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XLUUV:
THE UNMANNED EVOLUTION OF THE UNDERWATER COMPETITION

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DEFENCE & SECURITY

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Introduction

The underwater (almost) domain increasingly represents one of the most dynamic frontiers of the multisectoral and multilevel strategic competition that characterizes the contemporary international scenario, spanning the extremes of high-intensity conventional conflict. Concealed theatre not only of cross-cutting challenges for technological and information supremacy in the deep, but especially of a persistent hybrid struggle over the security of an ever-widening network of critical infrastructure, such as gas pipelines, power lines and telecommunications cables branching along the seabed (CUI – Critical Underwater Infrastructure). Indeed, the ongoing planning and conduct of demanding deep-sea patrolling and monitoring activities, including in the Mediterranean basin with the Italian Navy's *Fondali Sicuri* and the French *Marine Nationale*'s *Calliope* operations, underscore the utter importance of the underwater dimension in promoting national and allied security interests and protection. In this context, significantly marked by new technical requirements and incremental operational demands, the synergic advancement of robotics and artificial intelligence (AI) is driving a profound capacitive transformation, hinging on the development, testing, acquisition, tactical-operational integration and deployment of a wide range of Unmanned Underwater Vehicle (UUV) systems.

Although conventional submarines, regardless of their specific characteristics and type of propulsion, nuclear or conventional, continue to be the mainstay of contemporary underwater fleets, UUVs constitute a complementary segment of increasing significance. Removing the implicit engineering limitations generated by the need to embark, protect and sustain operators in an inherently physically, chemically and thermally hostile environment such as the deep sea, unveils a broad spectrum of innovations pertaining both to the architecture of the individual platform and to its deployment. The potential reduction in size, combined with accentuated modularity of cargoes and coupled with the ability to operate longer and deeper underwater are indeed significant advantages, capable of broadly changing the character of submarine operations along the entire continuum-of-competition and their contribution to the broader maritime and multi-domain manoeuvring in the event of conflict. The incremental focus on UUVs is also not only reflected in a comparison of technologically advanced powers, but also extends to include an appreciation of similar, more simplified platforms as a tool for asymmetrical combat. As an example, the Ukrainian Armed Forces, in the context of the battle for the Black Sea aimed at denying freedom of movement to the Russian fleet, has complemented the effective use of unmanned surface vessels (USVs) with the experimental deployment of both a kind of loitering torpedo, named *Toloka*, and a larger UUV designated by the manufacturer AMMO Ukraine, the *Marichka*. The evaluation of the use of underwater explosive drones by Hamas and the Houthis as much as it represents a highly rudimentary attempt to emulate UUVs underscores the widespread perception, even among asymmetric actors, of the transformative effects brought about by the introduction and refinement of unmanned submersible vessels.

Beyond marginal solutions closer to manoeuvring torpedoes or USVs capable of navigating on the water surface, the development and integration of UUVs within contemporary submarine fleets is expected to be functional for the implementation of more distributed operational approaches based on a mobile sensor and effector architecture, declining the Distributed Maritime Operations (DMO) concept into the more challenging subsurface environment. Indeed, the implementation of this is central as much to countering tactical asymmetry between areal defence requirements, especially with respect to CUIs compared to a point threat, as to generating persistent dilemmas in the eventuality of military confrontation, to adversary Anti-Submarine Warfare (ASW) capabilities. The underwater (almost) domain, however, presents significant technological challenges to the operational effectiveness of UUVs, with the water's scarce penetrability to almost all electromagnetic waves undermining the utility of command-and-control systems generally employed in all other domains. From this perspective, the use of AI is even more crucial in enabling these systems to conduct a wider range of technical activities and tactical tasks. In particular, machine learning is central in the calculation and maintenance of the vessel's course, in the data collection, processing and sharing phase by the on-board sensors, and as a tool for self-diagnostics and technical maintenance of the system. The use of software aimed at automatic recognition of potential static underwater targets (ATR – Automatic Target Recognition), such as naval mines, is then a good example of how AI can enable the attitude to proceed to perform its tasks autonomously without operator impulses.

In light of the growing attention and relevance of the segment, both in terms of military capabilities and industrial opportunities for development, this Focus Report aims to systematize the analysis of UUVs, delving into their technical characteristics and potential uses, as well as mapping in detail prototypes and models currently in the defence market. Building on this foundation, it specifically addresses the state-of-the-art and perspectives related to the specific category of Extra Large UUVs (XLUUVs), outlining their evolutionary impact in the underwater competition.

