# Unmanned Underwater Vehicle Independent Test and Evaluation

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*The Johns Hopkins University Applied Physics Laboratory (APL) has a long history of contributing to unmanned undersea or underwater vehicle (UUV) programs sponsored by several Navy acquisition program offices. Those contributions span the systems engineering realm, including leadership of independent test and evaluation for prototypes and systems fielded for military use. One of the most enduring relationships has been with Program Manager Naval Sea Systems Command (Expeditionary Missions) (PMS-408) for its acquisition of UUVs applied to mine countermeasures (MCM) missions. Since 2002, APL has served as the independent test and evaluation agent for the Mk 18 UUV family of systems. The fielding of key components of the Mk 18 UUV family of systems was accelerated as part of an Office of the Secretary of Defense "Fast-Lane" program to meet an operational need in theater. As a result, Commander Fifth Fleet now has an improved operational MCM capability, including advanced sensors.*

## OVERVIEW

In December 2011, the Office of the Secretary of Defense approved a Fast-Lane initiative to provide Mk 18 Mod 2 Kingfish unmanned underwater vehicle (UUV) systems and associated sensors and upgrades to Commander Fifth Fleet (C5F) on an accelerated basis. Seven months later, in July 2012, wave 1 of the Mk 18 Mod 2 Kingfish UUVs arrived in the C5F area of responsibility to begin search, classify, and map missions as part of a phased incremental-capability rapid-fielding plan that included an extended user operational evaluation system (UOES) period in theater. The purpose of the UOES period was to develop mine countermeasures (MCM) concepts of operations (CONOPS) for integration with other MCM platforms in theater and to receive operator feedback that could be used to improve the design. A second wave of Mk 18 Mod 2 UUVs arrived in theater in February 2013. The third wave arrived in October 2013 and included more UUVs and ancillary equipment. Advanced sensors and command and control technologies were demonstrated in theater in November 2013. After undergoing operational testing in February and April 2014, respectively, they were provided as operational capabilities. The rapid delivery of these capabilities to meet the commander's operational need was made possible by several factors, including the following:

- A technologically mature system design when the Fast-Lane initiative was approved
- Strong program office leadership of a multi-organizational integrated product team (IPT)
- Strict adherence to identified measurable and testable user requirements
- Outstanding testing and feedback support from operational units
- A competitive manufacturer selection process
- A "build a little, test a little, field a little" development process
- Responsive in-service engineering agent (ISEA) support

The Mk 18 Mod 2 systems in theater are being operated by civilian contractor crews led by a government civilian. The crews and their leadership are under the administrative and operational command of the C5F Explosive Ordnance Disposal (EOD) and MCM task force commanders, respectively. The civilian crews in the C5F area of responsibility will be replaced by military crews.

Advances in unmanned ground vehicles have reduced human casualty risk during EOD operations in Afghanistan and Iraq. Investment in UUV technologies is considered particularly important for the maritime environment because UUVs can "get the man out of the minefield" for some, if not all, required missions. The Mk 18 Mod 2 Kingfish UUV program is one of the acquisition community's initiatives to meet the fleet mission need to conduct EOD MCM operations more safely, efficiently, and effectively against a wide spectrum of current and anticipated threats in a variety of operational environments. UUVs of various sizes, with increasing levels of autonomy, sensor capability, and payload composition, comprise a rapidly expanding part of the "toolbox" available to address underwater domain mission requirements.

The Mk 18 Mod 2 was preceded by other systems used for hydrographic surveys and harbor defense and by the militarized remote environmental measuring units (REMUS), which were used in 2003 as part of the clearance of Umm Qasr, Iraq, during Operation Iraqi Freedom. According to Captain Michael Tillotson, Commander, Naval Special Operations Task Force 56 during Operation Iraqi Freedom, "If we didn't have UUVs, you could multiply the time to clear the [Umm] Qasr area by two-and-a-half, an additional 20 days."[1] In less than 15 years, this relatively small acquisition program [less than Acquisition Category (ACAT) IV in terms of programmatic expenditures] incrementally developed, tested, and fielded leading-edge unmanned vehicle and command and control technologies using both military and civilian crewing philosophies. As the Navy transitions to increased reliance on unmanned systems, as well as to the operational integration of unmanned and manned systems in the underwater domain, future acquisition programs might consider adopting aspects of this program's organization, development, testing, and fielding practices to help navigate the acquisition pipeline.

