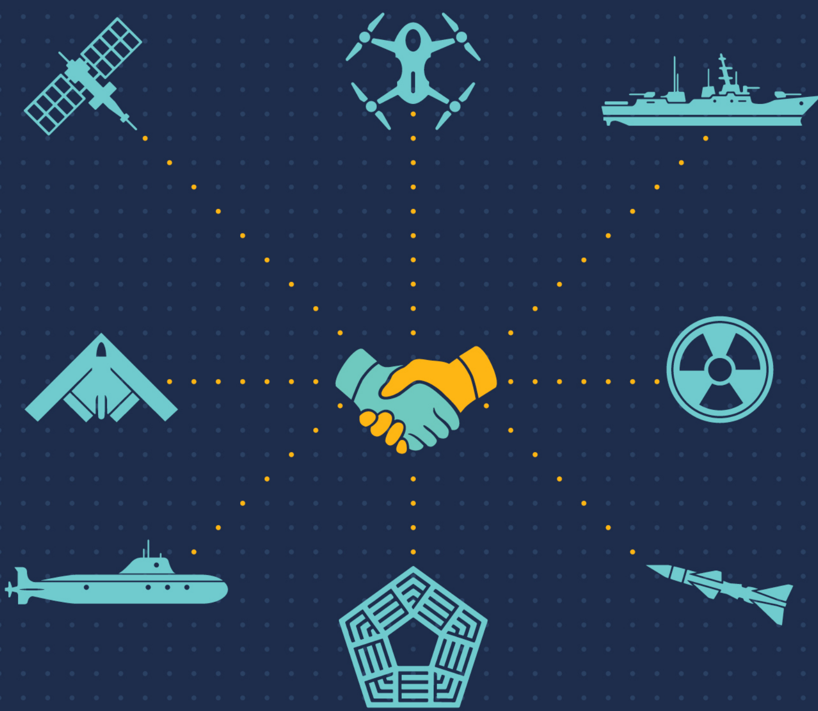
THE ARSENAL OF DEMOCRACY

TECHNOLOGY, INDUSTRY, AND DETERRENCE IN AN AGE OF HARD CHOICES



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SUBMARINES

Undersea capabilities are essential to showing China that the United States could defeat its air-naval forces within the First Island Chain and also potentially frustrate an attempt to seize Taiwan. The United States' submarine fleet is the best in the world and represents the US Navy's greatest asymmetric advantage over China. However, the US Navy is facing a readiness crisis within its attack submarine fleet. Around forty of its fifty attack submarines should be deployable, but maintenance issues severely limit their availability. Submarines require extensive upkeep, and the current backlog means that at any given time more submarines are out of commission than planned. This problem is compounded by an aging workforce and limited shipyard capacity. The situation could worsen during wartime because of supply chain disruptions. The fleet is projected to shrink by 2030, with only two shipyards producing new submarines at a slow pace. Australian shipyards cannot produce nuclear-powered submarines as of yet, and British yards are slow.[1] The AUKUS Agreement, which involves providing Australia with *Virginia*-class submarines and creating an Australian nuclear-powered attack submarine with British collaboration, will increase the total capacity available to the US alliance over the long term, but it risks further straining these production facilities.

Meanwhile, China's submarine fleet is modernizing and growing, and China's antisubmarine warfare (ASW) capabilities are improving.

To maintain an undersea advantage, the United States needs to make significant investments to expand the submarine industrial base and increase production. Congress should strongly consider appropriating tens of billions of dollars for this purpose over the next decade. Beyond that, more investment is urgently needed in US and allied yards so that, in a prolonged war, US and allied submarines could quickly receive necessary maintenance and return to combat. However, investments in infrastructure and workforce will be practical only if accompanied by an increase in submarine procurement.

Although these medium-term modernization imperatives are clear, several emerging technologies make the long-term future of undersea warfare highly uncertain. Unmanned underwater vehicles (UUVs), quantum sensors, advanced torpedoes, autonomous mines, and seabed sensors might revolutionize submarine operations, particularly in the late 2030s and 2040s. These technologies all face substantial developmental challenges, but it is essential for the United States and its allies to retain technological advantages over China in each of these areas. If history is any guide, the evolving cat-and-mouse game between submarines and ASW will continue for decades to come, and advanced detection and stealth techniques will define the future of undersea combat.

The Unique Value of Submarines

In modern combat—particularly naval combat—victory requires breaking an enemy's defensive system. Indeed, as we have seen, victory in major modern wars requires dismantling and penetrating the enemy's reconnaissance networks to enable attacks in depth.

