Rising tide: Submarines and the future of undersea warfare

David Szondy July 5, 2017

The submarines of the future will face an environment where it's harder to hide and where robots play a larger role (Credit: Royal Navy)

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The submarine is the single most powerful piece of military hardware ever devised. Inside the hull of a single nuclear ballistic missile boat is more firepower than was unleashed by all the armed forces of the world during the Second World War. Submarines played a key role during the Cold War, and in a modern world marked by globalization and emerging regional powers these undersea behemoths are more important than ever. But what role does the submarine play in the 21st century and how will emerging technologies change it?

The next time you're on a ship or at the ocean shore, look out at the water. It might be a quiet day with the sea as calm as a mill pond. There might not be a single vessel in sight from horizon to horizon, suggesting a scene as it was a million years ago. And yet, beneath that placid surface, silently cruising hundreds of feet below, may be a submarine – unseen and undetected.

A T-class submarine of the Second World War
(Credit: Royal Netherlands Navy/Koninklijke Marine)

And that is the essence of a naval submarine. Although the term "stealth" conjures up images of futuristic angular aircraft that can evade radar, military submarine development has been driven by a quest for stealth since their earliest days. Their job is not to be seen, to go where no ship can go and, if necessary, to strike without warning.

In many ways, the submarine is the opposite of the surface ship. Where an aircraft carrier gains much of its strength from being visible, the submarine is invisible. The carrier can show the flag, make a nation's presence known in disputed waters, act as a show of force, or display support for an ally via a friendly visit.

The submarine, on the other hand, is discreet. In volatile situations it can be quietly dispatched to keep an eye on things or it can apply pressure without being overt. In fact, being invisible means that a naval power can simply drop hints that a submarine is in an area and it can have the same effect, whether it's there or not.

This stealth allows a submarine to put a massive amount of uncertainty into the mind of an enemy, forcing them to waste resources trying to hunt down subs that they aren't sure are even there, or cause them to completely abandon an area. During the Falklands War in 1982, for example, the sinking of the General Belgrano by HMS Conqueror kept almost the entire Argentine fleet bottled up in port.

From a strategic point of view, this element of uncertainty has been key to nuclear deterrence. An enemy might be able to so precisely locate another nation's missile bases and airfields as to make a nuclear first strike something worth considering, but a submarine armed with nuclear missiles will still represent the threat of devastating retaliation, which is part of the reason the US keeps half of its nuclear forces – and the UK its entire deterrent – on subs.

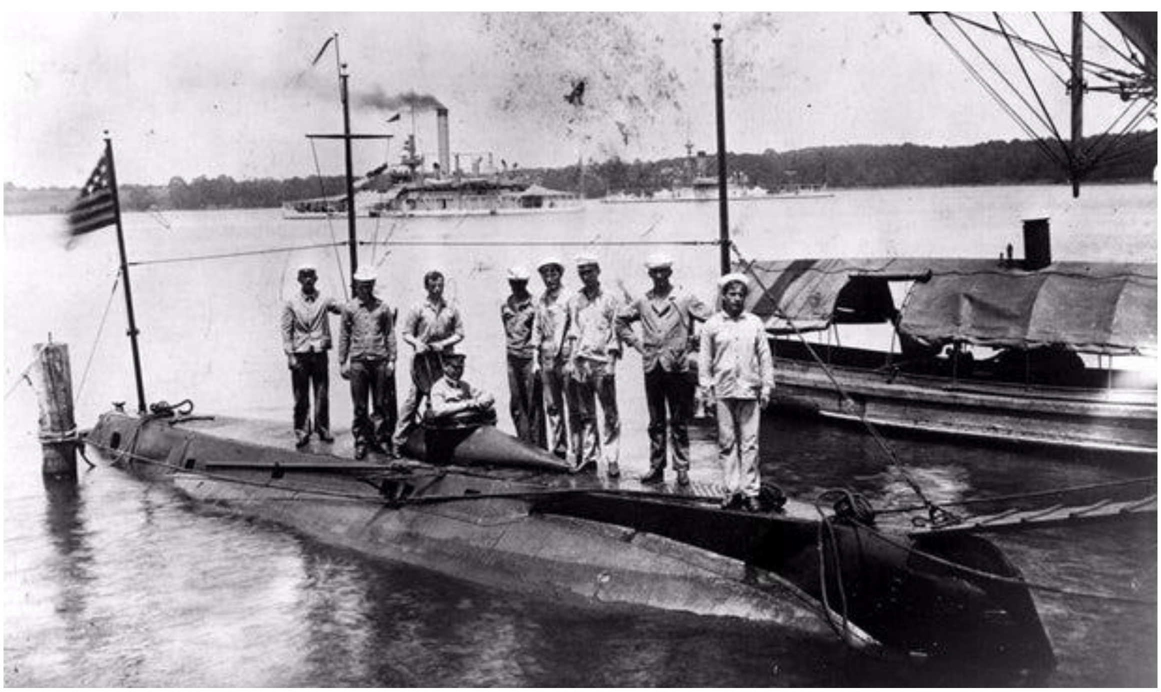
Small wonder that submariners regard their vessels as the true capital ships – whatever the carrier fans might say.

The coming of the

Submarines weren't always the stealthy warriors they are today. Captain Nemo's Nautilus notwithstanding, the submarines at the turn of the 20th century were dismissed as smelly little "pig boats" manned by rude mechanics in greasy overalls.

The sentiment was best summed by Admiral Sir Arthur Wilson, who called them "underhand, underwater, and damned un-English."

Submarines in one form or another had been invented and reinvented many times, going back to legends of Alexander the Great having himself lowered into the sea in a giant glass barrel so he could study the depths. The 19th century saw significant experimenting as ironclad hulls and portable power sources became available, but it wasn't until around 1900, when the navies of the United States, Britain, and Japan commissioned submarines based on the designs of the Irish engineer John Holland, that what we would recognize as a submarine emerged.



USS Holland, the first submarine in the US Navy (Credit: US Navy)

By the time the First World War broke out in August 1914, submarines had advanced rapidly and many of the systems that are still used today appeared.

How to build a submarine

The essence of the submarine is the pressure hull, which is a sealed cylinder designed to keep the crew on one side and the sea on the other even when submerged hundreds or even thousands of feet. Inside are the living quarters, controls, engines, and weapons.

Outside of this hull is the casing or superstructure, which wraps around the hull and provides a smoother, hydrodynamic shape that allows the craft to move efficiently and, more important, silently. This casing is not water tight and is designed so the sea can flow in and out easily when diving or surfacing.

