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# 翻译

TRANSLATIONS

**The Technical Evolution and Future Development  
of Chinese Navy's Third Generation Conventional  
Submarine**



**中国海事研究所**  
China Maritime Studies Institute



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## The Technical Evolution and Future Development of Chinese Navy's Third Generation Conventional Submarine (Part 2)<sup>1</sup>

Yin He<sup>2</sup>

### The 039B-Class: From Quantitative Change to Qualitative Transformation

While construction of the Type 039A submarine was underway, the Chinese Navy, guided by anticipated technological developments in future conventional submarines, its own operational requirements, and the potential threats it faced, initiated research/development and improvement efforts for a new generation of submarine technologies. By around 2010, several key technologies and systems required for these new submarines had achieved breakthroughs or completed development, clearing the obstacles for commencing construction of the new Type 039B. At the same time, this marked the beginning of the large-scale production of the Chinese Navy's core conventional submarine force for the 2020s.

The 039B largely retains the hull form and structural layout of the 039A, but several sections of the hull and its shaping were refined and optimized (resulting in a slight increase in submerged displacement). These changes further reduced hydrodynamic noise and drag. The number of flood and drain openings on the hull was also reduced, with most of them now concentrated toward the forward half of the submarine. The class adopts a newly designed, low-drag, low-noise streamlined sail. Compared with the 039A, the sail's height is reduced by roughly 0.8 meters and its length shortened by about 0.3 meters. The outer walls use an inward-sloping design of around 10 degrees on each side, and the top transitions into a rounded arc. The junction between the sail and the hull is also reshaped with chamfering and an aft-leaning curved transition.

Compared with the 039A, the 039B's newly designed sail reduces underwater drag by about 12 percent. In practical terms, this means the submarine can gain roughly 0.3 to 0.5 knots under the same conditions, and when using an AIP system, cruising endurance can increase by around 8–10 percent. High-speed turbulent noise underwater is reduced by 15–18 percent, and the submarine's overall center of gravity is lowered by about 6 percent, improving submerged stability and maneuverability. At the same time, vibration- and noise-reduction measures were further refined, and improvements were made to the propulsion and transmission machinery. These optimizations reduce mechanical noise and vibration across the submarine by about 12

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<sup>1</sup> 银河 [Yin He], 中国第三代常规潜艇的技术演进与未来走向（下部）[“The Technical Evolution and Future Development of Chinese Navy's Third Generation Conventional Submarine (Part 2)”], 舰载武器 [Shipborne Weapons], no. 3 (March 2026), pp. 23-38.

<sup>2</sup> The author's name, “Yin He” (银河), is a pseudonym.

percent compared with the 039A, giving the 039B an overall acoustic signature on par with mainstream foreign conventional submarines of the same class.



**Image 1:** Through continuous upgrades, the 039B, introduced around 2010, brought China's conventional submarine technology to near world-class levels.

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The major upgrades on the 039B center on its adoption of a completely new domestically developed AIP power system, along with improvements to onboard weapons and sensor suites. After the initial trial use of the “Stirling” AIP system on the 039A, the Navy had already validated its performance. In terms of cost, reliability, and safety, it proved to be a highly suitable AIP solution, fully capable of meeting the Navy’s operational requirements for enhancing conventional submarine performance. However, limitations in early technical maturity meant that the Stirling AIP system’s relatively low single-unit power output restricted the full potential of the overall system. Once China mastered the relevant core technologies, the new generation of Stirling engines underwent a comprehensive upgrade, significantly improving their performance.

First, by incorporating new heat exchangers and advanced materials, the system gained better high-temperature tolerance and reduced thermal losses, pushing overall thermal efficiency close to 40 percent. Second, improvements in manufacturing processes and higher machining precision increased the efficiency of the working-gas cycle. As a result, without any significant increase in the engine’s size, weight, or volume, maximum output power rose to 90 to 100 kilowatts, which is nearly a 40 percent improvement over the early model used in the 039A. With the 039B still equipped with four Stirling engines, total output could now approach, or even reach, 400 kilowatts. This allowed the submarine’s top submerged speed to increase by about one knot (relative to the 300-kilowatt configuration), extended underwater endurance by roughly 50 percent, and boosted high-speed submerged endurance at minimum noise levels by about 60 percent. The overall performance gains were substantial. Clearly, the Stirling AIP system used in the 039B achieved a technical and performance standard comparable to the latest foreign AIP systems of the same era.

The 039B carries an increased supply of liquid oxygen, up to 60 tons, which supports roughly 20 days of submerged endurance. This gives the submarine a maximum underwater range approaching 2,000 nautical miles, fully meeting the requirements for combat operations within the Second Island Chain.

In terms of onboard weapons, the growing demands of far-seas operations and the increasing complexity and unpredictability of potential targets meant that the 039A had to carry separate loads of anti-ship and anti-submarine torpedoes, as well as anti-ship missiles, to meet mission requirements. But for a conventional submarine with very limited size and displacement, both the number of torpedo tubes and the total torpedo load are inherently constrained. Moreover, the systems used on the 039A, such as the Yu-3B anti-ship torpedo, the Yu-5 anti-submarine torpedo, and the YJ-8 submarine-launched anti-ship missile, were no longer adequate for the operational demands and threats emerging after 2010. For this reason, work on a new generation of submarine-launched weapons began in the early 21st century. This included development of the dual-role Yu-6 torpedo for both anti-ship and anti-submarine missions, as well as the long-range YJ-18A submarine-launched anti-ship missile.



**Image 2:** With its across-the-board performance upgrades, the 039B has become a core element of the Chinese Navy's underwater combat force.

Although the Yu-5 anti-submarine torpedo could meet the ASW needs of the Navy's various submarine classes, its technology was limited by the era in which it was developed. Its overall performance still lagged significantly behind modern foreign ASW torpedoes, roughly comparable to the U.S. Navy's MK48 Mod 4 from the mid-1980s. As torpedo technology advanced, newer ASW torpedoes also gained effective anti-ship capability, becoming true dual-role weapons. This greatly improved the attack flexibility and battlefield adaptability of conventional submarines, and helped address the long-standing shortfall in the Navy's submarine-based anti-ship capability. For many years, the aging Yu-4B anti-ship torpedo had remained the backbone of submarine anti-ship operations. Even though it continued to receive upgrades into the late 1990s, its original structural design imposed hard limits on how far its performance could be improved. Developing a more advanced submarine-launched anti-ship torpedo therefore became an urgent priority for the Navy at the time. When the Yu-6 program was initiated, meeting both anti-submarine and anti-ship requirements simultaneously became the central technical challenge. Breaking through this bottleneck marked a major milestone, signaling that China's submarine-launched torpedo technology had reached world-class standards.

Overall, the Yu-6 can be viewed as a deep upgrade of the Yu-5. Without major changes to its basic structure or propulsion system, the focus was on redesigning the guidance suite so the torpedo could meet both anti-submarine and anti-ship requirements. In terms of guidance modes, the Yu-6 uses a combination of wire guidance, wake-homing, and active/passive acoustic guidance. For wire guidance, a lightweight, high-bandwidth fiber-optic cable replaces the copper cable used on the Yu-5. Compared with copper, fiber-optic cable offers vastly greater bandwidth,



**Image 3:** In recent years, China has made major strides in torpedo technology, and its advanced guided torpedoes have become one of the core weapons of the Navy's undersea forces

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tens of thousands of times higher, allowing high-speed, two-way data transmission between the submarine and the torpedo, such as changing attack targets or sending sonar data back to the boat. At the same size and weight, fiber-optic cable can also be made about 67% longer, and because optical signals are immune to conventional electromagnetic interference, the system gains much stronger resistance to jamming. This significantly improves the torpedo's effectiveness and reliability in complex combat environments. As technology advanced, modern anti-ship torpedoes found that wire guidance plus acoustic homing was already sufficient for medium- and long-range anti-ship engagements, one reason Western navies generally do not use wake-homing. Adding wake-homing to the Yu-6 clearly aimed to further strengthen its anti-ship performance.

For Chinese submarines, which have a strong need for anti-ship capability, adding an extra guidance mode to an anti-ship torpedo increases the complexity and difficulty for the target to defend against it, a clear advantage for improving strike effectiveness. The combined active/passive acoustic guidance system also has to detect and track both surface ships and submarines, whose acoustic signatures are completely different. This requirement became a central focus in the development of the Yu-6. The Yu-6's guidance suite uses a three-frequency approach: low, medium, and high. Low frequency, which suffers minimal attenuation underwater (often reaching beyond 10 kilometers), is mainly used for long-range detection of submarine targets. Medium and high frequencies offer better resolution against the acoustic characteristics of surface ships, allowing more precise localization. The system also improves multi-target tracking (typically through multi-speed sonar arrays), strengthens acoustic counter-countermeasures (against both submarine and surface-ship targets), and supports rapid switching between guidance modes. Together, these features allow the Yu-6 to meet anti-submarine and anti-ship requirements across a wide range of operational environments.

Foreign media have reported that the Yu-6's top speed is roughly comparable to that of the Yu-5, but its effective range is significantly greater. In wire-guided mode, its maximum range reaches about 40 kilometers at a speed of 30 knots, and even at 50 knots it can still achieve no less than 18 kilometers. In acoustic-homing mode, the maximum range is no less than 50 kilometers at around 35 knots. This performance profile allows the Yu-6 to meet the differing speed and range requirements of both anti-submarine and anti-ship missions.

