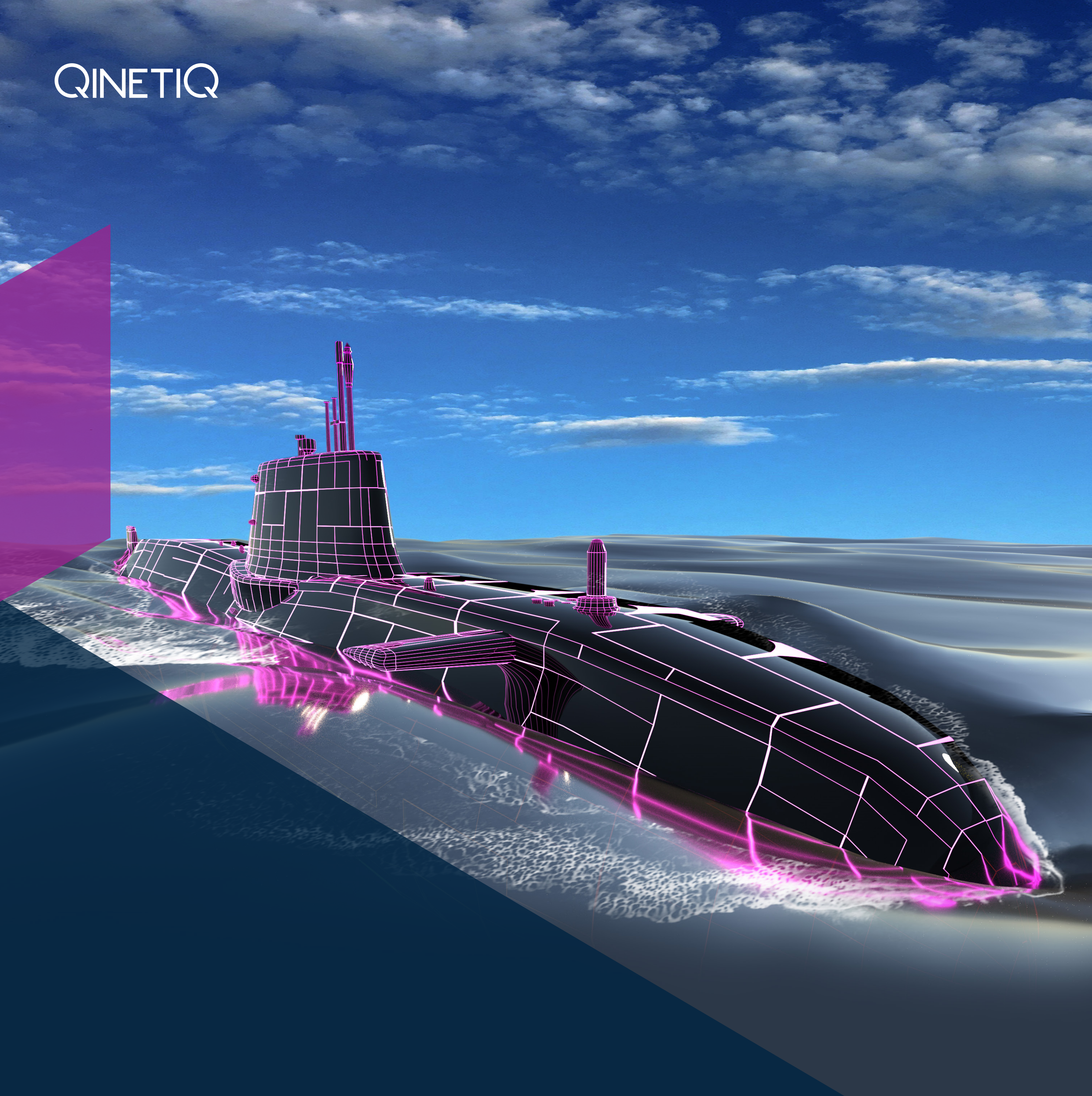

The Future of Underwater Test & Evaluation

The world's first military submarine, Turtle, initially saw action in 1776. Acorn-shaped, built from wood, and operated by a single crewman, it failed in all of its attempts to sink its intended targets, but demonstrated an ability to evade detection in the murky waters of New York harbour.