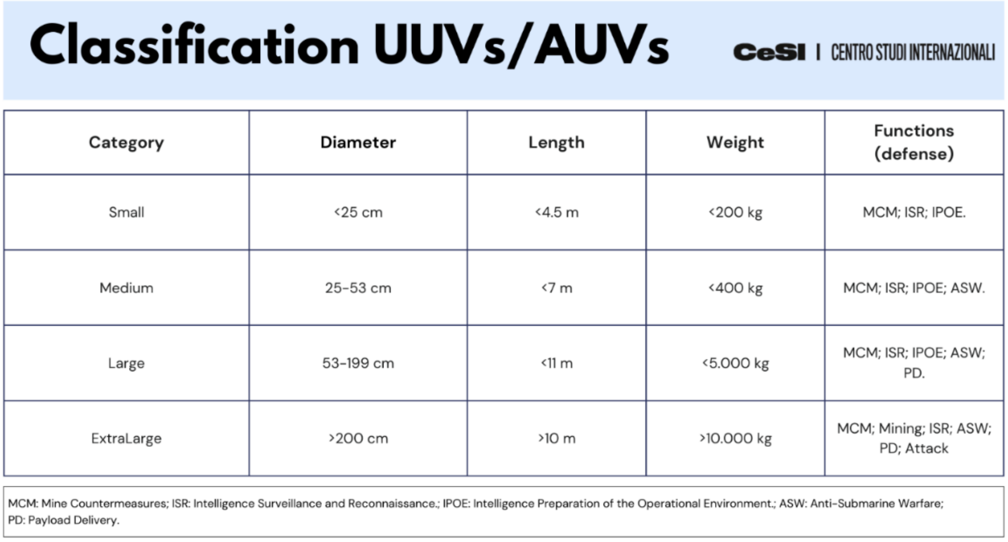
UUVs Categorization

UUVs are essentially distinguishable into two categories according to their degree of dependence on human control: Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs). The former, as their name suggests, are in fact connected to a surface vessel via an umbilical cable, which allows an operator to control their direction via a system known as a Tether Management System (TMS). ROVs vary in size and are equipped with a suite of modular equipment, which in the most basic configurations go as far as providing only a flashlight and a camera for visual exploration below the surface. The additional instrumentation optionally integrated on the system varies according to the class to which the ROV belongs, and usually includes sonar, pressure, salinity, and water temperature detectors, and, in more advanced classes, even machinery for interacting with the seafloor such as excavators, mechanical arms, or drilling equipment. The oldest uses of these systems include maritime scientific research, deep-sea exploration and the defusing of explosive remnants of war deposited on the seabed.

However, the most transformative category is AUVs, which are autonomous underwater drones. Indeed, independence from the operator makes the asset capable of performing missions at greater depths and distances, no longer limited by the length of the umbilical cable, and with a variable degree of autonomy. In this regard, it is possible to state the existence of three subcategories of systems: the first, designated human delegated, where the operator programs the mission; the second, designated human supervised, which sees a decision-making and operational autonomy of the drone subjected, however, to human control and eventual revocation, through the activation of a special command, according to a functional principle of the human-on-the-loop type; and finally, the last category, fully autonomous, in which the drone is completely independent of human control and decision-making.

In 2018, the US Navy proposed a classification for AUVs using diameter as decisive criterion for determining category membership. Length and weight, in fact, are excessively influenced by the modular architecture, a term by which is meant the possibility of adding or removing modules, i.e., the parts that make up the drone, so that the vehicle is best adapted for each mission. Generally speaking, four categories of underwater drones have been identified: small, medium, large, and extra-large. AUVs belonging to the first category do not exceed 25 centimetres in diameter and generally have a maximum length of around 2-2.5 meters, except in rare cases where the modular architecture allows for up to 4.5 meters, as is the case with the Gavia drone produced by the U.S.-based Teledyne Marine and the Eelume 500 M drone, produced by the Norwegian company Eelume, which can reach up to 6 metres depending on the configuration. Regarding weight, as the structures are small in size, 200 kilograms are usually not exceeded. AUVs belonging to this category can be released from any type of craft and, for the smaller ones, there is the possibility of being deployed directly by a single operator, acquiring the Man-Portable qualification, such as the Iver 3, produced by the U.S.-based L3Harris, and both versions of the Russian Amulet drone, produced by Rubin.

The second category, Medium AUVs, encompasses drones with a diameter between 25 and 53 centimetres, delineating a more robust structure than the previous category. Indeed, this is also witnessed by the length, which is mainly between 4 and 5 meters, and, if the modular architecture allows, lengths close to 7 meters can be achieved, as in the case of the Knifefish, by General Dynamics. Another figure affected by the more robust structure is the weight, which if generically between 250 and 400 kilograms, can be as high as 800-900 kilograms depending on the payload and the addition of optional instrumentation. Drones in this category can be released from any type of vessel, including larger UUVs, as well as, especially in civil uses, from offshore platforms.



Classification UUVs/AUVs

Category	Diameter	Length	Weight	Functions (defense)
Small	<25 cm	<4.5 m	<200 kg	MCM; ISR; IPOE.
Medium	25-53 cm	<7 m	<400 kg	MCM; ISR; IPOE; ASW.
Large	53-199 cm	<11 m	<5.000 kg	MCM; ISR; IPOE; ASW; PD.
ExtraLarge	>200 cm	>10 m	>10.000 kg	MCM; Mining; ISR; ASW; PD; Attack