To improve adaptability across different combat environments, the Yu-6 enhances both its shallow-water and deep-water performance. It can operate at depths of around 80 meters for close-in ASW engagements, and its maximum strike depth reaches no less than 800 meters. This allows the torpedo to meet the anti-submarine requirements of both conventional submarines and nuclear submarines operating in varied regions.

Development of the Yu-6 was essentially completed around 2010, and its overall technical level surpassed that of the MK48 Mod 5, which entered the U.S. Navy service in 1995. In several areas, its performance even approached Mod 6 standards. Beginning in 2013, the Yu-6 gradually replaced both the Yu-4B anti-ship torpedo and the Yu-5 anti-submarine torpedo, marking the first time the Chinese Navy's submarine force achieved true standardization of its torpedo armament. For conventional submarines that can carry only 18 torpedoes, a dual-role weapon like the Yu-6, capable of strong performance in both anti-submarine and anti-ship missions, provides a major boost in combat capability. It significantly enhances operational flexibility, reaction speed, and multi-target engagement capacity. This unified, high-performance torpedo has played an important role in strengthening the overall combat effectiveness of China's conventional submarine fleet.



**Image 4:** Equipped with advanced heavy torpedoes, the 039B's underwater combat capability has reached world-class levels



**Image 5:** For decades, the U.S. Navy’s MK48 heavy torpedo has undergone continuous upgrades, producing multiple variants and remaining the Navy’s sole submarine-launched heavy torpedo. China’s newly developed advanced heavy torpedoes are now comparable in capability to the later upgraded versions of the MK48.

Development of the YJ-18A began as early as around 2005, entering full-scale engineering in 2008. The missile is a long-range anti-ship weapon derived from the Russian “Club-S” submarine-launched system, and it exists in both submarine-launched and ship-launched variants. Because it uses a unique “combined subsonic–supersonic” flight profile, its penetration capability is far superior to that of conventional subsonic anti-ship missiles, while also offering a smaller size and longer range than traditional supersonic designs. In short, it is one of the more advanced anti-ship missiles in the world today.

However, due to technical limitations, the Club-S had a range of only about 220 kilometers, mainly because its turbojet engine consumed too much fuel and the missile’s aerodynamic drag was relatively high. This fell far short of the Chinese Navy’s requirements for long-range anti-ship strikes against targets such as aircraft carriers and large air-defense destroyers. That shortfall is also the main reason China did not procure the system in large numbers or import its production line. The YJ-18, by contrast, only borrowed the basic structural concept. Its aerodynamic layout and wing design were completely reworked to increase lift and reduce drag, and it adopted a small turbofan engine with roughly 35 percent lower fuel consumption. As a result, its range is about 1.5 times greater than that of the Club-S, no less than 600 kilometers.

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**Image 6:** The YJ-18A, with its combined subsonic–supersonic design, became the longest-range anti-ship missile in the Chinese Navy at the time

In terms of launch method, the submarine-launched YJ-18A uses a “dry” underwater cold-launch technique similar to the YJ-8, while the ship-launched version uses a vertical hot launch. But because the missile is significantly larger and heavier, its launch canister had to be redesigned, and engineers had to solve the challenge of controlling the missile’s attitude as it breaks the surface. These factors explain why the YJ-18A only completed full testing and entered mass production around 2015, whereas the ship-launched version began entering service as early as 2013.

Starting in 2017, China’s new generation of conventional and nuclear attack submarines, including the 039A, 039B, 093A, and 093B classes, began progressively integrating this new long-range submarine-launched anti-ship missile, greatly strengthening the Navy’s submarine-based anti-ship strike capability.

The 039B also received a new-generation integrated sonar detection and combat-command system. The detection suite includes a fully digital, new-generation medium-/low-frequency active passive bow array composed of 600 hydrophones using digital beam-forming technology. Thanks to advances in manufacturing and electronic components, the array achieves a major improvement in detection and bearing accuracy, about a 40 percent increase over the 039A, while maintaining roughly the same overall size and volume. The system is optimized for the 1.5—3 kHz band in active mode and the 0.1—6 kHz band in passive mode, allowing it to better adapt to the differing acoustic conditions of shallow-water and deep-sea environments. Overall, it significantly enhances long-range detection capability against both submarines and surface ships.

In addition, the 039B mounts three large passive flank-array sonar panels on each side of the hull. Each array contains 32 digital listening units, with six hydrophones per unit, and supports very-low-, low-, and medium-frequency modes. It can detect a submarine target with a 100-decibel noise level at ranges of no less than 70 kilometers, and can simultaneously track up to ten targets within a 100-degree sector. Overall, its all-around detection capability and battlefield situational awareness are significantly improved.

As the submarine’s acoustic detection systems improved, the 039B’s onboard combat command suite was upgraded accordingly. The focus was on strengthening multi-sensor data integration

and analysis, enhancing multi-target processing and engagement capability, and shortening the detect, track, decide, engagement cycle to about 60 percent of the 039A's. Overall combat efficiency and strike effectiveness saw a marked increase.

Overall, the 039B represents the most advanced and most widely produced conventional submarine the Chinese Navy has fielded since its founding, with performance fully on par with leading international designs. It has gradually replaced the more than ten imported Kilo-class submarines as the fleet's primary conventional platform, which is also why the Navy retired its first batch of four Project 877 boats in 2014.

Depending on when they were built, the 039B class can be divided into three batches, each incorporating continuous improvements and upgrades. The third batch is the most visually distinct, featuring a newly streamlined, low-drag sail with forward and aft blended fairings, updated non-penetrating masts, and trial installation of high-energy lithium-battery modules. At the same time, with new-generation conventional submarines emerging in neighboring countries after 2010, such as Japan's Sōryū class and South Korea's Type 214, the 039B is fully capable of competing with these designs. It serves as the Chinese Navy's primary platform for near-seas blockade and regional anti-submarine operations, representing the highest level of China's conventional-submarine technology around 2015.



**Image 7:** A 039B class submarine operating at high speed on the surface

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### **The 039C: culmination of this line's development**

From the 039A to the 039B, you can clearly see China's characteristic "small-step, fast-iteration" approach, a development strategy built around incremental but high-frequency upgrades that steadily reduce risk while continuously improving performance. In an era where new technologies advance at a rapid pace (for example, modern electronics can undergo a full generational refresh in just two years), this method has become an effective way to quickly raise the technical level and combat capability of frontline equipment.

For the Chinese Navy, the five years from 2015 to 2020 marked the beginning of a period of rapid technological advancement. A series of new technologies, new systems, and even new design philosophies matured during this time, pushing the development of next-generation conventional submarines into a phase of fast, iterative progress. Although the 039B entered mass production and reached a genuinely world-class level among conventional submarines, its

technological edge was not particularly pronounced when compared with the new-generation designs that neighboring countries began developing during the same period.

For example, beginning in 2015, the Japan Maritime Self-Defense Force launched the design and development of its next-generation Taigei-class conventional submarine. Built as the successor to the Sōryū class, the program calls for eight boats to replace the Oyashio class. The lead submarine began construction in 2018, was launched in October 2020, and entered service in March 2022. As of 2025, four Taigei-class submarines have already been built and commissioned, which marks a clear indication of the pace at which Japan is modernizing its undersea forces.

Compared with the Sōryū class, the Taigei class focuses on improving long-range deployment capability and acoustic quieting. Its submerged displacement exceeds 4,000 tons, and the hull is slightly larger, giving it nearly 30 percent more internal volume than the Sōryū. With roughly the same crew size, this translates into better space utilization and significantly greater endurance at sea. The Taigei class also replaces the Sōryū's lead-acid batteries and Stirling AIP system with an entirely new lithium-ion battery architecture—the main reason for its substantial increase in underwater displacement, as the battery mass alone approaches 10 percent of the submarine's submerged weight. This shift dramatically enhances its sustained underwater combat capability. Although Japan and China acquired Stirling engine AIP technology around the same period, Japan was never fully satisfied with the system. After making breakthroughs in lithium-ion battery technology, initially tested on some Sōryū-class boats around 2009 but discontinued due to unsatisfactory results, Japan began pursuing a completely new path for AIP-capable submarines.



**Image 8:** Japan's latest Taigei-class submarine delivers first-rate technical performance among modern conventional submarines, a potential adversary the Chinese Navy cannot afford to overlook.



**Image 9:** In the latest Taigei-class submarines, the Japan Maritime Self-Defense Force has, for the first time, replaced lead-acid batteries and the Stirling AIP system with lithium-ion batteries. This gives the submarine strong low-speed submerged endurance and high-speed underwater performance, while also delivering a significant improvement in acoustic quieting.

Compared with the widely used Stirling engines and fuel-cell AIP systems, lithium-ion batteries offer distinct technical advantages enabling true all-electric propulsion. Their energy density is four to five times that of lead-acid batteries; they charge in one-third the time (reaching 70 percent capacity in about two hours), and they have a service life roughly ten times longer. Although the Taigei class is still constrained by total battery capacity, about 14 megawatts, giving it 8 to 10 days of submerged endurance at 4 knots, the tradeoff yields far superior stealth. At low speed, acoustic output is only about 100 decibels, and there is no infrared signature. At the same time, underwater high-speed performance improves dramatically: its high-speed endurance is three to four times that of lead-acid submarines, with 20-knot submerged endurance increasing from 30 minutes to roughly 1.2 hours, something neither of the other two major AIP systems can achieve.

However, given the issues of technological maturity and manufacturing difficulty, the Taigei class still relies on traditional liquid lithium-ion batteries rather than the more advanced and safer solid-state lithium-ion type. Liquid lithium-ion batteries carry significant fire and explosion risks if overcharged, short-circuited, or mechanically damaged. This is the main reason why, aside from the Japan Maritime Self-Defense Force, no other navy in the world has adopted lithium-ion batteries on a wide scale.

