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Panel II: Obstacles and Breakthroughs in China's Defense Technological Development

China's Undersea Warfare

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A Note on sources

Undersea warfare is one of China's most heavily guarded military R&D fields, and publicly accessible information is therefore limited. Where applicable, this testimony reflects this by using language indicating a degree of uncertainty. The sources relied on for the assessments made include published reference works and analyses based e.g. on satellite imagery and other visual evidence, Chinese scientific journal articles, Western, Chinese, and Russian news reports, official websites, job adverts, and the like of Chinese companies and research institutes, industry brochures and presentations shown or collected at arms fairs and conferences on naval weapon systems, as well as published and own anonymized background interviews with undersea warfare experts and practitioners from the industry and military communities. Classified evidence that exists in Western militaries on the performance of Chinese submarines and ASW systems derived from direct encounters, technical measurements as well as other types of intelligence was not accessible to this author, and neither were Chinese internal evaluations of the quality and performance of systems; technical details of existing and planned submarines and ASW systems; and internal comparisons with Western and Russian submarine warfare systems. The resulting knowledge gap is likely considerable and cannot be bridged in a public testimony.

1. Overall comparison of U.S. and Chinese undersea warfare

Undersea warfare depends on a multitude of technologies, systems, and skills, including the production of hydrodynamically optimized submarine hulls; reliable propulsion plants (conventional and nuclear) with adequate sound insulation for quieting, and high-density energy storage systems; various navigation, communication, and other subsystems; active and passive sonars (bow-mounted and towed) and other sensors; various types of armament; ASW aircraft, sensors deployed on or from other submarines, surface warships, and aircraft (integrated active and passive sonars, dipping sonars, sonobuoys); as well as fixed hydrophone arrays (e.g. to monitor submarine traffic through chokepoints); and so on. Lately, unmanned undersea vehicles (UUVs) are being developed to conduct anti-submarine roles as well, and the latest developments in regional ocean surveillance networks aim to employ a great number anti-submarine warfare technologies that integrate manned and unmanned platforms, floating and fixed installations, using active and passive sonars in addition to gathering oceanographic background data, transmitted in near real-time to data processing facilities for the creation of hitherto unknown levels of undersea domain awareness through networked, multi-static anti-submarine warfare. Though that is still in development, even standard submarine operations require an extensive knowledge of the undersea natural environment, including, but not limited to, exact maps of the seafloor as well as detailed oceanographic data e.g. on salinity levels and temperature layering (for calculating sound propagation channels), as well as on the ocean background noise generated by marine life, seismic activity, and the like. For the latter, there exists a large degree of overlap with civilian oceanographic sciences, as all research that generates datasets on the oceanographic characteristics of any given sea area basically has the potential to become "dual-use", opening attractive research platforms for international collaboration with PLA Navy R&D personnel. Chinese studies openly reflect on this fact.[1]

The technological gap between Chinese and US undersea warfare technologies in quantity and quality has historically been large, but is shrinking thanks to a sustained effort to overcome remaining bottlenecks. This effort is driven by a perceived strategic need to find solutions for alleviating China's geographical disadvantages in undersea warfare, which are due to a unique maritime geography consisting mostly of shallow and crowded littorals on continental shelf without direct access to the open oceans - Chinese submarines must transit through heavily monitored choke points in the First Island Chain to reach oceanic waters. This puts them at a disadvantage when faced with US and allied ASW forces, and negatively impacts China's ability to conduct open ocean nuclear deterrence patrols untrailed. In terms of area defense, however, China's shallow littorals offer good conditions for deploying a force of smaller, hard to detect conventionally powered submarines.

Nuclear attack submarines (SSNs)

Despite having been cut off from international submarine design assistance between the Sino-Soviet Split in the early 1960s and an era of Western technology imports that lasted for a decade from the late 1970s, China managed to build at least 3 hulls of its first (now obsolete) Type 091 "Han"-class nuclear attack submarine (SSN) design, reportedly with support from a Russian design bureau. About 15 years after commissioning the first hull, China began to commission eight or nine of the currently active Type 093 and Type 093A "Shang"-class SSN, the last of these entering service around 2018 (see Figure 1). This compares with a fleet of ca. 26 currently active American Los Angeles-class SSNs (out of a class of 62) that are able to fire Tomahawk missiles in addition to torpedoes; 3 Seawolf-class SSNs, and already 21 commissioned boats of the latest Virginia-class SSNs that are to gradually supplant obsolete Los Angeles hulls and are seeing continuous further upgrades and development. Since two US shipyards share the building of SSNs in comparison with just one yard in China – Bohai Shipbuilding Heavy Industry Company (BSHIC) in Huludao – the US industrial base is broader and more experienced.[2]

From the third boat of the Chinese Type 093-class SSN onwards, Chinese SSNs have been equipped with low frequency towed sonar arrays in addition to integrated active/passive sonar, making them better able to detect adversary submarines than previous boats that were both comparatively noisy [3] and comparatively lacking in anti-submarine warfare capabilities of their own. A next-generation SSN design, dubbed variously the Type 093B or the Type 095, is already in the works, with at least one boat under construction in Huludao. Though no exact specifications are yet available, it is likely to be larger and faster than its predecessor; to be equipped with a vertical launch system for firing cruise missiles, in addition to torpedoes; and to use a pump jet instead of a propeller, which could significantly improve its acoustic signature and thus, reduce detectability.[4] All these as yet speculative features are however already long standard in the USN and would bring the Chinese boats closer to that standard, but it remains to be seen how well the newly developed prototype will ultimately perform. Drawing from experience with China's surface warship fleet, as long as the PLAN continues to produce only small numbers of incrementally improved design variations, this might indicate the presence of remaining design flaws, whereas the beginning of larger-scale production series would indicate satisfaction on the part of the PLAN.

Ballistic missile submarines (SSBNs)

China commissioned its first prototype Type 092 "Xia"-class SSBN only in 1993. It featured a vertical launch system for the relatively short-range JL-1A submarine-launched ballistic missiles (SLBM). This single, now obsolete hull reportedly never conducted a single actual deterrent patrol. China later built at least 2 Type 094-class SSBNs (the first commissioned in 2004) and at least 6 already commissioned 094A "Jin"-class SSBNs, all featuring a vertical launch system for firing the longer-range JL-2 or JL-3 ballistic missiles. The boats suffer from a hull design flaw dubbed the "turtle" back from the missile compartment that creates a relatively noisy hydroacoustic profile. The design has been described as "fundamentally flawed in that the large missile compartment at the rear of the vessel and the flood openings below the missile hatches create a detectable sonar signature" at higher speeds, making the acoustic signature of these boats even worse than that of 1970s era Soviet designs such as the Delta III SSBNs and the Victor III SSN.[5] Chinese commentators are blaming the less than ideal turtle shape on "poor technical strength at the time," and on the need to equip the boats with the JL-2 SLBM (whereas the JL-1 had been smaller). By contrast, the Type 096 SSBN is expected to be much quieter, with military expert Chen Guangwen giving an expected noise value of less than 105 decibels for the Type 096 SSBN.[6]