## BACKGROUND

APL has a long history contributing to UUV programs sponsored by the Defense Advanced Research Projects Agency, the Office of Naval Research (ONR), and several Navy acquisition program offices. Those critical contributions span the systems engineering realm, including leadership of independent test and evaluation for prototypes and systems fielded for military use. One of those contributions was to assist in the preparation of *The Navy UUV Master Plan* in 2000, which was updated in 2004[2] and identified nine high-priority UUV missions:

- Intelligence, surveillance, and reconnaissance
- Mine countermeasures
- Anti-submarine warfare
- Inspection/identification
- Oceanography
- Communication/navigation network nodes
- Payload delivery
- Information operations
- Time-critical strike

To perform these missions, *The Navy UUV Master Plan* characterized vehicle systems into four general classes:

- **Man-portable vehicle class:** Vehicles of approximately 25–100 lb displacement with 10–20 hours of mission endurance; no specific hull shape identified
- **Lightweight vehicle class:** 12.75-in.-diameter vehicles of approximately 500 lb displacement, 20–40 hours endurance, with payloads of 6–12 times the size of a man-portable vehicle
- **Heavyweight vehicle class:** 21-in.-diameter vehicles, up to 3000 lb displacement, 40–80 hours endurance, with 2 times payload capacity of lightweight vehicle class, suitable for launch from submarines

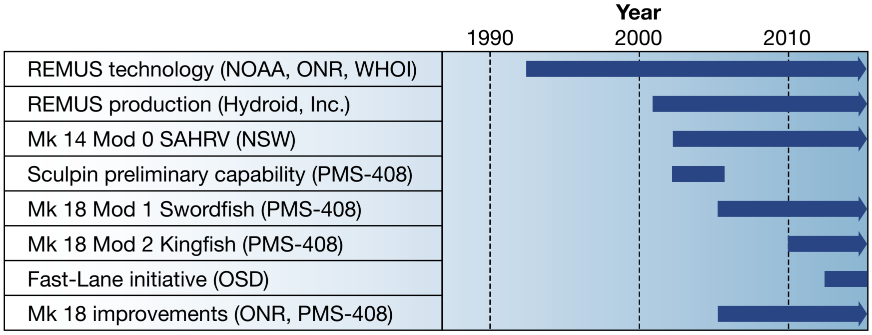



**Figure 1.** UUV acquisition time line. NOAA, National Oceanic and Atmospheric Administration; NSW, Naval Special Warfare Program Office; PMS-408, Program Manager Naval Sea Systems Command (Expeditionary Missions); OSD, Office of the Secretary of Defense; SAHRV, semi-autonomous hydrographic reconnaissance vehicle.

- **Large vehicle class:** Vehicles with approximately 10 long tons displacement and suitable for launch from surface ships (e.g., littoral combat ship) and submarines

The lightweight vehicle-class Mk 18 Mod 2 Kingfish UUV is a larger, extended-range version of the Mk 18 Mod 1 Swordfish man-portable search, classify, and map system currently deployed in several operational theaters. In accordance with Secretary of the Navy Instruction 5000.2E,[3] both systems were developed as Abbreviated Acquisition Programs (AAPs) under the sponsorship of OPNAV N957 and guidance of PMS-408 using an informal IPT organization from requirements development through system development, developmental testing, user evaluation, and operational fielding.

The Mk 18 family of systems (FoS) is based on REMUS vehicles built by Hydroid, Inc., a subsidiary of Kongsberg Maritime. The Mk 18 Mod 1 and Mod 2 vehicles are REMUS 100 and REMUS 600 vehicles, respectively, where the number denotes the rated depth of the vehicle in meters.

REMUS UUV technologies originated in the early 1990s at the Woods Hole Oceanographic Institution in Massachusetts. UUV systems based on REMUS vehicles are in use by the navies of the United States, United Kingdom, and others that leverage the REMUS UUV family of vehicles. The Navy tested and fielded earlier versions of small man-portable REMUS UUVs, known as the SAHRV, and the Sculpin (a predecessor of the Swordfish). REMUS vehicles are also in use by commercial, oceanographic, and academic organizations in several countries.

Commander Operational Test and Evaluation Force (COMOPTEVFOR, designated by the Chief of Naval Operations to be the Navy's sole independent agency for operational test and evaluation of ACAT I through IV programs) conducted the operational evaluation of the SAHRV vehicles in the late 1990s. After an agreement was reached between PMS-408 and COMOPTEVFOR, APL was tasked to take over the role of independent test and evaluation agent (IT&EA) for follow-on non-ACAT small UUV programs. Since 2002, APL has served as the IT&EA for the original very shallow water (VSW) UUV program, the Bottom UUV Localization System, and the Mk 18 FoS program. Figure 1 provides a chronology of system development that culminated in the initiation of the Mk 18 FoS program of record.