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**Image 10:** The third Taigei-class submarine of the Japan Maritime Self-Defense Force: *JS Shunjin*.

The Taigei class also features a new generation of three-layer composite anechoic tiles, combining both passive and active elements across the hull surface to further strengthen overall quieting. Given these improvements, it is entirely reasonable to regard the Taigei class as one of the most technologically advanced conventional submarines in service anywhere in the world today.

Against this backdrop, it is hardly surprising that the Chinese Navy has continued to develop and refine the 039B class. After all, in terms of service life, the twelve 039G submarines built in the early 2000s will reach about 20 years of age by 2025, and by 2030 they will all be approaching the 25 to 30 year retirement window. In other words, China's conventional-submarine force will shrink by nearly one-third over the next decade, a substantial gap that must be filled by a new generation of boats. Around 2020, foreign commercial satellites detected China constructing an entirely new conventional-submarine design. After its launch in 2021, several distinctive features became visible. According to publicly available domestic reporting, this new submarine type was delivered to the Chinese Navy in 2023.

Unlike Japan's Taigei class, which largely retains the hull form and internal layout of the Sōryū class, China's new conventional submarine shows clear structural differences from the 039B. Because of these changes, foreign media have referred to this new design as the 039C class. Compared with the 039B, the 039C's external redesign is striking. The "turtle-back" fairing along the upper hull has been enlarged and now extends all the way to the stern, forming a noticeably flat, straight deck at the rear, whereas the 039B uses a smooth, streamlined taper. This modification is clearly intended to increase internal volume without enlarging the submarine's overall dimensions, allowing room for new systems and equipment. As a result, the submarine's total displacement increases (by at least 300 tons), meaning the 039C's submerged displacement may reach roughly 3,300 tons, making it the largest operational conventional submarine in the Chinese Navy.



**Image 11:** Side profile of the newest member of the 039 family, the 039C-class conventional submarine

Compared with the relatively modest changes to the hull, the 039C's sail design is remarkable. The sail is divided into an upper and lower section: the upper portion forms a diamond-shaped structure, while the lower portion is trapezoidal. From the side, the overall silhouette resembles a Viking war axe, which is why this configuration is often referred to as an "axe-type" sail. This concept was first proposed by Sweden and applied to its latest A26-class submarine. Although construction of the A26 began as early as 2015, various delays have pushed its commissioning to 2027, making the 039C the first submarine in the world to adopt this design and actually enter service. The purpose of the axe-type sail is to trade a small amount of traditional hydrodynamic efficiency for a significant improvement in full-spectrum stealth, especially in countering modern active towed-array sonars widely used by anti-submarine surface ships. For a conventional submarine, this represents a major leap in overall acoustic concealment.

In this design, the sail is no longer built from metal but from high-strength composite materials, a major technological leap for modern submarines. To improve transit efficiency and shorten the time needed to reach an operational area, conventional submarines typically travel on the surface when outside combat zones. In this state, the tall sail becomes the most prominent radar reflector, whether it is a traditional vertical design or an optimized "axe-type" form. On submarines like the 039B or Japan's Sōryū class, the large all-metal sail usually has a radar cross-section of around 100 square meters. Modern maritime-patrol aircraft equipped with high-performance surface-search radars can detect such targets at ranges exceeding 100 kilometers in good sea conditions, and even in rough seas (around Sea State 4), detection distances rarely fall below 50 kilometers. By contrast, the 039C's sail, slightly longer but roughly one-third lower in height, uses composite materials that reduce radar cross-section to just one-fortieth of a traditional metal sail. This cuts the effective detection range of enemy surface-search radars by at least two-thirds. Additionally, the axe-type geometry scatters and refracts radar beams across its multiple angled surfaces. In theory, modern surface-search radars cannot achieve effective detection of such a sail beyond roughly 15 kilometers. The design's core purpose is to trade a small amount of hydrodynamic efficiency for a major improvement in full-spectrum stealth, especially against the active towed-array sonars now widely deployed on anti-submarine surface ships, a critical enhancement for the survivability of conventional submarines.

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**Image 12:** Although the axe-type sail concept was first proposed by Sweden and adopted on its next-generation A26 submarine, delays in the A26 program mean that the 039C ultimately pulled ahead, becoming the first submarine in the world to be fully built and commissioned with an axe-type sail.

In other performance areas, the 039C is likely not dramatically different from the 039B. The number and arrangement of bow torpedo tubes, torpedo loadout, propulsion system, diving depth, and similar parameters should remain largely unchanged or only slightly improved. Where the 039C is expected to advance further is in acoustics, electronics, weapons, vibration control, and noise reduction. These upgrades may include a new bow sonar array (third-generation digital sonar), an entirely new combat-management and display system, an integrated optronic mast, new anti-submarine and anti-ship torpedoes, a new long-range hypersonic anti-ship missile, and a new generation of adaptive dual-mode vibration-reduction systems paired with composite multi-chamber anechoic tiles, all derived from technological progress made around 2020. As a result, the 039C's overall technical sophistication and combat capability should be noticeably higher than that of the 039B, though it remains, in essence, an evolutionary development of the 039A family.

Current open-source information suggests that only a single 039C has been built so far. Since its commissioning, no signs of follow-on hulls have appeared, making it highly likely that this boat will serve for a period as a dedicated test platform, a “trial submarine” used to evaluate new design concepts, new equipment, propulsion technologies, and weapon systems. After all, compared with the 039B, the 039C represents another bold step by the Chinese Navy in exploring new technologies for modern conventional submarines, with development still centered on enhancing stealth and acoustic quieting.



**Image 13:** The 039C-class conventional submarine cutting through the waves on the surface

Unlike Japan's Taigei class, the 039C retains the advantages of China's mature AIP technology while improving overall quieting through a comprehensive redesign, optimization of the entire hull, and the adoption of next-generation noise-reduction measures. At the same time, it places particular emphasis on reducing radar and active-sonar detectability. In practical terms, this approach offers greater operational value than the Taigei class's more limited upgrade of switching to lithium-ion batteries alone.

At the beginning of 2024, the assessment that the first 039C serves as a test platform gained further support. In April of that year, foreign commercial satellites photographed a newly launched conventional submarine at a Chinese shipyard. Compared with the first 039C, its overall hull form is broadly similar, but the hull length has increased to roughly 85 meters, and its submerged displacement may approach 4,000 tons. At the same time, it features two major design changes: an X-shaped stern rudder and a pump-jet propulsion system. This strongly suggests that the new boat is the production model developed after the first 039C completed its associated trials and evaluations.

At present, publicly available information on this new submarine is extremely limited. However, based on China's current level of submarine-technology development and recent advances in related systems, we can infer its intended role: a next-generation conventional submarine whose overall technical sophistication and performance will surpass Japan's Sōryū class across the board, while offering world-class long-range operational and deployment capability.

First, in terms of hull-form design, the new submarine is likely to undergo further optimization based on the first boat, with a focus on reducing underwater drag and hydrodynamic noise—foundational steps toward improving overall acoustic stealth. At the same time, it will retain the first boat's axe-type sail, strengthening radar and active-sonar stealth and thereby achieving full-spectrum low observability.



**Image 14:** 039C-class submarine viewed from the aft quarter at the pier

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Second, with the hull length increased by 8 to 10 meters, the submarine's internal volume expands significantly, by nearly 400 cubic meters. In theory, this allows installation of larger liquid-oxygen storage tanks (for example, two tanks roughly 8 meters long, 3 meters in diameter, each holding about 60 tons). Using the same AIP system, this would raise submerged endurance by a factor of about 3.3. Even after accounting for practical losses, the new submarine's submerged endurance at 4 knots could exceed 30 days. This means that for operations 1,000 kilometers from port, the submarine could maintain its on-station posture for roughly 20 days; at 2,000 kilometers, on-station time would still exceed 10 days. It could even depart port, submerge immediately, and remain submerged for the entire transit into the operational area. No existing conventional submarine can match this capability, which approaches the deployment endurance of nuclear submarines conducting standard missions.

This means that in the operational theater, the new submarine can significantly enhance its stealth and survivability, strengthen sustained deterrence and presence, improve continuity of area coverage, increase tactical flexibility and mission adaptability, and optimize logistics support and equipment-use efficiency. China's surrounding waters include several key straits leading into the Western Pacific. In wartime, deploying just one submarine in each strait would allow long-duration monitoring and blockade, fully leveraging the Chinese Navy's large conventional submarine force. This carries substantial military and political significance.

The additional hull section can also serve as a dedicated weapons compartment, accommodating six to eight vertical-launch cells capable of carrying long-range anti-ship missiles or land-attack cruise missiles as required. Because conventional submarines are constrained by size and displacement, their bow torpedo rooms are extremely limited in volume; as a result, current conventional submarines rarely carry more than twenty torpedoes or missiles in total. Given the wide variety of mission types, once a submarine loads anti-submarine torpedoes, anti-ship torpedoes, anti-ship missiles, and even land-attack cruise missiles, its overall strike capacity becomes severely diluted. This is the main reason conventional submarines face significant limitations in mission flexibility and the range of tasks they can perform. With the new

submarine's dramatically improved deployment endurance, the requirement for sustained firepower becomes even more important. Since the torpedo room cannot be greatly enlarged and total torpedo/missile stowage cannot be significantly increased, adding a dedicated missile-launch compartment becomes highly meaningful.