All Chinese nuclear-powered submarines seem to run on pressurized-water reactors using low-enriched Uranium as fuel, and their submerged maximum speed is estimated to be not less than 26kts. At least one hull of a new, follow-on "Type 096"-class SSBN is currently already under construction at Huludao, with an estimated minimum of at least 3 further units planned. This new design is expected to be significantly larger than its predecessor to accommodate the ballistic missiles without a "turtle" design, and to feature a larger VLS, as well as very likely a pump jet instead of a propeller, which would result in a much improved hydroacoustic stealth profile.[7] Though a great improvement, this would nonetheless not match the US SSBN fleet's overall size and capability level. The USN is currently operating 14 Ohio-class SSBNs as ballistic missiles submarines plus 4 of these boats as cruise missile submarines for firing Tomahawk missiles, and is building the next-generation District of Columbia-class SSBNs. American SSBNs have continuously conducted nuclear deterrent patrols for decades on a worldwide basis, including under the Arctic ice. Their operational practice also in terms of maintenance and training therefore differs significantly from the experience of the PLA Navy, which is still in the process of developing all the associated skills, and for the time being, in regionally far more restricted patrol areas mostly in China's adjacent waters in the South

China Sea. Operating SSBNs in that crowded environment has its own challenges, as an incident in October 2017 showed, when a Type 094 "Jin"-class SSBN surfaced amidst Vietnamese fishing vessels near the Paracel Islands.[8]

The limited range of the Chinese JL-2 missile has so far hindered Chinese SSBNs from holding the entire US mainland at risk from patrol areas near China's coastal waters. This could change either if China's SSBNs gain the ability to transit into the open Pacific patrol areas while evading detection by US and allied anti-submarine warfare sensors when transiting the First Island Chain; or, if an even longer-range SLBM than the JL-3 is developed and deployed in China's coastal waters within defended submarine sanctuaries akin to the "bastion" off Russia's Kola Peninsula in the Arctic. That China is in principle interested in an Arctic basing strategy of its own is indicated by several relatively recent technical journal articles dealing explicitly with the challenges of designing submarine hulls for operations in arctic and ice-covered waters.[9] That would, of course, be contingent on Russian permission and support.

Conventional submarines

Unlike the US Navy, China is also operating a large fleet of smaller diesel-electric submarines for operations in China's shallow littorals, where they can mainly contribute to an area denial strategy (see Figure 2). Advanced models equipped with air-independent propulsion (AIP) systems can prove practically speaking undetectable even to advanced ASW forces within the loud, shallow and complex littoral undersea environment of China's coastal waters, posing significant risk to surface vessels. The USN has not operated diesel-electric submarines for decades, and due to their limited range and speed and a different maritime geography, also has no requirement for them.

After copying early Soviet submarine designs with its first indigenously constructed "Romeo" and Type 035 "Ming"-class submarines that are now technically obsolete, China between 1998 and 2006 imported and commissioned 2 Russian-built "Pr. 877 Kilo" and 10 more advanced "Pr. 636 improved Kilo"-class submarines, including all sensors and armament. The Pr. 636 boats remain in service today, and although not yet equipped with air-independent propulsion which limits their continuous submerged operating time to 2-3 days, are very quiet and hard to detect when submerged. This import happened in parallel to the already ongoing construction of the indigenous Type 039 and Type 039G "Song"-class submarines, which indicates that these Chinese designs were considered inferior to even the older Soviet-era Russian "Kilo" submarines. The Kilos at the time of their transfer reportedly required extensive Russian maintenance assistance, but the sensor technologies obtained through their transfer later informed many Chinese sonar developments.[10]

Where is China "ahead" and where "behind"?

Starting from a relatively low level of proficiency during the Cold War, China has made significant strides in the design of more hydrodynamic hulls and better propulsion systems (conventional and nuclear). In terms of operational practice, Chinese submarine operations have during the past 15-20 years been significantly extended from operating almost exclusively within China's near seas into at least the Northern Indian Ocean area, where Chinese submarines have taken part in anti-piracy patrol missions off the Horn of Africa and conducted port calls, e.g. in Karachi/Pakistan. Some gaps remain when compared with the globally operating US Navy and other advanced Western submarine-operating navies, in particular in command and control system design, quieting, and propulsion. These gaps are openly acknowledged in the Chinese research literature.[11]

The exposure to more advanced Russian technology via imports and consulting services has enabled China to develop its indigenous Type 039A, 039B and 039C “Yuan”-class conventional submarine designs that have successively and incrementally evolved to incorporate better stealth features, sensors, and armament. From the Type 039B “Yuan”-class onward, these submarines have been equipped with a Stirling air-independent propulsion system which significantly enhances the timeframe of maximum fully submerged operation from no more than 2-3 days to more than two weeks.

Several regional US treaty allies that share the maritime space with China, such as South Korea and Japan, operate comparably sized but technically more advanced diesel-electric submarines with air-independent propulsion systems based on fuel cell and lithium-ion (South Korea) or Stirling engine and lithium-ion battery technology (Japan).

In anti-submarine warfare, China is investing heavily into the build-up of extensive ocean surveillance systems, inspired by the Cold War era SOSUS system deployed at the Greenland-Iceland-UK (“GIUK”) gap for the monitoring of Soviet submarines.[12] Through creating a vast undersea surveillance network that combines and employs various emerging and disruptive technologies (EDTs) at the reported cost of more than 2bn RMB, China aims to create a real-time or near real-time undersea situational awareness and thereby, turn key parts of adjacent waters (in particular near the SSBN base on Hainan island) in the South China Sea and in the East China Sea “transparent” in an effort to discourage submarine operations of adversary nations in those areas. This ambitious effort is currently ongoing, as numerous research articles and exhibits at defense fairs attest. Next to this, China is heavily engaged in generating the necessary basic oceanographic and hydrological knowledge that is of foundational importance for potentially extending submarine operations into further areas along the Maritime Silk Road. There are indications that the level of ambition also includes the Arctic (see below). A large degree of overlap between civilian (e.g., climate change-related) oceanographic research and military uses of such research for submarine operations is openly acknowledged in Chinese research literature.[13] Based on that, Chinese initiatives to map the sea bottom, to deploy sensors for measuring salinity, temperature levels, or oceanic background noises (whether through fixed hydrophone arrays or gliders), and to gain access to related research databases of other nations have to be seen as potentially contributing to China’s undersea domain awareness improvement, which is a key enabling factor for submarine and anti-submarine warfare alike. Given the high degree of interest in Western countries to cooperate with China on environmental research, China will likely be able to make much faster progress than it would be if fending on its own by engaging and conducting joint research projects with oceanographic research communities worldwide.

China invests considerable state funds into related production, design, R&D and educational facilities and is additionally tapping into stock markets to funnel money into the system via cross-shareholdings with private and semi-private entities.

How “innovative” is China in this area?

China is still striving to close technological gaps in hull design, quieting, and particularly, propulsion systems that continue to exist compared with Russian, American and other advanced submarine technology producers that innovate at the technological frontier, whereas China is mostly still in the process of absorbing subsurface warfare technologies and conducting adaptive innovation based on these models.

From the beginning, China's efforts in subsurface warfare have heavily relied on foreign technologies, and in particular Soviet or Russian imports and design assistance for the development of its submarine fleet, both conventional and nuclear.

