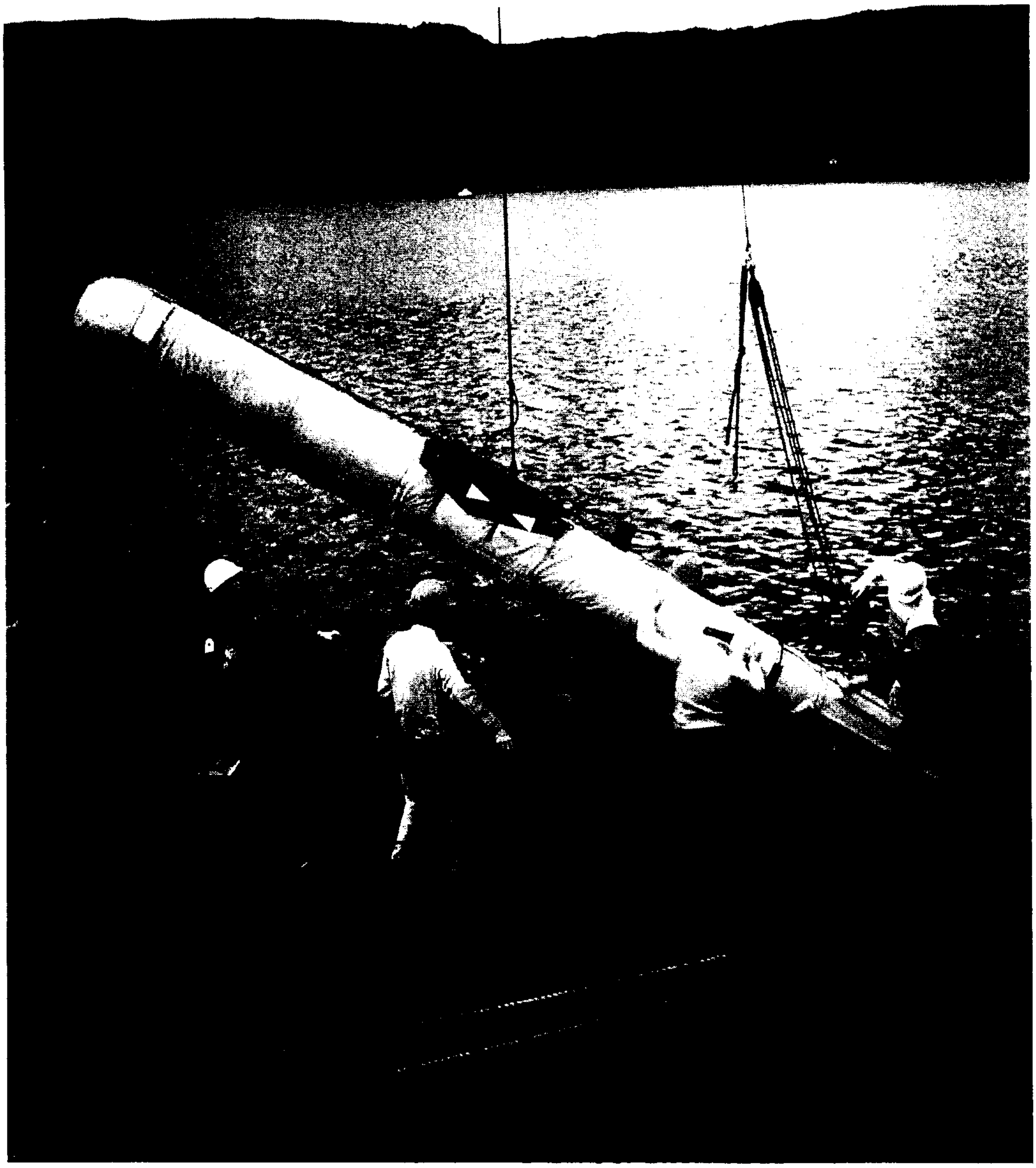

FIG. 1—SPEARFISH EMBARKATION AT FASLANE

Description

SPEARFISH is a submarine launched heavyweight torpedo, for use against both surface and submarine targets. It is powered by an open cycle gas turbine engine, fuelled by a mixture of OTTO fuel and an oxidant Hydroxyl Ammonium Perchlorate (HAP). This combination provides the weapon with a high sprint speed, a deep diving capability and considerable endurance, thereby maximising its performance against fast evading targets. Although provided with a copper wire command data link, the weapon is designed to operate autonomously from the firing platform. Once initialised with target and environmental data, the weapon searches for and homes on a target using a combination of passive and active sonar, the selection of which is controlled by the weapon's tactical software. Sophisticated tactical algorithms also enable the weapon to deal with complex countermeasure scenarios.

