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Some Design Considerations for Arctic-Capable Submarines

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The Arctic has become "an arena for power and for competition." That was US Secretary of State Mike Pompeo's forceful assertion when addressing the Arctic Council in May 2019. In issuing that grave warning he singled out China for particular condemnation, highlighting a recent US Department of Defense warning that Chinese submarines might soon extend their reach into Arctic waters. [1] A non-Arctic state with newfound polar aspirations, China's interest in the region has certainly grown. Whether that interest – which typically centres on resource development, science, and shipping – may lead to militarization remains to be seen. Secretary Pompeo's speculation has been accompanied by a growing chorus of expert commentators, warning that a People's Liberation Army Navy (PLAN) presence in the Arctic would be a serious threat to the United States and the West.[2] In previous (and forthcoming) work, we analyse both the strategic rationale for such operations and the severe challenges that the PLAN would face working in the Arctic.[3] While we conclude that the threat to the West is generally exaggerated, there remain real political and military advantages for China in developing a long- term under-ice capability.

Premised on the assumption that an Arctic submarine ambition exists within the PLAN, this paper goes deeper on the technical side of what this Arctic presence might actually require. While many of the technical requirements discussed herein can apply to any country's Arctic submarine, their significance in the context of the PLAN's submarine force structure will be highlighted. Understanding the technical element is important both in assessing theoretical operational potentialities, and because it may provide a set of markers for Western observers looking to predict Chinese intent. Naturally, any attempt to monitor PLAN retrofitting is handicapped by the extreme secrecy surrounding operations, and by the classified nature of modern sonar and submarine design. What we outline is therefore a best guess, based on publicly available information. Yet, even in the face of such restrictions and limited detail, there is value in occasionally ignoring the strategic forest for the gritty details of individual trees.

Getting about Under Ice: Propulsion

The most significant challenge to Arctic submarine operations is the ever-present threat of sea ice. In dense coverage, that ice can prevent or limit surfacing, keeping a boat under for extended periods. Because regular surfacing is needed to recharge the batteries of diesel-electric submarines, the presence of ice makes conventional submarine operations a dangerous (though not impossible, as demonstrated by USS *Boarfish* in the Chukchi Sea during a 1947 expedition [4]) affair, leaving nuclear propulsion to dominate the under-ice environment since the late 1950s. In the context of the PLAN submarine force this presents a problem. Of the PLAN's current fleet of approximately 66 submarines, all but ten are diesel-electric boats. With only an estimated seven operational nuclear-powered attack submarines (SSNs) and four to six nuclear-powered ballistic missile submarines (SSBNs), this leaves very few hulls available to conduct time-consuming and risky Arctic voyages.[5]

New battery technology has raised the possibility of extending the range of conventional submarines in ice- covered waters, with some proposals pointing to the promise of air independent propulsion (AIP).[6] Recent advances in AIP technology provide a submarine with extended submerged range up to several weeks (depending on speed). This is accomplished by virtue of having essentially a second, but still finite, fuel source running through a reaction that does not require fresh air. The most prevalent example is the Sterling engine, which uses heat generated by pressurized combustion of liquid oxygen and diesel. This was first adopted for submarine use by Sweden in the late 1980s, and the technology has since been installed on all of their submarines, as well as in most of Japan's *Soryu*-class boats.[7] More recently, fuel cell technologies are providing an alternative to the Sterling engine, with benefits including greater acoustic quieting and less maintenance at the cost of greater complexity. Instead of converting the heat generated by liquid oxygen and diesel into mechanical and electrical energy, as in Sterlings, fuel cells produce electricity by mixing hydrogen and oxygen. Newer techniques, such as those recently demonstrated by France's Naval Group, generate hydrogen on board the ship using the diesel and oxygen supplies already employed for conventional propulsion and crew needs, which obviates the requirement for separate hydrogen storage found in traditional fuel cells, like those installed on the German Type 212 submarines.[8] Regardless of the exact method by which AIP is achieved, its growing prevalence in non-nuclear submarines (SSKs) makes them increasingly suitable for long endurance underwater missions.

