Underwater and Waterborne Engineering
A Tool for Reducing Dock Dependency and Whole Life Costs

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Abstract
Underwater and Waterborne Engineering is a term applied to processes, and associated equipment, that enable the inspection, maintenance, repair and upgrade of a vessel’s underwater hull, appendages and hull mounted equipment while a vessel is afloat. It is applicable to all classes of naval ship and submarine, and offers reduced dock dependency, a key factor for deployed vessels. For those organizations, most noticeably the U.S. Navy, who have integrated Underwater and Waterborne Engineering into Fleet Upkeep management, the benefits reported are significant, reducing through-life costs and increasing platform and equipment availability. In the last 5-10 years the use of waterborne maintenance in support of the Royal Navy has evolved considerably and today a wide range of proven capabilities exist and provide realistic alternatives to the dry dock. This article explores the technical issues that support the realization of Whole Life cost savings and reduced dock dependency through appropriate use of Underwater and Waterborne Engineering.

Introduction
Traditionally, divers have been used to carry out temporary damage repair of a ship below the waterline, to enable the vessel to proceed safely to dry dock for rectification. Repairs were typically patching of holes in the hull or additionally for smaller vessels, the replacement of propellers.

In recent years, where docks are unavailable or cost savings can be achieved by keeping the vessel afloat, military and commercial ship operators have carried out selective afloat maintenance or repair of the underwater sections of ships and submarines. Commercial operators have made use of the capabilities for repairing hull plating below the waterline using techniques acceptable to the Classification Societies for permanent repairs. Military organizations have also adopted these techniques to avoid the expense and loss of platform availability through drydocking. Additionally, commercial operators in particular have obtained fuel efficiency benefits by the implementation of hull and propeller cleaning either at regular intervals, or by monitoring fuel efficiency and setting action levels for cleaning.

Realizing the opportunities offered by reduced dock dependency, the United States Navy and the United Kingdom Ministry of Defence (MoD) have invested in the development of processes, and associated equipment, that enable the inspection, maintenance, repair and upgrade of a vessel’s underwater hull, appendages and hull mounted equipment while a vessel is afloat. Within the MoD these activities are collectively termed Underwater Engineering (UWE).

History
The United States Navy has been performing underwater ship husbandry as a consequence of salvage and battle damage repair since World War II. The Underwater Work Techniques Manual (NAVSEA 0994-LP-007-8010 and

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NAVSEA 0994-LP-007-8020, published in 1971, was their first compilation of these procedures. By planned application of UWE, the USN has progressively extended the period between docking for a number of classes including their aircraft carriers (CVNs). To support a large fleet, the USN provides artisans qualified to dive.

The Royal Navy Diver Underwater Tasks Manual (BR 2808(1)) and the Marine Salvage Manual (BR 2808(2)) provide information on methodologies for a range of underwater engineering techniques such as welding and the use of cofferdams. Propeller and Blade exchange is addressed in a separate manual. Prior to these manuals basics techniques were summarized in a single Diving Manual, and with a larger fleet Artificer Divers were trained to provide technical support. Currently Royal Navy divers generally support repair activities, not routine maintenance, with commercial diving/underwater engineering companies carrying out the majority of the latter activity.

In 1996 the Warship Support Agency (then the Ship Support Agency) commissioned a study into the costs, and the benefits that could arise, from the utilization of Underwater Engineering in the Fleet. The study culminated in a Naval Support Command (NSC) strategy for the development of a coherent UWE Fleet support capability.

Subsequent investment in UWE capabilities has provided the RN surface and submarine fleet with practical benefits in support of platform hull availability and cost savings. The RN has reported savings of over 60% on unprogrammed docking over a three-year period.

Current status of UWE

In the last 5-10 years the use of waterborne maintenance in support of the Royal Navy has evolved considerably and today a wide range of proven capabilities exist and provide realistic alternatives to the dry dock. The hull components and equipment supported by a UWE capability are:

(a) Stabilizers (fixed fin type)

The MoD has developed procedures and equipment for removal and replacement of stabilizer fins and stocks on aircraft carriers (CVS), Type 42 destroyers and Type 22 and 23 frigates. Equipment is retained in Portable Specialist Support Equipment (PSSE) stores and all have been deployed, avoiding dry docking and minimizing effect on ship’s programmes. Removal of the fin/stock assembly, and temporary sealing outboard using a cofferdam, has facilitated afloat replacement or maintenance work on the main bearings.

