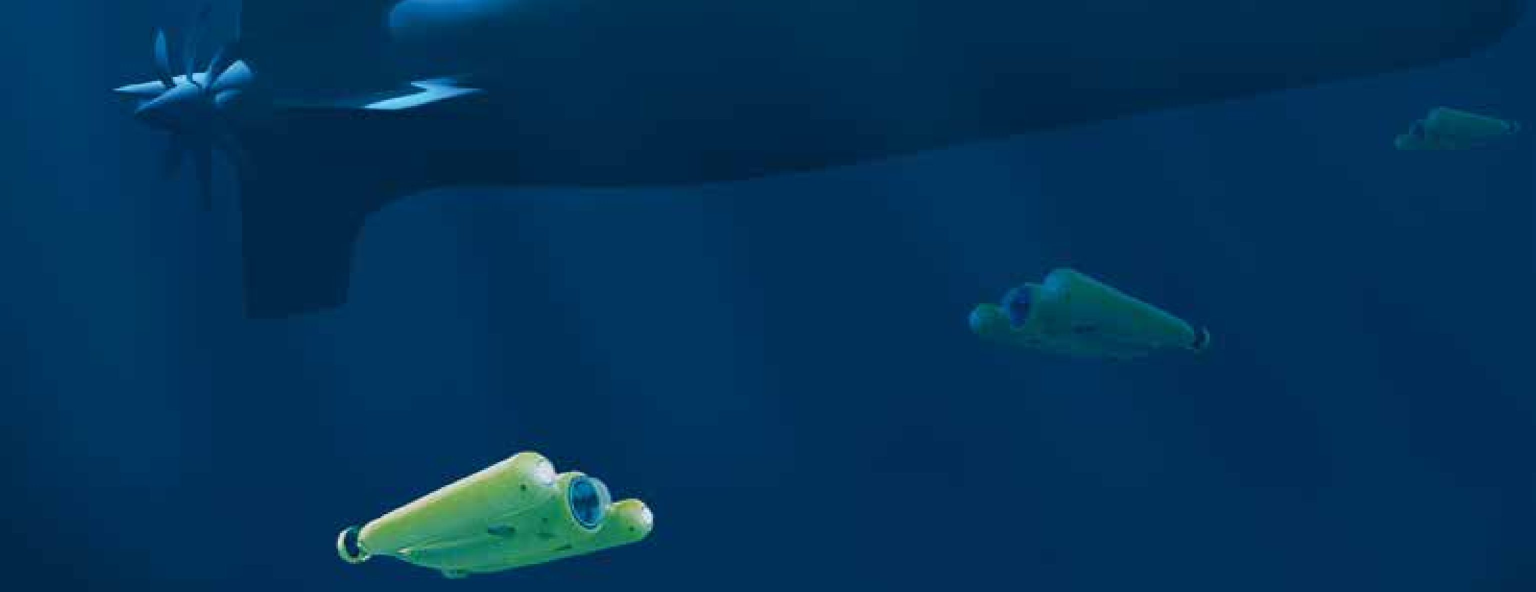

Commercial Unmanned Underwater Vehicles

The Next Asymmetric Threat

James M. Landreth, P.E.

SOMETIME IN THE NEAR FUTURE, QASEM PURCHASES FOUR TETHERED UNDERWATER CAMERA DRONES from the SCUBA shop for $800 each. The lithium batteries advertise 4 hours of bottom time at speeds up to 3 knots, which enables an endurance of 12 nautical miles during slack tide. Qasem mounts marine GPS antennae to the drone housings, and minor modifications to the free smartphone control application liberate the drones from their tethers. After a quick coat of black spray paint is applied, the drones disappear below the water.

The first drone follows its GPS waypoints to the submarine base. At the designated way point, it dives toward the river bottom. The integrated fish finding sonar enables the drone to sense the bottom and fly inches beneath the port security barrier. Bottlenose dolphins from the Navy's Marine Mammal Program (NMMP) patrol the waters behind the barrier for unauthorized swimmers, and the dolphins immediately detect the probing drone. When the underwater sentries challenge the drone, contact sensors release paralyzing toxins from the towed fishing bait container. After toxin release, a single line of code prompts the drone to surface and begin recording ultra-high definition (UHD) video. The remaining three drones follow their GPS waypoints toward the submarines undergoing refit. Seven-kilogram shaped charges fill the empty camera bays. The observer drone records as the shaped charges detonate and send jets of liquid metal through the submarine pressure hulls. After capturing 15 minutes of video, the filming drone returns home on its pre-programmed route. As emergency responders fight to save the submarines, Qasem's video goes viral across social media.