Submarines have been the premier reconnaissance-strike network penetration tool since World War II. During World War II, the Allies and the Axis both established robust anti-access networks in the

Mediterranean through a combination of ground-based airpower and surface ships operating near the coastline.[2] Submarines were the only tools that either side could use to push into the enemy's anti-access network. Allied submarines thereby ensured a steady UK advance in-theater, spoiled German resupply, and enabled seams for resupplying British positions in Malta and Tobruk.[3] Although surface warships required air support and interlocking defensive systems to survive, submarines could evade detection, penetrate the enemy's scouting networks, and attack surface vessels or land-based assets from close range.

The same set of factors obtained throughout the Cold War, when the United States and USSR constantly used submarines to probe each other's scouting networks.[4] Soviet submarines were meant to dash into the North Atlantic during a major war with NATO, using their stealth characteristics to avoid US antisubmarine warships and aircraft while harassing and disrupting follow-on US forces supporting NATO defensive units in Europe. The United States, by contrast, used submarines to push into the Soviet anti-access network in the Arctic, ultimately putting the Soviets' nuclear second-strike at risk.

Submarines are hard to detect because electromagnetic radiation doesn't travel well through water. Underwater sensors can pick up submarines' sonic signatures, but they work only at short ranges, and even advanced space-based technologies and antisubmarine aircraft struggle with detection.[5] The easiest way to track a submarine is by following it from its home port. Thus, the quieter a submarine is and the longer its range, the harder it is to detect. All US submarines are nuclear powered and, owing to design advantages, are quieter than their People's Liberation Army (PLA) counterparts.[6] Diesel-electric submarines with air-independent propulsion (AIP) are generally quieter than nuclear ones because their propulsion systems have fewer moving parts.[7] China fields several ultra-quiet air-independent propulsion (AIP) diesel submarines, but the challenge for Beijing is that their range is limited. In contrast, US nuclear submarines have an almost unlimited range, restricted only by the need to replenish munitions, food, and other essentials.

Submarines are strategically valuable for deterrence because their presence signals to the adversary that its scouting network and other capabilities could potentially be degraded quickly during a conflict. Submarines can also conduct intelligence collection operations, including against adversaries' undersea cables.[8] During the Cold War, the guided-missile submarine USS *Halibut* conducted an operation against Soviet communications cables in the Sea of Okhotsk.[9] Similar operations are probably ongoing today in the South China Sea and the Philippine Sea, with far more advanced sensors and collection mechanisms.

Subs in the Indo-Pacific

Submarines are the United States' most important relative area of military advantage in the Indo-Pacific. As previous chapters have described, China has established sophisticated networks for targeting and firing at US surface vessels and aircraft operating within range of Taiwan. China's goal is to ensure that the bulk of US forces are held at risk the closer they approach the First Island Chain, ideally making it nearly impossible for all but the most sophisticated air and surface assets to operate within around 600 kilometers of Taiwan. US submarines, by contrast, can operate far closer to China's shores without a high risk of detection and can therefore potentially fire at PLA targets at much shorter ranges. Although the PLA's antisubmarine scouting capabilities are improving, US submarines are still quite good at evading detection.

During the Cold War, the DOD made the key decision to maintain an all-nuclear submarine fleet. Cost was a major consideration, given the long-term life-cycle cost savings of nuclear power, but so was geography.[10] Because most US attack submarines are home-ported in the United States, they must travel thousands of kilometers to regions where they might plausibly have to fight.[11] The US submarine fleet is split into nuclear and conventional elements. At present, it includes fourteen nuclear-armed ballistic missile subs, which are used for strategic nuclear deterrence. Four older ballistic missile submarines have been converted to carry 154 cruise missiles. These are the fleet's assets with the deepest land-attack magazine—but if they ever launch their missiles in combat, they will quickly become detectable within an enemy reconnaissance network, so any employment within China's detection range would have to be carefully planned. The United States has around fifty additional conventionally armed attack submarines. These include the newer *Virginia* and older *Los Angeles* classes, along with three of the *Seawolf*-class boats.[12] Attack submarines are very stealthy and can deploy cruise missiles, torpedoes, and mines.

If a conflict broke out, US attack submarines would flood into the western Pacific on missions to strike People's Liberation Army Navy (PLAN) surface vessels and submarines. If ordered, they could also potentially threaten land-based assets in mainland China. US submarines might not be able to operate safely within the First Island Chain, given China's ability to conduct intensive antisubmarine warfare sweeps off its coasts. However, so long as US submarines can operate close to the First Island Chain, they can hit most combat-relevant targets. Unsurprisingly, the details are highly classified.