(b) Voith Schneider propellers

Exchange of Voith propeller units has traditionally, as with stabilizers, required drydocking. MCMV IPT has invested in a ‘fly away’ set of equipment including cofferdam and lifting frames. The equipment has been used in the UK and on deployment, proving quicker and less expensive than drydocking.

(c) Speed Log

Removal and replacement of cables and logs afloat is now common practice with a set of supporting equipment available from PSSE stores.
(d) **Hull inlets and discharges below the waterline**

A set of blanks, with operating instructions, are held in PSSE stores for use on HUNT class Mine Countermeasures Vessels (MCMVs). The set includes blanks to fit the complex curves of the bow thruster installation. Commercial underwater engineering organizations hold, or can manufacture blanks to suit arising requirements.

(e) **Submarine Ballast Tanks**

Designs, conceived by HMNB Faslane, are held for blanks to fit over S, T and V Class ballast tank grilles, the design being suitable for local manufacture if required. The design is supported by a safety assessment and blanks have been manufactured and used on several occasions.

(f) **Shaft Seals**

Temporary external seals have been fitted to HUNT class and LP(H) enabling work on inboard seals and associated lubricating systems. Two sets of equipment for Hunt class are held in PSSE stores. (FIG. 1) shows a temporary seal fitted externally to a 425mm diameter shaft.

![FIG. 1 – TEMPORARY EXTERNAL SHAFT SEAL](courtesy of UMC International plc)

(g) **Impressed Current Cathodic Protection (ICCP) system**

Anode and electrode replacement is now carried out afloat on ships as required, the UWE solution ensuring that full protection of hulls against corrosion is maintained.

(h) **Non-Destructive Examination (NDE)**

Regular inspections of specific propeller blades are carried using alternating current field measurement equipment. This is an adoption of an underwater technique in use in the offshore industry. Other methods, such as ultrasonic crack detection and radiography, are also available to the underwater technician.
(i) **Hulls**

Hull cleaning is carried out on ships and submarines, generally in response to diver inspection or fall off in performance indicated by loss of vessel speed. The capability rests with commercial organizations. For commercial vessels, fuel efficiency is often the indicator and cost driver for hull cleaning and propeller polishing. On submarines fitted with anechoic coatings, antifouling is not present and cleaning represents the only way, currently, of controlling fouling.

Routine external surveys and inspections provide early indication of coating failure or corrosion or cracking within the hull structure. The RN’s *Manual of Underwater Hull Survey* (BR 2000(94)) provides a basis for training divers in the techniques required to assist in the completion of effective underwater hull surveys and inspections, and further serves as a reference for trained divers. The manual is sponsored by WSA DTECH TS310b and includes guidance on the identification of defects, damage and fouling.

Hull inserts are used to replace cracked or corroded plate below the waterline, for example in fresh water tanks. The technique is described later.

(j) **Propellers**

For RN ships there is a requirement to polish propellers prior to docking to facilitate NDE inspections detailed in Def Stan 02-304 Part 5. Some military ships afloat are taking advantage of propeller polish before deployment. In comparison with a fouled propeller, vessels with a polished propeller will benefit from fuel savings, which may be up to 5%.\(^4\) (Fig.2) is an example of a diver polishing a propeller.

![Propeller Polishing by Diver](image)
Controllable Pitch Propeller (CPP) blades can be exchanged afloat using an in water method described in BR 2808(3)(F) (Controllable Pitch Blade Change by Divers). An alternative method of installing a purpose built flexible underwater habitat with the blade at top dead centre can provide an environment with reduced risk of cross contamination between the hydraulic oil and seawater. The habitat is currently approved by the WSA MPSIPT for inspection of blades and replacement of blade bolts.

(k) **Submarine hull cladding**

Methods have been developed and are used successfully to fit acoustic cladding underwater using epoxy adhesives. As for the application of acoustic cladding in drydock, strict process controls must be exerted by qualified applicators. A specific hull surface preparation technique is required to ensure affinity between the hull and adhesive. The underwater application process can also be used in drydocks where the specified environmental conditions for application to dry surface cannot be maintained. Def Stan 08-121 describes the *Requirements for the Application of Acoustic Cladding Treatments using an Epoxide Adhesive System*.