In such a foundational area as propulsion, China has continued to rely on key imported components, in particular German MTU marine diesel engines that have been built in China under a license agreement for many years. A recent incident in the context of China's submarine export to Thailand revealed that an indigenous Chinese submarine diesel engine that was offered as an alternative to the MTU diesel has apparently not yet been deployed on any Chinese submarines, as the Thai navy rejected it on account of not being a "proven" design (see below). This perhaps surprising weakness in submarine propulsion design mirrors similar situations with naval gas turbines for surface vessels (which China produces under a license agreement from Ukraine) and also in aero-engines.

China was however able to indigenously develop an air-independent propulsion system (AIP) for diesel-electric submarines based on Stirling-engine technology apparently legally imported from Sweden during the 1980s. Notably however, it seems to have taken China about two decades - until 2005 - to develop this into a deployable AIP propulsion system, despite the basic principle of Stirling engines being a legacy technology.

Recent Chinese research articles indicate that China has so far not been able to deploy any of the more advanced AIP technologies on submarines than Stirling engines, e.g. fuel cell technology (as is operational on the latest German, South Korean, or Singaporean submarines) or lithium-ion batteries (such as are already deployed by both Japan and South Korea). Though Chinese R&D in those areas seems to be a particular focus, research articles note that several difficulties need yet to be overcome for these technologies to be safely deployed aboard a submarine.[14] This points to a certain gap in innovativeness compared with the above mentioned leading producers of diesel-electric submarines.

For China's indigenously developed nuclear-powered attack submarines and ballistic missile submarines, the Russian Rubin Design Bureau in particular was reportedly heavily involved in assisting the designers of the Type 093 "Shang" class SNN in the areas of hull design, instrumentation, acoustic stealth improvement, and development of acoustic countermeasure systems.[15] One Russian military commentator points out that "Chinese engineers struggled for a long period with vibration suppression issues from the shock absorption platform that houses the steam turbine along with circulation pumps, turbo charger and other equipment."[16]

A recent book on the Chinese navy by PLA Colonel Ma Hongwei claims that the next-generation SNN – the Type 095 will feature "six world-leading new technologies": a new pump-jet propulsion system; ultra-high-strength steel (presumably allowing for greater diving depths); a single-double hybrid hull structure; new integrated shock-absorbing floating raft for improved quieting; a vertical launch system for cruise missiles; and China's "third-generation submarine reactor".[17] Another Chinese commentator likewise mentions "new generation of reactor technology" of the next-generation submarines, and points out that China has the world's largest 80,000-ton forging hydraulic press" as well as "super steel with a yield strength of 2000 MPa, which is the world's top level" – a precondition for more pressure-resistant hulls and deeper diving depths.[18] Colonel Ma gives the following performance data for the planned Type 095 SNN: A maximum underwater speed of no less than 33kn, silent speed of no less than 18kn, and a maximum diving depth of no less than 600 meters. This would put the new Chinese boat in a different league entirely than its predecessors. He also indicates that on the basis of the Type 095 SNN, China also intends to develop a cruise missile-armed nuclear submarine carrying multiple integrated cruise missile launchers.[19]

How long will it take China to "close the gap" with the United States?

Several difficult to assess factors influence the timeframe that China will need to catch up with current US standards. Heightened US wariness toward Chinese researchers in dual-use technology fields during the past few years, sharpened export controls and the like are bound to slow down direct technology transfers from the US. One decisive factor would be enhanced Russian design support. So far, Russia had been hesitant to transfer its most advanced nuclear propulsion and quieting technologies. Depending on the overall geopolitical interests of both countries, and given the growing Russian economic and political dependency on China as a result of the Ukraine war, this resistance could begin to melt. Already in 2020, official Russian media had announced that Russia and China were "jointly designing a new generation non-nuclear submarine."[20] And Russian and Chinese researchers have been actively cooperating on sensitive undersea sensor technology for use in the Arctic for a number of years, indicating the potential for further Russian openness to cooperation with China on subsurface technologies even in that sensitive area.[21] Should Russia however decide to withhold its most advanced technologies to keep an edge over China, China's progress would occur more slowly, while American and allied producers all the while will continue to innovate at the technological frontier.

Another key factor concerns the question of continued high-level political support and uninterrupted accessibility of large-scale state funding. As of now, China's government prioritizes the build-up of a world-class nuclear and conventional submarine fleet. Submarines are considered essential for the build-up of a full nuclear triad and contribute significantly to area denial in the context of China's near seas active defense posture. China is furthermore striving to deter foreign submarine incursions into Chinese-claimed waters, including the South China Sea, and wants to neutralize technological advantages of adversaries by quickly catching up in anti-submarine warfare, which includes the creation of extensive ocean surveillance networks in China's near sea areas to increase undersea domain awareness. Related survey activities have also begun in areas beyond the South China Sea and First Island Chain, e.g. the South Pacific and Indian Ocean,[22] and China has also started to export new submarines, so far to Pakistan and Thailand, which has the potential to strengthen strategic relations with submarine customer countries while providing China's submarine designers with valuable customer feedback.

Under the current great-power rivalry, high-level political support for China's undersea warfare development can be expected to persist. The availability of funds, however, depends not only on political will, but also on China's future economic growth and other pressing state spending needs. Here, adverse economic developments in China, e.g. a banking crisis, could potentially disrupt the flow of funding. But in light of the high strategic priority undersea warfare enjoys, cuts can be expected to occur first in other areas, such as surface fleet development.

In anti-submarine warfare, Chinese specialists working in the field have noted that high-level support for this research field is relatively recent and occurred mostly within the past decade. "Professor Tu Liangcheng of the Huazhong University of Science and Technology in Wuhan said in 2016 that funding for submarine detection technology had been increased in the preceding years: "There is a shift in the navy's attitude to submarine warfare". According to him, China previously focused more on enhancing the capability of its submarines rather than focusing on ASW. Tu was also quoted as saying that China was "desperately" striving for the ability to track foreign nuclear submarines, but that it was "30 years behind the capabilities of the United States" in submarine detection. He indicated that funding was sufficient, and R&D supposedly already "on par with the US and Europe," but noted that "the pressure is high, there is high expectation of a quick breakthrough, and we are short of hands."[23]

2. Specific technological obstacles that China has historically faced in its efforts to develop advanced undersea warfare capabilities

China's submarine-developing industries have enjoyed limited degrees of access to more advanced foreign technologies for most of their existence. During 1950 to ca.1960, the Soviet Union was the sole provider of legacy submarine technology. The diesel-electric Type 035A "Ming" boats China produced based on that basis proved relatively accident-prone.[24] During ca. 1980-1989, China gained access to some advanced Western naval technologies, including American and French sonars and ASW helicopters, German diesel propulsion (MTU) and also Swedish technology for Stirling-engines that was later indigenously developed into an AIP system after an arduous R&D process.

After the arms embargo following the Tiananmen massacre in 1989, China again lost access to the Western arms markets except in some dual-use fields. This did not impact the further transfer of naval diesels, and neither did it inhibit transfers of oceanographic and hydrographic research equipment necessary for mapping the sea floor. Following the demise of the Soviet Union, Soviet-era Russian technology became once again available to China, and China imported several batches of Kilo class submarines. These brought significant amounts of hitherto unavailable technologies to China, and modern sonars are mostly based on that imported batch of Soviet era technology. In particular, the Rubin design bureau seemingly assisted China in the design of nuclear-powered submarines.