China's air-naval ASW scouting system is improving but still underdeveloped.[13] The PLA's anti-submarine systems include dozens of anti-air warships, three aircraft carriers and the airborne early-warning planes they carry, multiple classes of drones, satellites, antisubmarine-focused surface combatants, civilian-flagged survey ships with deep-sea sensors, antisubmarine aircraft and helicopters, and an emerging seabed sensor network.[14] However, the ocean is a big place. US submarines almost certainly can come in closer than US surface ships or aircraft without risking detection. China is working hard to improve its ASW systems.[15] However, surface warships often struggle to integrate with patrol aircraft and sensors such as hydrophones and sonobuoys given the complexity of antisubmarine operations.[16] A warship can deploy a towed sonar array, but the ship itself generates so much noise that sonar contact with an enemy submarine is often disrupted. China needs much more practice operating all its antisubmarine assets together.[17]

The problem for submarine operators is that when submarines fire munitions, they give away their rough location, making it easier for the enemy to hunt them down. If US submarines are spotted during a conflict scenario, they could be quickly trapped and destroyed—especially in the relatively shallow waters of the western Philippine Sea. The Philippine Sea gets shallower the closer it gets to the First Island Chain—where the best launch points for the cruise missiles that might be needed to hit PLA targets are located.[18]

Meanwhile, China operates the world's largest fleet of AIP submarines and has made significant advances through collaboration with Russia. Their new Type 095 and Type 096 attack submarines could approach the capabilities of advanced Russian submarines in terms of propulsion, sensors, and weapons.[19] When these join the fleet, they will be quieter, have a longer range, and carry a larger and more diverse missile arsenal than China's existing nuclear submarines.[20] China's submarines are now equipped with advanced torpedoes comparable to US models and new cruise missiles that threaten both US surface vessels and land bases throughout the Western Pacific.[21] These are almost certainly designed to attack US surface combatants during the initial phases of a conflict. The PLA could surge a maximum of about two dozen submarines forward, with around thirty to forty-five in the water in total, depending on maintenance cycles and war warning.[22] Over the next decade, US submarines will remain far more technologically sophisticated. However, the numerical balance will tilt heavily toward China as the Bohai shipyard alone is expected to churn out at least eight new submarines by 2030.[23]

ASW is crucial for protecting US vessels in the Western Pacific. ASW can involve sonar-equipped warships, floating buoys with sonar (sonobuoys), and long-range patrol aircraft. PLA warships and aircraft are unlikely to travel more than around 1,500 kilometers from China's coast, because they will enjoy less missile support and fewer reconnaissance advantages and thereby be exposed to US counter-strikes.[24] However, if PLA submarines can break out beyond the First Island Chain to the far side of Taiwan, they could hold US surface vessels at risk.[25] Hence, US forces will have an acute defensive need to monitor the deep water channels around Taiwan, particularly the Miyako Strait and Bashi Channel, and maintain a large-scale antisubmarine dragnet around its major naval formations.[26] The US and allied undersea communications infrastructure could also be at risk during a conflict; China has already targeted it during its gray zone pressure campaign against Taiwan.[27]

In theory, around forty US attack submarines of the fifty-boat fleet are deployable at any given time.[28] Twenty-five to thirty are ported in the Indo-Pacific. Naval Base Guam, located in Apra Harbor, is home to submarine squadrons and has facilities for submarine tender support. The Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility in Hawaii is another key location, equipped to perform maintenance, modernization, and emergency repairs on submarines. On the US West Coast, the Puget Sound Naval Shipyard and Intermediate Maintenance Facility in Washington state is a major hub for submarine maintenance and refitting. The US Navy has roughly ten to fifteen attack submarines elsewhere. Unlike conventionally powered submarines, nuclear-powered submarines can be moved between theaters relatively easily.[29] Notionally, this means the US Navy could surge up to thirty-five submarines to the Indo-Pacific over a few weeks if needed.

As the United States seeks to enhance its naval presence and operational flexibility in the region, the Navy is exploring the potential of utilizing allied naval yards to support submarine operations. Several foreign bases, such as Yokosuka Naval Base in Japan, Subic Bay in the Philippines, HMAS Stirling in Australia, and Sembawang Naval Installation in Singapore, have existing ship repair facilities that could potentially be adapted for submarine maintenance.