Design changes and improvements made to the SAHRV and Sculpin, as a result of user feedback, enabled a running start for the Mk 18 FoS. Figure 2 shows the relative sizes of the Mk 18 Mod 1 man-portable and Mk 18 Mod 2 lightweight vehicles.

The Mk 18 Mod 1 vehicles are designed to be launched and recovered by operators in small boats such as the 4.7-m combat rubber raiding craft (CRRC) or 7-m

**Figure 2.** Mk 18 Mod 1 and Mod 2 UUVs. (Image courtesy of Space and Naval Warfare System Center, Pacific.)

**Figure 3.** Recovery of Mk 18 Mod 1.

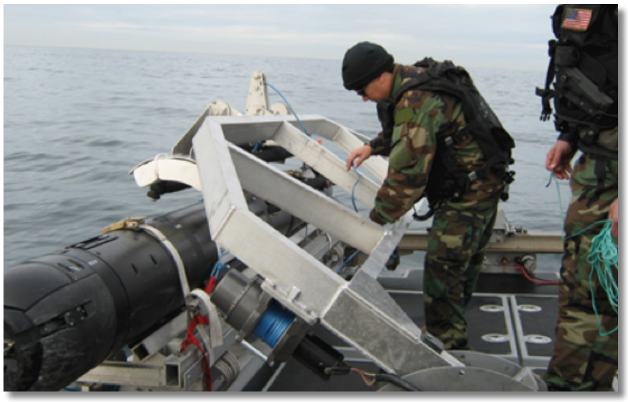


**Figure 4.** Launch preparations for Mk 18 Mod 2.

rigid hull inflatable boat (RHIB). The Mk 18 Mod 2 vehicles are designed to be launched and recovered from 11-m RHIBs using a specially built launch and recovery system or by crane from a ship. Figure 3 shows a Mod 1 vehicle being recovered from a CRRC by EOD Mobile Unit One (EODMU-1) operators during factory acceptance testing in 2006. Figure 4 shows two operators from EODMU-1 rigging the 11-m RHIB Mk 18 Mod 2 launch and recovery system before a vehicle launch during the February 2011 user evaluation testing.

The Mk 18 Mod 1 was required to address threats in the VSW and some parts of the shallow water region. The Mk 18 Mod 2 was also required to conduct operations in the VSW and shallow water region, but in addition, the fleet requested characterization of system performance in deeper water. Figure 5 shows the standard operating regions by depth for MCM operations.[4]

In December 2011, C5F submitted a request for additional expeditionary underwater MCM operations capabilities, and an Office of the Secretary of Defense (OSD)-funded "Fast-Lane" program was established to accelerate the transition of existing and planned Mk 18 Mod 2 UUV capabilities into theater as soon as possible.

In November 2012, unrelated to the Fast-Lane initiative and as part of the maturing of the Mk 18 FoS, OPNAV 957 established a consolidated requirements document for search-based UUVs in support of expeditionary operations and an ACAT IV program to continue the development of UUV underwater MCM capabilities. OPNAV 957 is currently coordinating the development of the Lightweight Expeditionary MCM UUV (LEMUUV) capability development document.

Key participants in the development of Mk 18 Mod 2 system capabilities are listed in Fig. 6.

## FACTORS FOR SUCCESSFUL DEVELOPMENT, TESTING, AND FIELDING

Several factors enabled the rapid delivery of Mk 18 Mod 2 capability in theater to meet the commander's operational need.

### Technologically Mature System Design

Much like the Mod 1 system development that leveraged the REMUS 100 vehicle technologies (including the propulsion design, battery power supply, sensors, navigation capabilities, and vehicle interface program), the Mk 18 Mod 2 system development leveraged the Mk 18 Mod 1 development and programmatic documentation (acquisition plan, requirements document, and performance specification) and the existing REMUS 600 vehicle technologies. The Mod 2 vehicles had already demonstrated reliable operations before mission testing started. The importance of starting operator testing with a reliable vehicle cannot be overstated. Fleet operators will not use an unreliable system despite any promise of new capability.