Physical Characteristics

6.12 metres long, 0.533 metres in diameter and weighing nearly 1800 Kg, the SPEARFISH torpedo is built up from seven hull sections. These are incorporated into a forward and after pressure hull, separated by a free flooding fuel and guidewire dispenser section (FIG. 2). The majority of the hull sections are of ribbed construction and are machined from forged aluminium. The exception, for safety reasons, is the oxidant tank which is made from titanium. The design of the sections allows for a high strength to weight ratio and enables the weapon to withstand the considerable pressures encountered at the extremes of its operating envelope. Similar sections are fully interchangeable and thus complete weapons can be prepared by combining appropriate sections as they become available from the maintenance and repair loops.

The forward pressure hull is divided into three sections:

- The nose, which houses the transducer array and the transmit and receive circuitry.
- The warhead.
- The electronics section, containing the homing and guidance systems.

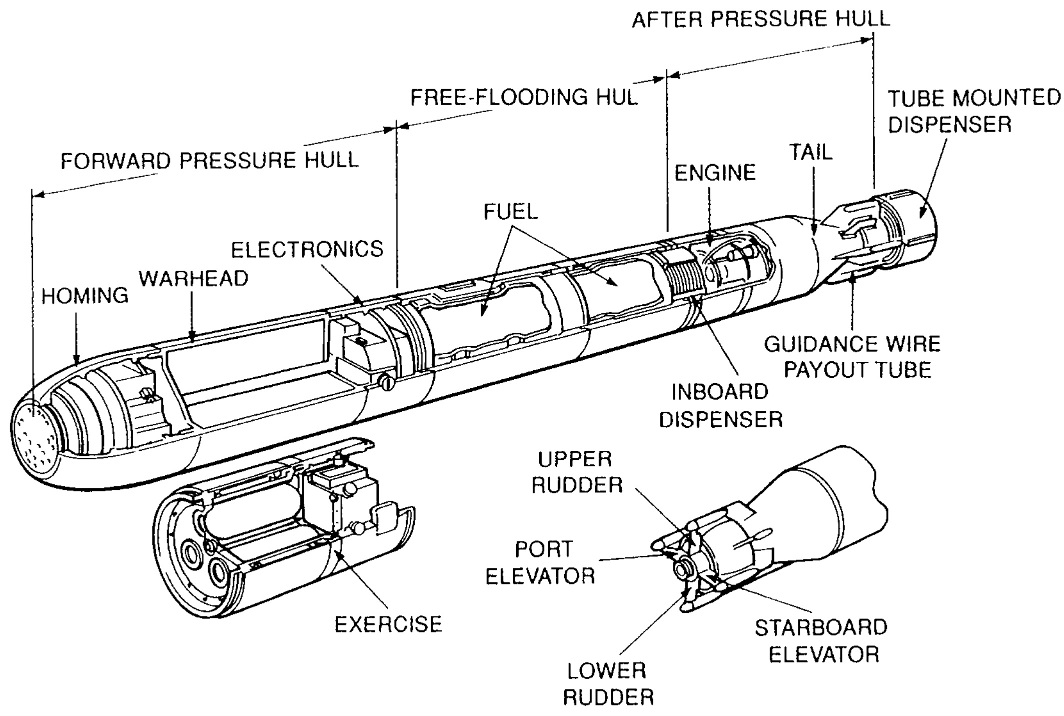

FIG. 2—WARSHOT AND EXERCISE VARIANT TORPEDO. GENERAL LAYOUT

Sonar data, either passive or active, is passed through signal processing and correlation units in the nose, and transferred to the homing and guidance computers. These computers run the algorithms, that control the weapon's tactics and homing mode, and pass guidance commands to the autopilot. For trials purposes the warhead, which separates the nose and electronics sections, is replaced by an exercise section. This houses the weapon recovery sub-system, additional safety hardware and the recording electronics.

The fuel section consists of two compartments, containing separate butyl rubber bags in which the OTTO fuel and the HAP are stored. The fuel section is free flooding which maintains a pressure on the fuel system and keeps the vehicle in trim as the OTTO and HAP are used. Attached to the aft end of the fuel section is the weapon's inboard dispenser, from which the guidance wire is paid out. The inboard dispenser is also free flooding, to compensate for the changes to the weapon's weight as the wire is dispensed. The guidewire deploys through a tube within the after pressure hull and out through one of the tail fins.

The after pressure hull contains the powerplant and its associated support systems. The powerplant is a single stage open cycle gas turbine, manufactured by the Sundstrand Corporation of Rockford, Illinois. This engine is connected through a gearbox to provide power to the propulsor, alternator, fuel pump and hydraulic systems. The tail section contains the majority of the potential sources of unwanted radiated noise within the torpedo. Significant efforts have been expended in the design of the whole section, particularly the propulsor and control surfaces, in order to minimise the noise signature from this area.

Safety

A fuelled SPEARFISH contains significant quantities of the mono-propellant OTTO fuel and the oxidant HAP. The latter must be kept isolated from other materials due to its highly reactive nature. In certain conditions mixing HAP and OTTO can cause a violent reaction and therefore for the first few seconds after discharge, the engine is run on OTTO fuel only. When the weapon has travelled a safe distance from the submarine the HAP valve opens and the engine runs on OTTO and HAP the mixing of which is controlled by a sophisticated fuel metering system.