The most prominent part of the casing is the submarine's trademark fin or sail – often erroneously called the conning tower. This metal projection acts as an observation platform with a small open bridge where the captain can pilot the ship while on the surface. It also contains the famous periscope, radio antenna, and radar masts. It acts as a way for personnel to get in and out of the sub without swamping the boat in rough seas and acts as a stabilizer while traveling underwater.

Between the casing and the hull are the ballast tanks. Wrapped around the pressure hull, these tanks are open at the bottom and have valves at the top. When diving, the valves open, allowing the air trapped inside to escape. As it does so, water rushes in through the bottom, making the submarine heavy enough to sink. To surface, the valves are shut and compressed air is blown in to make the boat buoyant again.

The ballast tanks are supplemented by the trim tanks. These allow the captain to fine tune the buoyancy of the submarine until it sits level underwater in a state of neutral buoyancy, neither rising nor sinking. For maneuvering, the sub has rudders like a surface ship for going left or right, and hydroplanes on the fore and aft parts to angle the boat up or down to aid in diving or surfacing.

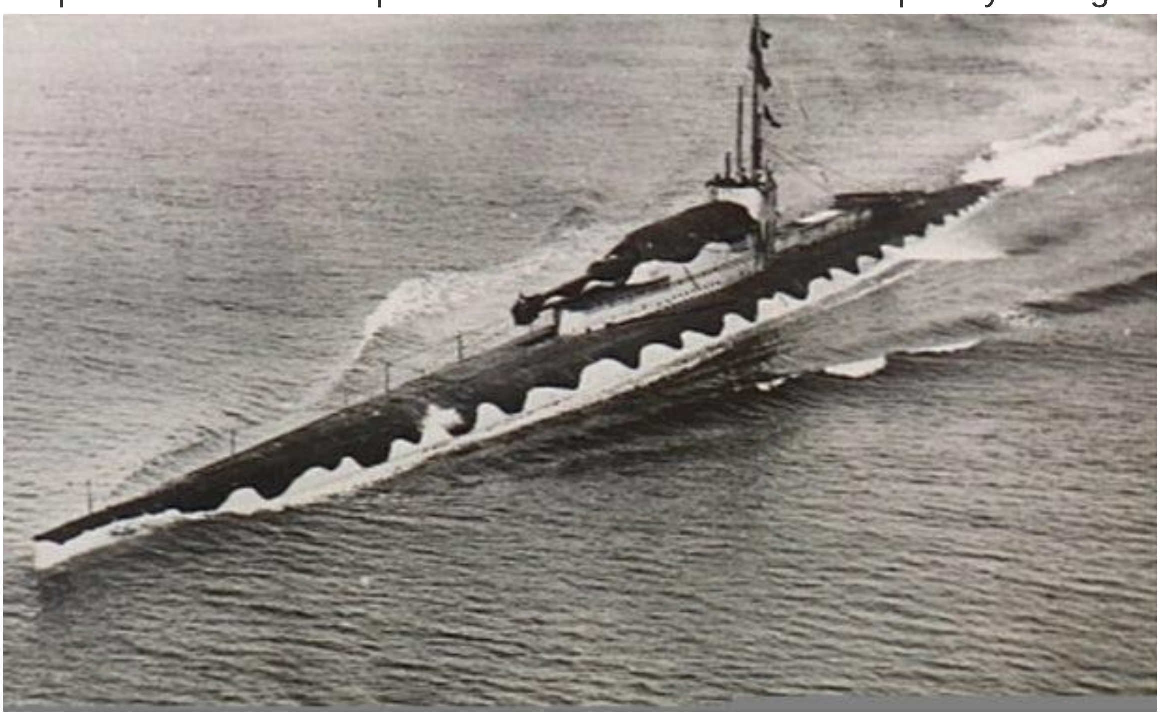
Meanwhile, inside the pressure hull are the boat's power plants. In the first half of the 20th century, this would have been a set of diesel engines for running on the surface, which also ran the dynamos that charged banks of gigantic lead acid batteries to power the electric motors that propelled the vessel underwater.

War and Cold War

It was this basic combination of elements that turned the submarine from a half-blind contraption into a deadly hunter. During the First and Second World Wars, the submarine became an unseen terror. Packs of them indulged in commerce raiding to starve enemies of food and raw materials, acted as fleet escorts to attack enemy warships, and layed mines to turn waterways into no-go zones.

So versatile were submarines that they were turned into blockade runners, recon platforms, and insertion vessels for spies and commandos. Mini subs were built to sink ships in harbor and, at the other end of the spectrum, giant submarines were launched as gun ships and even aircraft carriers.

So powerful was the impact of the submarine that it completely changed naval strategy and tactics, with anti-submarine fleets that were established to hunt the subs soon becoming the most important part of any operation. Without the sub hunters and the sub killers, the rest of the navy didn't dare leave port.



Submarine gunboat HMS M1 (Credit: Crown copyright (expired))

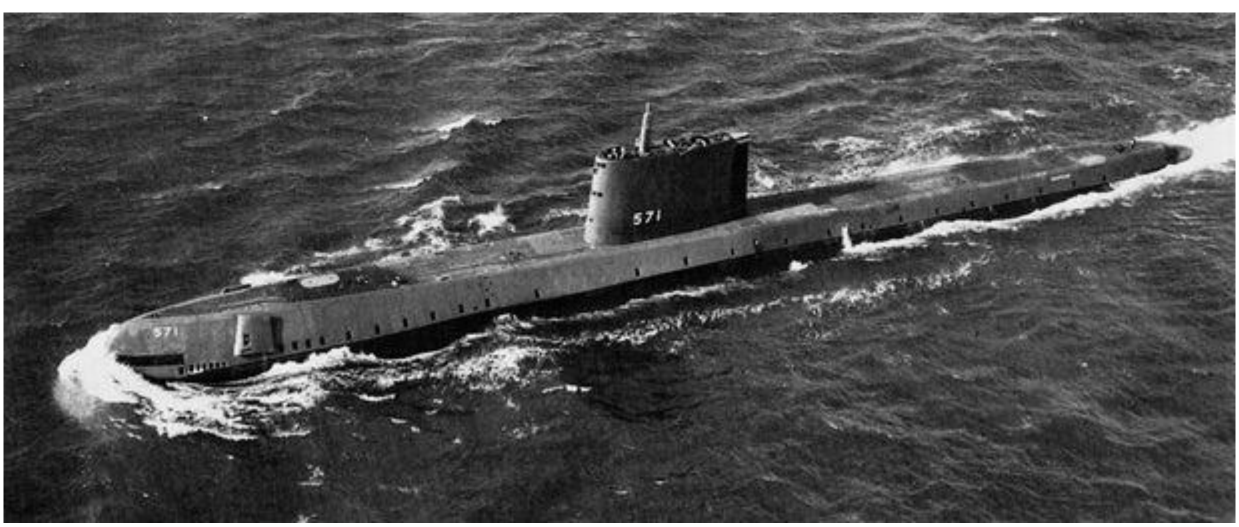
In fact, by the 1940s there was a parallel war going on. The Battle of the Atlantic was one of the great conflicts of the Second World War and not only involved fleets of Allied destroyers and patrol aircraft fighting to turn the tide of the German U-boat wolf packs that preyed on shipping, but was also fought in laboratories with slide rules and computers.