One area of heightened interest is AIP propulsion technology for conventionally powered submarines. Despite concentrated efforts, just like Russia, China has so far not deployed a fuel-cell AIP on submarines and is still working on lithium-ion battery AIP despite being a leader in electric car manufacture where lithium-ion batteries are already widely used. Chinese technical literature cites safety concerns, in particular the need to securely control the danger of thermal runaway.[25] Nonetheless, China can be expected to master lithium-ion battery AIP at some point and thus likely leap over the technically more complicated to copy stage of fuel cell AIP.

China seems to have only very recently developed an indigenous submarine diesel engine after license-producing the MTU 396 SE84 diesel engine for decades. This became apparent when after China had won a contract in 2017 to export one S26T Yuan class submarine to Thailand, to be delivered in 2023, the deal ran aground in 2022 once the German government would not grant an export license for the MTU engine. After Thailand threatened to cancel the contract, China offered its indigenous CHD620 diesel, but Thailand was as of March 2023 still hesitant to accept an "unproven" engine, which implies it has never been integrated into a submarine before. The inspection and negotiation process remains ongoing as of April 2023 writing.[26] This export contract points to an unexpected bottleneck in what a German submarine design expert interviewed by me considers a "relatively old" technology that is "not too complicated to master" and poses merely a "manageable" technical risk. Asked to speculate what elements of an "unproven" diesel engine might specifically be considered risky from the point of view of a submarine customer, the expert offered that the worries might conceivably be related to the performance of the exhaust back pressure system for discharging diesel exhaust below the surface when operating at snorkeling depth. Malfunctions in this area would pose a safety hazard for the crew, and reliability is therefore a key concern.[27] The reaction of Thailand also shows that Chinese submarine technology is so far not considered quite on par with leading Western technology on the export market.

3. Chinese attempts to address obstacles through greater investment in domestic R&D

As Kevin Pollpeter and Mark Stokes have pointed out, "Chinese defense enterprises approach indigenous innovation in three ways: original innovation, integrated innovation, and technology transfer, or what the Chinese call 'Introduction, digestion, absorption, and re-innovation'", in short: IDAR.[28] In submarine warfare, so far absorption and re-innovation or "IDAR" seems to be frequently employed.

A vast state-led high-tech development plan, ("863 Program") was created in 1986 in an effort to make China technologically more independent. Marine technologies were included from 1996. It seems to have been particularly important for funding R&D activities related e.g. to sonars and unmanned systems development.[29] The latter is a particular focus of current Chinese undersea warfare R&D. As a Chinese security firm's analysis of the undersea technologies market in China proclaims, "we will vigorously develop underwater unmanned submersibles, push forward the deployment of underwater shallow and deep-sea regional monitoring and early warning systems, focus on advanced technologies such as underwater navigation and positioning, communication, and autonomous coordination, and combine manned and unmanned equipment technologies to create a new type of underwater network combat system."[30]

In the context of overall structural reforms in the defense industries, and massive R&D and arms production funding, a vast and opaque system of interlinked shipyards, R&D institutions and subsystem developers has emerged in China that is characterized by cross-shareholdings among each other, with state-owned banks, and with listed private businesses within China and abroad; connects deeply with the academic R&D community worldwide; and is collectively engaged in a vast effort to overcome bottlenecks in critical arms technologies via ingenious methods beyond traditional espionage.[31]

For foreign businesses and research institutions, it can be hard to conduct due diligence on Chinese partners, or even to keep track on the activities of a single firm or entity, due to frequent renamings and asset reorganizations. To give an example, the CSSC China Marine Information Electronics Company Ltd. (a.k.a. China Haiphong 中国海防) is a leader in underwater communication technology, ultra-low power signal processing technology, high efficiency acoustic emission technology, broadband transceiver design and manufacturing technology and underwater system equipment, focusing in particular on the development of "autonomous unmanned underwater vehicles (AUVs), deep-sea vehicles and submarine-specific underwater operational equipment, including underwater phones, underwater information transmission, underwater television, underwater lighting, underwater navigation and positioning, underwater black box, etc." It was originally established in 1993 under the then name Gansu Sanxing Petrochemical, went public in 1996, was renamed "China Electronics Guangtong" in 2004, and in 2017, injected shares into Great Wall Electronics and Sesco. In 2018, it was renamed China Haiphong, and in 2019, purchased 100% of the equity of Haisheng Technology, 100% of Jereh Holdings, 100% of Liaohai Equipment, 62% of Qingdao Jereh, 54% of Jereh Electronics, and a China Ship Yongzhi 49% stake.[32]

The area of unmanned underwater vehicles is particularly prone to invite foreign researchers who may be unaware of the dual-use characteristics of the field. Software development and mathematical modeling of underwater robotic systems has for instance been a field where cross-national collaboration has been conducted between Western and Chinese research institutions. A 2019 study on software architecture for hybrid underwater robotic vehicles had co-authors from Chinese entities that are all listed as "high risk" in the ASPI's Defence Universities Tracker Database, plus one co-author from the department of computer science and electrical engineering at Jacobs University in Bremen, Germany.[33] Another recent anecdotal example concerns a renowned German climate research modeling scientist co-publishing with Chinese hydroacoustics researchers from a „high risk" background, while acknowledging having received state financing from Russia.[34] There are multiple similar cases where Western scientists were likely unaware of the military implications of their research.

The submarine-building shipyards of China in their turn conduct naval and commercial building simultaneously. Shipbuilding joint ventures with advanced shipbuilders, e.g. from Japan, France or South Korea, even in civilian commercial projects have in the past bolstered Chinese naval shipyards' technological and procedural skills, which ultimately led to China's technically upgraded and massively subsidized yards in 2018 surpassing even South Korea as the leading producer of commercial ships. Another factor is likely the goal to close technical bottlenecks in military shipbuilding via Military-Civil Fusion.[35] Bohai Shipbuilding Heavy Industry Company (BSHIC) shipyard in Huludao, the sole build yard for all nuclear-powered submarines, on a no longer accessible website in 2017 described itself as an "official research base" for "localizing (…) important technical equipment".[36]

Furthermore, as CSIS has pointed out, by attracting "billions of dollars of revenue and technology transfers from companies around the world", Chinese naval shipyards have benefited from significant shipbuilding technology upgrades, including modern design software, modular construction techniques, etc., and generated profits that may have been used to balance high costs of naval developments. "Between 2019 and 2021, four key Chinese dual-use shipyards received at least 211 orders for commercial vessels, 64 percent of which were placed by foreign companies—including companies based in Taiwan, France, Japan, and elsewhere".[37]