In order that SPEARFISH remains safe in service, the prevention of fuel or oxidant spills has been a critical factor in the design of the fuel section. In addition, the need to prevent the uncontrolled mixing of the two chemicals has led to a principle of triple separation being applied to their storage. Primary containment of both liquids is achieved by storing them in individual polymeric bags. A secondary containment system is provided for the HAP by sealing the HAP bag within a welded titanium alloy tank. The containment system has been subjected to extensive testing in order to prove its effectiveness. Therefore, the probability of losing a submarine, through an accident due to fuel/oxidant containment failure, is of the order of $1x10^{-8}$ per deployment.

The Royal Navy and the US Navy have had many years experience with OTTO fuel. A mildly toxic persistent liquid, OTTO fuel can be extremely difficult to clean up if spilled. In the unlikely event of an OTTO fuel leakage, rapid containment and decontamination is ensured by the use of specially developed monitoring and cleaning equipment.

Submarine interface and conversion

The conversion of a submarine to be SPEARFISH capable requires changes to both the weapon stowage compartment (WSC) and the fire control (FC) equipment. The major hardware changes to the FC system include:

- Improvements to the FC consoles.
- Alterations to the FC logic racks.
- The introduction of new weapon control modules (WCM).

Modifications to the weapon handling and stowage arrangements have also been necessary:

- The handling equipment has been up-rated to allow for the increased mass of the SPEARFISH.
- The bottom 1 metre of the WSC has been sealed to help contain fuel spills, in the event of an accident.

- The ventilation system in the WSC has been altered. This enables the compartment to be purged without jeopardising the atmosphere elsewhere in the submarine.

The Alterations and Additions (A&A) to convert a platform 'for but not with' SPEARFISH can be conducted within a Docking and Essential Defects (DED). Once the A&A is complete, the transition between a TIGERFISH and SPEARFISH capability, and reversion back is achievable in 3–4 days. The implementation of this latter hardware conversion (principally changing the WCMs and logic racks), can be completed in less than half a day. The remainder of the conversion time is taken up by a comprehensive set of system integrity checks.

SPEARFISH has been designed for use with both existing and future submarine tactical weapon systems (TWS). The FC aspects have been successfully implemented through a major modification to the DCB fire control system and progress with the Submarine Command System (SMCS) development is well underway. Both FC systems provide the operator with facilities for initialising the weapon with target and scenario data, as well as the preferred tactical options for the early phases of an attack. Weapon status pages allow progress of an engagement to be monitored. Although SPEARFISH is an autonomous weapon, the fire control team can interact with the torpedo if judged necessary.

A SPEARFISH Command Tactical Aid (SCTA) is being developed and prototyped on a modern workstation interfaced to the TWS. Once this prototype has been proven, the intention is to implement SCTA within the established command system. Additionally, facilities for On Board Training (OBT) have been provided and integrated with the existing TWS. The OBT caters for two levels of training; that dedicated for the FC team and the broader requirements for working up the full command team. Therefore, through the weapon project there has been a significant programme of weapon system software development to ensure that the interface between the torpedo and the operator is successfully managed.

Operation

SPEARFISH was developed as an autonomous weapon, with a guidewire enabling communication between the torpedo and the firing platform. Under normal circumstances the weapon is left to prosecute the attack without command intervention, because in its autonomous mode SPEARFISH can independently adopt tactics to match the developing attack scenario. During an attack the command can monitor weapon progress from data telemetered to the FC console. Should operator intervention be required, the weapon can be controlled through either semi-autonomous or manual command modes.

Whilst the submarine is on patrol, the weapon in the tube remains inert. Electrical connection to the torpedo is maintained via the guidewire and an 'A'-link. There is no communication with the FC computer, until the weapon is prepared for firing. When the intent to fire is established, the weapon pre-sets may be input to the FC computer, ready for transfer to the weapon during initialisation, which is the first of five phases within a weapon run:

(*a*) *Initialisation phase*. Once the fire push button is pressed, the weapon operates on platform supplies until power from a thermal battery becomes available. During this phase, data on the position of the target is passed over the guidewire. Once this is verified as being correctly received by the weapon, the automatic discharge sequence starts and the torpedo is fired.

(*b*) *Discharge and Safety and Arming phase*. When the weapon is clear of the submarine, the engine is started by the ignition of a Mechanite charge in the combustor chamber. This accelerates the turbine, which in turn powers up the auxiliaries. The OTTO valve is opened and the engine initially runs on OTTO alone. Once the safe distance (from the firing platform) is achieved, the HAP valve opens and a carefully controlled mixture of HAP, OTTO and seawater is sprayed into the combustor by the fuel pump. By this time, the weapon's alternator is providing all the electrical supplies and the hydraulic systems, that drive the control surfaces, will have pressurised. The weapon then conducts a series of manoeuvres to verify that the autopilot has control and that the automotive systems are functioning correctly. Once these manoeuvres are successfully completed, within a set time limit. The torpedo then enters its mid-course phase.

