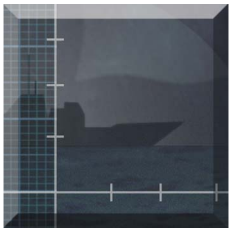

Ocean Engineering and Technology Assessment: An Overview

Ralph H. Brown and Bruce K. Newhall

From the birth of the Submarine Technology Department 25 years ago through today, we have been involved in the process of assessing and developing emerging technologies for undersea warfare (USW) applications. The assessment process has often required extensive ocean engineering efforts to validate concepts in the real ocean environment. Articles in this section of the *Technical Digest* present several recent examples of these assessments and associated ocean engineering activities. Whenever assessments prove technologies and concepts that have immediate potential useful application, system development can follow.

EMERGING TECHNOLOGIES ASSESSMENT PROCESS

The first step in the assessment process is to identify new technologies that may have potential USW applications. Sources for new technologies and concepts may arise internally or from maintaining contact with academic, Navy laboratory, and Office of Naval Research–funded researchers; literature or Internet searches; or even foreign intelligence reports. More often, a panel of experts meets for brainstorming sessions. The National Security Technology Department (NSTD) maintains a library with a large volume of both classified and unclassified reports that serve as sources of this material. Once a number of potential technologies emerge, the sponsors, often aided by their panel of experts, decide on a single most promising approach to pursue.

Initially, performance is assessed through modeling and simulation of the physics of the ocean process and the physics of the relevant technology. Sometimes this initial modeling is sufficient to assess whether the technology could perform. More often, however, the initial modeling identifies some ocean property that is both critical to the performance of the system and is not well understood. For example, one technology explored early in the department's history was the potential for long, towed passive acoustic arrays. Such arrays had been developed by the undersea oil prospecting industry, and were being used in an active acoustics application to search for undersea oil deposits.

It was proposed that the same technology could be used in a passive mode to listen for the noises emitted by submarines. Initial modeling showed that this might be possible if the array were long enough to achieve sufficient gain. However, the performance of the array to maintain gain across an extremely long aperture depended on the spatial coherence of the ocean. If the ocean were not highly coherent for acoustic signals, then long arrays would be limited in performance. It was known that the ocean contained internal waves whose fluctuations might scatter the sound and reduce its coherence. At the time, there was much academic debate on the characteristics of internal waves and the amount of their influence on acoustic propagation coherence.

If a critical physical property is not well understood, the assessment can only proceed by making actual ocean measurements. The requirements for the quantities to be measured are meticulously defined. Often, new measurement equipment must be designed, since these physical properties have not been measured before. This can involve significant ocean engineering efforts, as described in more detail below. The measurement system, while having many similarities to the technological system being assessed, may have significant differences specifically to meet the measurement needs.

Returning to our example of passive acoustics towed arrays, APL determined that an array much longer than current oil prospecting arrays would be required to explore the limits of ocean coherence. However, the measurement array could have large gaps between the sensors, a considerable savings over a fully filled array that would be an actual USW system. The Laboratory referred to the measurement array as the "Skeleton Array."

Once the measurement requirements and equipment are specified, the engineering of measurement systems commences and detailed test plans are developed. The chartering of suitable ocean research vessels is a considerable expense, so test time is precious. Meticulous plans for round-the-clock operations are developed so that no time is wasted.

The ocean is also an unpredictable and unforgiving environment, as storms and waves can break equipment or prevent safe deployment, and corrosive salt water may cause electronic or mechanical failures. Test operations plans must be modular and prioritized so that when conditions change, the test can be quickly restructured to obtain the optimum data. Measurement priorities may require that operations be conducted in discrete segments.

For the skeleton acoustic array, APL planned and conducted two major experiments: the Skeleton Array Experiment (SKELEX) in a warm summer convergence zone condition, and the Standard Aries test in a winter surface ducting condition. These two experiments measured the range of ocean coherence in the two most characteristic acoustic conditions of the deep ocean.