The Germans would invent ciphers to communicate with the U-boats. The Allies would break the ciphers and the Germans would then come up with new ones. Meanwhile, at sea, new sonars were developed to hunt the submarines while underwater. If they surfaced, new radars would seek them out. The Germans countered with snorkels to run their diesels submerged and anti-radar technology to evade the sensors. The Allies countered their counters with more sensitive radars. It was a struggle where technological advances that would previously have provided the upper hand for years, soon only gave an advantage for months. This set the tone for submarine warfare for the next 75 years.

The first true submarine

At this point, we must make a distinction. We've been using the word "submarine" a lot, yet none of the boats built up until the 1950s was an actual submarine. The proper term is "submersible." A submarine is a craft that operates underwater and only surfaces occasionally, if at all, between leaving and returning home. The conventional diesel/electric boats were nothing like that. They were vessels that ran on the surface and only submerged to attack or evade attack. Once underwater, they relied completely on their batteries for power and the air was limited to what was in the hull when the hatches were closed. This restricted them to submersed times of about 48 hours in an emergency.

It was during the Cold War that this changed and Jules Verne's vision became a reality. The previously impossible turned into a revolution in not only naval warfare, but global strategy. One we still live with to this day.



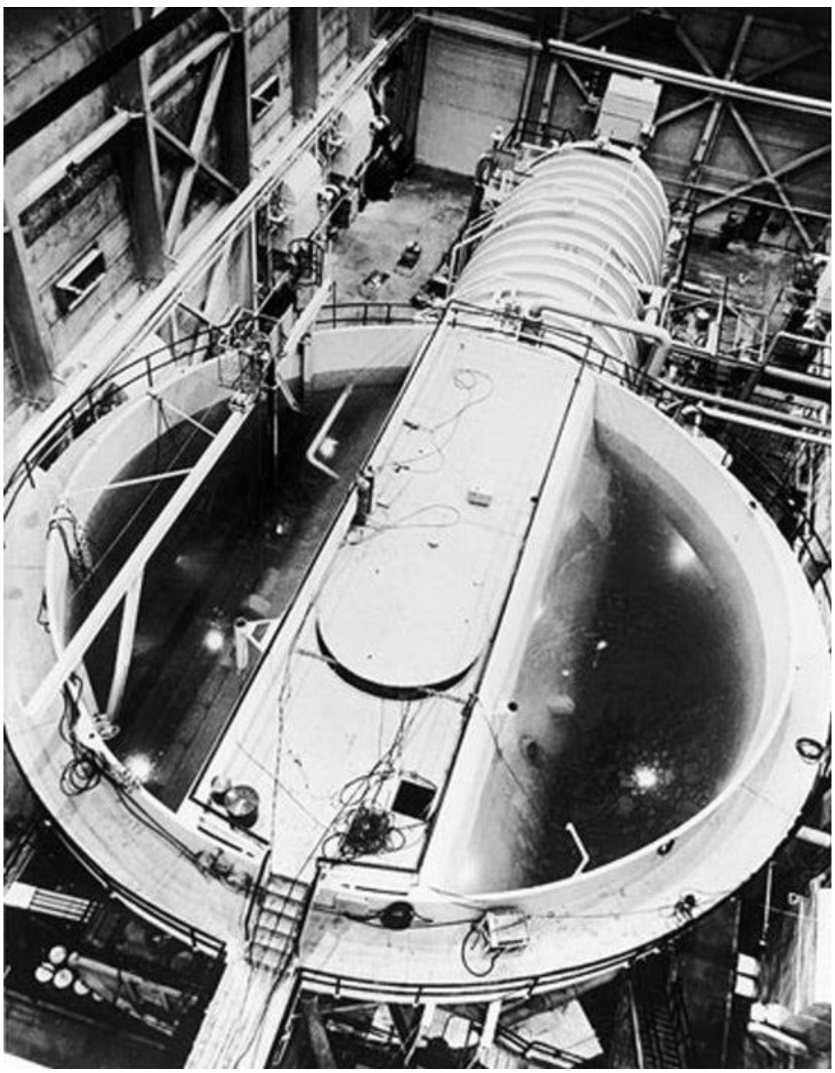
USS Nautilus (Credit: US Navy)

The first true submarine was the USS Nautilus. The brainchild of Admiral Hyman G.

Rickover, it was launched from the Electric Boat Shipyard in Groton, Connecticut in 1954 and was the world's first nuclear-powered ship, as well as one of the first practical applications of nuclear power. This meant that Nautilus could remain at sea for years without refueling and never needed air to generate power.

To this quantum leap in propulsion were added to other advances. Systems were developed to create oxygen from seawater and to scrub the air of carbon dioxide. More advanced freshwater makers came on line. Hulls were streamlined and the boats became bigger and more comfortable.

In addition, submarine crews were vaccinated, carefully screened for illnesses, and ruthlessly culled before patrols if even a sniffle was suspected. This resulted in crews so healthy that after a few years, the nuclear boats stopped carrying their doctors, who were dying of boredom.



Reactor core for USS Nautilus undergoing tank tests (Credit: Idaho National Laboratory)

All this allowed submarines to do things that were science fiction only a few years before. In 1958, the Nautilus became the first submarine to reach the North Pole under the ice. A week later, the nuclear-powered USS Skate surfaced at the pole by breaking through the ice. Then in 1960, USS Triton circumnavigated the world while submerged.