(*c*) *Mid-course phase.* During this phase, the weapon transits to the vicinity of the Target Uncertainty Area (TUA) at as economical a speed as possible. Passive data gathering may be conducted at this time and the weapon will pass this and other telemetry data back to the firing platform. Under normal operating conditions SPEARFISH will perform autonomously during this phase. However, should circumstances dictate, the command may take control of the weapon in order to change the tactics of the attack. On reaching a pre-determined distance from the edge of the TUA, the torpedo enters the search phase.

(*d*) *Search phase.* If the weapon has been commanded to conduct an overt attack it will start active transmissions immediately, thereby maximising the probability of target detection. However, most attacks are conducted covertly, in which the weapon initially adopts low speed passive search routines. Once a contact has been detected, the weapon evaluates the received signals and if these are sufficiently 'target-like', the source is confirmed as the target: Passive confirmation.

(*e*) *Active homing phase.* The weapon then commences active transmissions and attempts to achieve active confirmation, after which it accelerates to maximum speed to close the target as quickly as possible.

During terminal homing, the weapon arms and then manoeuvres either to hit a submarine or to detonate within a specified volume of water beneath a surface vessel. Lethality studies have shown that the accuracy of the terminal manoeuvres, is sufficient to ensure that a single SPEARFISH is capable of inflicting mission abort damage on even the largest of targets. The torpedo has been designed to operate in the presence of countermeasures. In such an environment, it is capable of maintaining contact with the target to enable its successful prosecution.

SPEARFISH has been carefully engineered to produce a highly manoeuvrable deep diving weapon capable of very high speeds; its operational envelope exceeds that of any known or projected target. This exceptional performance is matched by a highly sophisticated homing system that is able to acquire submarine or surface targets, in multiple countermeasure environments, without the intervention of the command. The weapon thus meets the very stringent NSR, that was originally conceived late in the 1970s and remains current today.

Development Programme

The development of SPEARFISH was split into two elements, the torpedo and warhead. The torpedo development was placed with MSDS. However the responsibility for the warhead development was placed with a Joint Project Team (JPT), headed by the Royal Armanent Research and Development Establishment and supported by the Royal Ordnance Factories, latterly RP plc.

Weapon Development

The MSDS plan for the development of the torpedo was based around a 'design-to-test cycle'. Designs were completed, the configuration registered and the manufacture begun under a disciplined process of drawing and material control. The use of such stringent processes, enabled material of a known standard to be produced for evaluation through tests and trials. Once trials data became available, design reviews were held and the torpedo's performance assessed. The design reviews provided a forum in which the MoD could formally scrutinise the design and, if it was satisfactory, agree its acceptance. Once 'chilled', the build standard of the sub-systems became the authorised specification to which the manufacture of subsequent material was conducted. This iterative process was applied throughout the design and development of the weapon.

The progress of SPEARFISH development was enhanced by MSDS's experience with the current naval lightweight torpedo STING RAY. Not only were there elements and sub-systems that were transferable from STING RAY but also, the existence of experimental vehicles enabled the rapid proving of modifications within the new hardware. The development project was thus operating on a sound base right from its start. One of the targets that was established early in the project, was the release of production standard weapons for pre-Contractor Acceptance Trials (pre-CATs) in 1986. This was an undeniably tight programme and left time only for one full design-to-test cycle. However, there was considerable confidence that this programme could be achieved, given the torpedo experience within the company.

Integral within the development programme were a series of tests and demonstrations designed to ensure that the requirement specified in the Agreed Characteristics (ACs) was met. The project thus encompassed a diverse range of activities that included environmental testing and the generation of reliability data, as well as the provision of test equipment, documentation and upkeep facilities.

Warhead Development

In parellel with MSDS's activities developing the torpedo, the JPT were progressing work with the warhead. At the time the weapon development contract was placed, very little feasibility work had been conducted into warhead concepts. The stringent lethality requirements placed on the weapon, coupled with restrictions on the mass of explosive that could be incorporated within the warhead, resulted in great emphasis being placed on optimising warhead performance.

Two types of warhead were developed in parallel:

(*a*) A blast type.

(*b*) A Directed Energy (DE) system.

The blast warhead provided optimum performance against ships but, due to mass restrictions, it was considered that its effectiveness against submarines might be reduced. In contrast, the DE warhead was originally assessed as offering a higher probability of sinking a submarine. However, when compared with the blast warhead, development of the DE charge was considered to be a higher risk programme.

Towards the end of development a reassessment of the lethality criteria was carried out. This included investigations into mining effects and whipping damage. Taking these effects into account, the most recent lethality study has shown that the blast warhead to be capable of destroying all specified surface and submarine targets. Therefore, the warhead development has been successful in meeting the requirements of NSR 7525.

RELIABILITY

Early Reliability History

In accordance with the Ministry's procurement guidelines, the MoD project team adopted a 'hands off, eyes on' approach to the development, leaving the Design Authority (DA) to manage the programme. The indications from the early development firings were promising and all appeared to progress smoothly until the pre-CAT firings, when the weapon demonstrated a reliability of around 36%. The contractor accepted that this was below the AC requirement and identified a range of solutions to resolve the problems.