With 24-hour-a-day operations, little time is available for careful and thorough analysis. Real-time analysis is generally limited to a minimum amount required to ensure that high-quality data are being collected and recorded. The recorded data are examined and analyzed extensively after returning to shore. This analysis can take 1 to 2 years. The SKELEX analysis showed that the ocean has remarkable coherence at sufficiently low acoustic frequencies. Internal waves were not as significant at scattering low-frequency sound as most academicians had predicted.

With the measurement obtained and analyzed, the new physical understanding is used to revise the physical models. The revised models can then be used to accurately predict the performance of the proposed USW system or to make a cost-benefit analysis of several related system designs, other than the one of the measurement system. They may also enable performance predictions to be extrapolated to ocean environments other than the ones where measurements were taken. The revised modeling may motivate the Navy to develop new USW systems. APL's involvement may end at that point, with the transfer of its technology assessment knowledge to external system developers, or the Laboratory may continue its own work in system development.

In the case of the Skeleton Array, APL's work motivated the Navy Surveillance Towed Array Sonar System (SURTASS) program. The SURTASS passive acoustic arrays provided a significant surveillance capability for detecting Soviet submarines during the Cold War. APL has continued to work with SURTASS developers to improve and refine the system, and to extend its capabilities to active sonar.

OCEAN ENGINEERING EFFORTS FOR UNDERSEA WARFARE

One of the core foundations of USW efforts in NSTD has been the development of state-of-the-art ocean sensor systems for surface ship, submarine, or airborne platforms. These unique sensor systems were conceived to demonstrate proof-of-concept principles for advanced U.S. Navy USW programs. The department has developed a considerable ocean engineering infrastructure for sensor systems including specialized personnel, fabrication and development laboratories and facilities, and test support systems.

Evaluating the performance of a newly developed sensor system in a full-scale at-sea test represents a considerable undertaking in terms of both personnel and equipment. The large-scale ocean tests that NSTD routinely performs can include multiple surface research vessels and Navy participants including submarines, surface combatants, and aircraft. Fifty to 100 APL personnel, representatives from government laboratories, and commercial subcontractors are dedicated to these operations. They are required to work aboard the participant platforms or support the operation from various land-based sites for 30- to 60-day periods.

Over its considerable history, NSTD has gained a national reputation in the Navy research community for being able to compile all the elements required to execute a major ocean test successfully. This is no accident. Through a tedious trial-and-error process, the department has developed a rigorous method of planning and executing large-scale ocean tests that greatly enhances the probability of success. This is a true team effort, with scientists, engineers, and support personnel all working toward a common goal. The first article in this section (Harris and Keys) provides an outline of how this complex process is accomplished.

Ocean engineering sensor development projects in NSTD often become long-term development efforts spanning many programs and years. Frequently, an ocean sensor developed for one investigation can be applied to another. As a result, there are several ocean sensor developments in the department whose origination can be traced back more than 20 years. NSTD has often developed unique ocean sensor systems to meet program requirements. Frequently, there is no expertise in a particular sensor system in either the U.S. government or commercial world. In such cases, NSTD independently undertakes the task of sensor development. Once the sensor is successfully fielded, other research programs become interested in the application of the system to their unique requirements.

The original sponsor of a task may also require a higher level of performance to meet future program goals. When this happens, the sensor system is not necessarily used "as is." In the majority of cases, each new application of a sensor system requires extensive redesign to provide increased operating characteristics and capabilities. The complexity of the sensor system can be dramatically enhanced over several of these cycles. Currently in NSTD, there are two discrete sensor systems, one acoustic and one nonacoustic, that follow this pattern of long-term development and enhancement. The nonacoustic sensor system is outlined in the second article of this section (Anderson et al.).

The successful fielding of ocean sensor systems has many aspects. The actual engineering of an ocean sensor system can be an ongoing effort that requires many iterative cycles of design, fabrication, testing, and redesign spanning multiple projects. The process of planning and executing a successful ocean field test is also a considerable undertaking that requires a specialized team of scientific and engineering personnel.