**Image 15:** Surface-transit view of the 039C-class submarine



**Image 16:** Detail view of the 039C's bow and axe-type sail.

Finally, the new submarine adopts an X-shaped stern rudder and a pump-jet propulsion system. Compared with the traditional cruciform rudder, the X-rudder offers numerous advantages. First, its four control surfaces can operate independently or in coordinated combinations, enabling far more precise control of roll, pitch, and yaw, which is crucial for maneuvering through complex seabed terrain or evading incoming torpedoes. Second, the X-rudder provides superior low-speed handling and higher control efficiency, making it an ideal choice for conventional submarines,

which spend most of their time operating at medium or low speeds. It allows the submarine to maintain a stable attitude even at very low speeds. Third, the X-rudder offers greater safety redundancy: even if one control surface or its actuator fails, the remaining surfaces can usually maintain basic control authority. A cruciform rudder, by contrast, would lose essential control under similar failure conditions, reducing survivability. Because the X-rudder is mounted higher and its tips generally do not extend beyond the hull diameter, the submarine does not need to worry as much about the rudder striking the seabed when operating in shallow waters or complex underwater terrain. This greatly increases maneuvering freedom. In addition, the X-rudder improves the aft flow field, reducing propulsor vibration and cavitation noise, enhancing propulsion efficiency, and improving the submarine's acoustic stealth while underway.

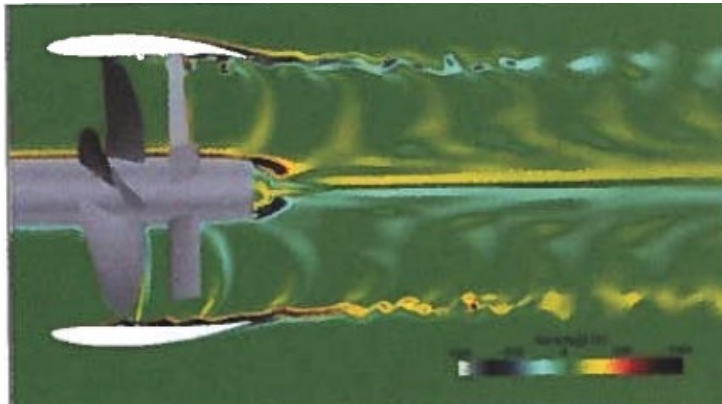
The pump-jet propulsion system encloses the rotor and stator within a duct, with the rotor typically using 9 to 11 blades. This configuration enables low-noise, high-efficiency propulsion and effectively reduces the operating noise of the submarine's propulsor, the main reason pump-jets were adopted early and widely on nuclear submarines. Pump-jets have clear advantages in low-noise performance: cavitation onset speed can reach 10 to 12 knots, whereas a seven-blade, large-skew propeller typically begins cavitating at 8 to 9 knots. Propulsion noise can be reduced by 6 to 8 decibels. For conventional submarines, which spend most of their time cruising below 10 knots, pump-jet propulsion further enhances acoustic stealth.

At extremely low speeds (below roughly 5 knots), pump-jet propulsion can produce intermittent low-frequency vibrations due to rotor-speed limitations, and overall noise levels may be slightly higher than those of a seven-blade, large-skew propeller. Conventional submarines typically keep speed under 5 knots to minimize propulsor noise, so the new submarine's quiet-speed envelope is likely raised to around 6–8 knots, with total acoustic output remaining below 100 decibels. Raising the quiet-speed threshold has major implications for a conventional submarine's battlefield survivability, penetration capability, and strike effectiveness, significantly enhancing combat performance at both the tactical and operational levels.

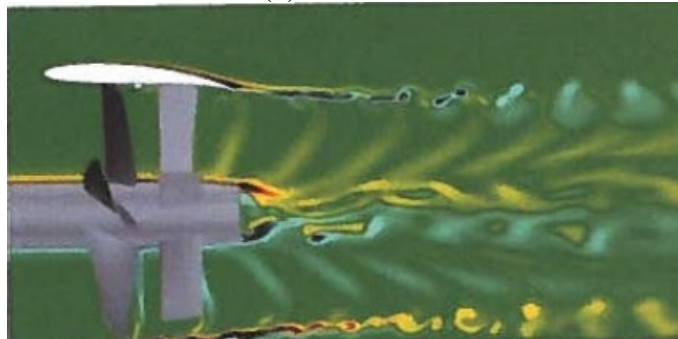
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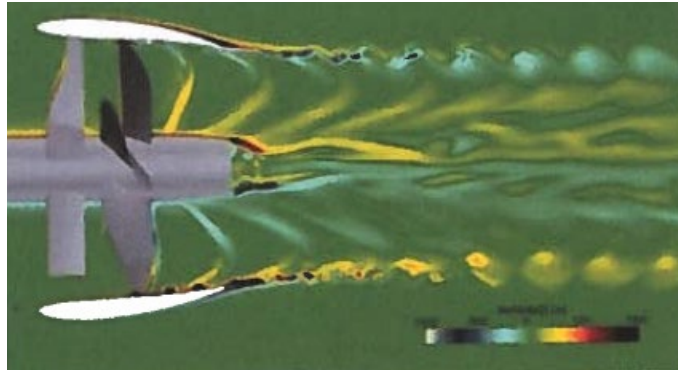


**Image 17:** X-rudders are now widely adopted on modern submarines; the Sōryū and Taigei classes both employ them. This image shows a close-up of the Taigei's X-rudder



(b) R/S-16666





(d) S/R-13663

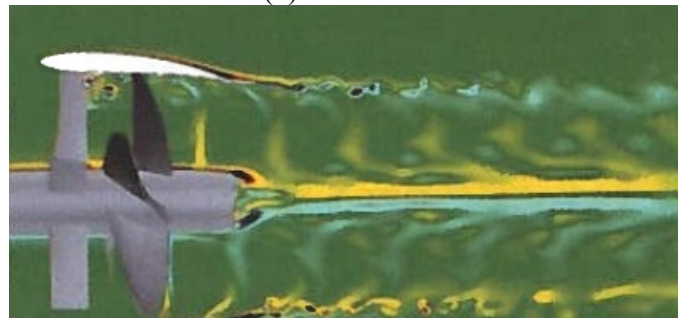


**Image 18:** Schematic illustration of a pump-jet propulsion system

Naturally, as a new-generation submarine built after 2020, this design will also feature comprehensive upgrades to its sonar suite, electronic systems, and onboard weapons. It may adopt a bow conformal sonar array for the first time, significantly increasing aperture size and thereby achieving longer detection ranges, higher angular resolution, and improved low-frequency detection capability.

While incorporating large flank sonar arrays, the new submarine may also be equipped with a towed low-frequency line array for the first time. This would fundamentally resolve the long-standing limitation of Chinese conventional submarines lacking full-azimuth detection capability, greatly enhancing underwater situational awareness and enabling the platform to better meet the demands of future high-intensity anti-submarine and anti-ship operations.

New electronic systems, including the combat-management system, fire-control system, network architecture, communications and navigation suite, and data-link system, will further shorten the submarine's command-and-control cycle and increase the number of targets it can detect and engage. The new submarine is also very likely to incorporate an artificial intelligence-assisted decision-support system, substantially enhancing overall combat effectiveness. This represents the most fundamental difference between it and traditional third-generation conventional submarines.

In terms of armament, the new submarine is very likely to be equipped with a new generation of anti-submarine and anti-ship torpedoes, and may even carry a new class of hypersonic anti-ship missiles. This submarine-launched, long-range hypersonic anti-ship missile will have a range exceeding 1,000 kilometers and use an air-breathing scramjet design, giving it extremely strong autonomous hypersonic flight and maneuvering capability in near-space. Its cruise speed will be no less than Mach 10, with total time-to-target under five minutes across the entire range.

Re-entry speed will be no less than Mach 12, giving it overwhelming penetration capability against virtually all current sea-based air-defense systems. It is expected to become the core long-range anti-ship strike weapon for future Chinese submarines. With this new long-range anti-ship missile, China's conventional submarines would gain the ability to execute strategic anti-ship missions.

It can be said that this new submarine represents the pinnacle of China's current conventional-submarine technological development, and it will be the primary model the Chinese Navy builds and fields over the next decade. It brings China's conventional-submarine technology into an entirely new era.

From the mid-1980s, when China began developing the third-generation Type 039 submarine, to the emergence of this new design, the country has made more than thirty years of sustained effort. China has finally caught up with, and in some areas surpassed, the world's major naval powers in the core technologies of conventional submarines, forging a fully independent and self-reliant path for their development.



**Image 19:** The new generation of large unmanned underwater vehicles displayed in the September 2025 military parade already adopted an X-rudder design and a pump-jet propulsion system, which from another angle shows that both technologies have become highly mature in China. Their widespread use on the new submarine presents no technical obstacles whatsoever.



**Image 20:** The YJ-19 submarine-launched hypersonic anti-ship missile publicly displayed at the September 2025 military parade

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### **The Technological Development Direction of China's Conventional Submarines**

As the overall strength of the Chinese Navy rapidly increases, moving toward distant-ocean operations and building a modern distant-ocean fleet has become its long-term objective. This means that future construction and development of the Navy's main combat platforms will center on large vessels better suited for extended deployments and operations at sea, such as the rapidly advancing large aircraft carriers, amphibious assault ships, major destroyers, frigates, and various classes of nuclear submarines. In this context, whether the Chinese Navy still needs to maintain a sizable force of conventional submarines in the future has become a question that warrants serious consideration.