Table 1 in the appendix contains an inexhaustive listing of some of the most important design, R&D, and production entities engaged in producing systems needed for undersea warfare, many of them dual-use. Western research institutions and industries would likely benefit from a more comprehensive and publicly accessible database of known contributors to Chinese undersea warfare capabilities covering also civilian commercial and dual-use fields that also lists the various aliases of entities, as it can be particularly hard to identify risky partnerships and commercial dealings in such areas.[38] Looking only at entities engaged in the development of autonomous underwater vehicles (AUV), Ryan Fedasiuk reported in 2021 that a listing published in 2019 had 159 AUV projects catalogued at over 40 universities, when only 15 universities had been active in that field four years earlier; and another catalogue by a professor at Hebei University of Science and Technology listed 48 universities and 45 enterprises engaged in research on UUVs and AUVs.[39] According to Elsa Kania, an "Underwater Vehicle Intelligent Equipment Base" was established in Qingdao, "undertaking research and development, as well as the design and manufacture, for a range of marine robotics and engineering equipment, including the white Dolphin (白豚) autonomous underwater vehicle." By April 2018, Qingdao hosted the "first forum on military-civil fusion in the AI industry" convened by Harbin Engineering University, which discussed intelligent underwater robots, high-speed unmanned boats, smart ships, and target recognition."[40]

4. Chinese attempts to address obstacles through the acquisition of foreign technology

During the process of restructuring the state-owned defense sector from 1998/99 and subsequent organizational reforms, China has created an non-transparent system of cross-shareholdings between private, semi-private and larger state-owned entities in the defense sector. On the one hand this enables the Chinese government to channel funds from domestic state-owned banks (in the form of credit lines) and from domestic and foreign stockmarkets into the defense industries. The private and semi-private listed subsidiaries of state-owned entities furthermore provide avenues for joint ventures and M&A activities with foreign partners that can contribute technical expertise, technologies, or in some cases also things like procedural knowledge and market access in other countries.

Energy generation and high-density energy storage solutions are an especially critical area of submarine development that has, however, also multiple applications in purely civilian technologies. Chinese firms active in this dual-use field can used M&A to bolster overall Chinese competencies in this field. For instance, the privately-owned Wolong Group: 卧龙集团, China's largest maker of electrical motors, also makes among other products "custom electric motors for nuclear power plants" as well as generators, drives and other electrical systems for "naval and defense vessels" according to its official website, although the exact types of vessels are not elaborated on.[41] Its subsidiary Wolong Electric has taken over a variety of western makers of electrical motors, among them General Electric's small electrical motor section. And in Germany, the medium-sized special electric motor producer ATB Schorsch that also makes special electric motors for submarines,[42] was taken over 100% by Wolong in 2011. The sale was conducted on the German side in the hopes the Chinese buyer would invest into production and R&D facilities within Germany and bolster the firm's business. But instead, contrary to previous affirmations, as the head of the Works Council Olaf Caplan said in an interview in 2019, "Ultimately, it is about know-how transfer and the relocation of components and ultimately complete products to China." As he reports, ATB Schorsch's management in Germany reportedly had no longer any say, as the company became de facto run from China in a time-delayed and non-transparent manner. Caplan also noted quality issues in the now Chinese-produced products which according to him, had the potential to damage the brand's international standing.[43] According to Chinese news reports, Wolong's "production network is strategically located in Asia, Europe and North America. Wolong Electric has established R&D centers for motors and drive controls in Europe, the United States, and Japan, and plans to open a Global R&D Center in Shanghai.[44]

Licensed production within China of some key technologies, such as the above mentioned German MTU diesel engines or the French ASW helicopters has been another legal way to absorb technologies. China's first anti-submarine helicopter, the Z-8, was manufactured under a license agreement following an imported batch of the 12 SA 321 Super Frélon from France in the late 1977s.[45] The latest anti-submarine warfare helicopter, the Z-20F, has been introduced during the past 5 years and was developed based on the American Sikorsky H-60 Black Hawk, which had been legally imported by China before 1989.[46]

As to sonars, after a history of indigenous developments based on older Soviet models, more modern hull-mounted active/passive sonar technology was legally imported by China during the decade before 1989 from the US, via Italy (the Raytheon DE-1160); and hull-mounted passive sonar technology from France (the DSUV-22 and DUUX-5). After 1989, China gained access to a variety of modern Russian sonar technologies through the import of the Kilo class submarines as complete weapon systems. Based on these technologies, indigenous development took off.[47]

A notable case of recent R&D cooperation concerns ongoing and intense research collaboration between Chinese R&D institutions with miliary ties (including Harbin Engineering University) and Russian counterparts on hydroacoustics communication and fibre-optic hydrophone development in Arctic waters for use under the ice. So-called "China-Russia Polar Acoustic Symposiums" have been organized since at least mid-2019, involving over 100 experts from Russia and China from 30 military research facilities and companies, indicating a surprising openness on the part of Russia to collaboration with China in this highly sensitive field.[48] A related high-profile supposed espionage case notwithstanding, this points to an institutionalized rather than ad hoc collaboration.

Illegal methods used by China to obtain underwater warfare technologies include the copying or reverse-engineering of legally imported systems, likely also from Russia. As recently as 2019, the Chief of Russia's defence conglomerate Rostec went public with complaints of massive copyright infringement by China, mostly however concerning the aerospace sector.[49] In how far the same applies to submarine technologies is therefore not entirely clear. A cryptic announcement of a planned joint development of conventional submarines with Russia would point to a new level of mutual trust in this field, but was so far not elaborated further.[50] Previous rounds of direct support from the Russian Rubin design institute point to potentially deeper exchanges also in nuclear submarine design. Nonetheless, there were charges brought in Russia against researchers and officials for transferring sensitive submarine-related knowledge, e.g. in hydroacoustics, or even, particular materials to China in violation of state security regulations as recently as 2021. As one Russian news report from 2021 notes, "last summer in Vladivostok, customs officers noticed four containers prepared for shipment to China. According to the documents, 106 tonnes of ferrous metal scrap were inside. However, it quickly became clear that the bills of lading had been cheated - the containers contained high-strength steel obtained by cutting up the solid hull of a nuclear submarine. It is forbidden to export such metal because, firstly, it can be reused, and secondly, the composition of the metal itself is a secret."[51]

A rather high-level espionage case occurred at the NATO undersea research center in La Spezia (NATO CMRE), which is responsible for research on multistatic and networked anti-submarine warfare, when its deputy director, the Estonian scientist Tarmo Kouts, was recruited by Chinese intelligence in 2018. He was sentenced to 3 years in prison in 2021.[52] Due to a lack of public reporting on the case, no detailed implications can be drawn, other than China paying attention to the individuals leading multilateral efforts among allies in the underwater warfare field.