To coin a phrase, it was a whole new ballgame. With nuclear power and its attendant technologies, submarines never had to surface and never even had to return to port. Endurance was now limited by how much food was aboard and how long the crew's morale would hold up confined in a metal tube without sunlight. Maybe that's why they always got the best food.

Even better – or worse, depending on your point of view – half the anti-submarine warfare book went out the window. Since subs never had to surface, radar and spotting aircraft were useless. As for the routine of dropping depth charges, nuclear submarines could just dive deep and flee the attacker. As for Nautilus' stunt of steaming under the polar ice cap, that had a very serious purpose. Where better to hide in wait than under a thick layer of ice?

As the Cold War progressed, submarines evolved rapidly. Hulls went from merely streamlined to smooth hydrodynamic shapes designed for maximum speed with minimum sound. Dead reckoning and sextant sightings gave way to inertial and satellite navigation. Submarines didn't even have to surface to contact base. Instead, they would listen for alert signals sent on special Very Low Frequency radio channels before rising to periscope depth to get in touch by more conventional radio or satellite links.

A Trident D5 missile (Credit: US DoD)

Then there were the sensors. During the First World War, all submarines had to see with were periscopes. During the Second World War, crude sonar devices were added. Then by the middle of the Cold War, miniature radar systems were being carried that could pop their scanner out of the water while the sub remained down. As for sonar, the systems for listening to the acoustic signatures of ships and other submarines grew and spread until sonar arrays filled the entire bow of the boat and ran down both sides of the hull. Subs even towed long, snake-like tails filled with all sorts of listening equipment to gather intelligence.

Despite all these advances, nuclear submarines were confined to the US, Britain, France, the USSR and China, while other navies still used diesel submarines. There were many reasons for this. Most nations had no access to nuclear technology, there were a lot of surplus (albeit modernized) submarine tonnage from the war that remained in service until almost 2000, conventional subs were less expensive to build and operate, and many of the advantages of nuclear power aren't really needed if the boats are going to operate close to home in shallow waters.

New duties

By the 1970s, the modern submarine forces as we'd recognize them today had emerged. These were broken up into three different classes based on their primary missions.

The first of these were the ballistic missile submarines – the boomers. First developed in the late 1950s, these giant submarines carry silos containing Submarine Launched Ballistic Missiles (SLBM) tipped with single or multiple nuclear warheads. Their primary mission is very simple. They are to leave port, disappear, and come back three months later – hopefully without ever receiving the coded orders to launch their deadly cargo.

One variation of this class is the guided missile submarine fielded mainly by the Soviet Union. These are boats carrying ship-killing cruise missiles or nuclear warheads for attacking short- or medium-range targets. Unlike the ballistic missile submarines, these are regarded as tactical rather than strategic weapons.


HMS Vanguard-class submarine (Credit: Royal Navy)

The second class is the attack, or hunter/killer, submarines. Designed for speed and agility, their main job is to escort ballistic missile submarines out of port until they can reach deep water and vanish. During the Cold War, NATO submarines had the additional mission of keeping Soviet ballistic and attack submarines bottled up in the Arctic, where they could do the least harm. This was a cheap strategy for NATO, but very costly for the Soviets protecting their "bastions" in the Arctic Circle.

As their name more than suggests, the attack submarine's job also includes hunting down and destroying enemy submarines and bottling up enemy surface ships. Using wire-guided homing torpedoes and advanced sonar, they can perform all-out attacks on enemy ships, use that threat to deny areas to them, or force an adversary to waste scarce resources hunting for a threat that might not even be there.

Finally, there are the littoral submarines, which are conventional craft operating in the shallow waters of the continental shelves. When on batteries, and if well designed, they are almost silent with the only noise coming from the shaft bearings, propeller, and flow noise around the hull. Nuclear submarines don't have this advantage because the pumps needed to circulate cooling water around the reactor core must run at all times. For this reason, nuclear subs prefer to keep to deep water.

Anti-submarine warfare

Arrayed against these submarines are the new generation of anti-submarine warfare (ASW) forces. The Cold War was a decades-long race between stealth and detection as the submarines became quieter and the hunters became better listeners.

The submarines became larger to accommodate platforms on rubber mounts to dampen vibrations and propellers were better designed, then shrouded, to prevent cavitation. Rubber was also used to create anti-sonar tiles to coat the hull, which became stronger to allow the subs to dive deeper and avoid probing sensors.

Meanwhile, the ASW forces had their hunter/killer submarines, specialized sub-hunting ships, and new patrol aircraft that were built to not only look for subs on the surface, but also seek their magnetic signatures and drop sonar buoys that could listen for submarines as they sank slowly to the bottom on a one-way journey.

Russian Typhoon ballistic missile submarine (Credit: Bellona Foundation)

Helicopters equipped with lightweight torpedoes had dipping sonars on long cables to fish for subs, while the US and European coasts, as well as the gap between the British Isles and Iceland, were protected by the US SOSUS system, which is a line of underwater sonar sensors that could detect submarines from hundreds of miles away. There were even intensive studies of ocean layering and the daily migration patterns of shrimp and plankton – all of which are used by submarines to avoid detection.

Ironically, just as the Soviets were building a new class of quiet submarines and NATO started adapting with new active sonars, the Cold War ended – but submarine advances didn't stop in 1992. They were merely postponed.

The future

The world of the submarine is now undergoing some of the biggest changes it's seen in 40 years and there are signs that those changes may be the biggest since the order was first given to "take her down." New technologies are producing capabilities long known to be possible, but not practical. Other technologies may change underwater warfare in ways that no one can fully understand until they're put to the test.

Then there is the political situation. The US has enjoyed the status of the world's only hyperpower for a generation, but new regional players are emerging and new threats are presenting themselves. In addition, the private sector is moving deeper and deeper into the ocean realm as industry makes advances in deep sea oil and natural gas exploration, seabed mining, and open ocean fish farming.

But the biggest catalyst is the aging Cold War fleets of the great powers that must be replaced over the next 20 years. There has been a drastic reduction in submarine fleets since the fall of the Soviet Union, and the remaining boats are reaching the end of their service lives. Building new ones is not just a matter of replacing and improving them, but also important for preserving and passing on the highly-specialized skills needed to build submarines.

Interior view of USS Columbia (Credit: US Navy)

France has already completed its building program, while the United States and Britain are in the middle of building new attack submarines before starting on a new generation of missile boats. Meanwhile, China and India are playing catch up as they modernize their fleets, and Russia keeps sending mixed signals as it vacillates between building new submarines and reverting to being a land power.