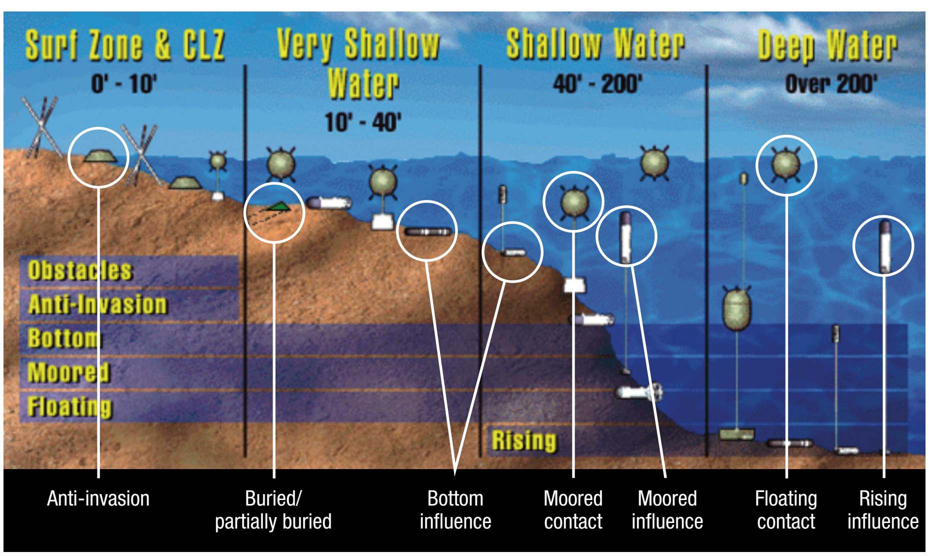
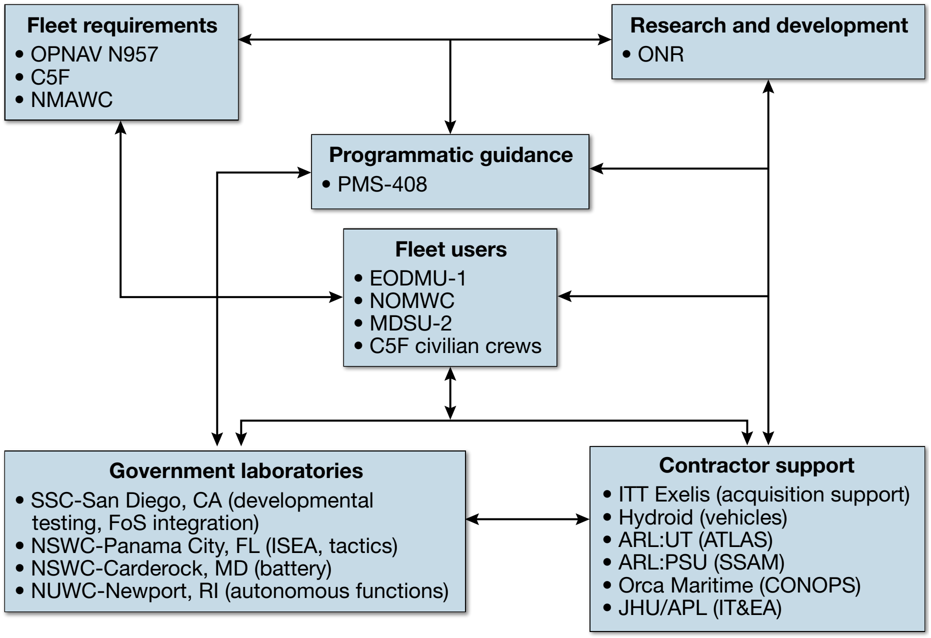



**Figure 5.** Littoral mine threats (Image courtesy of Office of the Chief of Naval Operations Expeditionary Warfare Directorate). CLZ, craft landing zone.

Because the vehicles and supporting equipment (e.g., laptops, software applications, and vehicle communications) were reliable, fleet, government civilian, and contractor operators had the opportunity to use the system in operationally relevant environments and provided early feedback. This led the developer and IPT membership to recognize, early in the process, the importance of operator training, the need to address




**ACRONYMS:** ARL:PSU, Applied Research Laboratories, Pennsylvania State University; ARL:UT, Applied Research Laboratories, The University of Texas at Austin; ATLAS, Autonomous Topographic Large Area Survey; MDSU-2, Maritime Diving and Salvage Unit Two; NMAWC, Naval Mine and Anti-Submarine Warfare Command; NOMWC, Naval Oceanography Mine Warfare Center; NSWC, Naval Surface Warfare Center; NUWC, Naval Undersea Warfare Center; OPNAV N957, Chief of Naval Operations, Expeditionary Combat Branch; SSAM, Small Synthetic Aperture Minehunter; SSC, Space and Naval Warfare Systems Center.