5. Dual-use technologies or research disciplines that overlap with undersea warfare

Ocean environmental monitoring in the context of climate change and other oceanographic research is a field with a lot of overlap to undersea warfare, even though scientists working in it may not even be aware of any military or dual-use implications, while many western governments actively fund related collaborative research projects with China in the interest of combating climate change. Projects like a "cloud platform for big data and artificial intelligence (AI) in ocean science'" that is operated by the Institute of Oceanology at the Chinese Academy of Sciences (IOCAS), however, have obvious usefulness for undersea warfare as well. According to a Chinese news report, the platform "acts as an information pool by integrating updated, wide spatio-temporal coverage range, open and shared oceanographic data" while including an "oceanographic data portal, an interactive analytics platform for large-scale data, an AI development service platform and application products of big data and AI." According to the report, there are "353 sets of ship-based survey data available on the cloud platform, with 59 sets of moored observation data, six sets of remote sensing satellite data, more than 10 sets of reanalysis data products and internationally shared data, and 500 sets of integrated software for ocean and atmospheric sciences."[53] A 2020 paper by PLA researchers eloquently describes the foundational significance of all foundational oceanographic and marine environmental research for submarine warfare.[54]

In that regard, a related area where exchanges with Western firms may have inadvertently contributed to enhancing Chinese undersea warfare capabilities concerns deliveries of advanced multi-beam sonar equipment for surveying deep-sea geography. A 2021 Chinese research paper particularly lists multi-beam sonar equipment by the Norwegian firm Kongsberg MBS as the main survey instrument. According to the paper, this particular survey was carried out in the northeast and central part of the South China Sea and lead to vastly improved awareness of the geomorphological features of the seafloor in the surveyed area.[55] Another Western maker of comparable multi-beam sonar survey equipment, Teledyne RESON, is also on record as having delivered its most advanced echosounder equipment to Chinese recipients, including the Qingdao Institute of Marine Geology (QIMG) and the Guangzhou Marine Geological Survey (GMGS), who received the ParaSound „Sub-bottom Profiler" P70 3G-Mk2 with „upgraded hardware and updated software".[56] The Norwegian company Norbit, yet another maker of multibeam echosounding technology, has also supplied its equipment (the NORBIT-iWBMS bathymeter) to the First Institute of Oceanography and the Key Laboratory of Ocean Geomatics under the Ministry of Natural Resources in Qingdao, where it was used alongside the Teledyne SeaBat T50-P multibeam echosounder to evaluate seafloor mapping software in a 2022 study.[57] The same echosounder was described its maker in a 2018 news release as a "key component to the (Chinese) Yun Zhou Tech M80B unmanned surface vessel", which was "recently deployed in Antartica on the Chinese Polar Research Vessel Xue Long (Snow Dragon)" where it successfully surveyed 5 square kilometres in the waters of Antartica."[58] This likely refers to the Xue Long's November 2017 Antarctic expedition. The Chinese USV on which Teledyne's multibeam echosounder was deployed, the M80B USV, was jointly developed by the PLA's Naval Surveying and Mapping Research Institute; the State Oceanic Administration's South China Sea Survey Technology Center, and Yunzhou Tech, as per Elsa Kania's testimony before the USCC on June 7, 2019.[59]

6. Reliance on foreign sources for the materials and technologies and chokepoints the United States or allies could leverage to degrade the PLA's military capabilities during a conflict

In the openly accessible literature, there is no sufficient data on the Chinese stockpiles of critical materials within China that would be needed to answer the question of chokepoints that could be leveraged.[60] In the area of lithium-ion battery production, the Chinese technical literature does note that there could be supply chain vulnerabilities concerning nickel and cobalt, and recommends an iron and phosphate variant of lithium-ion battery technology to avoid the risk of becoming dependent on imports for the latter.[61]

Some critical materials can likely be accessed by China with help from Russia. On December 12, 2022, the Russian state-owned Rosatom Corp. supplied 6,477 kilograms of highly-enriched uranium (HEU) to China's fast-breeder reactor CFR-600 on Changbiao Island. The weapons-grade plutonium this breeder will produce could be used for nuclear warheads, but alternatively, commentators have also discussed the possibility that it could also be intended as fuel for future nuclear-powered submarines – currently, Chinese submarines are however thought to rely on low enriched uranium (LEU) as fuel.[62]

7. Recommendations for Congressional action

As anecdotal evidence of technology transfers in dual-use areas conducive to underwater warfare development shows, industry needs clearer guidelines and likely, also more assistance on how to identify technologies that may not be obviously dual-use, but may nonetheless be critical or difficult to produce components that enable significant undersea warfare capability gains in a potential adversary.

Western research institutions and industries would in particular benefit from a comprehensive and publicly accessible database of known contributing entities to Chinese undersea warfare capabilities covering also civilian commercial and dual-use fields, that also lists their various aliases and cross-shareholdings, as it can be particularly hard to identify risky partnerships and commercial dealings in such areas. The existing "Chinese Defence Universities Tracker" database by the Australian ASPI institute[63] is a good start, as it covers R&D institutions well, but not necessarily business entities.

Cross-sectoral learning processes might be furthered through workshops targeting industry executives at various levels, in which intelligence and law enforcement personnel could lead "post mortems" of various types of real-world case studies where export controls in the underwater warfare domain have failed to be adhered to for various reasons, or where no export controls existed in the first place. Raising awareness for national security concerns and enhancing knowledge of tech acquisition approaches should be a goal targeting in particular those responsible for day-to-day business relations, as technology transfer approaches and business activities constantly evolve and cannot be well addressed by a cookie-cutter approach.

Likewise, the awareness level of civilian researchers in fields that are critical for generating oceanographic data needed for submarine warfare - even though that may not be obvious to many researchers – should be enhanced in order to focus their attention to security-related issues and gain their cooperation. As an example on how this could be done, the Finnish approach to enhancing overall societal preparedness for crises via a system of "national defence courses" targeting key executive personnel across all sectors of society might be a structural model for such an initiative, even though the goal in this case would not be general societal preparedness for national security crises as in Finland, but rather, awareness of interconnections between national security and various industrial products and sectors. The Finnish course system is credited as being an effective tool contributing to a high level of security awareness across all sectors of society.[64]

Cyber espionage, though not discussed in this testimony, is a pervasive threat facing researchers across many disciplines, and where that is not yet the case, for instance in many underfunded universities across the Western world, the cyber security of research facilities should be enhanced by making it mandatory for institutions to implement a minimum of cyber security measures that are standard in industry, such as 2FA for E-mail, and assistance by the security services should proactively be offered to bolster the cyber security of individual researchers and research facilities, e.g. through group trainings or the like.

Appendix

Figure 1: Approximate Type and Age structure of the Chinese nuclear submarine fleet