Back to Current Reality: In *A Design for Maintaining Maritime Superiority 2.0* and the *2019 Fragmentary Order*, consecutive Chiefs of Naval Operations designated unmanned undersea vehicles (UUVs) as platforms necessary for the strategic objectives of the Sea Services ("Services"), but U.S. adversaries also recognize the UUV potential. Since 2015, the

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Landreth *is a U.S. Navy civilian engineer, acquisition workforce professional and U.S. Navy Reserve submarine officer. In 2018, he was named one of the Top 10 federal government Professional Engineers by the National Society of Professional Engineers. He holds degrees from the U.S. Naval Academy (B.S.), the University of South Carolina (M.Eng.), and completed Joint Professional Military Education at the U.S. Naval War College. The views expressed are his own and are not to be construed as official or reflecting the views of the Department of the Navy or the U.S. Government.*

commercial unmanned systems (UxS) industry produced numerous low-cost, small UUVs (sUUVs). The rapidly increasing capability of these drones represent the next emerging and disruptive technology in the maritime domain. The sUUVs pose a range of kinetic and non-kinetic threats, and the low-cost of the sUUVs make them the latest and most potent asymmetric threat to high-value assets. The military Services must meld technology and innovation to counter the sUUV threat. The options include analyzing the dual-use potential of commercial drones, applying model-based systems engineering (MBSE) to physical security, deploying networked undersea sensors, and dominating UUV employment.

Understanding the Threat

The small, unmanned aerial system (sUAS) industry optimized size, weight, and power (SWAP) for drone batteries, and these batteries give sUUV manufacturers a running start. Additionally, positively buoyant sUUVs relieve the drones' burden of staying aloft as with the sUAS, so sUUV thrusters maintain depth while sipping only small amounts of power. The same battery that keeps a 2-pound sUAS aloft for 20 minutes can power a 14-pound sUUV for 4 hours. Once at desired depth, variable speed horizontal thrusters supply efficient propulsion and tight handling. For example, YouCan Robot BW Space Pro's large battery supplies power to the vehicle's larger thrusters for between 3 and 5 hours. Given that additional battery cells could be added with neutral buoyancy, engineers could cheaply extend sUUV endurance.

Advances in parallel industries delivered cheap sensors and robotic extensions to sUUV designers equivalent to advanced military hardware. Self-sensing allows precision employment. For example, depth sensors enable automatic depth control, and multiple vertical thrusters provide automatic pitch control. For sensing the environment, the standard for sUUV optics is a 12 mega-pixel camera that shoots ultra-high definition video, and most sUUVs can transmit sensor data to multiple devices via Chinese-made fast 5G WiFi repeaters. Integrated fish finders like the Powervision PowerSeeker act as chin-sonar arrays and enable onboard artificial intelligence (AI) algorithms to build detailed underwater topographic maps. Beyond sensing the environment, robotics generate real effects. Many sUUVs include towed fish bait containers that release payloads on operator command or at designated coordinates. Also, articulating arms can be added to sUUVs like the Geneinno Titan. And sUUVs like Titan allow a drone operator to achieve precision effects at more than 100 meters deep, more than 3 times deeper than SCUBA divers.

Now sUUV and marine GPS vendors have fewer regulations on GPS-enabled control software than the strict Federal Aviation Administration (FAA) control on sUASs. The lack of regulation on GPS-enabled autonomy makes sUUVs effective against a range of targets such as shore-based infrastructure, ships in port, and underwater utilities. Most sUUV are tethered to allow operator control, but the tether is not an unbreakable bond. The Powervision PowerDolphin already allows operators to build untethered search tracks with GPS waypoints. Beyond GPS, onboard fish finders could enable navigation based on bottom depth. Also, onboard inertial measurement units (IMU) like on the SeaDrone Inspector 3 precisely track the vehicle's orientation across 9 degrees of freedom (three-axes for gyroscope, accelerometer, and compass). Even without continuous GPS signal during submerged operations, reference coordinates at submergence, IMU awareness and bottom contour sensing offer a powerful combination for autonomous navigation.

The undersea lacks defense-in-depth strategies comparable to other domains. The September 2019 UAS attack on Saudi facilities at Abqaiq and Khurais highlighted a critical lesson for the Services. UxSs pose credible threats to advanced military defenses. The Iranian-made UAS swarm bypassed decades of U.S.-led investment in missile defense and counter-UAS systems. The undersea realm poses a more technically challenging environment for new entrants, but fewer layers of defense exist there than in any other domain. Previously, credible undersea attack was to be expected from expensive manned submarines like the Russian Severodvinsk. There were relatively few of these submarines, and they pursued high-end warfare. Also, large submarines require water deep enough for submerged navigation, which limits the possible vectors for submerged approach and attack.