MUSL implemented a number of modifications to the design and then applied discounting techniques to the previous failures, to predict the reliability figures that should be obtained during the forthcoming CATs. Using these discounting procedures, the company predicted that SPEARFISH could achieve a reliability figure of 95%. In the event, when the firings were conducted in 1988, the CATS weapon still only demonstrated 35% reliability, leaving the MoD staff with serious concerns.

Further modifications, additional checks and procedural changes were implemented, some of which were included in the later CAT vehicles. Once again, it was predicted that had all these changes been incorporated from the outset of the trials, the discounted reliability would have been 84%. It was further predicted that with the reliability growth that was anticipated, a demonstrable reliability in excess of 92% could be achieved in production.

Additional firings were needed to prove that MUSL had corrected the problems and that reliability had improved. Therefore, the MoD Project decided to proceed with Fleet Weapon Acceptance Trials (FWATs), in 1989. The trial proved to be a disaster and after only 10 firings the FWATs was suspended, pending detailed analysis of the failures.

The FWATs programme highlighted a range of issues that included weakness within the propulsion, recovery and power supply systems, as well as the guidewire link. In addition, questions were raised over the procedures developed by MUSL and used while preparing the weapons in the Royal Navy Armament Depots (RNAD). MUSL were required to undertake a series of investigations into the causes of the failures. This led to further changes both to the torpedo and to the preparation procedures used by the company, prior to delivery, and RNAD before outloading weapons to the submarine.

The inaccuracy of previous predictions and poor results from earlier trials, undermined the MoD's confidence in the company's forecast of the effect the changes would have on reliability. Therefore, in March 1990, once the modifications had been incorporated and the procedural changes introduced, an in-water reliability demonstration known as the Operational Reliability Evaluation Trials (ORETs) was conducted as a precursor to the repeat FWATs. The intention was to fire 40 weapons to assess reliability. The first 24 being used to prove the revised depot procedures; 12 being prepared by RNAD Beith and 12 by MUSL. Unfortunately after 21 firings, it was evident that the required reliability could not be achieved and this firing programme was abandoned.

Reliability Assurance Programme

The evidence from the FWAT/ORET programmes had confirmed the MoD's concerns about reliability weaknesses within the weapon. The Royal Military College of Science (RMCS) at Shrivenham, was commissioned by MUSL to conduct an independent assessment of the risk areas in the programme, particularly those associated with the reliability problems. This study included an investigation into the engineering of the whole weapon and a detailed assessment of the major sub-systems that it encompassed. The consultants also reviewed the philosophy and programmes adopted for the development of SPEARFISH, and the methods used to measure and predict weapon reliability.

The Shrivenham team concluded that, while the weapon demonstrated the potential to meet the requirements of NSR 7525, there were significant design and quality shortfalls. These shortfalls were felt to limit significantly the weapon's potential to meet the reliability requirements.

It was clear, from the in-water evidence, that the design certification would have to be withheld until a thorough review had been carried out by the DA. This was fully supported by the conclusions from the RMCS study. After vigorous contractual discussions, a negotiated agreement was achieved on how the original development and Initial Production Order (IPO) contract should be formally concluded. The settlement that was reached introduced the requirement for a full Reliability Assurance Programme (RAP), that was to be completed before further commitment to production would be made by the MoD.

The primary aims of the RAP were defined as follows:

(*a*) To conduct a comprehensive review on the design, manufacture and assembly processes to determine any factors likely to affect reliability, and to implement and prove changes to rectify the weaknesses.

(*b*) To provide confidence, through evidence from in-water demonstrations, that the reliability requirement could be met in production and to bring the IPO weapons to an acceptable standard for issue to the Royal Navy.

(*c*) To define the new build standard for the torpedo and establish the process and procedures needed to ensure that the required reliability could be achieved in the Main Production Order (MPO) and throughout the projected in-service life.

The RAP commenced in November 1990 and was planned as a 30 month programme of work aimed at resolving the reliability problems and achieving design certification. It introduced increased MoD oversight of MUSL activities and involved a range of different authorities such as RMCS, Directorate General of Supplies and Transport (Navy) and the Defence Research Agency. The RAP was split into the following areas of work:

(*a*) Review phase and proving trials.

(*b*) Assessment of Reliability Trials (ARTs).

(*c*) Data analysis and reliability assessment.

(*d*) Design certification.

(*e*) Modification of all IPO torpedoes to the design certified build standard.

Review Phase and Proving Trials

The review phase comprised an evaluation of every aspect of the weapon's design, manufacture, quality control, processing and assembly, in an effort to identify those elements that could limit the reliability. In addition a comprehensive investigation of the ORETs failures was completed. One of the recommendations from the RMCS study was that the weapon should be subjected to a more extensive and rigorous test regime. This would establish the true design margins and reveal incipient weaknesses in the design. Therefore, part of the RAP review was a Step Stress Testing (SST) programme, that explored the robustness of the weapon design well beyond the contractually specified environmental limits.