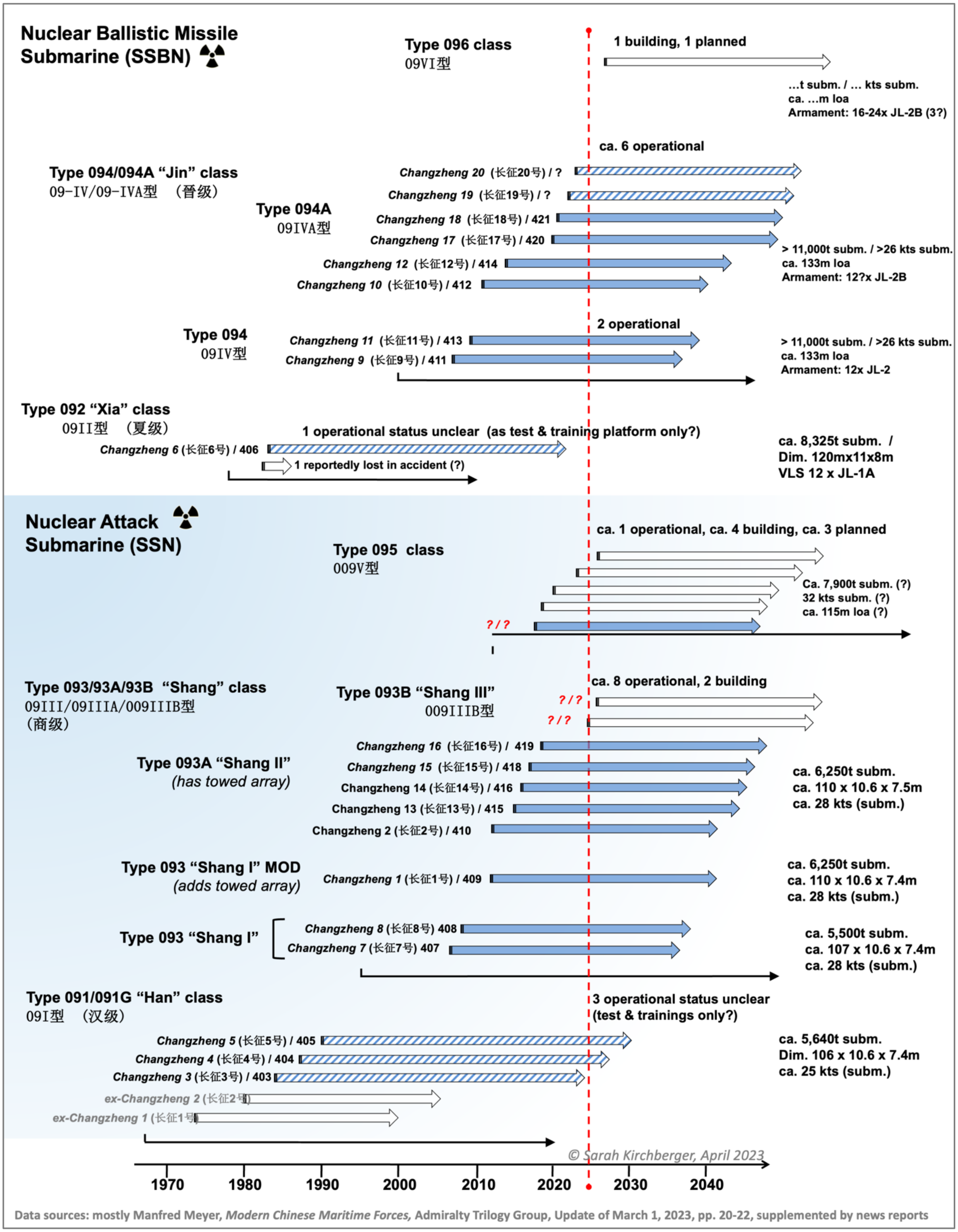

Figure 2: Approximate Type and Age Structure of the Chinese Conventional Attack Submarine Fleet

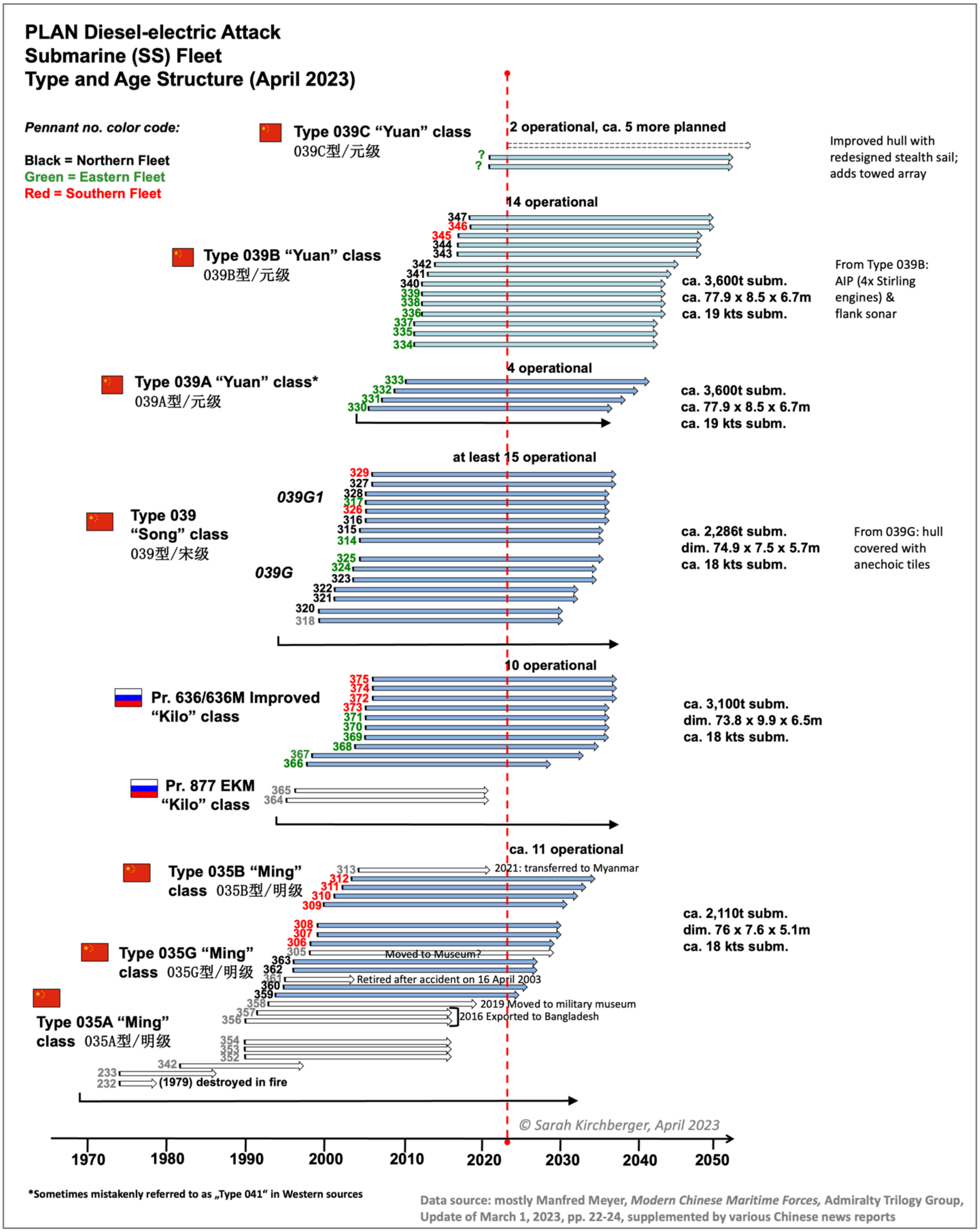

Table 1: Selected Organizations Contributing to Chinese Submarine Warfare

*On the US Entity List; **Newly added to US Entity List in Dec. 2020; + Apparently not on the US entity list.