Upgrading these foreign yards to fully service US nuclear submarines would be a complex and costly endeavor, requiring significant investments in infrastructure, equipment, personnel training, and regulatory compliance. Foreign yards would need to implement strict nuclear safety and security protocols, install specific equipment to service US nuclear submarines—particularly because nuclear submarines are significantly larger than conventional ones—train personnel in US submarine systems, and ensure compliance with US and international nuclear regulations. Given the sensitive nature of nuclear propulsion technology, the US Navy would need to maintain a significant oversight presence at these facilities. Detailed feasibility studies and negotiations with host nations would be essential to address political, legal, and security concerns.

Even if foreign yards are not equipped to handle nuclear reactor maintenance directly, they can still provide valuable support for US submarines. Capable allied yards could perform various nonnuclear tasks, such as hull and structural repairs, sonar and weapon system maintenance, propulsion system repairs, and resupply and crew support services. These yards could also handle emergency repairs, preventing further damage to submarines and ensuring their safe return to US bases. The availability of nonnuclear maintenance capabilities at strategically located foreign yards would significantly enhance the operational flexibility and readiness of the US submarine fleet in the Pacific, reducing the need for submarines to return to distant US bases for minor repairs and allowing for quicker responses to potential threats or emergencies. However, the decision to pursue such arrangements would require careful consideration of the associated risks, costs, and geopolitical implications.

The Readiness Crisis

Although the Navy is exploring the possibility of accessing foreign yards, existing US yards require an urgent recapitalization. Nuclear submarines are extraordinarily complex machines that require regular maintenance as well as periodic life-cycle overhauls. Currently, the entire fleet's maintenance cycle is badly backlogged. At any given time, an average of four boats beyond the standard cycle of ten boats are out of commission waiting for repair. Moreover, the average US submarine waits 1,500 additional days for maintenance during each half-decadal maintenance cycle.[30] Once maintenance begins, additional delays can compound. On average, the extra maintenance days take an additional three or four submarines out of action at any given time. These delays have occurred at a peacetime operational tempo, under which there are no additional external stresses on the US industrial base beyond that of supply chain blockages. During wartime, pressures would intensify rapidly. The same workforce issues that undermine the defense industrial base (DIB) in general acutely impact the submarine industry as well. A workforce that is, on average, over fifty years old will not be capable of rapidly accelerating construction and repair—even with large investments to expand physical facilities.

In a conflict scenario, the existing US submarine industrial base could struggle to source vital maintenance and repair parts, especially if many damaged submarines needed repair simultaneously. China might sabotage US repair facilities or even try to strike them with long-range missiles if a conflict escalated. Thus, the effective fleet size could sink rapidly after the first six months of a war, once wartime attrition and damage sets in. In this situation, US commanders might have to cannibalize older, moderately damaged boats to keep some of the fleet in the fight. The net result is that, rather than a fleet of around forty deployable boats, the United States typically has only around thirty deployable attack submarines at any given time. In a conflict, some might be lost very quickly. The rate of attrition would have enormous implications for the US military's ability to sustain high-intensity combat throughout a long war.

Space limitations at existing shipyards present a difficult trade-off between repairing and maintaining existing submarines and building new ones. US submarines are built only at two yards: General Dynamics Electric Boat in Groton, Connecticut, and Newport

News–Huntington Ingalls Industries in Newport News, Virginia. Together, these facilities can produce just 1.2 boats every year.[31] Given planned retirements, the net loss rate is 0.4 submarines per year.[32] Both yards currently lack the capacity to quickly scale up production. It would take around a decade of consistent congressionally sustained investment to ensure that these yards expanded their capacity significantly. The Navy is highly unlikely to switch to conventionally powered boats, both because institutional incentives within the Navy and the industrial base militate against it and because refueling is a complex challenge in a theater as large as the Indo-Pacific. Thus, at current trends, the nadir in US submarine fleet size will come around 2030—close to the worst possible time given China's likely threat trajectory vis-à-vis Taiwan.[33]

The two existing US yards also face the prospect of growing demand in the early 2030s. The AUKUS Agreement's Pillar I Pathway commits Washington to providing Australia three *Virginia*-class submarines in the early 2030s and gives Australia the option to buy two more.[34] It also launched a program to build a new "SSN-AUKUS" attack submarine that will be codesigned and coproduced in the United Kingdom, Australia, and the United States. Given the complexity of the project and the material constraints on the UK defense industrial base, this program may well be delayed. If it is, Australia is likely to want all five *Virginias*—which will test the capacity of US production facilities. Production might be slightly sped up if secondary repair facilities can be used for certain construction tasks and smaller producers decide to create modular yards. Fincantieri Marinette Marine (FMM) in Wisconsin and the proposed Bartlett Marine facility in Ohio are two actionable possibilities.[35] The fastest way to scale up submarine production is to create another yard, but it would be cheaper to expand existing facilities, including the yard in Barrow, United Kingdom.