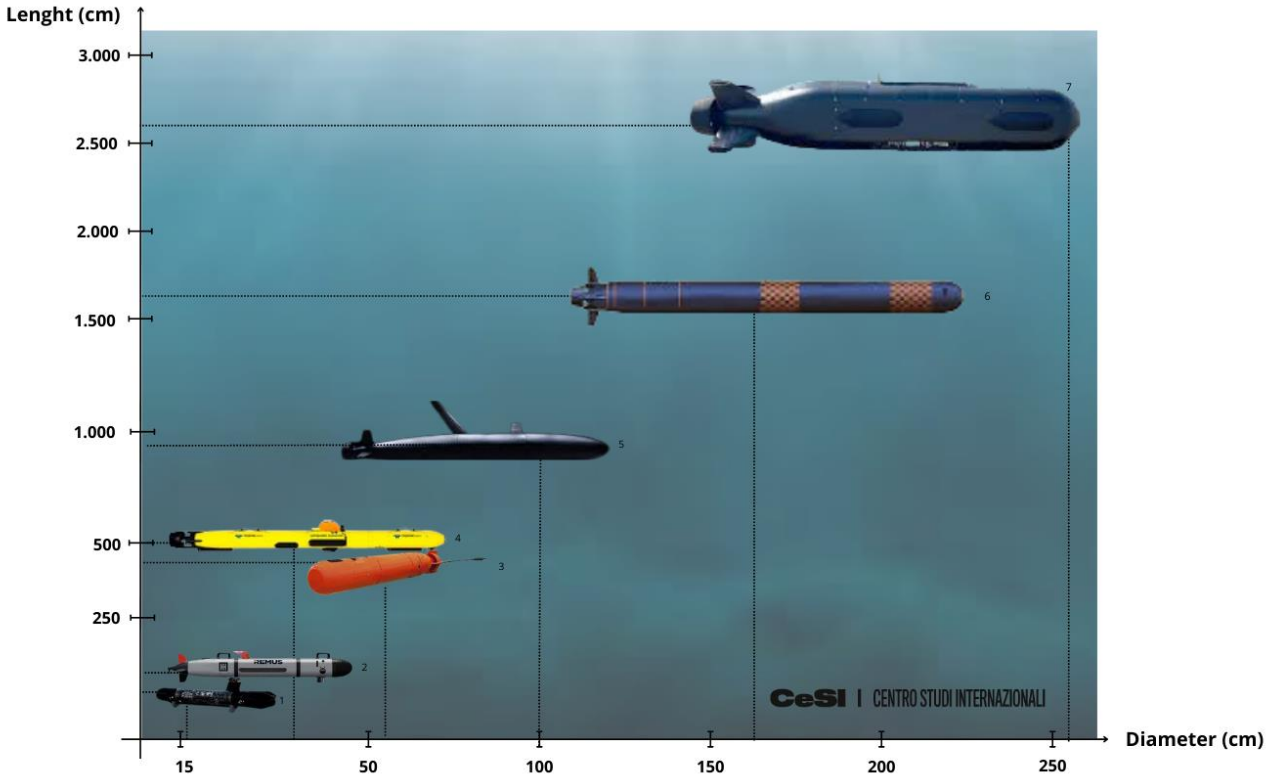
MCM: Mine Countermeasures; ISR: Intelligence Surveillance and Reconnaissance.; IPOE: Intelligence Preparation of the Operational Environment.; ASW: Anti-Submarine Warfare; PD: Payload Delivery.

The next category covers vehicles with a diameter between 53 and 199 centimetres, the so-called Large UUVs (LUUVs). The length of this category of drones can reach up to ten meters, as in the case of the Blue Whale AUV, produced by Israel Aerospace Industries (IAI) in collaboration with ELTA Systems. The weight, on the other hand, despite averaging between 2,000 and 5,000 kilograms, can be up to 9 tons, as with the South Korean Anti-Submarine Warfare Unmanned Underwater Vehicle (ASWUUV) drone, developed by Hanwha Systems, in collaboration with the Agency for Defence Development in Seoul. The structures of these drones allow them to be used in longer-lasting missions than their predecessors; this capacitive improvement, however, cannot be attributed solely to particular leaps in technological capabilities or manufacturing processes, but is a direct consequence of scaling up in size: more imposing structures resist water better by distributing its pressure over larger areas and allow the housing of larger, higher-performance batteries, usually lithium-ion. A clear example of the higher endurance of drones belonging to the large category concerns the Indian AUV High Endurance Autonomous Underwater Vehicle (HEAUV), produced by the Defense Research and Development Organization (DRDO), which has an estimated autonomy time of 15 days. In general, AUVs belonging to this category can be released from ships equipped with chutes or pneumatic systems, cranes and offshore platforms.

The last category of AUVs concerns vehicles characterized by a diameter that equals or exceeds 200 centimetres, or XLUUVs. It is intuitable that the structure of this category outclasses all previous ones in terms of size: the length sees a minimum of 10 meters and a minimum weight of 10,000 kilograms. Although the massive size allows maximizing the benefits of using UUVs in terms of operational capacity, there are not many examples in this category. Among the best-known examples is certainly Orca, produced by the U.S. company Boeing and of which the first prototypes were delivered to the U.S. Navy in late 2023. Even if the current number of models of XLUUVs is substantially limited, this category is expanding significantly. This is confirmed by the numerous experiments conducted by both private companies and navies, such as the test of the Herne drone, developed by the British BAE System, which took place on November 25th, 2024. The display at the China International Aviation & Aerospace Exhibition of a new XLUUV model, whose projected length would be between 38 and 40 meters, further clarifies the trend that the size of extra-large underwater vehicles is plausibly set to increase in the near future.

