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# Underpowered

## *Chinese Conventional and Nuclear Naval Power and Propulsion*

UNDERSTANDING CHINA'S TRAJECTORY in naval power and propulsion is critical to understanding its future at sea. Propulsion determines how fast and far a ship can go; overall power determines what it can accomplish in a given location. The density of water (829 times greater than air) imposes an unforgiving reality on these dynamics: the cubic relationship between power and speed. For a ship to go three times faster, twenty-seven times the power is needed. Furthermore, modern advanced weapons systems require high and growing amounts of power to operate. For all these reasons, an ambitious nation such as China would prefer to power its navy using the most advanced sources available. Propulsion has been one of the greatest weaknesses for China's navy and for its military in general, however. The main question is how quickly and effectively it can master the relevant technologies.

The chapter begins by briefly reviewing conventional propulsion requirements and Chinese capabilities in this regard. Given the disproportionate potential of nuclear propulsion and continued Chinese limitations in that regard, the majority of the chapter focuses on that subject. A conclusion then reviews China's remaining challenges and prospects for overcoming them.

## Conventional Power

### Diesel/Gas Turbines

Foreign-derived turbines continue to power the majority of China's surface fleet. China has drawn in particular on engines from Germany's MTU, France's SEMT Pielstick, Finland's Wärtsilä, and various Ukrainian manufacturers. In some cases, China has developed its own versions of these engines.[1]

### Air-Independent Power

For submarines, the next best thing to nuclear power is an advanced variant of conventional power. One approach that advanced navies, including the PLAN's *Yuan*-class submarines with their Stirling engines, have adopted is air-independent power (AIP). Beginning in March 2015, a *Yuan* conducted a protracted Indian Ocean patrol that included the PLAN's first submarine call on Karachi, Pakistan, at the end of May.[2]

This method greatly extends the time a submarine can cruise at low speed without draining its battery and risking detection in recharging it by raising an air intake and an exhaust tube (for perhaps as long as two weeks). It also allows saving Main Storage Battery energy accumulated for relatively fast evasive maneuvers (for perhaps as long as two hours).[3] AIP's biggest advantage is that it provides tactical flexibility to the submarine commanding officer. He now has both more leeway to choose when he recharges his batteries and the ability to use higher speeds if the tactical situation warrants.

Air-independent power is not quite as big a game changer as some advocates claim, however. AIP systems use liquid oxygen as the oxidizer, necessitating large tanks and cumbersome, dangerous processes. AIP cannot be drawn down quickly. Nor does it add to the time a boat can operate at a "burst" speed; the rate at which it can convert stored energy to power is small. Even with AIP, a commanding officer still only has several hours at flank from the Main Storage Battery, and little additional coverage. In sum, an AIP submarine has far too little power or stored energy to resemble a "baby nuke."

### Advanced Batteries

For conventional submarine propulsion, lithium-ion (Li-ion) batteries (锂离子电池) appear to be the wave of the future. They have great power density and weigh much less than their lead acid predecessors, but they have a problem with thermal runaway that occasionally causes them to combust.

Chinese specialists are scrutinizing these developments carefully and seek to parlay China's substantial if still limited Li-ion battery industry into submarine applications. Four Chinese-language technical articles lay out a natural progression. Two 2011 articles survey foreign journals on Li-ion technology and discuss the possibilities of using Li-ion batteries in submarines in the future.[4] These articles are a stronger indicator of keen interest in using Li-ion batteries in conventional submarines than in concrete demonstration of actual progress in that regard.

Yet China appears to be working hard to make concrete progress even in this cutting-edge area. The third article (2013) discusses actual funding and the goal of putting the batteries on submarines soon. The author, from China Ship Design and Development Center (CSDDC) in Wuhan, predicts that during the next Five-Year Guideline, they "will carry out modeled land-based experiments and experiments installed on ships at sea. The new generation of non-nuclear powered submarines will be equipped with these new types of Li-ion batteries."[5] The last article (2014) shows steps being taken in that direction. These authors, also from CSDDC, claim to have developed a simulation testing platform that can evaluate the properties of three different array connection configurations for Li-ion battery modules as well as scanning for constant power discharge. If this platform works as claimed, it will allow analysis of various Li-ion battery array connections to determine which type is best suited to their boats.[6] These four articles thus suggest a logical progression: from hoping, to funding, to testing and analysis. The next step is installation in Chinese submarines, a process the authors hope to finish in the 2015–20 time frame.