The fleets of today

Today's major submarine fleets break down as follows:

- **United States (all nuclear)**
  14 ballistic missile submarines
  4 guided missile submarines
  37 attack submarines
- **Britain (all nuclear)**
  4 ballistic missile submarines
  7 attack submarines
- **Russia**
  13 ballistic missile submarines
  7 guided missile submarines
  17 nuclear attack submarines|
  23 conventional attack submarines
- **France (all nuclear)**
  4 ballistic missile submarines
  6 attack submarines
- **China**
  5 ballistic missile submarines
  5 nuclear attack submarines
  56 conventional attack submarines
- **India**
  1 ballistic missile submarine
  1 nuclear attack submarine
  13 conventional attack submarines

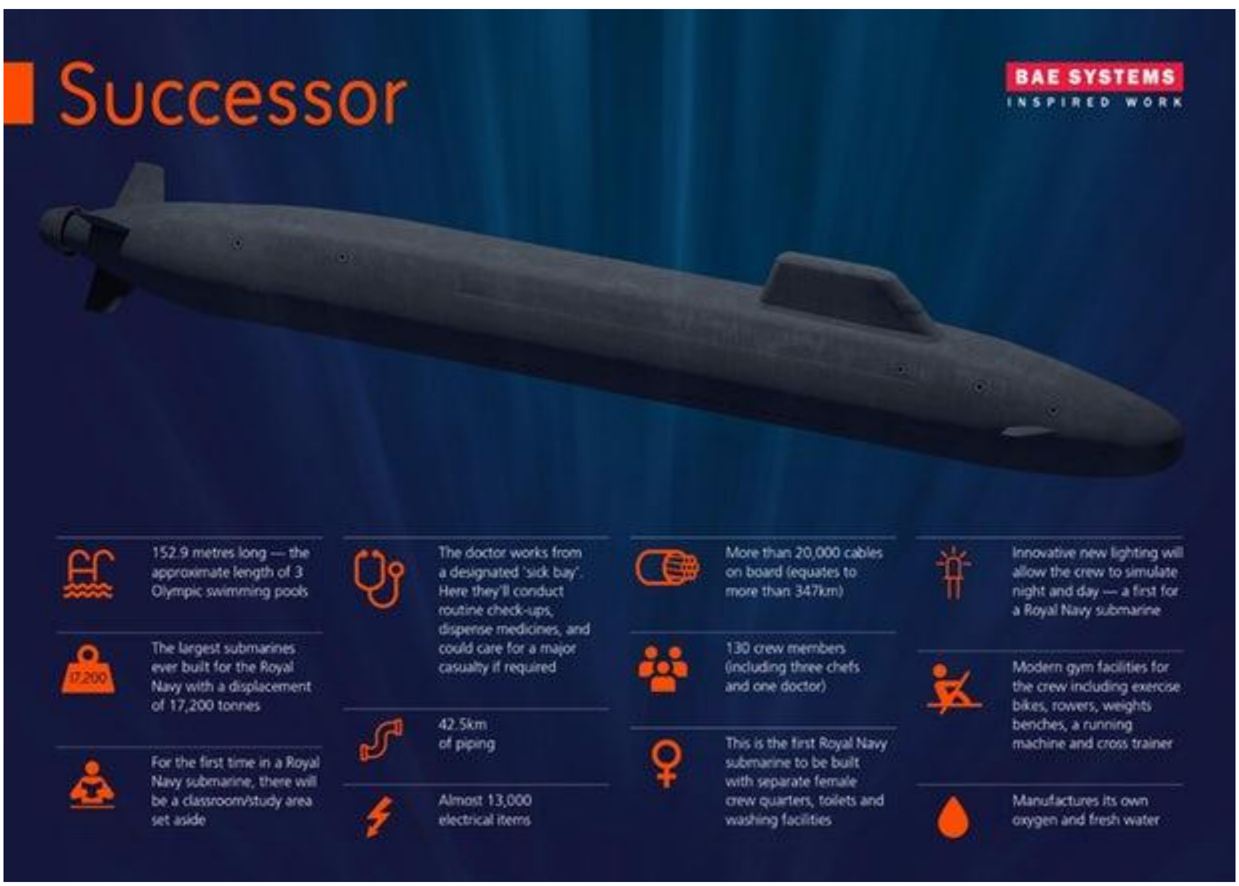
A word of clarification when it comes to these numbers. The non-Western submarine fleets may, at first glance, seem larger than the NATO ones, but the latter are all blue water fleets kept at a very high state of readiness at all times. Meanwhile, the Asian fleets include many littoral submarines for coastal patrols and the Russian fleet has suffered from a quarter century of minimal budgets and a lot of neglect, so much of it is a fleet on paper.

Also, the US fleet includes four submarines that were originally built to carry Trident nuclear missiles, but later had their missiles removed and their tubes altered to carry almost 150 conventionally-armed Tomahawk cruise missiles as well as a deck pod for commando operations.

The Special Relationship

To see what the future of the submarine looks like, let's look at the next two major sub projects: the US Navy's USS Columbia-class and the Royal Navy's HMS Dreadnought-class nuclear ballistic missile submarines. They're useful to look at together because they are not only being built at the same time and for the same purpose, but they are also, in many ways, a joint project.

The United States and Britain are working on very different levels. Both have Cold War nuclear submarine fleets that must be replaced in the near future. Both act as global nuclear deterrents. Both are also firm believers in technological superiority even at the expense of fleet numbers.



Currently, the US is looking to replace its Ohio-class nuclear missile submarines, the first of which launched in 1979, and Britain needs to replace its Vanguard-class missile boats that first launched in 1992. When taking into account the new American Virginia and the British Astute attack submarines now under construction, the result is four classes of submarines that are cutting edge, yet share similar designs and, sometimes, identical systems thanks to a close working relationship between the two navies.

This cooperation is remarkable because submarines are an area of defense spending where the usual laws of economics simply do not apply. There are six nations in the world that build nuclear submarines, and six nations that use them – and they are all the same ones. Each country that uses nuclear submarines builds its own fleet and neither exports nor imports boats from the others.

It would make more sense, for example, for Britain to buy American missile submarines and for the Americans to buy British attack submarines with each getting better boats more cheaply, but nuclear submarines are so vital to strategic defense that that's about as likely to happen as Britain asking Spain if it would mind keeping an eye on Gibraltar for a bit.

HMS Astute (Credit: Royal Navy)

However, though the United States and Britain build their own nuclear submarines, they have shared a lot of nuclear technology since the 1960s and for over 50 years all the American and British missile subs have shared the same missiles and launching systems.