The general architecture of UUVs

The increasingly prominent role assumed by AI naturally has direct impacts on the degree of autonomy, as do innovations pertaining to the propulsion and power component. Although to date the number of drones that have performed missions without any human intervention is small, the generally set goal is to make the vehicle capable, through AI learning processes, of calculating paths, avoiding obstacles and reaching targets, without outside intervention. As for navigation, satellite communication can be exploited on the surface, employing Global Positioning System (GPS) and Maritime Broadband Radio (MBR) systems. Instead, in the deep sea, which is impervious to radio waves, alternative systems such as the Inertial Navigation System (INS), which provides information on a vehicle's position, speed and acceleration without the use of radio communication systems, must be used. The INS does not need external references to determine its position once the drone is operational, this is because it calculates the position of the AUV by supplementing the initial geographic data, i.e. the point at which the



The choice of drones represented is motivated solely by graphical purposes.
1 **Amulete**, small class, produced by Rubin (RU); 2 **Remus 100 M**, small class, produced by Huntington Igalls Industries (US); 3 **AUV62-AT**, medium class, produit de SAAB (SE); 4 **Gavia**, medium class, produced by Teledyne Marine (US); 5 **Spearthooth**, large class, produced by C2 Robotics (AU); 6 Haeil, large class, (RPDC); 7 **Orca**, Extra Large class, produced by Boeing (US).

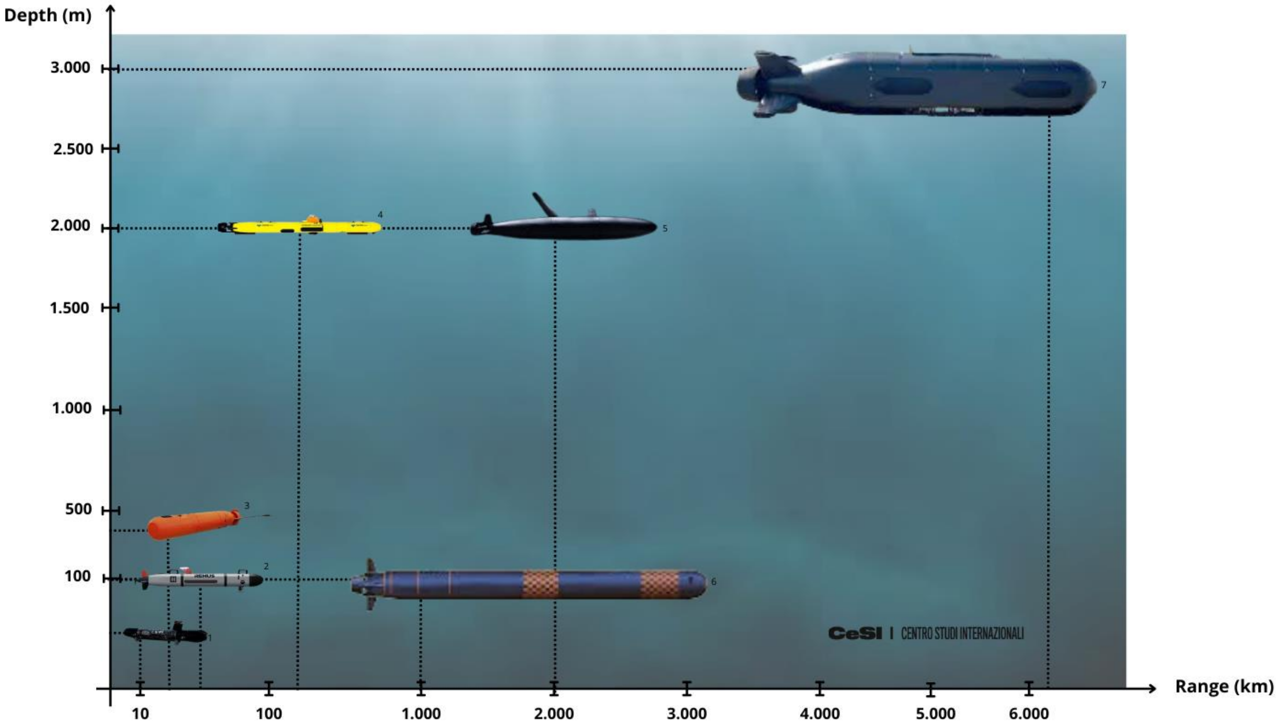
vehicle's activities begin, with the operational speed that is updated through the motion sensors. Although this system is susceptible to errors due to the perfectible computation of acceleration and angular velocity, it is the most widely used in AUVs. In fact, the density of water does not allow for transmission via satellite antennas except when the drone emerges at the surface or operates a few metres deep. In order to overcome this critical issue, two main technological solutions have been developed and are being further refined: acoustic and optical communication. The first is the one currently most widely used and exploits the propagation in water of sound for data transfer through the use of hydrophonic systems, which transform digital signals into sound waves, and vice versa. Although they enable communication even over long distances, these solutions have very modest modulation bands, often limiting the transmission rate to a few kilobits per second and with considerable power consumption. The speed of propagation of acoustic waves in water also introduces a high latency on the signal, leading to interference and distortion problems. Optical communication, on the other hand, most often applied through light emitting diodes (LEDs), exploits radiation in the blue-green range for data transmission. This technology can achieve transfer rates of several megabits per second for tens of meters, providing versatility and limited power consumption, but it still has critical miniaturization issues and is negatively impacted by water visibility conditions.