(l) **Masker belts**

Using the adhesive application technology developed for submarine hull cladding, masker belt sections are replaced afloat. Robust quality assurance with regard to surface preparation and cleanliness is necessary to achieve longevity from the bond.

**Underpinning techniques and technologies**

**Welding**

Several options are available to dockyards or ship repairers, the five processes generally used in the underwater engineering environment being described below. Three methods provide welding in air, and their use is only limited by the ability to install the appropriate cofferdam or chamber around the repair.

For the Royal Navy, wet welding is limited to steels of 0.4% Carbon Equivalent (CE) or less. This relates to MoD B quality steel and medium carbon manganese steels identified in BSEN 10025 grades S235 and S275 (Hot rolled products of non-alloy structural steels. Technical delivery conditions). Currently, Lloyds Register (LR) does not accept wet welding as a permanent repair method.

The five processes are:

- **Hull insert welding**
  Attachment of a hull insert using single sided welding from inboard. An external cofferdam provides a temporary watertight barrier for the process. This method provides access for non-diving welders. Hull insert welding is approved by LR for the provision of permanent repairs.

- **Friction stud welding**
  Welding of studs underwater by applying pressure and rapid rotational motion between the studs and hull plating.

- **Wet manual Arc welding**
  Arc welding using electrodes designed specifically for use underwater.
Hyperbaric chamber welding

Welding in air, inside a temporary, open bottomed, closure attached to the ship. Sea water is displaced from the enclosure using air or other suitable gas. The ambient air pressure is equivalent to the depth of the bottom of the closure.

Man entry cofferdam welding

Welding in air at atmospheric pressure, using an open topped cofferdam that extends above the waterline and is pumped dry allowing access by non-diving personnel.

These techniques are approved by the MoD and are fully described in Def Stan 08-172 Requirements for Welding below the Waterline External Hull of Afloat Ships and Submarines.

Coating repair

Steel warship hulls are reliant on an intact anticorrosive coating to avoid corrosion and the resultant need for un-programmed plate replacement. Local repairs to coatings can be carried out using a paint system that is suitable for application underwater but with limited success with regard to surface finish. Warpaint (issued by the Defence Procurement Agency STGMT) currently identifies three coating systems that have been approved for use on warships and can be applied underwater. Individual companies have developed techniques for ensuring that adequate adhesion of the coating occurs.

As with anti-corrosive coatings, anti-fouling can be applied underwater. Anti-fouling is generally easier to spread evenly than anti-corrosive coatings.

While surface roughness of such a coating over the whole ship is of significance, localized repairs with a rougher finish will have insignificant effect on the hydrodynamic performance of the hull.

Low surface energy anti-fouling coatings cannot, currently, be applied underwater but may be repaired by selecting a compatible non-low surface energy anti-fouling that can be applied locally where damage to the original anti-fouling has occurred.

Cleaning

Increase in hull surface roughness due to fouling will have a corresponding increase in power requirement (and increased fuel consumption) to maintain speed. While this fact is recognized, corrective action by ship operators is generally limited.

Long periods between cleans will permit larger quantities of fouling to become established with the risk that the removal of larger organisms by cleaning will result in coating damage exposing the shell plating and subsequent corrosion. Regular cleaning in-water will minimize this risk. Over aggressive or inappropriate cleaning may also result in hull corrosion and, in the worst case, a surveyor may require the ship to dry dock for further examination.

Underwater cleaning methods must, therefore, be selected on the basis of reliability, cost and ability to remove fouling without damaging the hull coatings. Underwater hull cleaning machines with superior brush control are now available that do not damage paint schemes, and can be used on submarine anechoic tiles and sonar external surfaces.

Diver operated vehicles may clean at rates up to 600 - 1000 m²/hr. Remote operation of this type of cleaning vehicle would reduce the constraints on
performance, and cleaning rates up to 1500m²/hr are theoretically attainable. Larger cleaning machines are effective on bigger areas that are flat or have large radii of curvature (Fig.3). Smaller, hand held machines will be required for smaller features in corners (e.g. at bilge keels) or tighter radii such as found on sonar domes but these machines have lower cleaning rates than larger equipment.