Business area	Enterprise or unit		Related military business
	Short Name	Full name / Alias	
General submarine design, ship hull development, and construction	701st Research Institute** 七〇一所	China Ship Design and Research Center** 中国舰船研究设计中心	The only general research & design unit in China that develops small and medium-sized submarines. Has national defense key laboratory for electromagnetic compatibility and acoustic stealth technology. Also active in marine dynamic environment monitoring buoys etc.
	719th Research Institute 七一九所	Wuhan Second Ship Design Research Institute 武汉第二船舶设计研究所	The only overall design institute for nuclear-powered ships in China, develops all nuclear-powered submarines including reactors.
	702nd Research Institute* 七〇二所	China Ship Scientific Research Center (CSSRC)* 中国船舶科学研究中心	Applied basic research of hydrodynamics, structural mechanics and vibration, noise, impact resistance and other related technologies in ship and ocean engineering, as well as research, design and development of high-performance ship and underwater engineering
	725th Research Institute* 七二五所	Luoyang Institute of Ship Materials* 洛阳船舶材料研究所	Development of ship materials and engineering application research. Has 4 seaport test stations
	11th Research Institute+ 一一所	Shipbuilding Technology Research Institute (STRI)+ 上海船舶工艺研究所 上	Research on shipbuilding technology and marine engineering; R&D on hull welding technology and equipment; large-scale CNC cutting and automation equipment production lines; coating technology and equipment; application and process R&D of marine non-metallic materials; development of shipbuilding software systems and information technology integration platforms; non-destructive testing of metal materials, technical testing of non-metallic materials
	(formerly: Bohai Shipyard)+	Bohai Shipbuilding Heavy Industry Co., Ltd. (BSHIC) 渤海船舶重工有限责任公司	Constructs all nuclear-powered submarines
	438 Factory+	Wuchang Shipbuilding Industry Group Co. Ltd. 武昌船舶重工集团有限公司	Main shipyard for building conventionally-powered submarines
	Jiangnan Changxing+	Jiangnan Shipyard (Group) Co., Ltd. 江南造船（集团）有限责任公司	Secondary shipyard for building conventional subs
Propulsion	711th Research Institute* 七一一所	Shanghai Marine Diesel Engine Research Institute (SMDERI) 上海船用柴油机研究所	Main research institution for conventional submarine power systems. Has developed power systems for multiple types of submarines, including Stirling AIP systems
	Micro Powers+	Shanghai Qiyao Power Technology, Ltd. (上海齐耀动力技术有限公司)	Maker of the Stirling AIP system for conventional submarines; a wholly-owned subsidiary of the 711th Research Institute.

	/	Shaanxi Diesel Engine Heavy Industry, Co. Ltd. (陕西柴油机重工有限公司)+	Licencse-producer of German MTU 396-series marine diesel engines for submarines.
	(719th Research Institute 七一九所 – see above – develops all nuclear propulsion plants)		
Detection and Countermeasures 探测与对抗	7th Research Academy 七院**	China Naval Research Institute** 中国舰船研究院	Research and design of submarine and ship-borne weapons and equipment
	/	Haiying Enterprise Group Co., Ltd.+ 海鹰企业集团有限责任公司	China's first underwater acoustic equipment manufacturer. Hydroacoustic equipment, marine engineering special equipment and other special equipment, diving and underwater salvage equipment, navigation, meteorological and marine special instruments and meters
	715th Research Institute** 七一五所	Hangzhou Institute of Applied Acoustics** 杭州应用声学研究所	Develops acoustic, optical and magnetic detection equipment. Has key laboratory of sonar technology, a first-level hydroacoustic measurement station, an underwater acoustic product testing center, and a second-level radio measurement station.
	/	Haisheng Technology Co., Ltd.+ 海声科技公司	Underwater acoustic detection, navigation, rescue, and underwater security. and underwater acoustic transducers; a subsidiary of 715th RI
	716th Research Institute** 七一六所	Jiangsu Institute of Automation** 江苏自动化研究所	Engaged in the research and development of electronic information transmission systems, etc.
	726th Research Institute** 七二六所	Shanghai Ship Electronic Equipment Research Institute** 上海船舶电子设备研究所	R&D of underwater acoustic countermeasures and anti-countermeasure systems, underwater acoustic navigation and marine development application instruments and equipment
	723rd Research Institute** 七二三所	Yangzhou Marine Electronic Instrument Research Institute** 扬州船用电子仪器研究所	Engaged in the development of electronic engineering systems and equipment
	704th Research Institute** 七零四所	Shanghai Marine Equipment Research Institute (SMERI)** 上海船舶设备研究所	Application research of special auxiliary electromechanical equipment and systems for ships; vibration reduction and degaussing
	368 Factory+ 三六八厂	Hebei Hanguang Heavy Industry Ltd.+ 河北汉光重工有限责任公司	It has key experimental facilities such as anechoic pools, and is a key research and development base for national underwater weapons.
	662 Factory+ 六六二厂	Chongqing Qianwei Technologies Group Co. Ltd.+ 重庆前卫科技集团有限公司	Integrating information technology, computing technology, and automatic control, research direction is command and control system technology and high-performance computer system technology
Command, Control and Computers 指挥控制与计算机	709th Research Institute** 七〇九所	Wuhan Digital Engineering Institute** 武汉数字工程研究所	Integrating information technology, computing technology, and automatic control, the research direction is command & control system technology and high-performance computer system technology
	724th Research Institute** 七二四所	Nanjing Ship Radar Research Institute** 南京船舶雷达研究所	Engaged in the development and production of large-scale device data detection and intelligent systems such as ship radar systems
	/	Institute of Acoustics (IOA) at the Chinese Academy of Sciences (CAS) 中科院声学研究所	Engaged in research on AI in command & control systems aboard submarines (intelligent support for sub commanders)

	5th Research Institute 五所 / Academy of Systems 系统院*	CSSC Systems Engineering Research Institute* 中国船舶工业系统工程研究院	Ship combat command system, formation command system, joint combat command system, aircraft carrier aircraft automatic landing system
Navigation and Communication 导航与通信	707th Research Institute** 七〇七所	Tianjin Navigational Instrument Research Institute** 天津航海仪器研究所	Technology research and equipment supply in inertial navigation, ship control systems, and hardened computers
	722th Research Institute* 七二二所	Wuhan Ship Communication Research Institute* 武汉船舶通信研究所	R&D and manufacturing of communication electronic engineering, such as integrated data communication systems, broadband high-speed data transmission, high-frequency adaptive instantaneous communication systems, high-speed optical fiber integrated service transmission networks, special antennae, information security equipment, communication control and distribution, ship internal communication systems
	717th Research Institute** 七一七所	Huazhong Photoelectric Technology Research Institute ** 华中光电技术研究所	Engaged in photoelectric detection information processing and photoelectric system integration, astronomical navigation and inertial navigation
	453 Factory 四五三厂+	Chongqing Huayu Electric Group Co., Ltd+ 重庆华渝电气集团有限公司	Marine instrumentation, equipment and supporting products, inertial navigation, positioning and orientation devices
	455 Factory 四五五厂+	Changjiang Technology Co., Ltd+. 长江科技有限公司	R&D and production of communication, navigation, positioning and orientation equipment
	/	Xi'an Dongyi Technology Group Co., Ltd.+ 西安东仪科工集团有限公司	Underwater acoustic testing, inertial navigation systems, radio assembly % debugging, reliability testing
	China Haiphong 中国海防+	CSSC China Marine Information Electronics Company Ltd.+ 中国舰船重工集团海洋防务与信息对抗股份有限公司	R&D, production and manufacturing in information electronics, including underwater information transmission equipment, special equipment for underwater weapon systems and other special equipment, series of special marine power supply products, etc.) and testing and testing services
	/	Chongqing Qingping Machinery Co., Ltd.+ 重庆清平机械有限责任公司	Manufacture of special instruments for navigation, meteorology and oceanography; also special precision equipment for gear production and gear testing; high-precision special gears and gearboxes

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