The most obvious difference between the Columbia and Dreadnought classes is in terms of scale. The US fleet needs 12 Columbias, while the Royal navy needs only four Dreadnoughts. Though both classes will use the Common Missile Compartment used to house and launch the Trident II D5LE SLBMs, Columbia will carry 16 missiles. This is eight fewer than Ohio, but four more than Dreadnought. This is one reason why Columbia is 561 ft (171 m) long, has a complement of 155, and displaces 20,810 long tons, while Dreadnought stretches only 502 ft (152.9 m), has 130 crew, and weighs 16,900 long tons.

The other big difference is in missions. The Columbia only has one, and that's acting as a nuclear deterrent. At the 2012 Naval Submarine League Symposium, Captain William Brougham, US Naval Sea Systems Command (NAVSEA) Ohio-class Replacement Program Manager made this clear, saying, "The Ohio Replacement is not, is not, a multi-mission platform. We don't turn into a multi-mission platform that's going to go off and do things that you see on television."

USS Virginia class submarine
(Credit: US Navy/ Mass Communication Specialist 3rd Class Jermaine M. Ralliford)

The Dreadnought class, on the other hand, is definitely a multi-mission platform as well as a "continuous at-sea deterrent" (CASD). The missile boats not only make up 100 percent of the deterrent force, they're also 4/11ths of the entire submarine fleet, so they need be available for more than doomsday patrols and the missile tubes are designed to carry conventional missiles if needed.

The other difference is that of the four classes under construction, Columbia is the only one not actually being built yet. Virginia and Astute have been rolling out of the shipyards for years and the keel of HMS Dreadnought was laid last year, but the first Columbia submarine isn't due to begin construction until 2021 and won't be ready until 10 years later. That may seem a ways off, but this is a class that has a service life of 43 years, so the last captain of USS Columbia hasn't been born yet. And since the entire class will be at sea until about 2085, the very last captain's parents may not be born yet.

Columbia may still be in the design phase, but many of its main features have already been fixed and, in the same way Dreadnought shares much of its design with Astute, Columbia shares a lot with the Virginia class attack submarine – for example, it has the same S9G reactor design as Virginia. Perhaps not coincidentally, though the Dreadnought class will use the same Rolls-Royce PWR3 reactor as Astute, there are reports that Rolls-Royce got a look at the S9G and may have incorporated some of its features into Dreadnought.

Columbia and Dreadnought also share similar propulsion systems from their attack predecessors. Instead of running off shafts turned by steam turbines, both use a shaftless electric drive designed to make them "all electric" boats. Removing the shafts not only greatly simplifies the submarine's design, but it eliminates a major 10-year refit to replace worn shafts. Dreadnought goes a step further by having the electric motor mounted outside the pressure hull instead of inside. In addition, the propellers themselves for both classes have been replaced with pump-jet propulsors.

1982 aerial view of the Clam Lake, Wisconsin ELF facility for submarine communications (Credit: US Navy)

As far as sensors are concerned, the new ballistic subs will have enlarged versions of the sonar suites from the attack versions, with the hydrophones and transducers outside the pressure hull. Since they are now surrounded by water, that is another 10-year refit item avoided.

Also, don't go looking for periscopes, because there aren't any. Conventional periscopes are essentially pipes with lenses and prisms at either end to convey images from the surface to the inside of the submarine. This is a major compromise of the pressure hull that engineers would much rather do without, so on Columbia and Dreadnought they've been replaced by a fiberoptic imaging mast that sits in the sail completely outside the hull and the images are sent electronically to anywhere in the boat where they're needed.

This being the 21st century, both Columbia and Dreadnought have other innovations. For example, both have accommodations for women designed in from the start. Dreadnought has a gym, classroom, and a proper sick bay. Meanwhile, Columbia has the new Submarine Warfare Federated Tactical System (SWFTS) to integrate sonar, optical imaging and weapons control, and X-shaped aft rudder/hydroplanes. It's an idea that was first tried in the 1960s, but it wasn't until the development of today's computerized fly-by-wire systems that it's become practical.

Return of the conventional

Nuclear submarines, with their ability to go so long between refueling that the US and British boats aren't even designed to do so, have significant advantages, but, as we've seen, only six countries operate them. Does this mean that the other navies of the world are relegated to sailing about in tubs trapped in the 1940s? Not quite.

A Scorpene-class submarine (Credit: Mak Hon Keong/Wikimedia)

Up until recently, conventional submarines were diesel/electric submersibles that were basically Second World War designs with a more streamlined casing and better sensors, but that's changing with the introduction of Air Independent Propulsion (AIP).

Put simply, these are power plants that can operate underwater without drawing air from the surface. They don't have anything like the endurance of a nuclear reactor, but they do allow conventional boats to act as true submarines.

In all, some 20 navies operate AIP subs. This includes Russia and China, though they use them largely for research purposes.

The simplest of the AIP systems is also one of the latest – and it makes use of technology that any smartphone user will be familiar with. Where older submarines rely on lead-acid batteries, the newest Japanese Soryu-class submarines will use lithium-ion batteries. Just as lithium-ion made the electric supercar a reality, they also allow the Soryu to remain underwater much longer.

How long the Soryu can stay down depends on the other half of its AIP system, which is an auxiliary Stirling engine made by Swedish shipbuilder Kockums. This is a closed-cycle engine that has the ability to turn any heat source applied to it into motive power. In this case, it's diesel fuel and liquid oxygen that powers the Stirling engine, producing 75 kW for propelling the submarine or charging its batteries. In Swedish submarines, this allows them to stay down for up to 18 days and it gives the Soryu an estimated submerged endurance range of up to 7,060 mi (11,300 km) traveling at 6.5 knots (12 km/h, 7.48 mph).

A Soryu-class submarine visiting Pearl Harbor (Credit: Christy Hagen/U.S. Navy)

The French Navy doesn't use AIP subs, but the French shipyard DCNS does offer the system for the Agosta 90B and Scorpène-class submarines built for the export market. This is a modification of the nuclear propulsion system used for the French Navy's submarines, but instead of a reactor, it uses ethanol and oxygen stored at 60 atmospheres to generate steam to run the turbines. The high pressure of the system allows it to vent carbon dioxide overboard even at depth without an exhaust compressor.