An additional technological landmark in the architecture of underwater drones, through which the AUV can detect external objects, is the Sound Navigation and Ranging (sonar). The first among the different types of integrated sonar is the Single Beam Sonar, which uses a narrow acoustic beam to measure the signal return time. Also known as split beam sonar, the device consists of two main components: a transducer, responsible for sending the acoustic pulse into the water column and receiving the response signal, and a transceiver, which encodes the response signal into computer data. Another acoustic detection tool that can be employed by AUVs is the Multi Beam Sonar, which behaves in substantially the same way as the previous one, but instead of using a single acoustic beam, it uses more than one at the same time. On the other hand, the Side Scan Sonar, among the most frequently used types of acoustic detection equipment in both civilian and military settings, locates external objects by emitting a cone- or helical-shaped acoustic beam projected to either side of the vehicle and capable of returning a particularly detailed and sharp image of the backdrop. Finally, another widely used tool is the forward-looking sonar (FLS), which projects an acoustic beam in front of the drone's position, essential for avoiding obstacles and collision with external objects placed along the vessel's course.

The complementarity of UUVs to manned platforms

Compared with manned submarine platforms, UUVs present certain operational advantages that make them valuable complementary assets with the potential to solve the problems associated with the use of manned systems in certain contexts and for the conduct of specific tactical tasks. Although they remain of utter importance in contemporary fleets, submarines do in fact have critical issues related primarily to the very high cost of the platform itself, which makes it difficult to replace swiftly and thus requires prudent and risk-averse tactical employment. Similarly, personnel training and deployment costs are significantly high, especially in light of the fact that prolonged stay underwater involves considerable stress on the physical and psychological health of the crew, who are inevitably fatigued by the peculiar and cramped environment experienced on a daily basis for the duration of the mission. Therefore, it is impossible to carry out long missions without interruptions, which are obliged both to supply the submarine with fuel, should it be conventionally propelled, foodstuffs and possible armaments, and to allow for personnel turnover. In addition, the technical capabilities of these vessels are subject to limitations caused by the harsh conditions of the operating environment, especially in terms of the pressure the water exerts on the vessel and the durability of the power systems of the propulsion compartment. In fact, in order to ensure the safety of the crew and the availability of an oxygen supply for both shipboard life and the combustion of non-nuclear engines, submarines equipped with the Air-Independent Propulsion (AIP) system cannot descend to a depth greater than 400 meters and have a maximum dive time usually not exceeding two to three weeks under optimal conditions, having to forcibly return to the surface to snorkel. Such constraints clearly do not exist for UUVs, which have no personnel on board and do not require the pressurized internal structure or oxygen reserves. Therefore, these instruments are particularly suitable for conducting seabed warfare operations even at much greater depths, and can remain underwater for considerably longer periods, even for months.

Thus, a subaltern and complementary role of unmanned platforms vis-à-vis manned ones is foreshadowed: indeed, it is not excluded that a variable number of UUVs, of different types and sizes, could act as a network of sensors and effectors distributed and coordinated by a manned submarine, expanding its situational awareness and increasing its operational capabilities. In detail, the drone could assume the role of underwater combat asset alongside a conventional attack submarine (SSK) in order to increase its ability to counter enemy boat activity. Conversely, should it be configured as a ground attack platform by launching submarine-launched cruise missiles (SLCMs), the strike capability would broaden the range of missions that can be carried out through the synergy between UUV and submarine, enabling the latter asset to perform tactical tasks that it would not be able to perform in stand-alone mode. The lower cost and absence of personnel also make the remote platform more scalable from a production point of view and more easily expendable from an operational perspective, allowing it to be used in high-risk missions to replace vessels with a specialized crew of dozens, the loss of which would represent human and material damage difficult to accept both militarily and politically. In this sense, cooperation between autonomous weapon systems and manned platforms (MUM-T – Manned-Unmanned Teaming) is a constant in the near future of all operational domains, and the underwater is no exception; on the contrary, it seems to be the most promising environment to implement such a strategy, being, compared to the others, the least suitable for human survival. Cooperation between UUVs and submarines is also facilitated by the possibility of releasing unmanned platforms via specially mounted Dry Deck Shelters (DDS) on top of the outer hull, which are usually used for releasing mini-submarines for infiltration of Special Forces operators, such as the SEAL Delivery Vehicle (SDV). It is therefore possible to theorize a kind of underwater swarming tactic, in many ways analogous to what is currently being studied for air and land systems, even in light of lessons identified from contemporary battlefields.