**Figure 6.** Mk 18 FoS IPT.

human machine interface issues to facilitate operator use, and the importance of having sufficient spares and logistics in place to support sustained operations.

## Program Office Leadership

The program manager worked closely with OPNAV, the Navy requirements community, ONR, prospective developers including Hydroid, government laboratories, and the fleet to forge a dedicated team with identifiable goals and milestones. The program manager dictated that a phased, walk first–run later development approach would be undertaken. The importance of getting something reliable into the hands of operators for evaluation and feedback was emphasized from the start. For the Mk 18 Mod 1 system, the size and weight of the vehicle was directly driven by the operator's ability to handle it during launch and recovery and during transport to and from the launch platform. Any manufacturer request to increase the size or weight of the vehicle was contingent on operator agreement and demonstration that the added weight or size could be safely integrated.

Enabled by the program manager, IPT members, including the small APL team (one to three part-time personnel at any time over a 12-year period), were afforded early access to the technology in development by ONR and the manufacturers. IPT members were educated on the maturity of existing and near-term sensor technologies and vehicle endurance characteristics. IPT members were also exposed early to operator requirements and feedback on design and CONOPS as well as lessons learned from the development and operational testing of the SAHRV and Sculpin vehicles.

Emphasis was placed on designing modular payloads so that systems could later be upgraded as sensor, vehicle navigation and stability, and battery technologies improved. It was recognized early on that sensor maturity would not support operations in the most rigorous of environments or in every sea state against every possible threat, so realistic, measurable, and testable requirements were established for what were to be considered first-generation vehicles and sensors.

The program manager actively championed the importance of evaluating the systems' operational suitability aboard ship and for use from all the expected launch platforms (e.g., amphibious ship well decks, 7-m and 11-m RHIBs, CRRCs, and piers). Figure 7 shows launch and recovery operations of the Mk 18 Mod 1 system during an EODMU-1 command exercise aboard USS *Denver*, amphibious transport dock 9 (LPD-9) in December 2006.

The program manager also recognized the need to provide a consistent and interoperable way to provide command and control of multiple and different UUVs and, after a thorough industry search, funded development of the Common Operator Interface Navy-EOD (COIN) software to conduct mission planning and post-mission analysis (PMA). The COIN output was compatible with the Navy's standard mine warfare tactical decision aid known as the Mine Warfare and Environmental Decision Aids Library (MEDAL). MEDAL compatibility made the UUVs interoperable with the larger Navy's activities. The program manager decreed that for any UUV manufacturer to compete for future production opportunities, the vehicles must be able to exchange information via the COIN system. The policy encouraged UUV manufacturers to make their systems compatible with COIN for mission planning and PMA.

The program manager worked closely with ONR to encourage the development of the next-generation sensor technologies so that UUVs could operate in more challenging environments and against a wider array of

**Figure 7.** RHIB launch and recovery aboard an amphibious ship.

threats. Desired sensor technology enhancements and increased endurance requirements eventually led to increases in the size and weight of the vehicles and to the initiation of the Mod 2 program.

## Measurable and Testable User Requirements

The initial requirements for the VSW MCM UUV were drafted by acquisition and technical subject-matter experts, followed by early input from the operational community. Formal requirements documentation was then influenced by experience gained during the SAHRV operations and the first VSW MCM UUV UOES period with the REMUS 100 system that later became known as Sculpin, as well as by expected CONOPS and knowledge of the existing and near-term threat. Early exposure to SAHRV and Sculpin lessons learned, near-term UUV and sensor technologies, and user requirements and CONOPS enabled the IPT to develop measurable and testable requirements.

APL, as the IT&EA, was part of the vetting of the requirements documentation and stressed that, if the criteria for the measurement and testing of a requirement were not clearly delineated in writing, the requirement should be rewritten until it was both measurable and testable. The program manager supported this philosophy and ultimately mediated and resolved several discussions where the operators, developers, and testers differed on the interpretation of the requirements. APL later used these requirements to prepare and deliver test plans, conduct user evaluation during several test periods from 2002 to the present, analyze results, and characterize the system's operational effectiveness and suitability in several formal reports.

A good example of a challenging test requirement was the "Probability of Classifying a non-mine as a mine ($P_{CXM}$)." This metric was recommended over using the more widely known MCM metric "non-mine density for classification" because $P_{CXM}$ could be more objectively measured during the brief user evaluation periods. The UOES experience with the REMUS 100 UUVs indicated that $P_{CXM}$ was not as straightforward as it sounded. Images provided by early-generation side-scan sonars made some commonly accepted non-mine objects appear mine-like. As a result, objects that did not produce mine-like returns, known as distractors, were placed on the ocean bottom among the exercise mines to unambiguously assess the $P_{CXM}$ metric. Although false contact density was not an imposed requirement, because it varies widely with the environment, the metric was routinely included in test reports.