In fact, the Chinese Navy originally considered building a large force of conventional submarines mainly because its surface fleet and naval aviation were at a decisive disadvantage against stronger adversaries. Submarines, with their high degree of stealth and powerful offensive capability, were clearly the most effective way to compensate for that gap at the time. Even before the 1990s, the widely deployed but technologically modest Type 033 submarine possessed significant deterrent value and played an important role in safeguarding China's coastal defense.

The Yellow Sea and East China Sea along China's southeastern coast are classic shallow-water regions, with highly varied and complex seabed terrain. Average depth is under 70 meters, and even the deepest areas are under 150 meters, with numerous underwater mountains and canyons, an ideal operating environment for submarines. However, these same characteristics pose severe challenges for nuclear submarines displacing more than 6,000 tons and measuring over 100 meters in length. Their advanced sensors (whose effectiveness is greatly reduced by complex terrain), high speed (to avoid collisions or grounding, top speed must be limited to under 15 knots), and deep diving capability (a 600-meter maximum depth is meaningless in waters shallower than 150 meters) cannot be fully utilized. Forceful entry not only carries an extremely high risk of collision or running aground (the minimum operating depth for nuclear submarines

is 150 meters); under favorable weather conditions the enemy can even detect a nuclear submarine traveling at a depth of 40 meters without the need for reconnaissance equipment.



**Image 21:** China's conventional submarines have strong environmental adaptability and maneuverability in coastal waters, allowing them to play an important role.

Conventional submarines have smaller displacement and hull dimensions, with a minimum operating depth of only about 30 meters, giving them an inherent natural advantage in this region. This is also why some high-performance conventional submarines can even challenge more capable nuclear submarines in shallow waters. Therefore, the Chinese Navy's need to maintain a sizable force of conventional submarines is rooted in objective geographic realities. Even if China achieves full national unification in the future and the coastal security situation improves, high-performance conventional submarines operated by neighboring countries such as Japan would remain a potential threat. This is why, even after becoming a world-class navy, China will still need to retain a force of advanced conventional submarines. Although the overall number of submarines in the future force will be significantly smaller than today, their technological sophistication and combat capability will represent a qualitative leap, achieving the goal of trading quantity for quality.

Modern conventional submarines worldwide have already achieved major advances in acoustic stealth, offensive capability, detection performance, and intelligent combat systems. In terms of technology, they no longer differ fundamentally from high-performance nuclear attack submarines (that is, there is no longer a generational gap). However, in speed and sustained underwater endurance, even the most modern AIP-equipped conventional submarines still fall far short. At present, both Stirling AIP systems and fuel-cell AIP systems require large and heavy liquid-oxygen and liquid-hydrogen tanks. Although increasing the amount of oxygen or hydrogen carried can theoretically extend underwater endurance significantly, doing so also brings problems: larger hull size, increased weight, reduced maneuverability, and a gradual loss of the compact agility that conventional submarines rely on—seriously degrading their ability to operate in shallow waters. Moreover, this approach greatly increases cost and technical complexity, reduces safety, and introduces severe engineering challenges, all while forcing compromises in overall performance.

At the current stage, all types of AIP systems can only support low-speed underwater cruising and cannot enable high-speed submerged operations. For example, the Stirling AIP system has a low power density and a hard physical ceiling on single-unit output, theoretically limited to around 150 kilowatts. Even for long-duration cruising at 4 to 6 knots, multiple engines must be

run in parallel, and achieving 20-knot high-speed cruising is impossible (the power shortfall reaches 96 percent). Fuel-cell AIP systems face the same issue of insufficient power density (though roughly 30 percent higher than Stirling systems). In practical use, multiple fuel-cell stacks must also be connected in parallel to provide enough power for sustained low-speed cruising, while high-speed underwater operation remains strictly constrained by total battery capacity. New lithium-ion batteries, such as the liquid-type lithium-ion batteries used on Japan's Taigei-class submarines, offer much higher power density, allowing a submarine to maintain high-speed underwater cruising for more than an hour. However, even this still falls short of meeting the demands of future complex and challenging maritime combat environments.

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Therefore, under the premise that future conventional submarines must keep their hull size and displacement essentially unchanged or only slightly increased (not exceeding 4,000 tons), they will need further improvements in acoustic stealth, low-speed endurance must reach more than twice that of current AIP submarines, and they must possess stronger short-duration high-speed capability to meet the operational demands of the next 15 to 20 years. China's next-generation conventional submarines will certainly undergo a leap in both technological sophistication and operational concepts. Based on domestic technological trends and projected mission requirements, it is likely that development will focus on fully electric conventional submarines built around all-solid-state lithium-ion battery systems.

Lithium-ion batteries (which, strictly speaking, are not AIP systems in the traditional sense but rather energy-storage devices meant to replace the technologically outdated lead-acid batteries on submarines) have already demonstrated clear technological and performance advantages on Japan's Taigei-class submarines. Even though the Taigei currently uses liquid-type lithium-ion batteries, which are not the most advanced form, they still show decisive superiority over existing AIP systems in mass power-density, volumetric power-density, peak power response time, energy-conversion efficiency, and operating noise. At present, the greatest problem with liquid lithium-ion batteries lies in safety, especially thermal runaway in confined spaces, which has long been the main obstacle to their widespread adoption. The organic-solvent electrolytes used in liquid lithium-ion batteries are extremely flammable; once a battery experiences a short circuit, high temperature, or mechanical damage, it can easily catch fire or even explode. Unless this issue is thoroughly resolved, liquid lithium-ion batteries, despite their significant performance advantages, will struggle to take the critical step toward practical, large-scale deployment. This is also the main reason why, so far, only Japan's Maritime Self-Defense Force has put them into operational use.



**Image 22:** All of the Japan Maritime Self-Defense Force's conventional submarines are large-displacement boats. Shown here is a Sōryū-class AIP submarine of the JMSDF operating on the surface.



**Image 23:** Because liquid lithium-ion batteries are less safe than traditional lead-acid batteries, Japan has not adopted them on any of its other advanced conventional submarines aside from the Taigei class. They have not replaced lead-acid batteries or AIP systems on the rest of the fleet.

Solid-state lithium-ion batteries offer an overwhelming advantage over liquid lithium-ion batteries in terms of technical performance. Their gravimetric power density can reach 400 to 500 watts per kilogram, and volumetric power density can reach 1,000 to 1,200 watts per liter, representing increases of 42 percent and 39 percent respectively compared with liquid lithium-ion batteries. This means that, for the same volume, a submarine equipped with a solid-state lithium-ion battery AIP system could double its underwater endurance. At the same time, safety performance is improved qualitatively.



**Image 24:** If the Taigei-class submarines of the Japan Maritime Self-Defense Force were to replace their liquid lithium-ion batteries with solid-state lithium-ion batteries, not only would their underwater endurance increase significantly, but their safety would also improve substantially

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Solid-state lithium-ion batteries use inorganic solid electrolytes or polymer electrolytes, giving them dramatically improved thermal stability (thermal-runaway temperatures exceed 400 °C, 2.5 times higher than those of liquid lithium-ion batteries). This completely eliminates the risk of electrolyte combustion or explosion. At the same time, solid-state lithium-ion batteries offer strong resistance to oxidation, excellent high-temperature tolerance, and a low rate of thermal runaway. Even when subjected to mechanical damage, they do not catch fire or burn, or release toxic gases. This has eliminated any obstacles to their widespread adoption.

Using the JMSDF's Taigei-class submarine as an example, simulation tests indicate that if its current liquid lithium-ion batteries were replaced with solid-state lithium-ion batteries, the number of installed battery units could increase by 50 percent without changing the available installation space (bringing total capacity to 30 MWh). Underwater cruising speed would rise from the current 4 to 5 knots to 6 to 7 knots, and continuous submerged endurance at 4 knots would increase from the present 8 days to more than 18 days. The performance gains are substantial.

After entering the 21st century, as China's new-energy industry entered a period of rapid development, the country also launched comprehensive efforts to tackle the key technologies of solid-state lithium-ion batteries. After nearly twenty years of work, China has achieved significant progress in solid electrolytes, cathode and anode materials, engineering design, and manufacturing processes. Around 2022, semi-solid-state lithium-ion batteries reached industrial-scale production (one of the main reasons China's electric-vehicle sector was able to grow so quickly). By 2023, China had achieved full technological breakthroughs in all-solid-state lithium-ion batteries, and the next generation of electric vehicles will adopt this new battery technology across the board.

Information released by a domestic automobile manufacturer shows that the solid-state lithium-ion battery it plans to install in vehicles in 2026 will achieve a gravimetric power density of 400 W/kg and a volumetric power density of 820 W/L. Under the same conditions, a vehicle's

driving range will increase from the previous 500 km per full charge to 1,200 km, and with ultra-fast charging technology it will be able to travel 400 km after just five minutes of charging, demonstrating exceptionally strong technical performance.

It is clear that applying these technologies in the military domain is no longer just a dream. According to reports from domestic media, multiple Chinese submarine-design institutes began preliminary evaluation and research on these technologies as early as around 2020. By around 2024, the first solid-state lithium-ion battery installation tests on submarines were completed, demonstrating the ability to sustain more than 13 days of continuous submerged operation at 4 knots under high-stealth conditions. Take the Type 039B submarine as an example, it is equipped with two sets of roughly 380 lead-acid batteries. If all of these were replaced with solid-state lithium-ion batteries, total electrical capacity would reach 12 MWh while occupying less than half of the original installation space. Assuming daily power consumption of about 1,500 kWh (cruising at 4 knots, keeping all onboard detection systems running, and meeting crew living requirements), the submarine could remain submerged for roughly 8 days. In a low-speed patrol state, where daily power consumption drops to around 1,000 kWh, submerged endurance could increase to about 12 days.