Determination of the need to clean can be a visual examination by divers, monitoring of fuel efficiency, or a combination of each. Some commercial shipping companies measure fuel efficiency as the indicator for hull or propeller clean, a method suited to their constant speed during passages. The variable role of a naval ship may limit the opportunity for effective monitoring of fuel efficiency. It is worthy of note that individual ships are monitoring loss of speed as an indicator that a hull clean is required. However, there is opportunity to establish visual metrics by noting loss of fuel efficiency as fouling increases on First Of Class (FOC) and establishing a visual standard for use by divers across the class (or similar classes).

An Alternative to Docking

Is UWE a serious alternative to docking? It is the author’s opinion that UWE will complement rather than replace docking with advantages from the inclusion of planned UWE as a tool for minimizing disruption to a vessel’s operational programme. For new Classes, the extent of UWE support will depend on the level of ‘design for UWE supportability’ that has been adopted and carried forward to Whole Life Support.

Within the current structure of Superintendents Fleet Maintenance (SFMs) and dockyards, UWE is generally used in response to unprogrammed repairs (to avoid docking) and where emergent work or delayed repairs to hull fitted equipment may delay undocking. Incentivised contracts should be considered for Contractor
Logistical Support (CLS) support where both customers and suppliers benefit from through life cost savings. Appropriate take up of UWE can be assured by including a requirement for its cost effective use within a CLS contract with the dockyard, or other CLS provider, being contracted to demonstrate cost savings in a win-win partnership with the MoD. This approach need not be restricted to UWE.

**Vessels on deployment**

Ships and submarines away from home port may have limited or no access to suitable docking facilities. Under these circumstances UWE can form a key component of the tool kit available to sustain Operational Capability.

Increased forward support capability will provide a basis for reducing upkeep constraints on extending deployment periods. This approach will be most cost effective if there is timely access to common support equipment (available from the Fleet) or dedicated support equipment held in PSSE Stores or available from equipment suppliers or UWE providers. Unless support equipment has already been designed and placed in PSSE stores as a result of MoD funding, undesirable lead times may be necessary to design and manufacture the necessary equipment. Some commercial organizations hold limited equipment (e.g. small cofferdams) that can be modified in response to the repair requirement. For new techniques or support equipment, their suitability should be demonstrated at an early stage in the project when risk is low (e.g. prior to commissioning of the FOC).

Additionally, for ships on deployment, the mobility of UWE support equipment and suitability for use from forward repair ships must be established.

**Future builds**

Planned, costed and integrated into a ship or submarine through life project from concept, UWE will aid realization of the following opportunities:

(a) Use of UWE to maintain programmed launch where non-availability of items such as hull valves adversely affect watertight integrity. UWE will enable blanking of openings and subsequent fitting of equipment afloat.

(b) Cost benefits from reduced risk of unprogrammed docking. Effective condition monitoring provides input to planning and timely UWE repairs as part of a seamless service. Key areas to be included in programmed monitoring include the hull structure, bilge keels and rudders, including coatings, combined with a ‘touch up’ service by underwater painting.

(c) Facilitation of estimates of repairs, including plating replacement, required during refit by the use of planned condition monitoring data. If the extent of plating repair/replacement is established prior to docking, use of afloat hull insert repair techniques may be cost effective and offer time advantage if such work is on the critical path for the docking programme.

(d) Reduction of critical paths within refit/maintenance periods by the selection of appropriate UWE tasks for inclusion in a CLS package, offering cost/time benefits to CLS providers and customer (the MoD).

(e) Commercial benefits from the provision of dedicated Underwater and UWE equipment and/or services for through life support. Options for manufacture and ownership of UWE specific tooling should be considered if financial benefits are identified. Provision of this
equipment will also reduce host nation dependency, and therefore costs, when deployed.

(f) Longer programmed docking cycles. Combining robust maintenance management with condition monitoring and prediction inboard and outboard below the waterline, a foundation for extending docking periods can be formed. With an ensured capability to effect maintenance and repair of the hull and hull fitted equipment below the waterline whilst afloat, this opportunity is achievable and maintainable.