With sUUV proliferation, the inland waterways, littoral seas, and open ocean face powerful new entrants. Chasing's Gladius Mini and similar sUUVs can generate effects in shallow or deep water, which changes the threat vector calculus. Inland, sUUVs could jeopardize the $4.6 trillion in annual economic activity generated by the U.S. Marine Transportation System. Immediately offshore sUUVs could wreak havoc on oil and gas platforms and easily catalyze accidents such as the 2010 Deep Water Horizon nightmare. In international waters, transoceanic cables that carry 99 percent of all international Internet traffic are vulnerable to sUUV attack.

There is a lack of legal basis for effective regulation. The majority of international and inland waterways are treated as public commons, which means maritime and riparian law create a permissive environment for malicious actors. Efforts to regulate the aerial commons teach important lessons for undersea planners. FAA regulations on sUASs only prevent errors of ignorance, and modified control

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software allows malicious actors to bypass regulation and leverage ubiquitous GPS signals.

Furthermore, the aerial commons are regulated based on altitude, but few regulations exist for undersea depth separation. The executive maritime law enforcement agency for the federal government is the U.S. Coast Guard (USCG), but maritime law as written gives few undersea regulations for the USCG to uphold. This is especially true at the boundaries of exclusive economic zones and international waters. Internationally, the United Nation's International Seabed Authority provides limited regulation, but this body has insufficient resources to police 71 percent of the Earth's surface.

The open ocean activities of the De Beers Group in Africa near Namibia highlight the absence of meaningful regulation. In 2018, De Beers Group used customized undersea mining equipment to haul 1.4 million carats of diamonds from the seafloor. Freedom from regulation and profit motive will incentivize the market to produce increasingly capable sUUVs that will be ever more potent in the hands of malicious actors.

Practical Approaches

Employ the plan, practice, perform, progress, promulgate (P5) cycle. Operational Commanders must generate plans to counter sUUV during Distributed Maritime Operations (DMO). Joint doctrine provides guidance on simulating adversaries with "Red Teams," and experts at the U.S. Marine Corps (USMC) Warfighting Lab, U.S. Navy (USN) Unmanned Undersea Vehicle Squadron 1 (UUVRON-1) and the USCG International Port Security Program could play the adversary role.

Practice is needed. The Services already coordinate joint security at places like Ballistic Missile Submarine (SSBN) Bases. USMC security battalions secure the ground; USN personnel provide security forces for each submarine; and USCG Marine Force Protection Units provide escort during transit. Such defense-in-depth makes a worthy testing ground. The USMC already employs "Red Battalions" for deployment certifications, and the Department of the Navy (DoN) should expand this activity. To effectively simulate adversary use of sUUVs, the DoN must equip Red Battalions with sUUVs and release them from U.S. doctrine and rules of engagement. Aggressive Red Battalions will identify vulnerabilities and inspire new doctrine for sUUV offense and defense.

Objective advisors from institutions like the University of Foreign Military and Cultural Studies ("Red Team University") should monitor the effectiveness of the P5 cycle and recommend improvements to executive stakeholders. DoN recently appointed a Chief Learning Officer (CLO) to optimize the DoN's academic enterprise, which includes the U.S. Naval Academy, Naval War College, Naval Postgraduate School, and Marine Corps University. The CLO must propagate the results of the sUUV P5 cSycle to operational commanders and across the academic enterprise.

Apply model-based systems engineering to physical security. The Services need to integrate joint contributions using a MBSE approach. The Services excel at joint operations, but generic joint proficiency does not equal readiness to perform all potential DMO assignments. The arrival of sUUVs has been a recent development, and legacy platforms lacked requirements to counter sUUV or integrate with counter sUUV systems. An MBSE analysis would simulate existing capabilities of U.S. and Coalition platforms to counter sUUV and identify performance gaps. A mature model would enable efficient integration of the lessons learned from the Department of Defense (DoD) and FAA experience in countering sUASs.

A MBSE model also would identify opportunities for scaling up. Previous security approaches such as SSBN Bases provide localized security around high-value targets, but such human-intensive approaches will be unsustainable across the 95,000 miles of U.S. shoreline and 25,000 miles of navigable channels. Also, the USCG possesses the needed authorities to defend the homeland from sUUVs, but it has limited experience in the undersea domain. An MBSE model would identify needed supporting relationships with DoD, other government agencies, law enforcement, and

Coalition partners. Finally, the model would reveal meaningful recommendations for regulation of sUUV vendors.