The possibility of adapting AIP to Arctic use has been debated for decades but is becoming more pronounced as the technologies mature. In 2017, a Canadian Senate Committee even recommended serious consideration of AIP-equipped attack submarines for Arctic operations.[9] China has also been incorporating this technology into its fleet, with the PLAN's newer AIP-equipped Type 041 Yuan-class known to have stayed underwater for over two weeks.[10] The share of such vessels is growing, with 17 PLAN boats now equipped with the technology.[11]

Despite the seeming potential for an Arctic (or "Near-Arctic") capability, AIP systems will likely continue to be insufficient for the harsh requirements of the Arctic environment. They are fairly low-power and do not appear capable of propelling submarines at high speeds for long durations, making their increased endurance more suitable for extended loitering missions within a relatively small area, rather than oceanic transits and distant- water patrols, as would be the case for any Chinese boat attempting to reach the Arctic. Even if an AIP submarine reaches the Arctic Ocean, air access would remain essential for when the AIP fuels are exhausted. Air-fed diesel operations will continue to constrain where and how such submarines could operate under ice. Indeed, the constant search for polynyas or transient leads would dominate AIP sub planning and areas of operation. Furthermore, non-nuclear submarines tend to be smaller than their nuclear counterparts, which reduces the mass with which they can push through the ice cover when surfacing.[12]

As a result, despite the narrowing gap in underwater endurance between AIP and nuclear propulsion, the latter remains necessary for any Chinese Arctic-capable submarine. In the context of the PLAN submarine force, this means that of the current fleet of 66 submarines, the 55 that are diesel-electric-powered are unsuitable for Arctic operations. Although nuclear submarine numbers are expected to grow to thirteen SSNs and eight SSBNs by 2030, any level of continuous Arctic presence would cut into this small force by at least 15% assuming the highly unlikely probability of 100% availability. As we have previously argued, given the limited land attack and sea denial opportunities available in the North American Arctic, this would be a poor use of resources.[13]

Looking Up and Getting Through the Ice

Pushing a delicate, multibillion-dollar piece of machinery through multiple feet of hard sea ice is no simple task. The stereotypical image of the Cold War submarine punching its way through the Arctic sea ice, monolithic black sail standing in stark contrast to the surrounding icescape, makes for striking imagery but oversimplifies the process. That manoeuvre is not only for dramatic effect; in both war and peacetime it is essential for communications, missile launch, and in the event of emergencies. While ultra- and very-low frequency radio waves can penetrate deep into the water to deliver crucial messages to submarines, these are one-way signals with extremely limited bandwidth.[14] That connection is important. For intelligence-gathering missions, for instance, there is always a requirement to extend communication antennas through the ice to transceive reports, updates, and orders. In the event of a strike order, that link is essential to launching ballistic or cruise missiles. Rapid ascent ability is also a necessity in the face of emergencies, either to access fresh air or as an escape route for the boat's crew.

Surfacing a submarine through ice requires that the vessel itself be hardened for contact. Historically, this meant adopting measures to reduce ice damage. Perhaps the most obvious and visible measure taken by navies has been adjusting the forward diving planes, which are used for angling the submarine up or down underwater. Starting with the Flight III variant of the *Los Angeles*-class SSNs, these planes were moved from their previous position on the sail to the forward hull. These could then be retracted into the hull, providing a degree of protection when surfacing through thicker ice.[15] Earlier submarines, like the Sturgeon class, were able to surface through ice despite sail-mounted diving planes but this was accomplished by rotating those planes to the vertical position so as to punch up through the ice with their edges, thereby minimizing damage. The drawback of this approach was that the planes would occasionally become "imbedded" in the ice while the submarine was surfaced, limiting the time that the boat could remain on the surface before it got stuck.[16] The planes of the Sturgeon class also took significant effort to rig into the vertical position: six minutes to fix into the vertical and ten minutes to re-rig for normal operations.[17] In an emergency or wartime scenario this would probably be unacceptable. Diving planes on the forward hull are therefore the preferred design for an Arctic capability and, while not definitive proof that a submarine is designed specifically for the Arctic, the re-design of an existing class to move the planes from the sail to the hull could indicate that under-ice operations are a consideration – much as it was with the Flight III Los Angeles-class redesign in the 1980s.

