China space 2.0

China's latest space plans are moving ahead at full speed, with new space vehicles, launch facilities, and manufacturing sites already taking shape. Success, however, will require that these complex elements come together simultaneously and work as intended, a daunting challenge. But if assets such as a new family of heavy-lift boosters perform as promised, they will greatly increase China's future space capabilities. What this may imply about the country's long-term national goals is an unanswered question.

The next LEAP forward

The Chinese space program, after an impressive two-decade progression through modest, year-by-year improvements, now faces perhaps the most challenging 'great leap' in its history. If the effort succeeds, it will enable far more ambitious space activities in the coming decade and beyond.

Years-long construction, development, and testing are on the verge of simultaneously activating a new spacecraft and booster production facility, a new family of boosters, and a new, more capable launch site. The era of 'China space 2.0' is about to begin, and Western observers are both impressed by the undertaking and uncertain about its national goals.

A primary principle of technological intelligence analysis is that observed capabilities under development reflect national intentions and goals. But China's imminent new space capabilities are ambiguous in this regard. They offer so many options that there appear to be virtually no constraints on any combination of new space goals.

Engines

The 'jewel in the space crown' of these new capabilities is the Long March 5 (LM or CZ-5) booster, an intermediate-class rocket (think Saturn 1B, or Proton, or Ariane 5) with an initial flight rate of up to 10-12 per year, and downstream capability to more than double that.

For the past 20 years, most Chinese spacecraft have been launched on variations of the Long March 2, 3, and 4 boosters. These rockets are based on the hypergolic-fueled military ICBM Dong Feng 5, whose two YF-21 engines had a thrust per engine of 284 tons. This Long March family with its paired core engines (YF-21B) has placed up to 9.5 tons in LEO with strap-ons or, with upper stages, carried 3-5 tons to GEO transfer orbit.

The fairing for the LM-5 is being developed with an eye to the future.

by James Oberg
Contributing writer

Soon after 2000, in a decision apparently made in several stages, the government approved the development of two major new engines that reflect more ambitious goals. They are the YF-100, a new kerosene-LO_2 rocket engine rated at 120 tons thrust (twice the thrust of the previous strap-on stage engine), and YF-77, an LH_2/LO_2 core engine with a thrust of 50 tons.

A new family of smaller upper-stage engines, both hypergolic and cryogenic, was to be created as well.

As engine development proceeded, design work on the booster family that would use these engines proceeded in parallel. Three tank diameters were envisaged: a 2.35-m tank with a single YF-100 engine, a 3.35-m tank with two YF-100s, and a 5-m tank with two YF-77s.

The design of the biggest version, the LM 5, specifies a length of 60 m, with four engines. For LEO missions, the central 5-m core is assisted early on by four 3.35-m liquid strap-ons, and goes all the way into orbit. The payload weight would increase two-and-a-half to three times over that of current boosters—up to 25 tons in LEO.

The LM 7 variant, which is looking more and more likely to be the first of the new family to actually fly, will use a 3.35-m core with 2.35-m strap-ons plus an upper stage. It is also considered likely to become the replacement for most LM 2 variants over the next 10 years.

Breakthroughs in logistics and design

The new booster family was not the only needed breakthrough. Up until then, Chinese spacelift was constrained by limited thrust, but also by a very down-to-Earth practical limitation: the logistics of transporting booster components from their factory to launch sites that were all far inland. Although stretched central cores and added strap-ons allowed incremental enhancement of performance, a design ceiling had been reached, literally: Rockets bigger than about 3.35 m in diameter and 14 m long did not fit through the railroad tunnels.

To break this impasse, space planners began an across-the-board infrastructure upgrade. This involved construction of entirely new booster and spacecraft fabrication and test facilities with seagoing ship access, along with a coastal launch site at the other end of the water route. For range safety as well as launch dynamics considerations, the site chosen was on Hainan Island, near 19 deg N.