## Nuclear Power

Nuclear power is the ultimate gold standard in submarine power. It is essential for long-term, long-range, high-performance operations. While conventional power or a small (~300 kilowatts) nuclear reactor may be adequate for slow, stealthy anti-access operations close to home waters, full-scale nuclear power is needed for high-speed, high-performance, long-range submerged operations. Demanding arctic or tropical environments only increase the disparity. For example, submarines must typically reduce speed in warm-water environments such as the Persian Gulf.

That said, deploying nuclear naval power requires overcoming major engineering challenges, developing comprehensive infrastructure, and training crews to operate sophisticated, sensitive, dangerous equipment. Nuclear-powered submarines require two fundamental characteristics: extremely high power density (for an advantageous power-to-volume ratio) and long core life for economic and operational efficiency. China entered this club long ago, but has yet to emerge in the top tier inhabited by the United States, Russia, France, and the United Kingdom.

Civilian nuclear industry is not an indicator of naval nuclear competence because the technologies and skill sets are so different. High-temperature gas-cooled reactors, for instance, while exhibiting significant promise for civil land applications and studied widely in China, cannot be taken to sea because they lack requisite energy density.

These factors represent the state of the art and pose key questions regarding China's pursuit of these standards, such as:

- To what extent is China transitioning from Soviet technology, and what countries or designs influence its current design choices?
- How would China develop or acquire such advanced designs? What foreign technologies is China drawing upon in its efforts to improve?
- Finally, given the lack of transparency on China's military technology development and nuclear propulsion, how can analysts answer these questions?

The authors surveyed Chinese views on relevant subjects to answer these questions and help elucidate the extent to which China is taking a Western versus a Russian approach regarding key naval reactor design aspects, and how realistic its approach is in practice.

## Current State of China's Nuclear Propulsion

The role of China's nuclear-powered navy is growing and will be critical for China's strategic missions and securing growing interests abroad. From December 13, 2013, to February 12, 2014, a *Shang*-class (Type 093) nuclear-powered attack submarine navigated near Sri Lanka and into the Persian Gulf, transiting the Strait of Malacca on the way to and from its homeport on Hainan Island.[7] For "more than two months," until returning to Qingdao on April 22, 2015, an updated *Han*-class (Type 091) supported antipiracy patrols in the Gulf of Aden, escorting two ships and a supply vessel.[8] This is the latest in China's incremental approach to increasing out of area operations, and demonstrates the importance of nuclear propulsion to a blue-water navy. Compared to conventional powered submarines, these nuclear attack submarines are more capable of operating farther from China, conducting intelligence, surveillance, and reconnaissance and antisurface warfare missions. According to the U.S. Office of Naval Intelligence (ONI), Type 094 *Jin*-class ballistic missile submarines (SSBNs) will soon assume a central role in Beijing's nuclear deterrent as they conduct China's first SSBN patrols with submarine-launched ballistic missiles.[9] The Pentagon forecasts the first deterrent patrol to occur by the end of 2016.[10]

## Current Priorities

China is prioritizing advanced designs and reactors for an improved variant of its 093 *Shang*-class attack submarine (SSN). Initial production halted after only two hulls were launched in 2002 and 2003;[11] they entered service in 2006 and 2007 after lengthy trials.[12] A Chinese news article circulating in online forums claims the 093 is comparable to later second-generation designs by the United States and Russia.[13] China launched in 2012 and 2013, and commissioned in 2015 and 2016, two hulls of a hydrodynamically improved variant, the 093A. Two more are expected by 2020, for a total of six *Shangs*, before China transitions to producing the Type 095 SSN.[14]