125 years later, the Royal Navy launched Holland 1. Described by Military History Matters as "the first recognisably modern submarine", Holland 1 (or 'HM submarine Torpedo Boat No. 1') took an eight-man crew and could carry three 18-inch torpedoes. Underwater craft have come a very long way in the twenty-five decades since Turtle's deployment.

Operating in a highly challenging and unforgiving environment, the need for absolute engineering excellence for today's submarines is paramount. Submarines play a hazardous game of hide and seek against enemies equipped with increasingly sophisticated and novel sensors. As a result, submarines must be designed to be as stealthy as possible across a very wide frequency spectrum, and regularly tested both during design before being accepted and once in service to ensure that they remain this way. In a 2021 news story published by the Ministry of Defence, Ian Booth, CEO of the UK's Submarine Delivery Agency described the design and construction of such vessels as: "...one of the most complex and challenging feats of engineering that the maritime industry undertakes". Of course, as well as submarines, modern underwater military system providers are continually developing and exploiting emerging technologies, uncrewed systems for example, to increase their effectiveness.

QinetiQ, and its predecessors has been involved in Test and Evaluation (T&E) in the maritime domain for over 100 years. This heritage, alongside our experience, gives us a unique insight into the future of T&E in this challenging domain. It is, of course, hard to know precisely what the future will bring, but here we explore four areas, all of which are based in the extrapolation of current trends.

The Adoption of Digital Engineering

Stealth is one of the most, if not the most, critical characteristic that future underwater platforms must achieve to ensure continuing operational effectiveness. This must be delivered against the continual development of improved technologies to detect conventional signatures and the development of novel modes of underwater platform detection, both of which are happening at pace. Matching this pace will see the increased convergence of several emergent themes; digital twinning and data analytics underpinned by increasingly complex modelling and critical live testing.

Digital twinning, driven by improvements in computational power and storage, is defined by IBM as 'a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making. It is currently more prominent in the civil industry than defence, where digital twins are used to provide predictive diagnostics for jet engines for example. Integration of data from suitable sensors into a digital twin of a maritime platform could provide a real-time insight into emergent signature issues. The confidence in this process will be underpinned by the validation of the physics embodied in the predictive tools that exploit the digital twin to generate signature insights. This will shift the emphasis of live testing from one of direct signature measurement to validation of the physical processes that map platform features to detectable effects. However, it is worth reflecting on the complexity of a modern submarine and resulting difficulty in the successful realisation of this approach.

This leads to the second enabler; data analytics and machine learning. Many of these physical processes are highly complex and trying to embody them directly in conventional physics based modelling will be increasingly challenging. However, the integration of data from physical measurement both at full-scale and sub-scale, computational modelling and historical measurements provides a large data base to which modern tools can be applied to 'learn' and embody the physics. Computational Fluid Dynamics (CFD) and other approaches can be expected to grow in effectiveness and areas of use. However, physical experimentation, including sub-scale, will be needed to increase confidence in the predictions of modelling - as well as address the issues currently (and for the foreseeable future) that are beyond synthetic modelling's capability.

Both of these initiatives fall under the purvue of digital engineering and exploit the benefits of much more deeply integrating test data derived throughout the design, development and deployment of the platform. Consideration of the lifecycle holistically allows for the balance of sub-scale, full-scale and computational techniques to be tuned in-line with risks and unknowns. For example, the need for new forms of instrumentation to understand and quantify phenomena that are poorly understood. As synthetic approaches then improve, experiments will be needed to validate new modelling techniques or assess novel designs where the confidence in the modelling has yet to be established. This deep integration will be key to understanding and mitigating the performance of new technologies designed to detect very stealthy, but large masses, moving under the sea-surface.