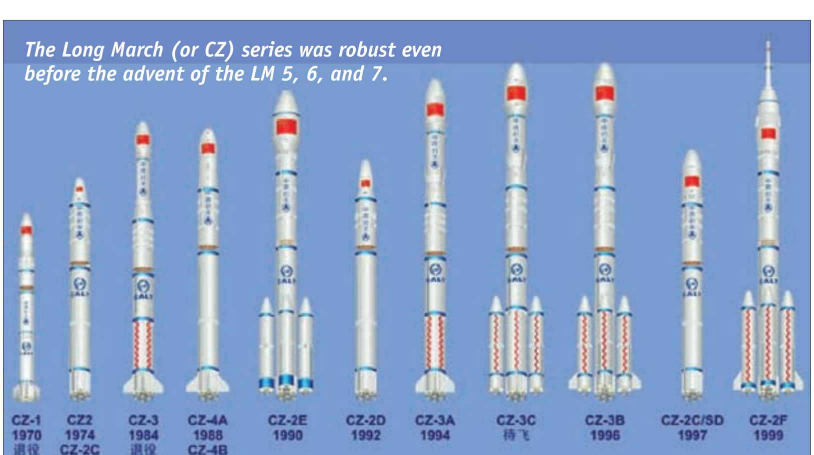
As noted in a 'space white paper' in late 2011, the new booster family was designated Long March 5, 6, and 7. The papers, released by Beijing at five-to-six-year intervals, have proved to be reliable indicators of broad national space goals, although they are not complete (no military applications are mentioned). First flights were planned for late 2014, a date that has now begun slipping.

One indicator of the care that developers were taking in these fundamentally new design efforts was a February 20, 2012, article on digital prototyping of the booster. According to the article, published on the China Aerospace Science and Technology (CASC) website, this is the first time in the history of Chinese rockets that an entire rocket model has been digitally engineered. The most difficult aspect of the effort was that in the absence of past experience, all-new computing methods and design concepts were needed.

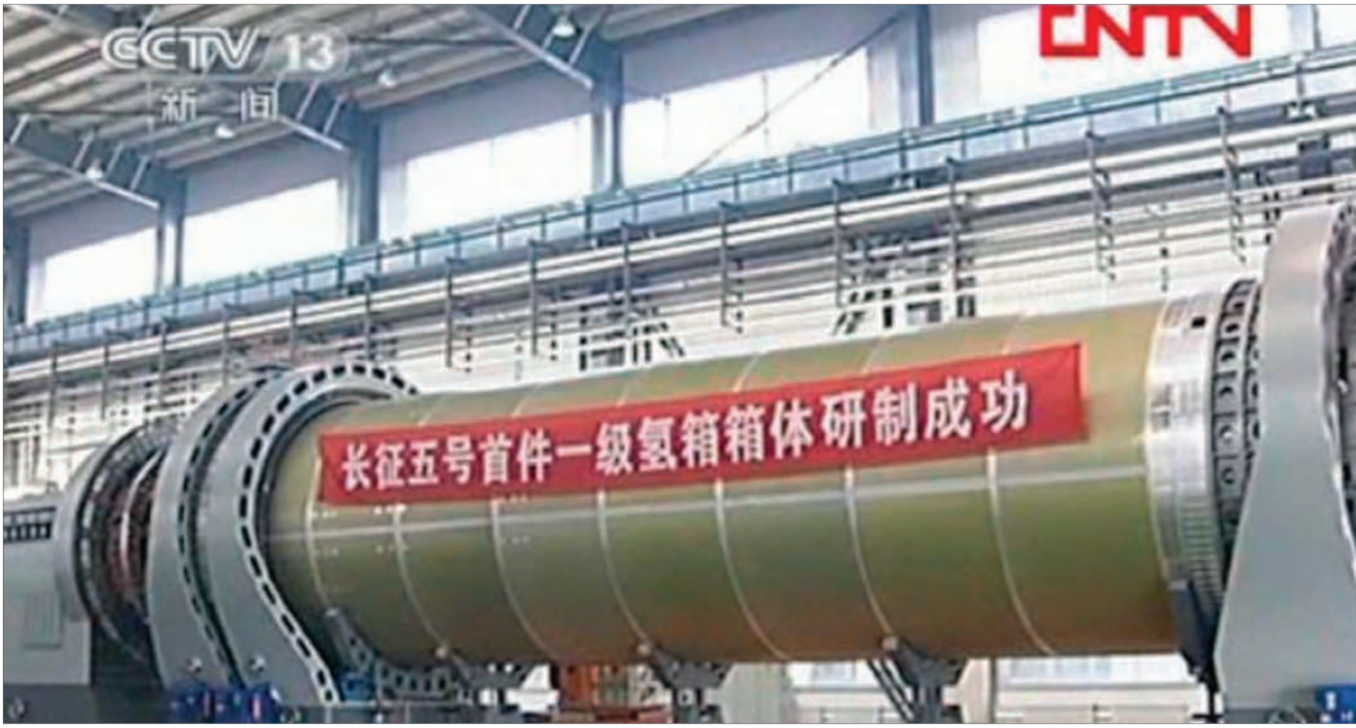
Unlike its predecessors, the LM 5 program uses 3D design methods. Tests are now conducted through simulation software, which increases reliability and saves great amounts of manpower, material, and money. The CASC article explained that digital model testing is done prior to testing on a physical model. Then, after the digital and physical models are compared for any differing results, the digital model's parameters are further refined.