(g) While Type 45 Destroyers are to be fitted with Rolls-Royce WR-21, offering up to 27% fuel reduction in comparison with preceding gas turbines, this saving will only be maintained if the hull and propeller are regularly inspected and action levels for cleaning or polishing are set. A loss of 2 knots hull speed due to fouling may completely negate this saving.

(h) The ASTUTE class of SSN is fitted with reactor Core H, designed to eliminate the need to refuel during the planned 25-year service. Failure to maintain hydrodynamic efficiency of the hull by regular monitoring and on-condition removal of fouling may reduce the design margins for achieving this service period.

(i) Naval and commercial vessels can benefit from consideration of removal of equipment below the waterline while the vessel is afloat. For equipment that cannot be handled through hatches to the lower decks, opening the hull below the waterline while afloat, using a cofferdam to maintain watertight integrity and to form part of the removal route, may provide a cost effective alternative to docking. This approach may be particularly applicable to configuration change while a platform is in service. FIG. 4 shows a 9m x 7m cofferdam fitted to a commercial vessel. This cofferdam was used for hull plate repair, but a similar type of cofferdam would provide a machinery removal route for a warship.

FIG. 4 – 9M X 7M COFFERDAM FITTED TO A COMMERCIAL VESSEL
The following is a summary of factors against which the effective upkeep of equipment using an UWE capability can be challenged:

(a) Is the required maintenance or repair activity a driver for docking periodicity?

(b) Are demonstrated solutions available from UWE providers.

(c) Are UWE resources available and sustainable?

(d) Does a UWE solution increase risks to platform or personnel? Do these offset risks from postponing tasks until drydocking?

(e) Ability to recover hazardous waste/pollution from UWE process.

Maintenance and development of UWE Capability

The maintenance and development of the UWE capability required to support the RN, or any other military fleet, requires identification of the skills source(s) and the process for maintaining and developing the skills. To ensure that RN Divers and Ship Divers are equipped with the basic skills to support UWE, the Warship Support Agency (WSA) DTECH TS310b has provided training aids simulating parts of a ship’s underwater features and typical defects. The training aids have been installed, and are in use, at the Defence Diving School.

The MoD requires assurance of the level of skills of commercial organizations. Traditional shipyard work is accessible by suppliers’ and customers’ quality controllers. With tasks undertaken below the waterline, and limited third party inspection while the vessels are afloat, the MoD is reliant on the quality assurance systems of the commercial organizations. It is therefore important that UWE suppliers are selected for their proven ability to provide the required level of service or quality of equipment. Some processes (for example propeller polishing) require initial approval before contracts are placed. The MoD would benefit from periodic re-assessment of contractors’ capabilities and the maintenance of feedback records on contractors’ performance. Taking the quoted example of propeller polishing, where this is carried out prior to docking, a report on the quality of surface finish by the waterfront organization (generally independent of the underwater engineering contractor) can form a basis for maintaining (or withdrawing) the contractors approval.

Conclusions

Investment in UWE capabilities has provided the RN surface and submarine fleet with practical benefits in support of platform hull availability and cost savings. The RN has reported savings of over 60% on unprogrammed docking over a three-year period.

The techniques are mature and provide a facility for reducing costs of upkeep for the current surface and submarine fleets.

UWE is a proven tool for the provision of effective condition monitoring. The monitoring of hull and propeller condition, together with fuel consumption, has been demonstrated as an effective tool for realizing through life cost savings and offers opportunities for fleet wide savings.

The capability to maintain and repair ships and submarines afloat provides opportunity to extend docking cycles. The capability to extend docking cycles by the use of UWE is currently being demonstrated by the US Navy. Additional savings may be obtained by enlisting input from UWE providers into planning/costing of maintenance periods, refits and upgrades.
For new classes of ship or submarine, whole life cost savings may be realized by consideration, at the design stage, to through life UWE support. The design would benefit from establishing the current and projected capabilities of organizations with the capability to assist the class worldwide. The key skills and training requirements for divers and ships staff should be identified at the design phase.

References

3. JESSUP Stuart D. ‘Prediction of Power Losses due to Propeller Roughness.’ Naval Surface Warfare Center, United States Navy, CDRKNSWC-HD-1269-03.