Like most military platforms, submarines are only as useful as the munitions they carry. Attack submarines carry many of the same munitions as surface ships, including cruise missiles. Torpedoes, the classic undersea combat weapon, have their own complex industrial base.[36]

There are two main kinds of torpedo: heavy and light. Light torpedoes are analogous to short-range anti-ship missiles. Heavy torpedoes are analogous to precision-guided cruise missiles. Submarines typically carry heavy torpedoes, which have advanced targeting systems and stealth characteristics.[37] The United States' mainstay heavy torpedo since the early 1970s has been the Mk-48, which can target both major warships and submarines.[38] Unfortunately, the Mk-48 torpedo supply chain faces many of the same industrial bottlenecks as other munitions discussed earlier in this book. Based on limited open sources, we estimate that around 1,000 to 1,500 Mk-48s are held in inventory, enough to sustain the US fleet at war for just two rounds of deployment and rearmament. Depending on the intensity of a conflict, this could mean that supplies would last for just a few weeks to a few months.[39] Only three companies produce the weapon—Raytheon (now RTX), Lockheed Martin, and Northrop Grumman—and only RTX is the historical contractor of choice, likely to be able to scale up production quickly. As of the late 2010s, Lockheed Martin was producing only around fifty torpedoes a year.[40] Despite the obvious demand signal, none of these companies has publicly indicated a plan to expand production.

Recapitalizing the broader submarine industrial base, including munitions and related components, is the most expensive line item that we recommend in this book. If the United States wants to keep a fleet of at least fifty attack submarines through the 2040s, it will need to build three boats per year—more than double the current pace of production. Expanding procurement to three boats per year would cost roughly $13 billion annually and demand new capital funding for industrial base expansion—which is already set to receive an additional $2 billion over five years to cover current gaps—plus another maintenance expansion, which has already received $2.2 billion in special appropriations.[41] Combining yard capacity, annual shipbuilding appropriations, and the maintenance costs of a larger fleet, the total amortized cost of accelerating to three boats per year would probably be around $14 to $16 billion annually—or roughly a 50 percent increase in the Navy's current shipbuilding budget.[42] Political leaders will have to explain to the public why maintaining US advantages undersea is imperative.

Emerging Tech Trends

Despite the obvious need to modernize the US submarine force over the medium term, the longer-term future of undersea warfare is highly uncertain. As discussed previously, planners in the early twentieth century thought the submarine would be a perfectly stealthy battleship killer. In fact, because of scouting and accuracy issues, it was not so easy for subs to destroy battleships with torpedoes. Submarines scored kills against large warships in World War II, but they were mainly used to terrorize merchant shipping and transports.[43]

Planners today rely on guesswork in anticipating the efficacy of submarines, since submarine combat has been extremely rare since 1945. Indeed, in all of history, only one submarine has ever sunk another submarine while submerged. This was the British HMS *Venturer*, which sank the German submarine U-864 in 1945 when it was bound for Japan with approximately sixty-five tons of explosives.[44] The only submarine to have scored a combat kill since World War II is the HMS *Conqueror* during the Falklands War.[45] US and Soviet submarines stalked each other throughout the Cold War, and submariners exercised regularly to ensure the accuracy of their targeting systems.[46] Still, US and PRC planners face similar uncertainties in thinking about submarines' role in the broader military balance, and emerging technologies continue to inject even more uncertainty. Submarine-launched anti-ship missiles, longer-range torpedoes, and better quieting techniques have made submarines stealthier over the past century. At the same time, ASW techniques have improved, and submarines have become harder to build and more expensive to replace, which has made navies less willing to put them at risk to attack low-value targets. In the twenty-first century, this cat-and-mouse game between submarines and ASW is likely to continue.

Although Congress must spend tens of billions of dollars on new manned submarines that will operate for decades, it must also keep an eye on emerging technologies that may revolutionize undersea combat starting in the 2030s. Advanced seabed sensors, quantum sensors, underwater drones, smart mines, and advanced torpedoes might eventually do to undersea warfare something similar to what satellite reconnaissance and long-range strike have done to surface warfare. This revolution is likely at least a decade away, so in the short term, Washington has no alternative but to expand the existing submarine fleet and industrial base. The history of undersea warfare suggests that traditional submarines will remain useful, although tactics will evolve.