The first production YF-100 engines had completed acceptance testing by June 14, 2012. In a statement released by the Xinhua News Agency, the State Administration of Science, Technology and Industry for National Defence reported:

"The 120-tonne liquid oxygen/kerosene high-pressure staged combustion cycle engine will provide an effective guarantee



The Long March (or CZ) series was robust even before the advent of the LM 5, 6, and 7.



The LM-5 first stage hydrogen tank is part of a breakthrough in Chinese rocket design.

for the country's manned space and lunar probe missions. This high-performance engine is nontoxic, pollution-free and reliable.

"It is the first kind of high-pressure staged combustion cycle engine for which China has proprietary intellectual property rights," the statement continued. "It also makes China the second country in the world, after Russia, to grasp the core technologies for a liquid oxygen/kerosene high-pressure staged combustion cycle rocket engine."

Lai Daichu, the test commander, told newsmen that the tests were designed to see how the engine would respond to rotational speeds of nearly 20,000 rpm and temperatures of 3,000 C for 200 sec. "The successful tests confirm the reliability of China's LOX/kerosene engine," he said.

A few weeks later, Luan Xiting, identified as deputy director of the Academy of Aerospace Propulsion Technology under CASC, elaborated on the testing process: "Adequate tests are essential to expose its weaknesses and discover its problems, so we can come up with right solutions," he told a Beijing television station. "For some 60 engines, we have tested over 120 times and trial-run more than 30,000 seconds." He added that over the 12-year development period, China developed more than 50 new materials and achieved more than 80 key technology breakthroughs.

"The building of a space station requires carrier rockets with greater thrust, as each capsule of the station will weigh about 20 tonnes," Jing Muchun, chief engineer for the carrier rocket system of China's manned space program, told Xinhua on September 29, 2011."We have been preparing for the launch of the space station, slated for 2020." Jing's deputy, Song Zhengyu, told Xinhua that the new generation of carrier rockets, using digital flight control systems and nontoxic, nonpolluting propellants, would take about seven years (2014-2021) to phase in. During that period existing Long March 2, 3, and 4 series would be replaced sequentially.

While LM 5 was the heavy lifter, the smaller LM 6 and LM 7 would have special missions. LM 6 is to be a new type of quick-response launch vehicle, capable of placing not less than 1 tonne of payload into a Sun-synchronous orbit at a height of 700 km. The LM 7 will be able to place 13.5 tonnes in low-inclination LEO (it is expected to be human rated for Shenzhou spacecraft), and 5.5 tonnes of payload into a Sun-synchronous orbit at a height of 700 km, according to the white paper.

Hu Haifeng, a designer at CASC, told Xinhua that Long March 5 will help China return to the forefront of launch vehicle technology. China's vehicles have "a fairly good record for reliability," he was quoted as saying. "However, they lag behind other leading countries' vehicles in terms of payload and thrust capability because they were built based on early 1990s plans. Now we need vehicles with a greater capability to send more payloads into space.

"The U.S. and Russia are also developing launch vehicles with the highest impetus capability in the world, and it is still unknown which country will be the first to succeed," Hu added.