The drones represented were chosen based on graphical purposes.
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Such a posture appears very consistent with the tactical-operational dictates of DMOs, a strategic framework that places specific emphasis on the importance of deploying naval units across a wide maritime quadrant in order to better evade enemy detection capability so not to offer a paying-off target to hostile anti-ship systems. The concept was developed in recent years by the U.S. Navy in relation to the operational needs its assets might face in the South Pacific. Integrating the use of UUVs into such a strategy would not only bring substantial advantages in terms of cost-effectiveness of material resources and personnel but is a potential solution to the long-standing problem posed by Anti-Access/Area Denial (A2/AD) bubbles, for which submarine warfare is a main pillar. The use of an overwhelming number of submarine drones as false targets results in difficulties in reconnaissance and engagement by both surface and submarine enemy vessels, forcing them to waste their offensive vectors (torpedoes, depth charges) in an attempt to hit non-existent or non-valuable targets. Similarly, UUVs, like their surface counterparts, USVs, can be integrated into the naval device aimed at generating effects in the electromagnetic environment by creating phantom fleets for the purpose of confusing the enemy and forcing them to deploy resources unproductively, in turn exposing themselves to the counter-fire of real assets. Such is the goal of a classified program being developed by the U.S. Navy and known as Netted Emulation of Multi-Element Signature against Integrated Sensors (NEMESIS), which aims to achieve the capability to generate multi-source, multispectral signatures in all respects similar to those of naval units to deceive the enemy early warning apparatus based on the integration of multilevel sensors. The project, which has been under study since 2014, would represent a significant qualitative leap from conventional electronic warfare (EW) measures, partly due to the massive use of both submarine and surface drone swarms, called Distributed Decoy and Jammer Swarms (DDJS). The goal remains to invalidate the opponent's Intelligence, Surveillance and Reconnaissance (ISR) capabilities to irreparably hinder the smooth execution of the kill chain by its coastal defence systems.

The top category: the XLUUVs

XLUUVs are described by the U.S. Navy as those autonomous submarine systems characterized by a diameter of 213 centimetres or more and having a minimum length of 10 meters, as well as a minimum weight of 10 tons. Thus, these are true medium-sized vessels whose tonnage does not allow conventional submarines to transport and release them, forcing them to be put into the water in special port basins near the area of operations. Alternatively, it is conceivable that these systems could be released via floodable docks of large amphibious naval vessels, such as those found on amphibious assault helicopter carriers (LHDs – Landing Helicopter Docks) and amphibious transport units (LPDs – Landing Platform Docks). This increase in size generally results in a significant increase in the range of the system, both in terms of nautical miles and negative altitude attainable, as well as an extension of the period that these assets are able to spend in the depths. In detail, depending on the different models, most XLUUVs are capable of covering distances in the range of thousands of nautical miles, diving thousands of meters deep, and remaining underwater in some cases for months at a time. XLUUVs generally have a tripartite structure, consisting of three sections: a first guidance module, which contains the on-board sensors deputed to vehicle navigation and control systems of the vehicle; A modular mission compartment that can accommodate different types of payloads depending on the mission profile assigned to the vehicle; and finally a propulsion module, usually consisting of the engine and power system.

The modular structure of these vehicles is results in great adaptability both in terms of the hardware component of the vehicle, which can accommodate hull sections of constant diameter but varying lengths suitable for carrying and operating different types of payloads, and in terms of the software and electronics component. These are in fact based on an open computing architecture that allows them to be constantly updated in order to prevent their premature tactical obsolescence attributable to the adoption of possible countermeasures by the adversary.

Case in point in this regard is that of the aforementioned Orca, an XLUUV developed by Boeing and currently being acquired by the U.S. Navy under a program launched in 2019 for the development, testing and delivery of five prototype examples. The structure of the drone is divided into three sections giving it a length of 15.5 meters without a cargo module, which in turn is over 10 meters long. The fully loaded displacement of the vessel reaches 60 tons, a significant weight that makes it difficult to dispose of the vessel, as well as operate it, without setting up an adequate supporting logistics chain near or within the area of operations (AOO). On the other hand, the Orca nearly increases its diving capacity tenfold compared to that of a normal submarine, being able to reach a negative altitude of more than 3,000 meters deep. Its cruising speed remains a potential concern as it is limited to 3 knots per hour, or about 6 kilometres per hour, with maximum acceleration not exceeding 8 knots. Although these figures are not very high, it should still be considered that such an asset aims to make stealth its strong point, rather than to achieve particularly significant hydrodynamic performance. In spite of its reduced speed, however, the Orca can boast an impressive operational range of more than 6,000 nautical miles, making it notably suitable for operating in the boundless ocean expanse of the Pacific.