For the future Type 095, Chinese media coverage indicates new technologies needed.[15] An article lists a new pump jet propulsion system, high-strength steel, mixed single- and dual-hulled structure, new comprehensive shock absorption rafting system, possibly improved vertical launch tubes for cruise missiles, and a third-generation submarine reactor.[16] For the reactor, priorities include the reactor design, natural circulation, and the reactor's loops (there is no mention of prioritizing the primary or secondary loop).[17] It is important to treat this media coverage with caution, although numerous Chinese websites host it.[18]

## Russian Technology

Russia has been, and continues to be, a major source for Chinese naval nuclear power technology. Lacking access to much other foreign knowledge, China based its first- and second-generation submarines largely on early Soviet reactor designs. The 1960s and '70s first-generation design drew from nuclear reactors installed on the Soviet icebreaker *Lenin*, a decision based more on information availability and bureaucratic politics than technological merit, and it posed enormous challenges in noise levels and containment design.[19] Since the end of the Cold War, China has obtained significant Russian technology and even technicians for direct work.[20] Russian resource constraints likely exacerbated this trend. Chinese researchers with China Shipbuilding Industry Corporation's (CSIC's) 719 Research Institute (RI), a lead design institute for China's nuclear submarines, commented in 2008 that Russia's development of fourth-generation nuclear submarines had encountered financial difficulties and outflows of personnel, trends that hindered the submarines' development.[21]

Consequently, Russian conglomerates have been willing to sell China nearly all their products and some technologies, although it is unclear if nuclear reactors represent a bridge too far. In the submarine sphere specifically, the *Song*'s seven-bladed skewed screw suggests that China acquired and implemented technology associated with the twelve *Kilos* it purchased from Russia. China designed the Type 093 in conjunction with Russian experts.[22] Regarding nuclear reactor designs China may target, in 2009 professors at Harbin Institute of Technology stated that the natural circulation abilities of France's nuclear submarine equipment CAS-48 and K-15 integrated pressurized water reactor (PWR) could reach 80 percent natural circulation, while the ABV-6Y under research in Russia can realize 100 percent natural circulation.[23]

Aside from Russian technology, China also monitors U.S. designs. A senior engineer from the Navy 991 Engineering Office credits natural circulation reactors as a key factor in the quietness of U.S. submarines.[24] According to his analysis, the S5G reactor natural circulation PWR begun in 1959 was a key starting point. The S9G in the *Virginia*-class is both the most advanced and the model for the next generation of U.S. nuclear submarines. The next generation would turn the S9G into a transformational technology core (TTC). The first TTC design was started in 2004 and delivered in 2014. The analysis also states nuclear propulsion will be the basis of any future all-electric-propulsion U.S. submarines.

## Chinese Nuclear Reactor Development and Training

Chinese nuclear submarines must be supported by an effective research, development, and acquisition process that handles the "growing pains" for which Soviet submarines were notorious. An overall Chinese priority for nuclear submarine and propulsion design is better modularization. Modular designs facilitate more efficient construction and allow new technologies to be inserted into a submarine without an expensive redesign.[25] Beginning in 1990, China emphasized improvements not only for the submarines themselves, but also for mass production capabilities.[26] According to online accounts, during the tenth Five-Year Plan (2001–5), China began a new generation of submarine and nuclear propulsion development research and development, a focus of which was greater modularity.[27]

In 2014 Chinese media covered work by Liu Chunlin at CSIC's 719 RI on China's new generation of submarine nuclear propulsion.[28] Liu joined the institute in 1998 after graduating from Harbin Institute of Technology, and in 2005 he was made assistant designer in charge of an unnamed system, which many speculated involved the propulsion system for the 093 SSN and 094 SSBN. Liu's team focused on technologies relevant to the secondary loop of a reactor, including integrated secondary loop system technology, emergency cooling, and secondary side passive residual heat removal technology for steam generators. He also led teams on numerous priority projects for national defense, although specifics were not provided.