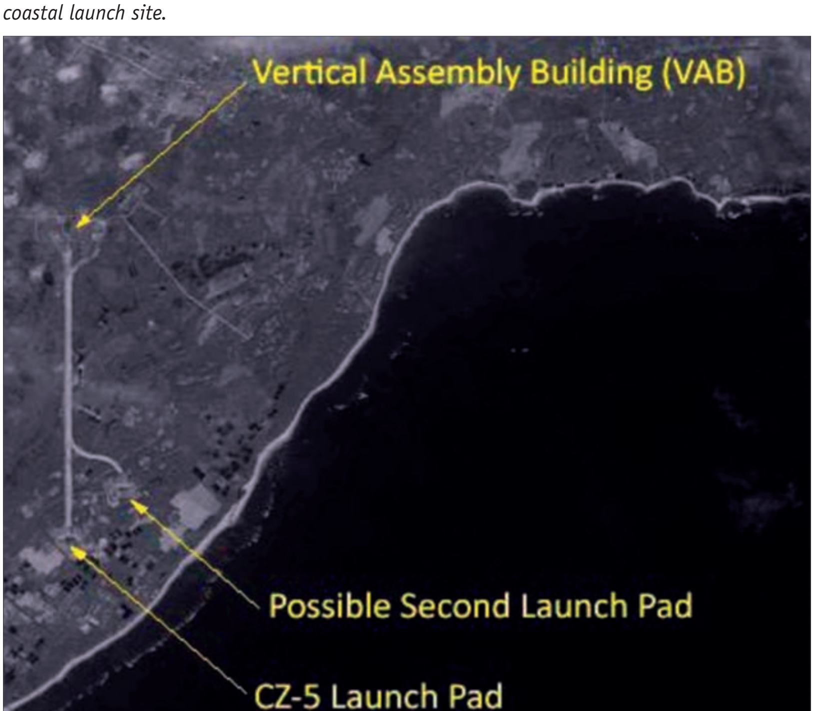
Daunting challenges

Hu's candor was refreshing, because the technological challenges are widely considered the most significant since the beginning of Chinese spaceflight in the 1970s.

Morris Jones, a noted Australian observer of China's space activities, told *Aerospace America* by email, "Previous Long March rockets have been augmented with boosters and improved upper stages, but this is the first time that a system has been modular from its conception. China is also introducing more powerful engines with cryogenic propellants. New engines are usually the greatest technical challenge in a new rocket."

Jones added, "Although the various stages and boosters are designed to work together, a system is more than the sum of its parts. It's possible that some mechanical, vibrational, or thermal issues will only make themselves visible when certain combinations are actually flown."

A satellite photo shows the advantages of a southern coastal launch site.



Chen Lan, a Chinese citizen who runs a respected independent commentary electronic magazine and a website on Chinese space activities (http://www.go-taikonauts.com), agrees:

"It's undoubtedly a big leap," he told *Aerospace America* by email. "Long March 5 has a lot of breakthroughs: new design philosophy, new engines, including the staged combustion kerosene/LOX engine, new materials and FSW [friction stir welding], new control system including use of the fiber channel bus, as well as all-digital design. In short, it's a brand new rocket, and much more advanced than the previous launchers.

"There are indeed challenges," he said. "For example, the YF-100 engine. It took China nearly 20 years to learn [from the purchased RD-120], develop, and mature it. Both the YF-100 and the YF-77 engines met serious problems. Slow engine development is one of reasons of the many-year delay of the project approval." But he expressed confidence: "Up to today, it seems that all critical issues have been solved."

Launch site

Chinese officials have been talking about the advantages of a southern coastal launch site since 1999. A small sounding rocket base had been established in southeastern Hainan Island in the 1980s, and with the decision to proceed with the LM 5, development of the site was approved. A formal groundbreaking ceremony for the Wenchang Satellite Launch Center took place on September 14, 2009, about a year after construction began.

Managing the project is the administration of the Xichang launch site in Sichuan. Previously the southernmost inland site, it specialized in GEO missions. Initially it was expected that this site would include pads for the current Chinese launcher families. But in January, comments by Fan Yimin from the Engineering Construction Command Dept. cast doubt on this. "As China's fourth space launch site, [Hainan] will not duplicate the existing space launch sites," he told a newspaper, "but make a breakthrough in many key technologies." Xichang and the other sites, using older rockets, are to stay in operation through 2020.

Compared with current launch facilities, Hainan has unique advantages, Fan continued. Its low latitude (19 deg N) gives a 7% performance boost over Xichang. The new site will have a high launch capability and allows the transport of rockets with diameters of 5 m without using railways and tunnels. The rocket overflight area and debris impact area will be very safe, posing no threat to ground personnel or buildings. The launch site also will be open to the public and serve as a space education base.

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The Xichang official's interest in safety for people on the ground may have grown out of personal experience. As detailed in *Air & Space* magazine (http://www.airspacemag.com/history-of-flight/Disaster-at-Xichang-187496561.html?c= y&page=1), a long-rumored launch disaster at Xichang 20 years ago killed more than 100 people when the GEO-bound foreign communications satellite's booster swerved suddenly on liftoff and crashed into a nearby village.

The most bizarre aspect of the new launch site is the construction of a 1,000-acre theme park next door. Supposedly, the park will employ many of the 6,000 inhabitants evicted from the launch zone. In addition to space-themed roller coasters, it will offer tram rides past the actual launch pads, between launch campaigns.

Satellite imagery of the launch base was difficult to come by for several years, but the location has now been spotted, reportedly at 19.668 N 111.013 E. The first overhead view was published in Chen Lan's magazine, and other commercial imaging services have produced usable views. But port facilities for receiving booster and spacecraft components remain undefined. Some sources believe docks were being built at the launch site (imagery is unclear), while others report that existing facilities at the West Qinglan Seaport will be used, followed by overland road transport.