Uncrewed Platforms will Proliferate

Robotics and Autonomous Systems (RAS) is a major defence focus area for all operational domains, but Uncrewed Underwater Vehicles (UUV) are not new, and have seen military use for decades. The first autonomous underwater vehicle (or 'AUV' - often used synonymously with UUV in a military context) was the 'Special Purpose Underwater Research Vehicle' (SPURV), which was developed in the late 1950s.

In the intervening six decades, UUVs have come a long way. Advances in battery and materials technologies have helped to drive progress, along with improvements in communications technology to allow the underwater networking of capabilities. Autonomous and semi-autonomous systems already see extensive use in the oil and gas industry, being perfectly suited for surveying remote assets in challenging and changeable sea conditions. It is clear that defence has something to learn from the oil and gas industry in this regard, but defence is also making progress of its own. In March 2020, the Royal Navy announced the acquisition of Manta, its first autonomous extra-large uncrewed underwater vehicle ('XLUUV'). In the longer term, the Royal Navy has outlined within its Atlantis concept, its intention to bring an increased number of autonomous systems into operation.

Many now predict a move to crewed maritime platforms as 'hosts' for smaller uncrewed and automated vessels. Such small uncrewed vessels could extend the host vessel's search range and capabilities, being used for mine detection, forming a protective perimeter around their host vessel, and eventually engaging the enemy directly, for example.

Many elements of the design and performance of the UUV will be evaluated through the use of physical, computational and operational models. Assuming the validity of the models, this clearly allows a much broader range of test conditions to be considered and is much more cost-effective than a large live T&E programme. However, it is important that the limitations of the modelling environment are well understood.

Exploring this in a bit more detail for the sensors and decision making within autonomous systems highlights some of the T&E issues that will need to be considered. By definition, such systems react to how the platform sensors, sonar for example, perceive the outside world. During a development programme, there are likely to be specific measurement campaigns to capture data in specific domains to support both off-line sensor and algorithm development. These will be complemented by closed-loop simulations using synthetic data-sets to provide the breadth of operationally relevant conditions. However, to have confidence in the overall predicted platform capability, it is important that the sensors are stimulated accurately within the simulations. What constitutes sufficient accuracy is not always obvious, requiring a deep insight into the physics of the sensors, the developed algorithms and the properties of the environment that they use to inform decision making. Only through this understanding, can a synthetic test environment be developed that is validated for appropriate use. The danger is a perception that the synthetic environment is the complete answer and its development becomes expensive, time consuming and of limited value.

Ultimately, critical to the successful exploitation of such UUV will be gaining the confidence of the operator. Such confidence could need to be established in a range of conditions from a simple case of a single UUV to, potentially, a complex multi-platform mission comprising an integrated UUV swarm package. Again, although the majority of this would be expected to be completed within a synthetic environment, it will likely still be necessary for the operator to experience the UUV behaving appropriately in a safe live test environment. This will be especially true during the initial instantiation of such a capability where user confidence is still being established. It likely that between these two steps, hybrid approaches combining live and virtual components would be adopted to maintain the pace of the testing whilst minimizing the cost of the assets required.

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Novel designs will require different kinds of testing

A range of animal-inspired (biomimetic) propulsion mechanisms offer unusual alternatives to the mechanical turbines in use today, and could be far more appropriate for the propulsion of small UUVs for example. As an example, Festo's AquaJelly is 'an artificial autonomous jellyfish with an electric drive unit and an intelligent adaptive mechanism that emulates swarming behaviour.' EvoLogics' Bionic Observation and Survey System (BOSS), Manta Ray, is described as an 'experimental bionic vehicle', is modelled on the manta ray, and can move through water by the wing-like movements of its 'pectoral fins'. The third example is Animal Dynamics' Malolo, which uses a tuned flapping foil for propulsion. Its developers claim that it 'has the potential to be more efficient than a propeller, and deliver a higher thrust coefficient over a greater range of speeds than a propeller can.' Both AquaJelly and Manta Ray are swarm-capable.