Advanced Seabed Sensors

Advanced seabed sensing will eventually have a transformational effect on submarine warfare, but it is some time away from maturity. Civilian firms are developing seabed sensors that can detect movements from the ocean's floor for mining, monitoring, and environmental reasons. These sensors typically relay information through fiber-optic cables. Though individual cables are easily damaged if targeted, they are also hard to find owing to their small size, their positioning along the seafloor, and the use of backup cables and other redundancies. Hence, identifying these systems would require extensive pre-conflict surveillance and granular oceanographic mapping.

A robust seabed sensor network would allow a country to identify an enemy's submarine movements far more accurately than other methods. The best historical analogy is the Sound Surveillance System (SOSUS), which provided valuable continental defense and early warning for the US Navy during the Cold War.[47] Developed in the early Cold War and deployed throughout the North Atlantic, the SOSUS system tracked Soviet nuclear-armed submarines.[48] Initially, hydrophones, which are underwater microphones designed to capture sound waves in water, were installed on the ocean floor in strategically chosen locations and connected to shore installations via undersea cables. These arrays could detect extraordinarily faint sounds from several hundred kilometers away. This capability allowed the United States to map Soviet nuclear-armed submarine deployment patterns to the Western Hemisphere with startling accuracy. During the late Cold War, the United States combined the SOSUS hydrophone network with Surveillance Towed Array Sensor System (SURTASS) oceanic surveillance ships, equipped with powerful mobile sonar. Together, they create a particularly effective detection network.[49]

Next-generation sensors could detect heat and other environmental changes caused by submarine movements.[50] Over time, the large-scale installation of such sensors will enable more precise identification, reducing the stealth of submarines, particularly near coastlines. Deploying these extensive sensor networks will take time. Extremely sensitive passive hydrophones already exist, but the challenge lies in distinguishing relevant data from background noise. The more sensitive a hydrophone is, the more background noise it picks up, necessitating complex analysis to distinguish submarine sounds from other irrelevant noises. This is fundamentally a computing problem: A system is needed to sift through background noise to detect actual submarine sounds. Although it is a solvable issue, there are significant technical and physical hurdles to overcome, including the placement and networking of the hydrophones. In addition, deploying hydrophones takes time as only a few ships are capable of laying them with the necessary cables.

Quantum Sensors

Submarines are essentially large underwater metal tubes filled with advanced electronics, subcomponents, and weapons. Hence, they generate large magnetic fields that, with the right device, should be detectable.[51] Traditional magnetometers detect magnetic fields to identify metal objects and have ranges of only a few hundred meters. They are most effective when paired with other detection devices, such as sonar. Theoretically, quantum magnetometers could have much greater sensitivity to anomalies.[52] Miniaturized magnetometers with quantum technology could even be placed onto aircraft, providing an antisubmarine sensor without needing to be placed in the water.

Similarly, a quantum-enabled gravitometer could detect the minute gravitational shifts caused by a submarine.[53] To pinpoint the submarine's location and movement, these measurements must be synchronized to a precise reference time. By combining a gravitometer with a quantum clock, whose stable atomic transitions provide ultra-precise timekeeping, the readings can be time-stamped with exceptional accuracy.[54] This synchronization could in principle support effective tracking, especially when drawing on multiple gravitometers deployed on satellites or aircraft. Quantum computing could accelerate the use of imaging technology in antisubmarine warfare.[55] Large undersea objects like submarines cause subtle changes to the ocean surface that are undetectable to the naked eye but might be detectable by well-trained AI algorithms and/or quantum computing.[56]

Quantum sensors are probably a decade or more away from operational maturity, and all three of these quantum-related antisubmarine techniques face major technical hurdles in scaling. There will inevitably be trade-offs among miniaturization, power generation, sensitivity, and accuracy that necessitate embedding these new technologies in a broader detection system. Nevertheless, the possibility of a future quantum revolution within the lifetime of submarines built today means that submarine designers must consider new stealth techniques. In particular, new detection mechanisms are likely to prompt naval engineers to build submarine hulls capable of withstanding greater pressure, allowing submarines to dive deeper to avoid detection. This cat-and-mouse game might revolutionize undersea warfare over the next several decades, reshaping submarine operations and mission capabilities.

XLUUVs

Every major power is developing unmanned underwater vehicles (UUVs) for its battle fleet (see table 8.1). Militaries have historically employed UUVs for limited missions like minesweeping and mine hunting. Civilian companies use them for oceanographic research. As a result, current UUV capabilities remain relatively basic, though technology is advancing fast.