To transport the large booster segments and payloads (and probably large prefabricated launch hardware) two seagoing cargo ships were built at Shanghai Jiangnan Shipyard on Changxing Island. Yuanwang 21 was launched on November 29, 2012, and an identical Yuanwang 22 on January 24 of this year. According to commemorative first-day covers, the ships are 130 m long with displacement of 9,080 tons.

Tianjin industrial facility

With a new coastal launch facility for larger boosters and spacecraft, China also needed a new coastal site for fabricating them. Through a selection process that has never been described, officials settled on the city of Tianjin (http://www.tj.gov.cn/english/), more familiar to Westerners under its old spelling of Tientsin. It is China's fourth-largest city, and the main port for Beijing, on the Yellow Sea.

Construction of the complex was announced in 2007, but little news—and none on the actual location—came out subsequently. Even without official information, overhead satellite views are now available.

Then, in April 2011, inauguration of the 'China Space Environment Reliability Tianjin Experiment and Test Center' was announced. Tao Gang, general manager of Tianjin Aerospace Long March Rocket Manufacturing, revealed that the fabrication center's first-phase construction was "initially completed," and that production of key components for the booster had reached industrialized production capability. The general assembly workshop was also supposed to come into use during the first half of 2011.

Cargo ships were built at Shanghai Jiangnan Shipyard on Changxing Island to transport booster segments and payloads to Hainan Island.

A static load test facility was one of the structures built for the Tianjin test center.

Ma Xingrui, general manager of CASC, which designs and manufactures the Long March rocket series and Shenzhou manned spacecraft, described the facility to Xinhua in September 2011. Called the Tianjin Aerospace Industry Base, it covers an area of 313.33 hectares and cost over 6 billion yuan ($938 million), according to CASC. It includes a 220,000-m^2 assembly building for the launch vehicles, space stations, and "special equipment" (presumably other large satellites).

The facility, says Ma, is designed to meet China's growing demand for space technology R&D over the next 30-50 years. Integrating the fabrication steps will enable the base to produce an entire spectrum of rockets of different sizes and types for the nation's Moon probe project, space station, and other efforts. Along with support for design, production, assembly, and testing of new rockets, it provides high-end services such as aerospace software.

Phase One of the construction plan was completed in February 2012. The facility had been equipped with all the operational capabilities for the processing of modules, for general assembly, and for testing of high-thrust vehicles. By March 2012, Liang Xiaohong, deputy head of the China Academy of Launch Vehicle Technology, was able to announce that development of the first hydrogen tank for the LM 5 had been completed. He added that production of the rocket's key parts—the 5-m-diam. fairing structure and other major fuel tanks—would be completed by the end of 2012.

Then in January of this year, the second major facility was described, four months after its televised cornerstone-laying ceremony. This 100,000-m^2 payload fabrication center is to have the capacity to deliver six to eight oversized payloads a year. According to an official announcement, these will include space station sections, large communications satellites, large remote sensing satellites, large unfolding precision structures, and other unspecified objects.

Construction was due to be completed in August. A year later, after outfitting of the interior, spacecraft fabrication will begin.

Early press descriptions of Long March 5 missions appear to be a wish list of all possible space projects. Jiang Jie, Long March 3A chief engineer, told *China News Service* in March 2012: "The new generation will feature heightened capacity, high reliability, robust adaptability, and clean energy use, shouldering the launches of near-Earth orbit satellites, geostationary transfer orbit satellites, satellites in Sun-synchronous orbit, space stations, and lunar probes."

Other press reports mentioned large Earth observation satellites, which some Western experts interpret as military reconnaissance craft. The main payload will be modules for the Mir-class manned space station planned for after 2020.

The LM-5 could theoretically support human missions beyond LEO, and with multiple launches would enable a Shenzhou/Tiangong-class months-long expedition to and beyond cislunar space. One NASA study recently portrayed a human lunar landing mission based on a large number of separately launched payloads. No Chinese media discussion of such options has been detected, but the significance of that absence is obscure.

All of these dreams depend on a critically large array of first-ever engineering breakthroughs, to be orchestrated in unison. Even if the LM 7 is the first (and easier) new family member to fly, the challenge of getting the LM 5 into service remains the greatest space leap China has ever attempted. The Chinese are reaching for an impressive new level of spaceflight capabilities. More delays (now reportedly into 'early 2015' for the LM 5), and even major flight anomalies, would not be surprising. Nor would they be a reason to question the ultimate success of these ambitious efforts.