But, how do you test and evaluate a flipper, or an air pump? Time will eventually tell. There are challenges to overcome. New testing capabilities will be required to meaningfully measure noise and performance with confidence at the model scale. The wakes from flapping paddle type solutions, particularly with interacting fins (which can be highly non-linear) can create challenges for analytical modelling, and for moving from model scale to the larger scale. Work may need to be done to further develop CFD or to bring in other novel techniques, such as Fluid Structure Interaction.

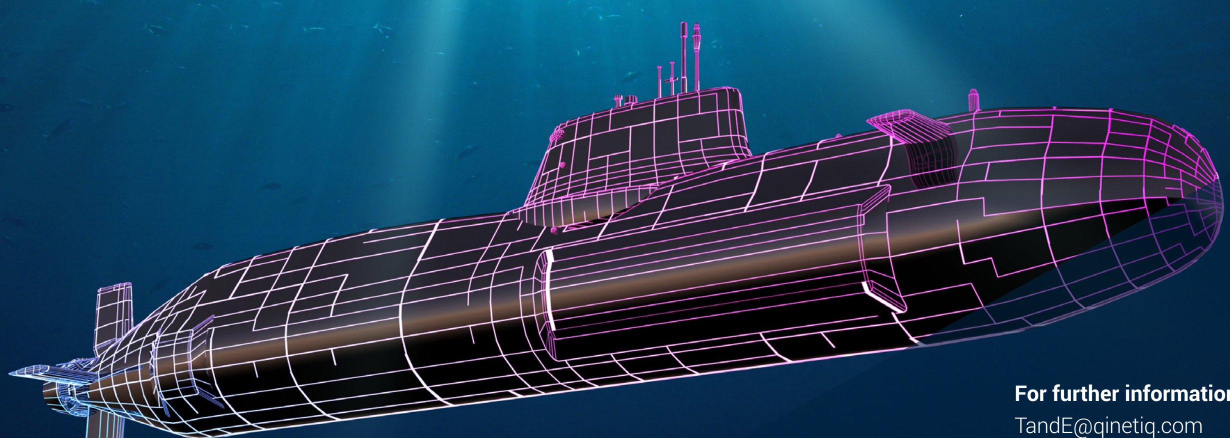
Assuring Frontline Capability Through Deployed T&E

Looking to the future, naval operations are ever-evolving as operational theatres and requirements change. Regularly bringing maritime assets back from their forward stations to a fixed range for testing puts a strain on forward deployed forces. One way to negate this is through the use of deployable T&E and training capabilities that allow units and task groups to remain deployed for longer periods. Put another way, instead of taking the platform to the range, the range is taken to the platform or indeed the platform carries the range with it.

Such deployable T&E facilities might not be able to provide as high fidelity data as specialised fixed ranges, but could, if suitably integrated with prior data from these fixed ranges, allow a frontline commander a more timely level of operational assurance or highlight emerging issues that require specialist facilities to assess further. Examples include deployable signature measurement (acoustic, IR, RCS, magnetic signature, etc.) and deployable training (deployable/portable ranges, novel threat representation, etc.) which could help to provide operational capability 'top-ups', mid deployment.

A good example of such a capability is a deployable underwater tracking range. The oil and gas industry have been using sensors that, with simple modifications, can be used to provide such a capability that is easily deployed and recovered. Such a range provides a temporary instrumented water space for the development of tactics for UUV working in conjunction with conventional platforms, the operational testing of new software deployed to UUVs for new missions or for the continued training of sonar operators with the range instrumentation providing the ground truth for the target position and its manoeuvring.

In this short paper we have captured some thoughts and suggestions about how we believe T&E will need to evolve to address the challenges and opportunities that new and emerging technologies will present. We are in a very exciting, and rapidly changing, world where digital innovation will really drive the pace for the adoption of these new technologies. T&E tools and techniques will need to evolve at pace to continue to give the military user the confidence in the capabilities at their disposal. Achieving this will require a seamless integration across digital engineering and modelling and simulation, whilst not losing sight of the critical role of focused sub-scale and full-scale live test events, which ultimately provide the designer and the user the confidence they need.



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