To ensure an understanding of the UUV system's capabilities, the IT&EA participated during key parts of UOES periods, such as command exercises where the UUV system was used operationally. In addition, developmental testing personnel invited APL staff to observe whenever fleet operators were operating the vehicles. The early use of the system by fleet operators provided valuable feedback on the expected CONOPS and an appreciation by the IPT members for the "must-haves" versus the "nice-to-haves," and it also enabled realistic planning for the subsequent user evaluations. During user evaluations, all UUV operations were planned, conducted, and analyzed by fleet operators. User evaluation is to an AAP what an operational evaluation is to an ACAT program.

System performance specifications, key performance parameters, and critical operational issues were identified and approved by the program manager after endorsement by members of the IPT. Although requirements were informed by existing intelligence agency threat characterizations, the system requirements did not require threshold performance against every conceivable underwater threat. Provisions were made in the acquisition program testing plan to characterize performance against more challenging threats and environments without mandating specific performance against all anticipated threats.

APL staff also leveraged the COMOPTEVFOR SAHRV program documentation and testing methodology to help ensure that user requirements for operational effectiveness and operational suitability were adequately represented in the requirements and testing documentation.

## Outstanding Operator Support

Outstanding support was provided during all UOES, developmental testing, and user evaluation testing periods by the EODMU-1 UUV platoon (previously known as Naval Special Clearance Team One) and later by other military and civilian UUV operators from Naval Oceanography Mine Warfare Center, Maritime Diving and Salvage Unit Two, and Space and Naval Warfare Systems Center Pacific. Operators willingly executed a myriad of testing operations. Operators diligently completed surveys and interviews and attended and provided regular formal presentations at program reviews. This feedback was essential for the program. The fleet's buy-in to the objectives of the testing program was critical to the identification and implementation of UUV improvements. Figure 8 shows EODMU-1 personnel during the February 2011 user evaluation rigging Mk 18 Mod 2 vehicles onto an 11-m RHIB pier side at Space and Naval Warfare Systems Center Pacific.

All user evaluation operations were conducted as blind tests. Similar to real-world operations, UUV operators were provided a mission and asked to plan, search, and report results of operationally representative missions. Tests were designed to represent a wide variety of operational environments. For example, maximum-endurance and short-duration operations were conducted during daylight and at night, in sea states that varied from 1 to 3, in various bottom types, using a variety of launch and recovery platforms, and with little to no advance notice on the detailed tasking to be executed. Operators had the flexibility to determine the battle rhythm so long as all vehicle operations and PMA were completed during the evaluation. Figure 9 shows an EODMU-1 operator conducting PMA.

Testing and feedback from operators led to UUV system requirements such as improved planning and PMA software functionality; more rugged and water-resistant computers with larger, more viewable screens; tamper-proof vehicle design; modifications to the battery charging and safety considerations; P-code Global Positioning System (GPS), vehicle launch, and recovery handling modifications; modified vehicle lighting for low-visibility operations; more extensive training; and system documentation including detailed operator and maintenance manuals. For the Mk 18 Mod 2 program, operator feedback was used to design, deliver, and upgrade launch and recovery systems for individual vehicles onto 11-m RHIBs and for 11-m RHIBs carrying Mk 18 Mod 2 vehicles onto ships.

Figure 10 shows civilian operators conducting Mk 18 Mod 2, 11-m RHIB stern gate launch and recovery system

**Figure 8.** Mk 18 Mod 2 pier side loading onto 11–m RHIB.

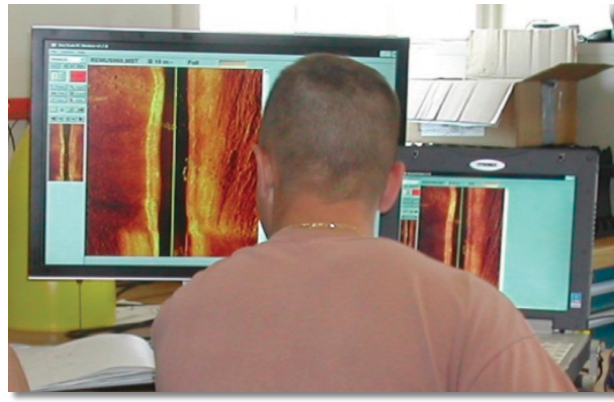


**Figure 9.** EODMU-1 operator conducting PMA.

**Figure 10.** Mk 18 Mod 2 11-m RHIB stern gate launch and recovery system.

operations during April 2013 testing aboard USS *Ponce*, Afloat Forward Staging Base Interim 15 [AFSB(I) 15], in the Arabian Gulf, with APL participation as IT&EA. The alternative to the stern gate launch and recovery is craning the 11-m RHIB off the ship as shown in Fig. 11.