Many of the past weapon failures that had occurred were attributable to poor build quality. While the complexity of the design imposed limits on improvements in this area, there was much that could be done to eliminate the occurrence of manufacture related defects. It was decided that the weapon should be subject to a conditioning test regime, to prove that the hardware was free from faults before it was released from the contractor.

The conditioning, conducted at weapon section level, took the material through a series of thermal cycles and a controlled random vibration test whilst electrical power was applied. Stressing the sections in this manner, precipitated incipient failures that could be corrected before delivery. The conditioning exposed several inherent weaknesses which have subsequently been rectified by modifications to the design. By identifying these weaknesses, the conditioning element of the RAP has enabled the weapon's robustness to be improved. It has also helped to minimise the possibility of transferring latent manufacture related failures to the build standard for the MPO, and establishes the mechanism for maintaining build quality during the future production of the torpedo.

Another investigation conducted within the review phase was a Failure Mode Effect and Criticality Analysis (FMECA) study. Once again the intention was to increase the reliability of the delivered product, in this case by testing mechanisms used to clear the weapons for release. The FMECA exercise focused on identifying critical components, within the weapon, that were not tested during vehicle preparation. Where neither direct nor functional tests of these critical items existed, further tests were devised.

The review phase of the RAP proved to be significantly longer and more comprehensive than was initially envisaged, and thus early milestones were not met. However, the results from the work were very encouraging. The review generated over 90 modifications to the weapon builds standard, including several significant design changes to overcome the problems seen during ORETs. Particular problem areas which were addressed included guidewire telemetry, stop-on-wire-break failures, homing and safety and arming unit failures, and power supplies anomalies. In an attempt to recover the programme, MUSL elected to conduct its modification 'proving' trials before the SST programme and the ORET defect investigations had been completed. The trials were necessary to allow the efficiency of the build standard changes to be demonstrated, prior to a commitment to the 40 ART firings.

The proving trials were conducted in July 1991. Notwithstanding the small sample (6 torpedoes), there was a marked improvement in weapon reliability. However, two of the weapons exhibited homing and power system failures, similar to those observed during previous trials. The MoD insisted that these 'systematic' faults be investigated and suitable modifications be implemented in the ARTs build standard. The combination of the homing system changes and those outstanding from the later ORETs investigations, were sufficiently extensive to warrant a further set of trials prior to 'freezing' the ARTs build standard. Therefore, in December 1991 a set of validation firings were conducted to achieve positive confirmation that the causes of the homing failures had been eliminated and the other changes proven.

The validation firings fell at a critical time, for at that stage the Director General Underwater Weapons (Naval) project, was preparing its submission for re-endorsement of the NSR. Therefore, well founded evidence of progress was required if a convincing case for the completion of SPEARFISH development was to be presented. The results from the validation trials were encouraging; the majority of the runs were successful, although some further anomalies were observed. Most significantly, however, the substantially improved reliability during the firings permitted some of the best demonstrations of SPEARFISH performance that had been achieved. The previous 2 years of intense activity were seen to be paying off.

The 12 proving and validation firings indicated the achieved reliability to be around 64%. While still short of the requirement, the small sample size meant that there were wide confidence bands on this assessment. Also the additional modifications, that were to be introduced after analysis of the validation trial failures, offered the prospect of considerable further reliability growth.

It was assessed that the limits of reliability enhancement, through the modification and screening of IPO hardware, had effectively been reached. These factors and the need to minimise further delays, led to the MoD freezing the build standard in 1992 and be committed to the larger sample of 40 ART firings. The ARTs would provide the evidence needed to determine, with confidence, the level of reliability being achieved by the weapon (FIG. 3). The timing of this decision was critical; it being a fine judgment between the need to achieve significant progress, while containing delays to the programme thereby ensuring the project's survival.