Given the substantial advantages of solid-state lithium-ion batteries in both gravimetric and volumetric energy-density, the existing battery-compartment space on the Type 039B submarine could theoretically accommodate 150 percent more solid-state battery units. This would raise total capacity to around 30 MWh, extending low-speed submerged endurance to more than 25 days (assuming daily power consumption of roughly 1,000 kWh). This far exceeds the endurance of current submarines equipped with Stirling AIP or fuel-cell AIP systems.

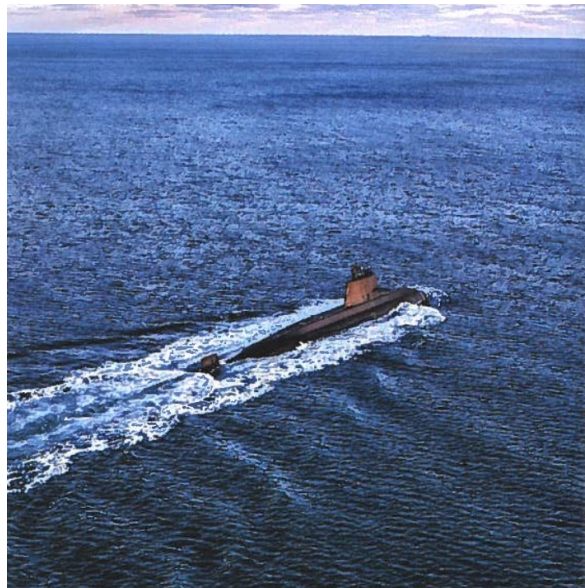


**Image 25:** If the Chinese Navy's Type 039B submarine were to adopt solid-state lithium-ion batteries, its technical and tactical performance would increase by an entire order of magnitude

If new generation power transmission and management technologies are applied, and the submarine's structural design is re-optimized to maximize usable battery compartment volume, the total capacity of solid-state lithium-ion batteries could be further increased to 35 MWh. In

that case, the submarine's submerged endurance would be enhanced even more, fully meeting the requirements for long-duration far-seas operational deployments.

More importantly, large-capacity solid-state lithium-ion batteries give submarines the ability to sustain high underwater speeds (greater than 20 knots). Because of the inherent limitations of traditional lead-acid batteries, they can only support 40 to 60 minutes of high-speed submerged operation (for example, the Kilo-class has a battery capacity of 4,000 kWh and can maintain high-speed cruising for about 40 minutes). In contrast, a 35 MWh solid-state lithium-ion battery pack, while still retaining a 30 percent reserve, can support more than 4.5 hours of high-speed submerged operation. This represents a four- to six-fold increase over existing AIP equipped conventional submarines, enabling conventional submarines to undertake new mission types such as active interception, area denial, and strategic interdiction, fundamentally overturning the traditional tactical employment model of diesel-electric submarines.

Of course, this conclusion is theoretical, but the technological advantages of solid-state lithium-ion batteries have already begun to emerge. Once the relevant technologies fully mature and reach industrial-scale production, they could completely replace current Stirling AIP systems. Moreover, unlike Stirling AIP systems, which lose their ability to sustain low-speed submerged cruising once the onboard liquid oxygen is depleted, solid-state lithium-ion batteries, even after their usable charge is exhausted (in practice, at least a 20 percent safety margin must be retained), can be recharged by the submarine's diesel engines, restoring full operational capability.

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**Image 26:** Conventional submarines must surface to start their diesel engines and recharge their batteries, which greatly increases their exposure risk. But if solid-state lithium-ion batteries are used, the number of required surfacing events drops significantly, and each charging cycle becomes much shorter. Exposure is therefore reduced dramatically, and survivability improves substantially.

Because of this characteristic, solid-state lithium-ion batteries have far greater adaptability in charging power, giving them a charging speed that is an order of magnitude faster than traditional lead-acid batteries. For example, when a submarine is moored in port, if shore facilities provide a robust charging network with 20 MW fast-charging capability, then fully charging a 35 MWh solid-state battery pack (from 0 to 100 percent) would take only 90 minutes. Even if charging power is intentionally reduced after reaching 80 percent capacity to protect

battery health, dropping below 8 MW, the total charging time would still not exceed 130 minutes.

Of course, the diesel engines used on submarines have limited output, so charging capability while operating in snorkel mode is far lower than that of dedicated port-side charging systems. Using a modern conventional submarine equipped with two 4,000 kW diesel engines as an example, after subtracting the roughly 1,000 kW needed to maintain normal onboard operations and accounting for various losses, it can deliver about 7,000 kW of effective charging power. Under these conditions, fully charging a 35 MWh solid-state battery pack would theoretically require only about 220 minutes. Even if charging power is reduced to below 40 percent after reaching 80 percent capacity to protect battery longevity, total charging time would still not exceed 280 minutes.

However, under normal circumstances, a conventional submarine will not wait until its batteries are completely depleted before surfacing to recharge (a minimum 20 percent reserve is always kept). In most cases, only 50 or 60 percent of the battery capacity needs replenishment. For a 35 MWh solid-state lithium-ion battery pack, this means only about 18 MWh must be recharged, allowing total charging time to be kept within 1.5 hours. If the submarine's diesel-engine output were increased by 30 percent, charging speed would rise correspondingly by about 20 percent. In other words, even if a solid-state battery is drawn down to half capacity, the submarine can still guarantee 8 to 10 days of submerged endurance. This increases battlefield survivability sixfold and reduces exposure probability by 75 percent, a transformative improvement for conventional-submarine combat capability.

But simply replacing the batteries of current conventional submarines with next-generation solid-state lithium-ion batteries does not meet the Chinese Navy's requirements for future fourth-generation submarines; it should still be viewed as an upgrade to existing third-generation boats. To fully exploit the advantages of solid-state batteries and achieve a true leap in combat capability, future all-electric submarines will also require three core technologies: integrated electric-propulsion systems, medium-voltage DC power-distribution systems, and supercapacitor energy-storage systems. Combined with solid-state batteries, these technologies will elevate the overall technical level and combat effectiveness of conventional submarines into a new era, marking a genuine generational transition from third-generation to fourth-generation designs.

The first of these is the integrated electric-propulsion system, which represents a disruptive technological innovation for conventional submarines. By centrally managing the generation, distribution, and consumption of all onboard electrical power, it fundamentally changes the traditional power-usage model. It offers major advantages in combat effectiveness, stealth, optimized hull design, and efficient use of internal space. For example, in terms of propulsion efficiency, traditional diesel-electric submarines typically use a diesel-engine + battery + motor configuration with about 40 percent efficiency. A submarine equipped with an integrated electric-propulsion system instead uses a diesel-engine or battery + power grid + motor configuration, raising efficiency to 85 percent and more than doubling overall effectiveness.



**Image 27:** For China's conventional submarines to achieve comprehensive performance improvements, they must not only adopt solid-state lithium-ion batteries but also upgrade many other technologies in parallel.

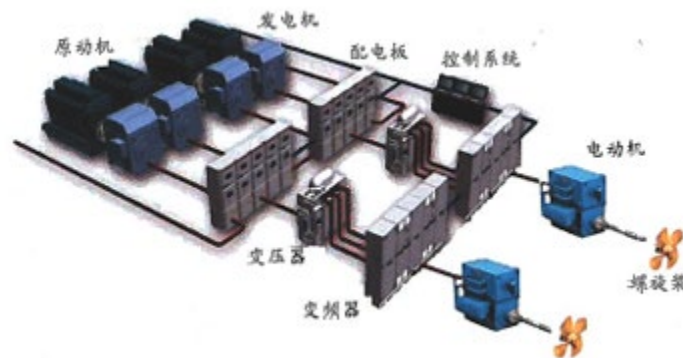


**Image 28:** Integrated electric-propulsion systems represent the developmental trend for the power systems of both surface ships and submarines.<sup>3</sup>

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In terms of power-distribution losses, an integrated electric-propulsion system can reduce losses from the 15 to 20 percent typical of traditional conventional submarines to under 5 percent. This greatly lowers the load on the cooling system and reduces electromagnetic noise by 60 percent, thereby decreasing the submarine's electromagnetic signature. Moreover, every 2 percent improvement in power-distribution efficiency translates into an additional 6 to 7 hours of submerged endurance. Integrated electric-propulsion systems can achieve 95 to 98 percent efficiency, an improvement of more than 15 percent, which theoretically can add up to 49 hours of submerged endurance. At the same time, submerged speed can increase by roughly 80 percent (for example, from 4 knots to 7 knots), and fuel consumption can drop by 30 percent. These advantages are far beyond what traditional submarine power-distribution systems can offer.

<sup>3</sup> **Translator's Note:** Graphic labels are translated as follows: 原动机 (Prime mover), 发电机 (Generator), 配电板 (Switchboard), 控制系统 (Control system), 变压器 (Transformer), 变频器 (Frequency converter), 电动机 (Electric motor), and 螺旋桨 (Propeller).

The second key technology is the medium-voltage DC power-supply system (already applied on the Chinese Navy's new-generation surface combatants). Compared with the medium-voltage AC systems used on traditional submarines, transmission efficiency increases by 15–18 percent, cable weight and volume decrease by 50 percent, electromagnetic noise drops by 20 dB, fault-response speed improves thirtyfold, and overall system reliability increases tenfold. In addition, the entire system uses a modular, damage-resistant design: as long as no more than 30 percent of the system is damaged, the submarine can continue operating normally, giving it extremely strong survivability. This plays a major role in enhancing a submarine's stealth, maneuverability, sustained firepower, and combat endurance. Such strong survivability will significantly improve a submarine's stealth, maneuverability, sustained combat capability, and overall battlefield resilience.