The violence of surfacing through ice also requires a robust sail. In the American experience, this manifested in both extra room on top of the sail to protect the fragile periscopes, communication antennas, radars, and electronic support measures mounted there, as well as the use of stronger steel. Exemplifying the former, the Flight III Los Angeles sails are twelve inches taller than those of their predecessor, and even the first nuclear- powered submarine, USS *Nautilus*, had her sail modified to provide an extra 8-12 inches of recessed room for her masts.[18] In terms of extra strengthening, USS *Skate*, one of the first SSNs, had its sail hardened with HY-80 steel, which was adapted from World War Two-era armour that the Navy's Arctic Submarine Laboratory estimated could break through 15-18 inches of ice.[19] HY-80 would later be used for the entirety of the hull starting with the Skipjack class.[20] The ice strengthening of the Sturgeon-class sails performed better than expected when punching up through ice, which was recommended to be no thicker than six to twelve inches. As the captain of USS *Pargo* cheekily replied during a post-Arctic mission debriefing: "I must have misread the OP-ORDER; I thought it said 'six to twelve feet.'" *Pargo* had punched through ice more than forty inches thick during that mission with minimal damage.[21] That being said, not all parts of a sail can be hardened: the vital upward and forward-looking sonars – so crucial for navigating in ice – require relatively thin "windows" for their signals to propagate, and these remain susceptible to damage. *Pargo* had some tears on the rubber covering of its BQS-8 sonar on the front of the sail, and the Flight III *Los Angeles* class employs a steel covering for extra protection.[22]

While sails can be hardened with specialty steel, the vital propeller (or 'screw') cannot be strengthened. The danger posed to propellers became very clear during the US Navy's Arctic surface operations in the mid-1950s and it is not surprising that it extended under the water as well. In 1962, USS *Skate* damaged her starboard screw sailing in the icy waters of the Kara Sea, resulting in crippling vibrations that limited her speed to 13.5 knots. To inspect the damage, the captain surfaced the boat through a large polynya. Scuba divers found one of the blades had been "bent aft about one- and one-half inches, beginning five inches from the tip." Thankfully it was otherwise intact, and the divers were able to force the metal back into its proper position, allowing the submarine to return to normal operations.[23] Obviously, having to surface off an enemy's coast for repairs is far from ideal and measures have to be taken to minimize that damage and protect the screw. Identifying any such attempts and connecting them to under-ice operations would be difficult. The Flight III *Los Angeles*-class boats have been photographed with a thin ring connecting the tips of the blades of their screw. This may well be an attempt to increase its structural integrity in the face of sea ice and would be consistent with the other measures taken to increase the class's Arctic capabilities. Naval historian Norman Friedman believes that similar, robust cowlings around the propellers of the Russian *Typhoon*-class ballistic missile submarines were specifically designed to protect them from ice while working in their under-ice "bastions."[24] While this may be indicative, there is no direct line between that design and an intent to operate in the Arctic. Such rings for the propeller could, for instance, serve a hydrodynamic purpose.[25]

Because of the difficulty and potential damage from surfacing through ice, submarines try to avoid it when possible. As such, one of a boat's chief navigational concerns is keeping track of polynyas, thin ice, and open leads. This consideration means equipping submarines with upward-looking sonar or light sensors, which allow a boat to detect thin ice, at least when sailing directly beneath it. The ever-shifting nature of leads, and to a lesser extent polynyas, means that any submarine seeking assured access to the air above will need to continually map the underside of the sea ice with these sonars, potentially revealing their location to enemies, despite the relatively short range of these sonars. In areas of thinner ice, light-based sensors can accomplish the task with greater stealth and, as such, the equipping of vessels with that technology is a potential indicator that a submarine is being prepared for Arctic operations.[26]