The most interesting component of the system is reasonably the mission module, with a load capacity of 8 tons and powered by an 18-kilowatt autonomous battery. Although to date it is formally designed to perform naval Mine Countermeasures (MCM) detection and defusing tasks, the U.S. Navy itself recognizes the great versatility of the system and includes, among the possible payloads that can be integrated by the drone, instruments ranging from Synthetic Aperture Sonar (SAS) for mapping the seafloor to ISR resources and components for EW. However, a possible kinetic use of the Orca is not ruled out, consisting mainly in the release of attack vectors for submarine warfare, in mining, both offensive and defensive, and possibly by conducting ground attacks by launching SLCMs such as the BGM-109 Tomahawk, already long in use by the US Navy on underwater platforms. Regarding mine laying, the XLUUV is capable of carrying both moored and bottom mines, and in detail, it appears that the most suitable naval ordnance to be released from the system is the Clandestine Delivered Mine (CDM), a supposedly cylindrical-looking mine whose technical details have not yet been revealed. At the same time, the U.S. Navy, jointly with General Dynamics Mission Systems, is developing the Hammerhead mobile mine, specifically designed to stand on the seafloor after release, waiting to be automatically activated by the acoustic signature of a passing submarine vessel. The latter system also looks set to be integrated into the Orca's mission compartment. Finally, it is conceivable to use the submarine drone as the mother platform of a swarm of small- to medium-sized UUVs released from the mission module, thus structuring the set of remote assets as a system of systems. At present, the first specimen delivered to the US Navy is in the process of finishing basic sea trials. The company is scheduled to deliver an additional four vessels in the first quarter of 2025, which will be allocated to Unmanned Undersea Vehicle Squadron 3 (UUVRON 3), the Armed Force command specifically created in 2023 to test, integrate and, in the future, operate the XLUUV Orca.

Instead, in the 2024 timeframe, the Royal Australian Navy received two of the first three prototypes of the XLUUV Ghost Shark, jointly designed by Anduril, the Royal Australian Navy itself, and the Defense Science and Technology Group, an Australian government agency dedicated to applying science-technology solutions to the Defence sector, with support from the Advanced Strategic Capabilities Accelerator. Characterized by a rather boxy design, the trim is an upscaled derivation of the Dive-LD, a 5.8-meter long by 1.2-meter diameter LUUV weighing 2,700 kilograms capable of operating underwater for ten days at a maximum depth of 6,000 meters. Significantly improved in cargo capacity and flexibility, as well as in range, the Ghost Shark, whose transition from experimental to production phase is expected to be completed by the end of 2025, is designed for the conduct of long-range stealthy ISR and attack operations in high-risk contexts, with a focus on the operational conditions of the archipelagic environment that characterizes the Indo-Pacific. Transportable inside a container that can be boarded on a C-17 Globemaster III, the vessel is a significant departure from the form of the Dive-LD, which appears to have served primarily as a technology experimenter for AI solutions and onboard sensors rather than a hydrodynamic profile. Although information on the asset is strictly confidential, a peculiar aspect of the outer hull, and one that distinguishes it from the totality of other XLUUVs, is the presence of a small recumbent sail near the prow, while the mission-configurable central module would be designed to be able to deploy its payload in different directions. Finally, the Ghost Shark incorporates the Lattice system developed by Anduril, i.e., an open, agnostic software platform designed to integrate multi-sensor data, analyse and enhance it through a combination of AI and machine learning, informing and enabling a coherent adaptive attitude response.

Although the U.S. and Australian programs appear to be the most advanced in terms of implementation timelines, other countries have decided to undertake similar development initiatives to equip themselves with large UUVs. There is particular interest from the United Kingdom, which has already presented a plurality of experimental projects in recent years that are substantially similar to the Orca: among them, the aforementioned Herne represented BAE Systems' proposal originally developed in accordance with a call for contributions made by the Royal Navy for the acquisition of an XLUUV in the British fleet. Although the final choice of the British Ministry of Defence fell on another model, BAE Systems proceeded independently to complete the development of a prototype in order to position itself for a hypothetical domestic market expanding in the near future as well as the foreign market. Designed for reconnaissance, mine warfare, and electronic warfare tasks, the system is powered by lithium-ion batteries and has performance in terms of attainable depths substantially similar to its U.S. counterpart, although it has a significantly smaller operational range and dive time. These limitations are attributable to the significantly smaller size, just 12 meters in length and about 2 meters in diameter, but these are also inherently an advantage for the deployability of the drone, which is deployable from naval surface platforms such as the Royal Navy's Type 26 City-class frigates, from particularly capacious DDSs mounted on the hull of a submarine, or even from tactical airlifters such as the A400M Atlas, currently operated by the Royal Air Force (RAF). First unveiled at Defence and Security Equipment International 2023, BAE Systems' XLUUV completed an initial round of sea trials in November 2024, and the company aims to introduce it to market in the first half of 2026.