UUVs present unique technical challenges compared with aerial, land-based, or surface drones. Underwater communication is difficult because of signal interference, which limits remote control and constrains real-time coordination. Consequently, for UUVs to achieve operational impact comparable to aerial drones, they would need either advanced autonomous systems or to function within sophisticated networks. Given the difficulties of both power generation and communications, extra-large UUVs (XLUUVs) with more robust onboard sensors may prove more effective than smaller platforms. However, current battery limitations require UUVs to return frequently to motherships for recharging, even if this can be done underwater, likely necessitating the accompaniment of crewed vessels or a reliable power relay system.[57]

Integration with existing naval forces poses additional challenges. UUVs are unlikely to replace manned submarines as quickly as unmanned systems are replacing surface vessels and aircraft. Although automation may reduce submarine crew sizes, designing fully automated submarines is a formidable engineering challenge. Instead, XLUUVs are more likely to complement existing manned submarines, operating alongside the current fleet rather than replacing it. This shift may affect submarine force culture as command sizes decrease from medium surface combatant levels to those of smaller warships, potentially fostering greater independence and tactical flexibility.

Several major powers are currently testing advanced XLUUVs, such as the US Navy's Huntington Ingalls Orca, China's dual-use

Table 8.1 Major XLUUVs under development

Model and country	Specs	Speed	Price per unit	Status
Orca (US)	15.5 meters, with modular payload 26 meters total (a)	Max 15 kph, service speed 5.5 kph (b)	More than $113.3 million (c)	First delivery to Navy 2023 (b)
Several designs (d) (China)	15–18 meters (d)	Unknown	Unknown	Prototypes in water since 2021 (d)
Ghost Shark (Australia)	11 meters (e)	Unknown	Unknown	Prototype delivered 2024 (f)
Cetus (UK)	12 meters (g)	Unknown	Unknown	Sea trials beginning 2024 (g)
Sarma (Russia)	Unknown, likely close to a full submarine (h)	Unknown	Unknown	Unknown

Sources: (a) Tim McMillan, "Look: New Images Showcase the Navy's Cutting-Edge 'Orca XLUUV' Autonomous Underwater Drone," The Debrief, June 18, 2024; (b) Naval Technology, "Orca XLUUV, USA"; (c) US Naval Institute Staff, "Report on Navy Large Unmanned Surface and Undersea Vehicles" (Congressional Research Service, August 29, 2023); (d) China may have upward of five XLUUV designs. See H. I. Sutton, "China's New Extra-Large Submarine Drones Revealed," *Naval News*, September 16, 2022; (e) David Axe, "Australia's 36-Foot 'Ghost Shark' Is Just the First of the New, Huge Robot War Submarines," *The Telegraph*, April 26, 2024; (f) Anudril Industries (@anudriltech), "We're gonna need a bigger boat! Meet Ghost Shark, an extra-large autonomous undersea vehicle (XL-AUV). That's right, a massive underwater drone. As a defense prod," X, April 18, 2024, 8:50 a.m., https://x.com/anduriltech/status/1780987267630395454; (g) Navy Lookout, "In Focus: CETUS the Royal Navy's Next XLUUV," November 14, 2023; (h) H. I. Sutton, "Russia's Answer to the US Navy's Orca XLUUV: Sarma-D," Covert Shores, October 13, 2022.

gliders, Australia's Ghost Shark, and Britain's Cetus (see table 8.1).[58] Current technology remains too immature to determine which major power is in the lead, but advances in battery technology, materials science, and computing power over the next two decades should significantly enhance XLUUV autonomous capabilities. However, military requirements for endurance and reliability far exceed civilian standards, so the timeline for operational integration is highly unpredictable.

Autonomous Mines

Autonomous mines, which will likely be integrated with light torpedoes, will be more responsive and capable of homing in on enemies and thereby will serve as more effective offensive weapons.[59] Autonomous mines are self-operating naval mines that can detect, track, and engage enemy vessels without human intervention. These advanced mines use sensors and onboard decision-making systems to identify targets and trigger detonation, making them more adaptable and effective in various maritime environments. As discussed in chapter 5, Ukraine has shown how unmanned surface and underwater vehicles can be used to seed mines and also to operate as naval loitering munitions.[60]

Both the United States and China have autonomous mine programs and are likely pre-positioning them in inactive form. Encapsulated torpedoes, such as the US Navy's Mk-60 mine, are mines with torpedoes attached that can attack deep-diving submarines. Longer-range mines can be seeded by aircraft, surface vessels, or submarines and then move by themselves hundreds of kilometers forward into position.[61] Even with range limitations, more modern batteries and better power management technology can allow these to lie dormant in crucial chokepoints for months before war begins. In a Taiwan conflict, both sides might use these devices to obstruct traffic in and out of each other's harbors. Production will be challenging, as the United States has not produced a torpedo-enabled mine since the 1980s and has not purchased mines in quantity since the Cold War. Building a robust allied industrial base for advanced mines—potentially including Taiwan—could be a prudent idea.