### Aircraft Carrier

In 2012 China commissioned its first aircraft carrier, *Liaoning*, which employs conventional propulsion. It is currently building its first indigenous carrier in Dalian. Many analysts believe China is also interested in additional aircraft carriers that use nuclear propulsion. In 2013 the Ministry of Science and Technology "formally launched Project 863 to research key technologies for nuclear-powered vessels" and "S&T [science and technology] support project for small-scale nuclear reactor technology and its demonstrated applications."[29] Key objectives for the plan include developing core technologies and safety studies for nuclear-powered ships and technical support for small nuclear reactors. One article notes, "Industry insiders [suggested the original CSIC announcement] signified China could be setting out to research a nuclear-powered aircraft carrier or similarly large aircraft."[30] An analyst pointed out that it made sense strategically for China to "work toward a nuclear-powered one after the technology was mature."[31]

## Bringing It All Together: Integrated Electric Propulsion?

One of China's fundamental challenges is that even as it seeks to close the gap with the state of the art, that frontier continues to advance. Integrated electric propulsion (IEP) is one major trend in naval power, though thus far only the U.S. *Zumwalt*-class destroyer has fully adopted it. China may seek to pursue this approach for future aircraft carriers, though it currently lacks IEP experience almost completely. China's scientific survey[32] and coast guard ships[33] are initial adopters of IEP.

## Conclusion

Power, including both propulsion and the powering of onboard systems, is of vital importance to any navy. It is an indicator of overall capability and blue-water progress. As such, it is a field in which China must make major achievements in order to realize the great power navy that it seeks.

The complexity and demanding performance parameters of naval propulsion make this a difficult field to master. Piecing together foreign and indigenous technologies of civil and military origin has served China relatively well in some other areas, but does not work so well here given the degree to which components must work together as a sophisticated system-of-systems. Some types of propulsion, particularly nuclear, are guarded zealously by leading foreign powers such as the United States and Russia. For these reasons, propulsion remains an area of enduring weakness across China's military, and the navy is no exception.

Yet Beijing is determined to succeed here, and it continues to progress. It has developed its own versions of foreign diesel and gas turbines. It has deployed AIP on its most advanced conventional submarines and is working to progress to next-generation Li-ion batteries. Of greatest significance for China's long-term naval capabilities and scope will be its mastery of naval nuclear power. Here China continues to suffer major weakness in performance and quieting. It still lacks experience with nuclear power for aircraft carriers, having only one hull in service with gas turbines. But China is making a broad-based effort to improve, and it should not be underestimated in the long run. In the nearer term, the degree of Russian assistance that China is able to obtain will be a key variable influencing its rate of progress.

## Notes

The authors thank CAPT Christopher P. Carlson, USNR (Ret.), CAPT James H. Patton Jr., USN (Ret.), and an anonymous reviewer for invaluable inputs.

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apparently foreign imports; China is just figuring out how to build them. Unlike any PLAN vessels to date, many also have azipods, fixed-pitch propellers mounted on steerable gondolas containing the propeller's drive motor. This gives them greater efficiency and far greater maneuverability than ships with standard shaft/propeller and rudder fits. See "Chinese Shipbuilders Develop Integrated Electric Propulsion Technology," *Next Big Future*, August 26, 2013, http://nextbigfuture.com/2013/08/chinese-shipbuilders-develop-integrated.html. Regarding CMS 83, see苏涛 郝冬 [Su Tao and Hao Dong], "中国海监装备建设系列报道之—船舶篇—卫海疆 '剑' 出鞘" ["Report in Series on the Construction of China Marine Surveillance Equipment—Part on Ships—The 'Sword' Guarding Territorial Seas Comes out of its Scabbard"], 中国海洋报 [China Ocean News], March 15, 2011, A5, http://epaper.oceanol.com/shtml/zghyb/20110315/29507.shtml. Regarding CCG 1306, a new three-thousand-ton cutter with IEP, see "中国最先进海警执法船入列: 原地调头可横走(图)" ["China's Most Advanced Coast Guard Law Enforcement Vessel is Commissioned: Can Move Laterally, Turn Around in Place (Photos)"], CCTV via凤凰网资讯 [Phoenix Network News], October 16, 2014, http://news.ifeng.com/a/20141016/42221643_0.shtml. Thanks to Ryan Martinson for these sources.