The final component is the supercapacitor energy-storage system (a technology already applied on China's new-generation aircraft carriers and amphibious assault ships). Its primary function is to provide "instantaneous high-power output," maintain stable voltage and frequency across the submarine's electrical grid, and increase the grid's redundancy and rapid-recovery capability. For example, during a full-salvo torpedo launch, the six 533 mm tubes in the bow of a typical conventional submarine draw an enormous amount of power from the onboard electrical grid, often up to 30 percent of the submarine's total stored electrical energy. After firing, the submarine's remaining power reserve is minimal, reducing its sustained submerged endurance by about 70 percent, and forcing it to consider surfacing for battery recharging in the near term. At the same time, the submarine must keep its detection systems, combat-command systems, control systems, and basic life-support systems operating normally. Sudden, large fluctuations in grid voltage and frequency are extremely dangerous for a conventional submarine: they can degrade the performance of onboard sensors and command systems, cause data loss or protective system reboots, and even disrupt the normal functioning of the submarine's control systems, introducing severe and unpredictable risks to navigational safety.



**Image 29:** Supercapacitor energy-storage technology is developing rapidly and will see extremely widespread application in the future. Submarines are one of the platforms on which supercapacitor energy-storage systems can be effectively employed.



**Image 30:** To achieve widespread application of supercapacitor energy-storage systems on submarines, many technical challenges still need to be resolved.

When a conventional submarine is submerged, it relies primarily on its onboard batteries for power. Traditional lead-acid batteries cannot withstand short-duration, high-current surges (modern AIP systems cannot solve this problem either), and such surges drastically shorten battery life. Although new-generation lithium-ion batteries have stronger tolerance, the underlying principle remains the same, and damage is still unavoidable.

The emergence of supercapacitor energy-storage systems provides an excellent solution to these issues. First, supercapacitors offer a gravimetric power density of 10 to 15 kW/kg, a service life exceeding 100,000 cycles, and charge/discharge times controllable to around 30 seconds, giving them outstanding instantaneous-energy-release performance. During a full-salvo torpedo launch, a supercapacitor system can independently supply the enormous burst of electrical power required, preventing disruptive current, voltage, and frequency shocks to the submarine's electrical grid (kept within 2 percent). This greatly improves battery efficiency and lifespan. In addition, a fully charged supercapacitor system can support the electrical demands of three full torpedo salvos, theoretically increasing a conventional submarine's attack capability more than eightfold, approaching the level of a nuclear submarine.

Second, supercapacitor systems provide major benefits for rapid maneuvering (such as evading anti-submarine torpedoes or seizing an attack position). In such situations, the submarine must accelerate, turn, and perform rapid dives or ascents in the shortest possible time, which imposes extremely high instantaneous-power demands on propulsion, steering gear, and ballast systems. Traditional diesel-electric submarines rely solely on battery reserves to meet these combat requirements, but this leads to sudden voltage drops across the electrical grid and accelerates

battery wear and degradation. Moreover, battery output power has a hard upper limit, and its response capability falls far short of what high-intensity combat maneuvers require.

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Although supercapacitor systems have relatively low energy density, they can serve as a “buffer zone” within a submarine’s electrical architecture. Because they provide extremely high instantaneous power output, they can change the submarine’s attitude in a very short time. With such a system, the time required for a submarine to accelerate from 4 knots to 20 knots can be reduced from 120 seconds to 45 seconds; dive-response time can be shortened from 30 seconds to under 5 seconds; and maximum turning angle can be increased from 60 degrees to 90 degrees. While a supercapacitor system can sustain high-maneuvering operations for only a few minutes (no more than about five), this duration is already sufficient for a conventional submarine to execute emergency evasive actions. More importantly, once its stored energy is depleted, the system can be rapidly recharged by the submarine’s onboard batteries. For example, a 300 kWh supercapacitor system can be recharged from 20 percent to 100 percent in under three minutes using the submarine’s solid-state lithium-ion batteries. In emergencies, charging from 20 percent to 60 percent requires less than 30 seconds, enabling a conventional submarine to maintain repeated high-maneuver evasive operations. This dramatically enhances its combat resilience and survivability.

Finally, supercapacitor systems further reduce overall submarine noise, which is one of the greatest performance advantages of all-electric submarines. At very low speeds (below 6 knots), they can achieve noise levels close to ocean background noise (around 90 dB), whereas traditional AIP submarines generate roughly 100 dB at 4 knots. An all-electric conventional submarine produces no mechanical-transmission noise during submerged operation (diesel engines are used only for battery charging) and employs low-noise shaftless pump-jet propulsion. As a result, its acoustic signature can be reduced from the 100 to 105 dB typical of third-generation AIP submarines to around 90 to 95 dB, with strong suppression across low, medium, and high frequencies. Under equivalent conditions, this can reduce enemy sonar detection range by more than 60 percent while increasing the submarine’s own sonar detection range by over 90 percent, fully surpassing existing AIP submarines. At low speeds (below 6 knots), thanks to its much lower acoustic signature, an all-electric conventional submarine can even gain certain advantages over nuclear attack submarines, fundamentally overturning traditional perceptions of diesel-electric submarines.

It can be said that a new-generation all-electric conventional submarine, designed around solid-state lithium-ion batteries and built on entirely new design principles, has enormous development potential. For a 3,500 to 4,000-ton all-electric submarine, its overall performance would surpass that of all existing AIP submarines across the board, especially in quieting, offensive capability, survivability, low-speed sustained submerged endurance, and long-duration deployment capacity, where it would hold an overwhelming advantage.



**Image 31:** If solid-state lithium-ion batteries, supercapacitor energy-storage systems, and related technologies are successfully applied to submarines, the underwater combat capability and survivability of conventional submarines will increase severalfold.

Of course, the development of all-electric submarines still faces several technical challenges that must be resolved. These include increasing the power density and improving the reliability of solid-state lithium-ion batteries, enhancing resistance to hydrostatic pressure, optimizing energy-management and electrical-grid architecture, and improving system electromagnetic compatibility. In addition, breakthroughs are needed in submarine spatial-layout design, thermal-management efficiency, and safety redundancy. Production capacity for key materials must also be expanded and manufacturing costs reduced (for example, solid-state electrolyte materials for solid-state lithium-ion batteries). Overall, however, all-electric submarines remain the most promising development path for next-generation conventional submarines over the next 10 to 15 years. Given China's extensive experience and major achievements in these related fields, it is very likely to become the first country in the world to successfully develop an all-electric conventional submarine.

Beyond all-electric submarines, there is an even more ambitious technological path: a hybrid submarine combining a low-power reactor with solid-state lithium-ion batteries. This approach would completely eliminate the need for periodic surfacing to recharge, an inherent limitation of all current conventional submarines (including future all-electric designs), and would provide sustained underwater endurance comparable to that of nuclear submarines. The core concept is to replace the diesel engine with a small nuclear reactor (a traditional pressurized-water reactor). Because submarine size and displacement must remain within the limits of existing large AIP submarines, the reactor's volume, weight, and production cost must be tightly controlled. Therefore, the reactor's output does not need to be high; achieving 15–20 MW is sufficient, roughly one-tenth to one-fifteenth the output of a full-size nuclear-submarine reactor. From the standpoint of maximizing reactor safety, 15 MW is likely the ideal choice.

In theory, a submarine using a 15 MW small reactor combined with a 35 MWh solid-state lithium-ion battery pack would achieve exceptional propulsion and combat performance. Its sustained submerged endurance (6 to 8 knots, unlimited duration) would reach nuclear-submarine levels, aside from high-speed performance, and its overall capability would surpass both current AIP submarines and future all-electric submarines. A single submarine's

combat effectiveness could reach three to four times that of a traditional AIP boat. This is the most attractive aspect of this technological route.

However, this approach also presents several technical challenges. The first is reactor reliability. Because a small reactor has extremely high energy density (thousands of times greater than solid-state batteries), its cooling system is more complex, and the risk of primary-loop leakage is three to five times higher than that of a hundred-megawatt-class reactor. It also requires uranium fuel enriched to over 90 percent (to ensure a theoretical service life of 30 years), which increases nuclear-related risks and complicates logistics and maintenance. If the reactor uses low-enrichment uranium (around 30 percent), safety improves significantly (and costs decrease by about 85 percent), but core life drops to 5 to 6 years. This would require the submarine to undergo a refueling overhaul every 5 to 6 years, with at least 12 months of downtime, reducing fleet availability and increasing overall costs by roughly 30 percent.