The risk of discovery through the use of active navigational sonar also applies to the journey to the Arctic. Chinese submarines would need to traverse the narrow and shallow Bering Strait to reach polar waters and those geographical constraints are an important consideration. As a submarine attempts to make its way through the confined waters of the Bering Strait, it encounters not only the relatively shallow bottom, but – especially in winter – compressed sea ice above that reaches down for dozens of metres below the surface in the form of ice ridges and pinnacles. This unpredictable "ice jungle" defines the Bering region (as well as other marginal ice zones) and requires specialized systems. A safe path has to be identified using the boat's obstacle avoidance sonar, systems that are also used to look for underwater mines. As with the upward-looking sonar search for polynyas, the use of such forward-looking sonars, combined with the Bering Strait's narrowness, makes submarines vulnerable to detection. Any Arctic submarine would therefore have to be equipped with both upward- and forward-looking navigational sonars, generally mounted on the sail, in order to operate successfully in the region.

While specialized equipment is essential, optimizing an Arctic submarine is also a matter of size. In peacetime, transits through the worst of the ice jungle can be made without much trouble. In a wartime environment, however, it becomes more difficult because of the need to minimize active ice-avoidance sonar and transit at greater speeds. A quick transit is also safer and easier for smaller craft, a conclusion that the US Navy's Arctic Submarine Laboratory (ASL) came to decades ago. Waldo K. Lyon, ASL chief and father of the US Arctic submarine program, argued that contrary to Cold War trends, smaller and shorter submarines would have a dramatic combat advantage in the marginal ice zone.[27] Their ability to sail between and under the ice both allows them to hide from other submarines and position themselves for an attack. Cold War torpedo trials showed the difficulties of tracking and identifying targets in the ice jungle, owing to interference with sonar signals. Meanwhile, a submarine already within the ice could more reliably achieve an accurate torpedo track on a submarine that was outside the ice.[28]

A submarine built to maximize its ability to fight in ice-covered waters would be relatively small, closer to second generation American SSNs like the 292-foot *Sturgeon* class than the current 362 foot *Los Angeles*, 353-foot *Seawolf*s, or the 377-foot *Virginia*s (increased to 460 feet for the future Block V variant).[29] A smaller diameter hull would also be favourable, as it reduces the clearance needed to sail safely between ice keels and the seafloor, increasing maneuverability as the boat banks during turns. Such maneuverability would also be assisted by retractable auxiliary motors, enabling the submarine to move with much greater agility at low speeds between ice keels. Such motors were employed by the Sturgeons to position themselves under polynyas in preparation for surfacing and have since been installed on all American SSNs to assist with docking and special warfare missions.[30]

Conclusion

Making a submarine Arctic-capable is not a simple proposition, nor is it a clear-cut transformation. While most of the current American nuclear-powered fleet is capable of some degree of Arctic operations, none of them can be truly said to have been designed to prioritize the Arctic. Their large (and growing) sizes render them suboptimal for conducting antisubmarine warfare within the marginal ice zone. If China is seeking an enduring Arctic submarine presence, a smaller submarine with all of the ice-strengthening features mentioned in this article would be a strong indicator that the PLAN is moving purposefully in that direction.

From an intelligence-gathering perspective, the difficulty lies in identifying the specific technologies involved, not all of which are outwardly visible or essential for limited Arctic operations. Forward-looking sonars, for instance, are a staple piece of equipment for many submarines as part of their mine-avoidance suite. Indeed, the prototype iceberg-detection sonars in the American submarine fleet were converted from mine-detection sonars.[31] This dual-use nature renders them a poor indicator of Arctic intent despite the vital role played in under-ice navigation. Meanwhile, the sail-mounted diving planes hardly prohibit ice operations, as indicated by the Sturgeon class, though they certainly introduce limitations. Other characteristics, such as extra protection for the masts in the sail, are difficult to identify in imagery in the absence of an ‘unprotected’ sail for side-by- side scale comparison.

Ultimately, an Arctic capability is not a binary proposition. There is no single set of features that make it possible or impossible. Rather, successive decades of experience by the American and Russian navies have arrived at some common characteristics that increase the *degree* to which their submarines can safely operate in Arctic waters without compromising other capabilities. How far the PLAN might go in pursuit of the optimal Arctic submarine design is as yet unknown, but history indicates important features that would greatly improve their ability to operate in icy waters, and for which we should watch.

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