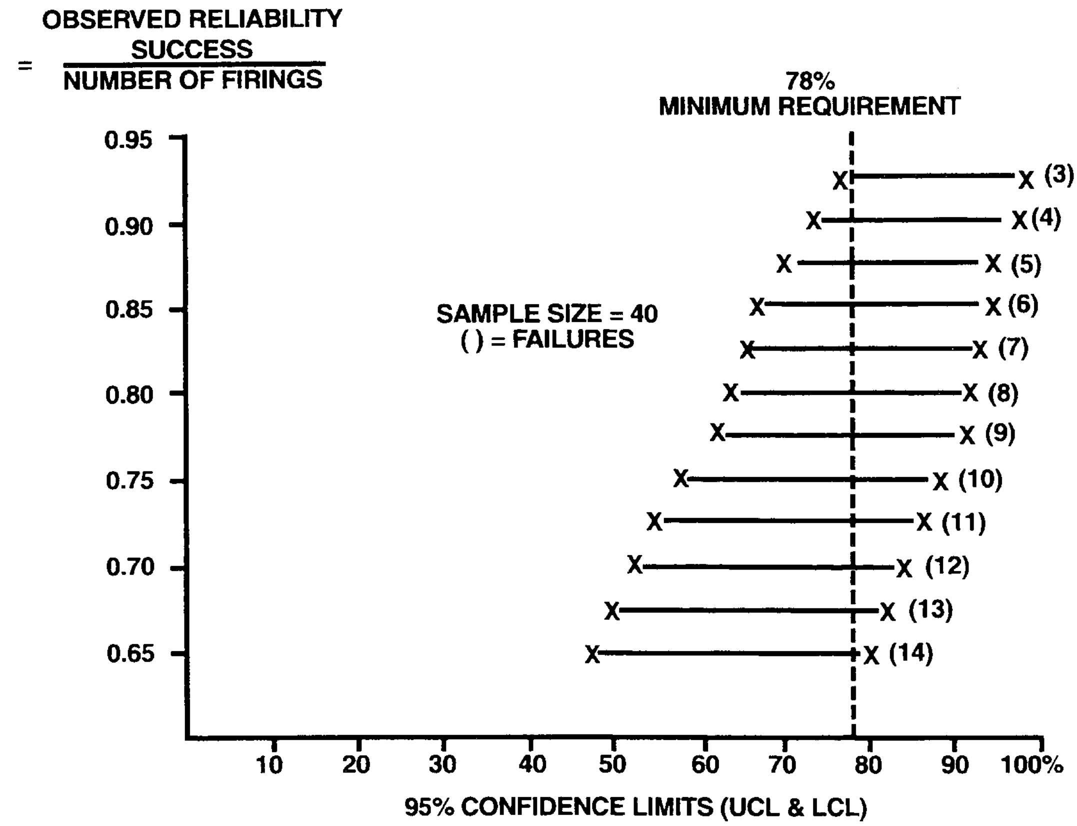

FIG. 3—GRAPH SHOWING THE LEVELS OF CONFIDENCE IN A 78% RELIABILITY RESULT, FOR VARYING NUMBERS OF FAILURES.

Assessment of Reliability Trials

Having frozen the build standard, exercise weapons were prepared by MUSL and the ART firings commenced in July 1992. The firing programme was nominally split into 4 groups of ten, spread over the subsequent 12 months. The initial progress was most promising and the improvements derived from proving and validation were demonstrated. At the time of writing (June 1993), five sets of ART firings have been completed (28 weapons). The demonstrated in-water reliability is approaching 80%.

Throughout ARTs, confidence in SPEARFISH has grown. The significantly improved reliability enabled notable performance achievements to be realised in several areas:

- The weapon successfully ran at the sprint speed, when close to its designed maximum operating depth

- Impressive passive and active acquisition ranges were gained against both ships and submarines.
- The weapon's homing performance was repeatedly demonstrated.
- The weapons resistance to countermeasures was repeatedly demonstrated.

The accumulated evidence indicates that SPEARFISH will successfully meet the requirements of NSR 7525.

Design Certification and Fleet Weapon Acceptance

The final phase of the RAP will comprise work towards achieving design certification. During this period all the hardware and documentation will be updated, to reflect the build standard proven during the ARTs in-water phases. The RAP was constructed so that the procedures, documentation and methods used to improve reliability, were well established and readily transportable into activities linked with the MPO. In this way the MoD will be able to ensure the progression and maintenance of reliability into the main production weapons.

Fleet weapon acceptance evidence is being gathered throughout the RAP. This, along with previously collected data, is being assimilated through the usual acceptance questionnaire mechanisms. The problems of demonstrating all aspects of weapon performance in-water, were recognised at the outset of the project. Safety constraints placed on SPEARFISH when running against manned targets, either surface or submarine, are so stringent that the full discharge to impact sequence cannot be demonstrated. Therefore, it had been agreed that simulation and modelling would provide a significant portion of the performance evidence, supported where possible with confirmatory data from in-water trials. Extensive use of mobile artificial targets has also been necessary, even though it is recognised that these targets can never be fully representative.

The performance data sought for fleet weapon acceptance has been gathered during a group of acceptance firings, interspersed with those for ARTs. These FWAT firings have bespoke run plans designed to investigate specific aspects of weapon performance.

In summary therefore, during the course of the RAP, the design and capability of SPEARFISH has been explored in great detail. The structured programme of investigations and trials, encompassed within the RAP, suggests the successful resolution of the reliability problems that had dogged the weapon throughout its earlier development. Once the full evidence demonstrating improved reliability had been obtained, approval will be sought to proceed to the MPO, for the balance of the warstock weapons. Weapons under the MPO will be required to demonstrate reliability beyond that achieved in ARTs, thus making SPEARFISH performance comparable with that in other modern guided weapons.

Lessons to be learned from the Procurement of SPEARFISH

As indicated in the introduction, the procurement of modern weapons is a complex, time consuming and costly business. The experience of the MoD (PE) during the procurement of SPEARFISH has borne this out. However, many of the lessons that can be extracted from the programme are not new.