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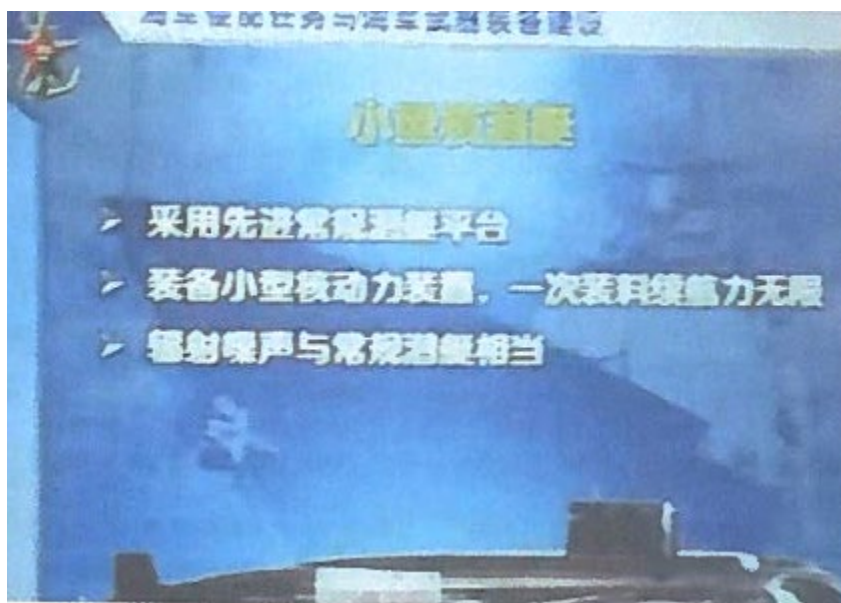


**Image 32:** Concept for installing a small reactor on a submarine

At the same time, because a small reactor must be integrated with solid-state lithium-ion batteries, a contradiction arises between the reactor's constant-power output and the batteries' fluctuating charge/discharge cycles. This increases overall system complexity and raises the failure rate by more than 30 percent.

The next issue is the extremely high cost. The construction cost of a small reactor does not decrease proportionally with reduced power output; components such as the containment vessel, control systems, emergency-power systems, and other safety equipment cannot be scaled down in cost. As a result, the unit cost is nearly 60 percent higher than that of high-power reactors (150 to 200 MW). Although the total cost of a small reactor may be only one-fifth to one-sixth that of a large reactor, it is still more than fifteen times higher than the traditional diesel-engine + AIP combination. When paired with solid-state lithium-ion batteries, total cost rises to more than twenty times higher. This means the construction cost of a single submarine would be four to

five times that of a traditional AIP submarine. For example, the Pakistan Navy's S20 submarine costs about USD 500 million with a domestic AIP system; replacing its propulsion system with a 15 MW small reactor and supporting lithium-ion batteries would raise total cost to roughly USD 1.3 billion, approaching half the cost of a 7,000-ton attack-class nuclear submarine. Over a 25-year service life, operating and maintenance costs would be more than 3.5 times higher than those of a traditional AIP submarine (even though conventional submarines consume nearly twice as much fuel).

Another challenge is port-based support and maintenance. Although a small reactor has lower power output, its requirements for port facilities and maintenance support are essentially identical to those of a full-size nuclear submarine. Dedicated nuclear-fuel storage facilities, specialized maintenance dry docks, emergency-response infrastructure, radiation-monitoring and protection systems, and dedicated electrical-supply systems must all be independently established. This severely limits the number of ports capable of hosting such submarines, restricting their forward-deployment time, reaction speed, and deterrence coverage.

The final issue is acoustic stealth. Although the use of a small reactor gives the submarine unlimited submerged endurance, the presence of reactor-cooling pumps and primary-loop piping inevitably introduces mechanical noise and vibration. Modern noise reduction and vibration-damping technologies are highly advanced, but on a medium displacement submarine of no more than 4,000 tons, their effectiveness is limited (the smaller internal volume restricts the measures that can be implemented compared with a 7,000-ton attack-class nuclear submarine). Furthermore, due to design constraints of small reactors, their available power under natural-circulation conditions is only about 23 percent (roughly 3.5 MW). In this mode, the submarine's maximum quiet speed can reach 6 knots, but noise levels still exceed 100 dB, 5 to 8 dB higher than those of a new-generation pure-electric conventional submarine. This means the probability of detection under comparable conditions is nearly one-third higher.

If the submarine is simultaneously charging its batteries while cruising at low speed (for example, when battery power has dropped to the critical 20 percent level and the submarine must maintain low-speed maneuverability), the total power available for both onboard systems and charging is only about 3 MW. At least 1 MW is required to support basic submarine operations (sonar, life support) and maintain a speed of 4 knots, leaving only about 2 MW for battery charging. Even in this state, acoustic levels remain no lower than 100 dB.

For a 35 MWh solid-state lithium-ion battery pack, charging at 1 MW would require about 35 hours to reach full capacity. Using 2 MW can shorten the time to roughly 17 hours, but cruising speed must not exceed 2 knots, severely limiting maneuverability.



**Image 33:** China's S20 conventional submarine, offered on the international market, uses a Stirling AIP system (with a streamlined stern section for integration, a high-efficiency cooling/heating system, and a lightweight radiative cylindrical liquid-oxygen tank). It has already been exported to Pakistan



**Image 34:** No matter what noise-reduction measures a nuclear submarine adopts, its noise level will always be higher than that of a conventional submarine

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海军使命任务与海军武器装备建设

**核潜艇和小型核潜艇性能比较**

| 名称    | 核潜艇     | 小型核潜艇      |
|-------|---------|------------|
| 性能    |         |            |
| 核动力装置 | 高温高压反应堆 | 低温低压一体化反应堆 |
| 核装置结构 | 两回路     | 三回路        |
| 主推进方式 | 汽轮机推进   | 发电机电力推进    |
| 速度    | 高       | 低          |
| 噪声    | 较高      | 低          |
| 续航力   | 无限      | 无限         |

**Image 35:** Performance comparison between nuclear submarines and small-reactor submarines.

Although a 15-MW small reactor can, at full power, sustain a maximum submerged speed of over 25 knots for a 4,000-ton submarine (the theoretical limit being no more than 28 knots), noise levels at that speed rise to around 120 dB. For modern acoustic-detection systems, this is essentially equivalent to “walking at night with a searchlight on.” There is no meaningful stealth at all. Modern nuclear submarines can reach speeds above 30 knots (for example, the U.S. *Seawolf* class can reach 36 knots), but except in life-or-death situations, they almost never exceed 20 knots during normal operations.”

Therefore, the practical significance of a small reactor enabling higher underwater speed is highly questionable. After all, a submarine equipped with a 35 MWh solid-state lithium-ion battery pack can also reach a maximum submerged speed of 25 knots under extreme conditions (with a cruising duration of only 3 to 5 hours), yet its noise level can be kept below 110 dB. This provides a greater advantage for maneuvering to evade anti-submarine weapons and increases the probability of escape.

In short, a small-reactor submarine can achieve far greater sustained underwater endurance than a conventional AIP submarine, both at low and high speeds, and it also has clear advantages in electrical-power availability (meaning it can support higher-power sonar systems). Thus, its overall combat effectiveness is unquestionably superior to that of conventional AIP submarines. However, the extremely high construction cost, more complex logistical-support and maintenance requirements, and greater technical risks remain key obstacles to its future development. In particular, several critical technologies still face major uncertainties over the next decade: production capacity for high-enrichment uranium, compact long-life ultra-high-enrichment reactor cores, low-noise reactor designs, compatibility and integration between reactors and lithium-ion batteries, high-efficiency cooling/heating systems, lightweight

radiation shielding, and nuclear-safety systems. All of these factors make it highly unlikely that this development path will yield practical results in the short term.

For the Chinese Navy, whose ultimate goal is to build a world-class maritime force, future near-seas defense concepts, mission scope, and operational requirements will differ greatly from those of today. This means that technologically advanced small-reactor submarines will remain one of the most suitable options in the future (after 2040), with very promising development prospects.

In the future, China's underwater combat forces will inevitably transition toward an "all-nuclear fleet," and such hybrid submarines will serve as a powerful complement to large, distant-ocean nuclear submarines. Because China and the United States differ significantly in geography, mission profiles, and threat environments, an all-large-attack-submarine nuclear fleet, like that of the U.S. Navy, is not suitable for China. Small-reactor submarines are clearly better suited to near-seas operational environments and are key to surpassing all AIP submarines in China's surrounding region in terms of technological performance. Moreover, by trading "quality" for "quantity," the number of small-reactor submarines may only need to be half the current size of China's conventional-submarine fleet to achieve a comprehensive improvement in overall combat and deterrence capability. Although small-reactor submarines are more expensive than conventional submarines, they still offer a clear cost advantage over large nuclear attack submarines (the construction and maintenance cost of four 7,000-ton high-performance attack submarines can basically fund the construction of twelve small-reactor submarines). In this sense, they also help reduce total fleet-wide costs.

Compared with conventional submarines, small-reactor submarines not only possess stronger near-seas, shallow-water combat capability, but are also better suited to supporting the operations of distant-ocean nuclear submarines. If the future force structure ratio between the two reaches 1.5:1, then after 2040 the Chinese Navy's underwater combat force would consist of 15–20 small-reactor submarines of around 4,000 tons and more than 30 new-generation large nuclear attack submarines, completing the historic transition from a mixed conventional-and-nuclear fleet to an "all-nuclear submarine force."

In summary, after the development of three generations of conventional submarines, the Chinese Navy has achieved the goal of catching up to world-class technological standards. Building on this foundation, continuous technological iteration has pushed China's conventional-submarine technology into the front ranks of the world's leading group, achieving a breakthrough from catching up to surpassing.

However, given current technological foundations, conventional submarines have reached the upper limit of further performance improvement. Their core technologies no longer offer disruptive breakthroughs, which is the main reason China is investing heavily in developing key technologies for small-reactor hybrid submarines.

As China's defense-industrial research and manufacturing capabilities continue to advance, China may become the only country capable of developing entirely new-concept submarines. In the future, the underwater operational posture and force balance in China's near seas and the

broad Western Pacific, both in quantity and quality, will shift dramatically, signaling that the Chinese Navy's underwater combat capability is entering a completely new era of development.



**Image 36:** In the future, the Chinese Navy will field a relatively large number of full-size nuclear attack submarines. Even if small-reactor submarines are developed, they will serve only as a numerical supplement rather than the core of the force.

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