Many of the elements needed for optimum ocean testing are subtle but crucial for attaining measurements. An example is environmental measurements. To successfully plan and execute an ocean test and subsequently analyze data, one must know certain critical characteristics of the ambient ocean structure. Recall that the ocean sensors are prototypes designed to demonstrate proof of principle. When designing the test, the scientist must select an ocean area that optimizes sensor performance. This requires detailed ocean environmental historical data. During the conduct of the test, it is paramount that one thoroughly understand the small- and large-scale dynamics of the ocean area on a near-real-time basis and how they impact sensor performance. These systems often operate at high sensitivity and are susceptible to localized or wide-area changes in ocean dynamics. Environmental measurements are also crucial in post-test data analysis efforts.

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Through the years, NSTD has developed considerable mastery in each of these environmental measurement areas. Our expertise has been successfully used to support NSTD projects and other government research programs and has been recognized by the Navy research community. The third article in this section (Mandelberg et al.) briefly summarizes the extensive environmental measurement capabilities of the department.

The department has had a significant role in active as well as passive sonar. In the early 1980s NSTD participated in and had chief responsibility for several active sonar exercises and tests. These activities considered various types of continuous and impulsive low-frequency active sources with potential application to the detection of submarines at surveillance ranges.

In the mid-1980s NSDT planned and conducted a series of trials originally envisioned as testing the use of sources and receivers that were fixed on the ocean bottom. During planning, these trials evolved into major Navy exercises, with many towed receivers from Navy surveillance and tactical platforms complementing the fixed receivers.

Coordinating such complex exercises led to tasking to plan and conduct two additional series of such exercises during the late 1980s through the early 1990s. Each series comprised about 10 major exercises conducted throughout the oceans of the world and involved a large number of Navy platforms. During the earlier testing, it was determined that certain issues such as bottom scattering and reverberation were not sufficiently understood, and that these issues were critical to the performance of low-frequency active sonar. One of the series of exercises, appropriately named the Critical Sea Test, was designed to measure and gain a scientific understanding of these critical issues across a range of frequencies. Another series was devoted to developing, testing, and refining the Navy's Low Frequency Active SURTASS system, which operated in a single low-frequency band.

In the mid and late 1990s, the Navy's attention turned away from deep water to littoral waters, the shallower seas surrounding coasts where the Navy would most likely be called to operate next. The Littoral Warfare Advanced Development (LWAD) Sea Test Program investigates a number of USW technologies including active sonar, passive sonar, and nonacoustics. These technologies are emerging from scientific research conducted by a number of investigators for the Office of Naval Research. APL's experience in planning and conducting major series such as Critical Sea Test is now being applied to the LWAD series. More details of LWAD are given in the article that follows in this section (Arvelo and Hanson).

After extensive data are collected during at-sea testing, the data are processed, analyzed, and compared with physical models that are refined to include the relevant physics discovered in the testing and analysis process. These sophisticated physical models are then available for prediction of performance in other ocean environments. The accurate simulation employed during war games requires extensive use of precise models among large numbers of simulated platforms. However, accurate, sophisticated models often cannot be run with sufficient efficiency to permit timely predictions during a war game simulation. The last article in this section (Newman et al.) describes a novel approach for running sophisticated models in advance of the simulation and reducing the essential features to a smaller, rapidly accessible set, allowing efficient and accurate simulations.

CONCLUSION

The assessment process described above combines ocean engineering for thorough at-sea testing with rigorous physical modeling to produce an understanding of the first principles fundamental to newly emerging USW technologies.

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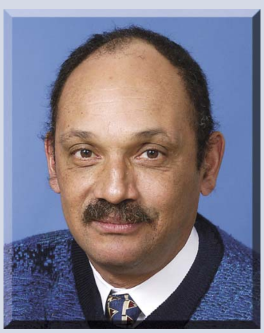

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