Early investment during the feasibility phase of the project is essential, if areas of potential risk are to be identified and the ability to achieve required performance targets is to be properly assessed. Although it required considerable 'up front' expenditure by the MoD, the competitive evaluation of the primary contenders for the NSR 7525 contract proved most valuable. It also helped to ensure that both the MoD and the contractors better understood the requirement, before development was commenced.

The adoption of a 'hands off, eyes on' approach to major procurement projects, may leave the MoD open to considerable risk; particularly as a project approaches maturity. If, as was the case with SPEARFISH, problems are identified late in the development programme, the MoD has only limited influence in how the situation can be recovered. This can lead to extensive contractual disputes concerning liability, which do little to resolve the engineering problems and have the potential to greatly increase costs and cause delays.

There is merit in transferring risk onto the contractor through prime contractual arrangements and fixed prices. However, this must be tempered with the need for the company to remain solvent and the MoD to maintain access to the detailed information, that they require to identify weakness within a project. If suitable conditions are built into the contract, the principles of 'hands off, eyes on' can allow the MoD project team visibility of problems as they arise, and how the prime contractor has resolved them. Evidence from the SPEARFISH development suggests that it was only once the RAP had commenced, did the MoD truly gain this detailed level of knowledge. Only then, was the MoD able to influence how the efforts of the contractor should be targeted.

In the case of SPEARFISH the tight timescale, against which the development was conducted, was driven largely by the perceived threat and the consequent need to replace TIGERFISH. However, current trends suggest that there will be continuing pressure to shorten development programmes. This may lead to problems similar to those seen at the end of the SPEARFISH development. As this project shows optimistic estimates of the speed at which systems can be developed, may considerably reduce the probability of a timely and successful completion. The complexity of modern weapons is such that it is imperative that sufficient time and money is apportioned to the prototyping, testing and proving aspects of a development programme.

The need for the RAP might have been avoided, had the MoD requirement called for a more specific and comprehensive demonstration of reliability growth during development. However, it could be argued that the two and a half year RAP programme of investigations, resultant modifications and subsequent performance demonstrations, effectively represents what should be an integral part of all development programmes from their outset. For successful developments, project plans must include sufficient provision for these important activities in the early stages. If these activities are omitted from a programme, due to an overly demanding timescale requirement, the resultant design weaknesses in the equipment may only be identified once CATs or FWATs are conducted. It then becomes necessary to undertake the test, modification and prove activities retrospectively in order to resolve the problems. This inevitably leads to the project overrunning in both time and cost.

During negotiations over design certification and the RAP, both the MoD and MUSL placed different interpretations on some elements of the development contract. This greatly complicated the negotiations and led to considerable conflict concerning where liability lay for shortfalls in performance and reliability. Therefore the development of SPEARFISH has demonstrated, once again, the need for an unambiguous and taut contract, if costly and time consuming disputes are to be avoided.

Conclusions

SPEARFISH was designed to counter the threat presented by the ships and fast, deep-diving submarines of the former Soviet Union. However, its capability also encompasses ships and conventional submarines of the rest of the world navies. The torpedo's long range and fast sprint speed, coupled with its advanced homing system and good countermeasure resistance, makes SPEARFISH a most versatile and effective weapon.

Problems were encountered during the development programmes for both the warhead and weapon. In both cases these difficulties were overcome and robust solutions implemented. The most significant of the problems was that associated with the weapon's reliability. This was addressed through the RAP, which has provided a mechanism to achieve successful project completion.

The RAP aimed to identify and correct any factors that were limiting SPEARFISH's reliability. Weaknesses in the weapon were discovered by a series of extensive studies (FMECA and SST) and modifications introduced. Weapon build quality was also improved by the introduction of a more rigorous conditioning policy. An integral part of the RAP are the 40 ART firings, which are intended to demonstrate that the reliability target for the weapon will be achieved. The RAP therefore, provides a structure of investigations and trials that has enabled both the DA and the MoD to review, modify and prove the design of SPEARFISH.

The procedures and modifications introduced during the RAP were tightly controlled and documented. This was done so that they could be transferred successfully to the balance of the warstock, when this is procured under the MPO contract.

There are many procurement lessons to be drawn from the SPEARFISH project:

- Up front expenditure on the feasibility and definition stages is vital.
- Realistic estimates of timescales for development should be encouraged.
- Detailed risk assessments will provide the MoD with essential information for monitoring prime contractor activities.
- The essential requirement for comprehensive reliability growth programmes, including reliability demonstrations, throughout development.

Unfortunately, most of these lessons are not new. However, if the MoD demonstrates its firm commitment to the application of the principles, as occurred during the RAP, success can be achieved.

Despite the problems experienced during development, the SPEARFISH project has eventually been successful in providing a heavyweight torpedo that will meet the stringent requirements of NSR 7525. SPEARFISH has an operating envelope which exceeds that of all existing (and current projected) platforms. More complex than many sophisticated air flight weapons, SPEARFISH has a formidable homing performance against ships and submarines. The weapon is able to operate autonomously, even in multiple countermeasure scenarios. SPEARFISH is probably the most capable heavyweight torpedo in the world.

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