The Services must deploy networked undersea sensors that enable manned and unmanned teams (MUM-Ts) to increase the area monitored and decrease the detectable size of sUUVs by orders of magnitude. The United States has decades of experience in monitoring the undersea presence of manned submarines like the Russian Losharik, but current systems are not optimized for sUUVs. The Services will need to use facilities like the Atlantic Undersea Test and Evaluation Center to develop sensor suites that maintain three-dimensional awareness of the ocean environment.

In order to defend against sUUVs, proven technologies must be managed by MUM-Ts and have autonomy. MUM-Ts will require robust AI/machine learning (AI/ML) capabilities to maintain domain awareness in the undersea. New AI/ML systems designed for sUUV detection should be federated with national assets like satellites and the Integrated Undersea Surveillance System. Additionally, the Services should identify ways to further integrate marine life into its sensor network. For decades, the NMMP has trained dolphins and sea lions to perform undersea missions, and this type of man-animal-machine teaming must be extended dramatically. As an illustration, the Defense Advanced Research Projects Agency (DARPA) Persistent Aquatic Living Sensors (PALS) program offers opportunities to integrate marine organisms in the threat recognition cycle. DARPA's experimental work with PALS should combine MUM-T advances with legacy methods of man-animal-machine teaming.

The best way to maintain undersea superiority is to dominate all classes of UUVs. In addition to the threat posed by commercial sUUVs, nation-states are fielding special-purpose UUVs like China's HSU-001. Organizations with UUV expertise must be identified and reinforced at the strategic, operational, and tactical levels for the Great Power Competition. At the Theater Strategic Level of War, combatant commanders must coordinate U.S. and Coalition forces to deny adversaries the ability to achieve effects with sUUVs. As an example, U.S. Indo-Pacific Command should integrate South Korea's Anti-Submarine Ware Unmanned Undersea Vehicle into U.S. strategic and contingency plans.

From the Service Secretary level, the DoN's establishment of the Program Executive Office for Unmanned and Small Combatants (PEO USC) provides the strategic-level leadership to identify requirements and spend acquisition dollars efficiently across the enterprise. Given the rapid growth of the number of sUUVs, PEO USC will have an essential role in executing the research and development needed to counter them. In addition to new UUV development, PEO USC must work with other PEOs to ensure that larger platforms can launch and coordinate UUV operations. PEO USC should leverage the proposed MBSE analysis to define requirements for new acquisition programs and upgrade legacy platforms. Given the emerging threat from sUUVs, the DoN should leverage nontraditional funding vehicles such as other transaction authorities to integrate capabilities as rapidly as possible.

At the operational level of war, UUVRON-1's and Submarine Development Squadron 5 must develop doctrine for UUV dominance during DMO. UUVRON-1 must meld technology and innovation to meet the sUUV challenge. Satellites, ships, and radars effectively monitor the oceans' surface, but the sensor-per-area ratio on the surface poorly approximates undersea monitoring. New insights will be critical to raising domain awareness since thermal strata, depth, and other factors offer layers of shadow for sUUVs.

At the tactical level of war, the Services need the Joint Staff to endorse tactics, techniques, and strategy for UUV training and operations. With requirements similar to the Joint Unmanned Aircraft Systems Minimum Training Standards, the Services should develop specific qualification programs similar to the Basic UAS Qualification program that defines requirements for the five classes of UASs. Given the already diverse family of UUVs in the existing portfolio, the Services need an equivalent set of training standards to build competency in UUV and counter-UUV operations. Also, the Naval Air Training and Operating Procedures Standardization (NATOPS) manual is worthy of emulation. Just like NATOPS promulgates and deconflicts UAS policies and operations with manned flight, the Services must ensure effective water space management and prevention of mutual interference between manned and unmanned systems. Given the inherent stealth and secrecy of undersea deployers, developing and executing effective UUV policy must be a top priority.

Conclusion

On Oct. 12, 2000, al-Qaeda terrorists used a manned zodiac inflatable boat to inflict $250 million in damage in an asymmetric attack against the USS *Cole*. Today's sUUVs offer even more credible and potent asymmetric threats, and the capability of sUUVs will continue growing exponentially as the cost of dual-use technologies collapses, according to Moore's Law about increased use and reduced unit costs. An unlimited number of threat scenarios are posed by sUUVs—and the Services must develop strategic, operational, and tactical responses. The Services must meld technology and innovation to counter the threat of sUUVs through the P5 cycle, applying MBSE to physical security, deploying networked undersea sensors, and dominating UUV operations.

The author can be contacted at **james.m.landreth@navy.mil**.