## Competitive Manufacturer Selection Process

After a broad agency announcement, multiple companies participated in a demonstration at the Naval Amphibious Base, Little Creek, Virginia, to enable the Navy to select potential UUVs to enter into the acquisition process. This demonstration and down-selection allowed PMS-408 to begin a UOES period with two technologically mature man-portable UUVs.

The UOES period and Mk 18 Mod 1 developmental test periods yielded two UUV systems provided by different manufacturers that were assessed and determined sufficiently ready to proceed to user evaluation to support a production decision. For the user evaluation in 2004, vehicles from the two manufacturers were tested in the same minefields over a rigorous 6-week test period. Fleet operators from Naval Special Clearance Team One (later called EODMU-1) operated the vehicles in daytime and nighttime conditions similar to

**Figure 11.** Shipboard crane operations for Mk 18 Mod 2 11-m RHIB.

those anticipated during amphibious operations. Environmental testing (vibration, shock, and temperature) was later conducted to ensure that both vehicles were capable of sustained operations in more challenging environments.

After review of the developmental testing, user evaluation, and environmental testing results in 2005, APL as the IT&EA endorsed the Hydroid vehicle as operationally effective and suitable, and the program manager selected the REMUS 100 vehicle for production of several systems (consisting of three vehicles each) that later became known as Mk 18 Mod 1 systems. The Mk 18 Mod 2 was developed as an engineering change to the Mod 1 because the REMUS technologies were readily scalable.

The program manager continued to investigate other technologies, some provided by foreign manufacturers, to improve performance of UUVs or their supporting software. To avoid interoperability (and cost) issues, the program manager hired a software consultant to oversee the selection and development of a mission-planning and PMA software package that would enable any willing manufacturer's vehicle to be interoperable with fleet needs for required analysis and reports. COIN, initially developed by SeeByte, a small foreign company, was chosen as the software technology, and the government team worked to purchase the rights to the software and sufficient licenses to support operations.

## "Build a Little, Test a Little, Field a Little" Development Process

As indicated above, the program manager determined that a phased, walk first–run later development approach would be used. This translated first into the identification of reliable trucks (Mod 1 and Mod 2 vehicles) to haul payloads (sensors and navigation equipment) in the required operating environments. Once the reliable trucks were chosen, focus shifted to incremental delivery of increasingly capable sensors and navigation equipment. In several cases, testing revealed incomplete sensor-to-vehicle or navigation-to-vehicle integration and less-than-anticipated improvement in navigation or sensor PMA results. End-to-end system performance observations were identified during UOES or dedicated developmental testing or user evaluation periods.

PMS-408 applied the acquisition concept of low-rate initial production to order small quantities of vehicles to support improvement testing and, when system performance was characterized as meeting requirements, additional quantities of systems were procured. The importance of delivering reliable equipment to the hands of operators for evaluation and feedback was emphasized from the start.

### Responsive ISEA Support

The Naval Surface Warfare Center Panama City Division is the ISEA for both the Mod 1 and Mod 2 programs. A small Naval Surface Warfare Center Panama City Division staff works closely with the operators and the manufacturer to manage the repair, component upgrade, and replacement of UUVs.

The maintenance philosophy, instituted by the program manager, is to provide vehicles as part of a system. For the Mk 18 Mod 1 and Mod 2 program, a system consists of three vehicles. A multi-vehicle system with a tailored onboard repair parts kit allows the forward-deployed units to ensure that at least two UUVs are available and to perform organizational-level repairs to the third. Additional spares are kept at the depot level (manufacturer's facility) and are shipped by commercial or military air to facilitate quick turnaround. In some cases, it is more efficient to swap entire systems of vehicles.

For both the Mod 1 and Mod 2, there is no intermediate maintenance facility. The operating command has a stockpile of spare parts, and the manufacturer is under contract to provide maintenance support if the repair is beyond operator capability. Manufacturer responsiveness for maintenance has improved under the guidance of the ISEA thereby meeting fleet needs.