In contrast, the model chosen by the Royal Navy was the XLUUV Cetus, manufactured by the Plymouth-based company MSubs. Weighing more than 17 tons, 12 metres long and about 220 centimetres in diameter, Cetus is derived from an experimental autonomous submarine vehicle developed by the British company, the Manta, and is Europe's most significant extra-large submarine drone development project. The system is primarily designed to operate alongside the Astute-class nuclear-powered attack submarines (SSNs), the last two of which are awaiting delivery, thus implementing the cooperative combat between manned and remote submarine platforms previously analysed. The British XLUUV is structured according to the usual tripartite architecture and includes a main payload space of 8 cubic metres, located in the centre of the vessel, as well as additional smaller secondary cargo compartments. The vehicle's logistical footprint is also reduced by its transportability in a standard commercial container, which therefore allows it to be stored and handled at any port equipped with cargo loading and unloading cranes, as well as, theoretically, deployed in the water from the body of a semi-trailer truck. Although the project is still at the experimental stage and unlikely to enter service before late 2025, the Royal Navy is proceeding to carry out a long series of tests, primarily employing the drone as an ISR asset in order to carry out Intelligence Preparation of the Operational Environment (IPOE) in the coastal area for insertion into the AOO of Special Forces detachments or for reconnaissance prior to an amphibious operation, taking advantage of the acoustic, electro-optical and radar sensors which the craft is equipped with. The technical specifications of Cetus, however, are significantly lower than those of other XLUUVs, with a maximum attainable depth of no more than 400 meters and an operational range of just 1,000 nautical miles.

Finally, among the most promising initiatives in the field is the Unmanned Combat Underwater Vehicle (UCUV), the result of an agreement signed in December 2023 between the *Direction Général de l'Armament* of the Ministry of the Armed Forces of the French Republic and the national company Naval Group. According to information made public by the French Defence, the technical-operational requirements imposed on the development of the vehicle include a modular structure, compatibility with medium-sized air transport, and above all, a marked autonomy in terms of both range and integration of the AI into the vessel's command and control system. It is also required that the future XLUUV have a length of more than 10 meters and a minimum displacement of 10 tons, as well as a diameter of not less than 2 meters. Currently, Naval Group is working to unveil a demonstrator within the next year, the cost of which, moreover, is already covered by the Military Programming Law (*Loi de Programmation Militaire*) for the years 2024-2030. However, more detailed information regarding the size and characteristics of the payload has not yet been made available.

Additional countries, most notably Israel and the Russian Federation, have put considerable effort into the development and production of autonomous submarine systems. Such vehicles, however, do not possess the size requirements of XLUUVs according to the classification adopted by the US Navy, falling rather into the category of LUUVs. Mostly at fault is the diameter of the hull, which in most cases does not reach 2 meters, in the same way as the weight, which is usually well below the 10-ton threshold.

Conclusions

The persistent and covert ISR capabilities provided by conventional submarines, as well as that of generating effects, kinetic and otherwise, when needed, suddenly against high-value adversary targets before disappearing back into the deep sea, continue to be major operational requirements for Navy Submariners. However, the growing infrastructure of the deep, beginning with contemporary societies' well-established dependence on Internet backbones and underwater pipeline networks, outlines a potential attack surface for malicious actors that is becoming more extensive. While technological development and the use of hybrid tactics has increased its vulnerability, the consolidation of strategic competition has made not only the surveillance and protection of the seafloor and what lies above and below it, but also the ability to project deterrence from and through the underwater (almost) domain, an essential imperative.

The increasingly contested nature of the deep and the decisive effect that superiority, or even technological and especially operational supremacy in these generates both in multidimensional confrontation across the grey zone with competitors and adversaries and in military confrontation in the multi-domain battlespace against the enemy underscores the need for constant doctrinal, organizational and capacitive evolution. The inherently challenging and hostile nature of the underwater depths, however, implies a simultaneous and coordinated technological transformation to expand technical, tactical, and operational options. The pragmatic integration into the underwater (almost) domain of the converging advances in robotics and AI represents in this view one of the most relevant metamorphoses in the making in the planning and conduct of operations from and below the water surface. The slow, but seemingly inexorable, transition from the sporadic deployment of small ROVs for seafloor mapping and support for demining activities, toward the systematic deployment of increasingly larger AUVs capable of performing increasingly complex tasks delineates a scenario in which mixed fleets of manned and unmanned vessels will manoeuvre synergistically to maintain a constantly updated Underwater Domain Awareness (UDA), generating dilemmas for the adversary and securing the initiative for allied forces.

While the full spectrum of UUVs presents considerable potential in terms of complementarity and capacitive redundancy compared to traditional submarines, enabling the deployment of a distributed, mobile, resilient, and sustainable underwater swarm of sensors and effectors included in the persistent surveillance of CUIs, the category of XLUUVs properly delineates itself as a class of first-line cooperative drones acting as mass integrators and force multipliers for the submarine components. The reduction in acquisition, operational, and employment costs, combined with the elimination of personnel safety from the tactical equation, opens up the possibility to a much more proactive approach in the employment of the submarine military tool to identify and prevent threats, protect national and allied interests, deter adversaries, and to the need to engage its offensive capabilities. From under-shore multispectral surveillance to area interdiction to enemy vessels, to the delivery of kinetic effectors against targets beneath the surface, above it and on land, the modularity offered by XLUUVs indeed offers relevant possibilities for operational innovation.

Although the underwater (almost) domain remains the most challenging area for MUM-T implementation, AI developments outline significant evolutionary prospects for the UUVs segment and in particular for the XLUUVs segment. Indeed, productive scalability, multimodal projectability, operational flexibility, tactical configurability and, above all, persistence represent the distinguishing characteristics of these assets. The cross-cutting attention paid by global navies to UUVs in general and XLUUVs in particular and the related significant investments made by national defence industries in their testing hence underscore their transformative potential in submarine competition

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