But it was the Germans who took the lead in AIP. Towards the end of the war, the Kriegsmarine commissioned advanced U-boats that used hydrogen peroxide for fuel for running underwater. However, the Germans found it to be extremely unreliable and dangerous, as did the British and American navies that tried to adapt the design after it was captured.

Germany was still the first in AIP with the creation by Siemens of the first modern system for the Type 212 U-boat that entered service in 2002 and was later incorporated in the Dolphin, Type 209 and Type 214 export submarines. These use hydrogen fuel cells to generate between 30 and 120 kW per module. Since the 212 carries nine of these modules, that adds up.

A Type 212 submarine (Credit: Deutches Bundeswehr)

The Spanish Navy has its own twist on AIP for its S-80 submarines. Like the German U-boats, it uses fuel cells burning hydrogen and liquid oxygen, but the Spanish system gets its hydrogen from bioethanol that's broken down in a reaction chamber before the resulting hydrogen is fed into fuel cells built by UTC Power. Meanwhile, the Indian Defence Research and Development Organisation is working on a Phosphoric Acid Fuel Cell (PAFC) for its Kalvari-class submarines.

Sub hunting

The only reason that navies invest in submarines is their stealth – their ability to disappear and go unseen and unheard without a potential enemy knowing they're there. As we've seen, during the world wars and the Cold War, there was a constant race between the ability of the submarine to hide and the sub hunter to seek. Since submarines play the part of hunted and hunter, the submarines of tomorrow will be even more like one gigantic sonar receiver designed to pick up the faint noises of other submarines.

Modern submarines use Medium Frequency (MF), or 1,000 to 10,000 Hz, as their main band to listen, but a new field of Low Frequency (LF), or under 1,000 Hz, is starting to change things. LF has a much longer range than MF, but it hasn't been used previously because the resolution is much lower than MF and it requires an enormous amount of computing power to make it practical.

Until now, as anyone who's watched a submarine movie can attest, sonar operation has been a skill with highly trained and talented technicians being highly prized by their captains. But dealing with LF means processing so much data over such a long period of time that it becomes a job for "big data" to correlate incoming sonar signals to the complex physics and topography so as to create sophisticated oceanographic models needed for interpretation.

Once the preserve of supercomputers, this type of massive, fast processing can now be fitted into submarines and may soon be part of individual weapons. This means that some descendant of today's torpedoes could one day be fired at a long distance from an identified, but not precisely targeted enemy. The autonomous weapon could then close with the target, lock on, and press the attack with minimal human intervention.

UUVs will play a major role in underwater warfare (Credit: Boeing)

Unfortunately, sensors can also be a double-edged sword. They can help submarines find targets and evade pursuers, but the sub is entering a phase of diminishing returns where every reduction in noise and detectability is achieved at greater costs. At the same time, sensors are becoming smarter, more diverse, and more numerous. It won't be too long before submarines will face "big data" fed by networks of sensors on ships, aircraft, Unmanned Underwater Vehicles (UUVs), and on the seafloor that will make the coastal areas and then the deeper regions near the continental shelves more dangerous for manned submarines.

Increased processing power also makes other new, non-acoustic detectors possible, including lasers or LEDs tuned to penetrate deep water. The physics of such devices has been known for decades, but until now the computers weren't available to exploit them. To this could be added measuring the swell of water as a submarine passes by or seeking chemical or radioactive traces from submarines.

It's all very disheartening.

To counter these new sensors, the submarines of tomorrow will be equipped with new devices. Today, submarines are often equipped with dispensers that shoot out barrels filled with active chemicals or compressed air to make loud noises or imitate the sound of machinery. Future submarines may use UUVs to drown out the boat's noise or act as an intelligent decoy to lure hunters on a wild goose chase.

The sub commander of tomorrow may even have devices like the noise canceling headphones of today. Instead of drowning out sonar, it may send tuned counter frequencies that simply cancel the noise out. In addition, big data can help the submarine. If a detailed knowledge of oceanography can reveal submarines, it can also reveal hidey holes in the thermoclines and shrimp schools.

Weapons

But what happens in an actual battle? In the old days, submarines relied on deck guns and torpedoes running on compressed air that (hopefully) ran in a straight line. The deck guns were gone by 1975, but the basic torpedoes remained until well into the 1980s. By the year 2000, these were replaced with wire-guided smart torpedoes like the US Mark 48 and British Spearfish that could automatically home in on a target or be steered from the submarine. These can shoot along at 100 kt (120 mph, 190 km/h) and instead of compressed air they use a pump jet powered by gas turbines fueled with Otto fuel II and hydroxyl ammonium perchlorate.

It all sounds very sophisticated, but even these tin fish will change in the coming years. Russia, Iran, and Germany are developing supercavitating torpedoes that are powered by rockets and form a bubble around themselves that so reduces drag they can reach 220 kt (253 mph, 370 km/h). And instead of being fired from individual tubes, torpedoes will be shot out of multi-role containers, which are like huge revolvers that can hold a combination of torpedoes, cruise missiles, and supersonic or hypersonic anti-ship missiles.

Communications

One major problem that submarines face is communications. Today, submarines run so deep that they can only be contacted by very low radio frequencies from stations located far inland that only have enough bandwidth to send short code words that tell the commander to ascend to periscope depth to use the satellite or short wave systems.

The trouble is, that makes the submarine extremely vulnerable, so new systems are being developed that use the same lasers and LEDs that the sub hunters are working on. The hope is that by modulating or pulsing these it will be possible to communicate directly with submarines at depth with large data flows. Not only that, but such a system would allow submarines to communicate directly in real time with distant undersea platforms with tie-ins to cable communications, GPS, UUVs, and even airborne drones.