The ISEA and operators normally rely on express commercial shipping to transport Mk 18 Mod 1 whole man-portable vehicles for repair or to ship parts that can be installed when a Hydroid representative is present for on-site repairs. The larger Mk 18 Mod 2 is transported aboard military aircraft, but spare parts are shipped using express commercial shipping.

## LOOKING TO THE FUTURE

The 2013 Department of Defense *Unmanned Systems Integrated Roadmap FY2013–2038*[5] identifies six technology areas to enhance capability and reduce cost:

- Interoperability and modularity
- Communications systems, spectrum and resilience
- Security
- Persistent resilience
- Autonomy and cognitive behavior
- Weaponry

The Mk 18 FoS program has a plan to continue upgrading vehicle and sensor technologies along with adding communications/networking and autonomy as the systems mature into future increments. Table 1 illustrates the incremental capability improvement approach that the program office has implemented to the baseline capabilities to meet fleet requirements. Currently, the baseline Mod 1 (man-portable) and Mod 2 (lightweight) UUVs have been tested and are deployed. Improved modular sensors for the Mk 18 Mod 2 system, which is now formally designated as an ACAT IV program, have also been delivered to the fleet. Mk 18 FoS testing and evaluation efforts are ongoing in parallel to develop and incrementally deliver capabilities for autonomy, command and control and sensor improvements, and advanced sensors across the future-year defense program. These incremental upgrades leverage technologies previously demonstrated by ONR and other science and technology investments. Concurrently, science and technology efforts for future UUV capabilities are ongoing. Depending on the success of these investments, they may be implemented in the form of future block upgrades to the Mk 18 Mod 2 or as a future Mk 18 Mod 3 UUV program. Near-term to midterm initiatives planned for the Mk 18 UUVs include introduction of an internal payload computer and supporting architecture to enable automated target recognition, autonomy, and additional plug-and-play payloads. These initiatives, along with regularly improved sensors, will build on the baseline capabilities of the systems for use in more complex operational environments.

**Table 1. Mk 18 Mod 2 incremental improvement milestones**

| Phase | Activity |
|---|---|
| Prototype | Used for requirement compliance test and evaluation |
| Initial production system | System 0, block A vehicles |
| Production system | Follow-on systems, block A+ vehicles |
| Synthetic aperture sonar | Synthetic aperture sonar sensor module integration |
| Forward-looking sonar | Forward-looking sonar sensor module integration |
| | **August 2014** |
| LEMUUV improvement increment 1 | Autonomy and optics enhancement |
| LEMUUV improvement increment 2 | Command and control and sensor improvements |
| LEMUUV improvement increment 3 | Multi-sensor integration |

**Figure 12.** Civilian crew recovers Mk 18 Mod 2 UUV in CRRC during overseas sensor testing.

Due largely to successes in fielding the Mk 18 Mod 2 UUV and advanced sensors in support of the OSD Fast-Lane initiative, efforts are underway to procure more UUV systems and more advanced capabilities than were originally planned under the AAP strategy. In accordance with acquisition policies, Staff of the Chief of Naval Operations (OPNAV N957) and PMS-408 have transitioned from AAP processes to the Joint Capabilities Integration and Development System (JCIDS) process for future development and procurement efforts.

**Figure 13.** Civilian crew recovering UUV in 11-m RHIB with forward-looking sonar module.

Consequently, future incremental upgrades for the Mk 18 Mod 2 UUV program will be implemented using ACAT IV-level program management guidance that adds rigor and discipline to the development, testing, and fielding practices.

APL remains ready to support future testing as evidenced by recent experience in early 2014 with one of the most intense periods of UUV independent test and evaluation for PMS-408. A two-person team, with reach-back to a third person at APL, deployed overseas for a two-week evaluation of a synthetic aperture sonar followed seven weeks later by a two-week stateside evaluation of a forward-looking sonar. The tempo included finalizing test plans, conducting test readiness reviews, coordinating placement of exercise mines, performing analysis, presenting quick-look results, and summarizing requirement compliance test and evaluation results to support production decisions within a few weeks after completing each event. Figure 12 shows civilian crews conducting Mk 18 Mod 2 operations from a CRRC during advanced sensor testing conducted overseas in February 2014. Figure 13 shows sensor testing stateside in April 2014.

## SUMMARY

The Mk 18 Mod 2 program is an example of an AAP that successfully responded to a rapid fielding request by a fleet commander. From the perspective of the IT&EA, the history of the Mk 18 program indicates that, if "the build a little, test a little, field a little" process is followed, there is confidence that the team assembled by PMS-408 will meet schedule and system integration challenges and continue to provide useful capabilities to the fleet.

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## The Authors

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