Advanced Torpedoes

Torpedo design has not changed much since the late Cold War and the combination of super-cavitating torpedoes and smaller, higher-performance light torpedoes is likely to prompt some changes in undersea combat. Traditional torpedoes travel at 50 to 100 kilometers per hour, far slower than any missile. A super-cavitating torpedo would move between 300 and 400 kilometers per hour by creating a gas bubble around it to reduce drag—still slow for any object flying through the air but notably faster than current underwater weapons.[62] If combined with an effective sensor system and reliable targeting data, super-cavitating torpedoes could provide submariners with an undersea weapon equivalent to ship-launched cruise missiles. Much like a top-line high-speed missile, a super-cavitating torpedo could travel fast enough to avoid traditional response mechanisms, greatly increasing the odds of a successful hit.[63]

Super-cavitating motion comes with trade-offs. First, it makes a torpedo much easier to detect. That means if the torpedo misses its target—or if the enemy has other assets in the area—then a submarine that launches a super-cavitating projectile can potentially be identified and neutralized. Super-cavitating torpedoes are also likely to be significantly less maneuverable than traditional torpedoes, a very important limitation in combat.[64] Even so, super-cavitating torpedoes are likely to be deployed in the next fifteen years or so, potentially coupled with next-generation guidance mechanisms. They could prove deadly against both surface ships and less stealthy submarines.

Miniaturization in torpedo designs will also make it easier for surface warships and UUVs to deploy more firepower against submarines. Light torpedoes are deployed from surface warships, mounted on missiles, or launched from aircraft.[65] They can also be launched from submarines. Light torpedoes are primarily designed to fire at submarines. Defense contractors in the United States and allied countries have been working hard on lighter torpedoes that nevertheless retain good range, accuracy, and payload characteristics. The United States has a Very Lightweight Torpedo program. India, France, Sweden, Turkey, and the United Kingdom have their own programs. Next-generation light torpedoes will be deployable in high numbers from small warships, helicopters, and unmanned surface and underwater vehicles. They will make undersea warfare much more lethal. The most mature programs, mostly based in the United States, could start production by around 2026, but they are unlikely to reach the field before the late 2020s.[66]

Conclusion

Undersea warfare will be critical to any future conflict in the Indo-Pacific. For now, submarines are a key area of US advantage, but China is closing the gap in hardware—even as it continues to struggle with operational competence issues. The PLA still faces significant technical hurdles but faces a much more favorable geographic and operational context for the military problems it seeks to solve. Thus, the United States faces a perilous deterrence environment over the next five to fifteen years if it lets its submarine force keep shrinking. Tens of billions of dollars of up-front capital investment are necessary if the United States is to retain the capacity to keep its fleet size stable, but again it is not just a question of money.

Ideally, Congress would provide the funding and support for the Navy to take several additional steps. First, Congress should pause all attack submarine fleet retirements and keep older *Los Angeles*–class boats in the fleet until the mid-2030s. Next, it should approve long-lead multiyear contracts for submarine subcomponents—without appropriated boats alongside them—for maintenance, repair, and industrial revitalization purposes. Third, it should appropriate specific funding for state governments to support smaller yards for repair and overhaul. It should also instruct the DOD to accelerate efforts to develop a network of yards in allied countries for submarine tendering, maintenance, and repair.

Emerging ASW technologies seem unlikely to greatly undermine the US undersea force within a five- to fifteen-year horizon, but the United States should still deepen collaboration with allies and the private sector to retain an edge. As these technologies emerge, they could have strategic effects, and they will also likely cause changes in tactics, even if the cat-and-mouse game between submarines and ASW is not decisively resolved. For the next decade or so, navies will therefore need to keep building and maintaining traditional submarines while supplementing or partially replacing them with UUVs for certain missions. Maintaining the US and allied submarine industrial base therefore remains an important priority. The United States could also build a constellation of satellites in low-earth orbit (LEO) to track adversaries' submarines, perhaps in cooperation with allies. It is also probably a prudent idea to increase the funding of UUV and XLUUV development, ensuring that Virginia Payload Module (VPM) *Virginia*-class submarines can field and rearm UUVs, and to procure large numbers of autonomous mines that field lightweight torpedoes.