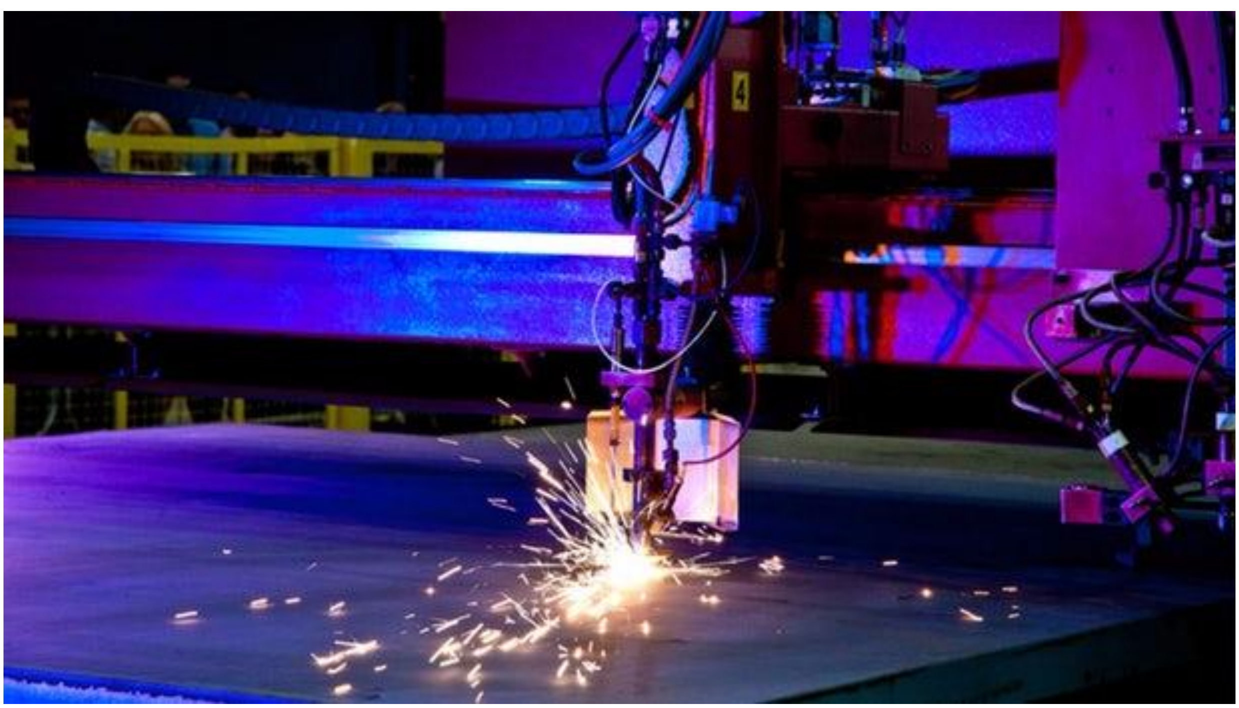
The upside is that submarines would have the potential to act as part of a battle network. The downside is that it makes them much more vulnerable to cyber-attack. The middle ground is that such attacks can be initiated in a virus lurking in any chip or thumb drive aboard, so it just confirms that old submariner's suspicion of automatic systems.

The robot revolution

Submariner jobs are under just as much threat from automation as anyone else's. Today's boats rely more than ever on automated systems to keep costs down, but robotics promise more than redundancies. The very roles of the submarine and the submariner are changing in fundamental ways.

UUVs have evolved in the past 20 years as much as their aerial counterparts have, but they are still marginal players at sea. To date, their role has been that of remotely piloted vehicles for deep or hazardous operation or as mine hunters. But with the development of small, powerful computers, networking technology, and AIP, their role will soon expand as they evolve from remotely piloted drones to autonomous craft with less and less need to report back to command.

With the growing sophistication of AIP, we're bound to see UUVs growing larger and able to remain at sea for weeks or even months without human intervention. At first, UUVs will act as simple auxiliaries to manned submarines or smart weapons, acting as nodes for ad hoc networks, engaging in hazardous missions, like mine hunting and disposal, or operating close to enemy coasts. Eventually they'll become fully autonomous units equal in capability to the manned submarine.



Cutting the first steel for HMS Dreadnought (Credit: BAE Systems)

UUVs will become cheaper and safer to use than manned submarines and will allow commanders to take greater risks. In addition, new weapons will change things further. The US Navy Common Very Lightweight Torpedo (CVLWT), for example, is a third of the size of the smallest torpedo currently in inventory. It's short range, but an unmanned submarine could carry a number of them and fire them much closer to target than a manned submarine would dare to.

Another robotic element will be airborne drones like the US Navy's Experimental Fuel Cell (XFC) UAV. Submarine launched drones could become common as would those launched from UUVs, which could put the UAVs closer to targets. These would allow submarine commanders capabilities previously the monopoly of the surface fleet, including providing communications links; reconnaissance using electro-optical, infrared, and radar sensors; electronic warfare; and inland strikes using anti-radiation homing weapons to attack enemy air defense radars and allow bigger warplanes in.

Future battles

If we look forward to a future battle scenario of around 2050, it will be a long way from a Tom Clancy novel. Surface fleets may become increasingly vulnerable and may need to stay much farther away from littoral areas, which will be a major problem. That's because the great powers will place greater emphasis on such areas due to the changing emphasis from global to regional disputes.

Meanwhile, submarines will be more vulnerable to detection, though far more capable than today's boats. The sub will be less of a front-line weapon and more of a Command and Control platform like an aircraft carrier. Like a surface carrier, the manned submarine will act as the mothership for other craft, but instead of fighter bombers and helicopters, the sub, which will be larger than present boats, will accommodate UUVs and UAVs. It will have workshops complete with 3D printers to build and maintain drones on the spot, and advanced Command and Control systems for drones and battle networks.

The sub commander's role will be less romantic. It won't involve steaming into the teeth of the enemy, but standing off in deep water the same way a carrier remains clear of shore defenses. From there, the submarine will launch its robotic fleets and weapons. Many of these UUVs will be larger than a present day nuclear attack submarine and may look very like an updated USS Virginia.

Intelligence and command would be conducted through undersea battle networks to coordinate various units into an organized ASW fleet that will put old fashioned independent submarines at a disadvantage. They'll still be able to operate, but only in a very limited fashion as they try to avoid coordinated UUV/UAV hunter/killer swarms.

This future battleground will also change rapidly. As commercial undersea work expands, so will the pace of technological change. It won't be long before even the basic assumptions about undersea warfare or even naval combat in general may be questioned.

So, the future will see submarines operating in an increasingly crowded ocean with greater capabilities and dangers with robotic subs taking point. There will be fewer places for the human-in-the-loop, who will be at less risk, but will be lumbered with greater executive responsibility.

That said, the intangible human factor will still be critical. It's the reason that the Royal Navy puts future submarine commanders through a training and selection course called the Perisher, which is as rigorous as anything a fighter pilot goes through. It's one where you either come out a sub captain or never serve in a submarine again.

History has shown that undersea warfare is something that hinges on the spirit of crews sealed for months in tin cans in an atmosphere of easy informality, close camaraderie, and iron self-discipline. It comes from intense, highly technical training, and it comes from experience at sea. It's something that takes much more than technology to produce and doesn't take much more than a few years' laxity to destroy – new toys notwithstanding.