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Chapter 12

The Development History of Chinese Launch Vehicles*

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Abstract

China's development of launch vehicles has been driven by both a need to enhance national capacity to ensure access to space, and by the requirements of specific launch missions In doing so, it has followed a path of "self-reliance and independent innovation." Over more than four decades, China's launch vehicle development progressed from research tests to flight application to industrialization. During this time, China successfully developed more than ten models of launch vehicles. Such development has promoted the development of satellites, satellite application technology, and manned space technology. It has strongly supported the successful implementation of major projects in China, with the "manned space project" and "lunar exploration project" as leading examples. This chapter primarily surveys the development history of China's launch vehicles. It also outlines the launch vehicles currently in service, profiles the new generation of launch vehicles under development, and describes the efforts made by China in the field of space exploration.

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Introduction

This chapter focuses on tracing the development history of China's Long March launch vehicles. The past, present and future goals for Chinese launch vehicles are: ensuring that access to space is safe, reliable, rapid, economic and nonpolluting, further developing space exploration technology, and promoting the process of human civilization.

Development Background of Chinese Launch Vehicles

China was first to introduce launch vehicles to the world. In the 11th century, specialists during the Song Dynasty invented the black powder rocket, which spread to Arabia and Western countries in the 13th century.

The development of modern Chinese launch vehicles began in the mid-1960s. After initial exploration and concerted efforts, the LM-1, -2, -3, and -4 series were successfully manufactured. China is now developing a new generation launch vehicle. The LM family consists of more than ten types of launch vehicles. After 40 years of development, Chinese aerospace technology has yielded remarkable achievements. Chinese Long March series launch vehicles have achieved several technical innovations, including progressing from using conventional propellants to cryogenic propellants, from upper stage single-ignition to multiple-ignition capability, from series to parallel structure, from cargo transportation to manned spaceflight. Today, China has the ability to launch different types of satellites and manned spacecraft into low, medium and high Earth orbits. It can launch 12-ton payloads into low earth orbit (LEO), 6 tons into sun-synchronous orbit (SSO), 5.5 tons into geosynchronous transfer orbit (GTO). It is a world leader in orbit injection accuracy, which can meet the needs of different users. Additionally, the existing Long March Launch Vehicle has the ability to launch spacecraft into lunar orbit and beyond.

In April 1970, the LM-1 launch vehicle was successfully launched and sent Dongfanghong-1 into LEO. This made China the fifth country to use an indigenous launch vehicle to launch its own satellite successfully.

In 1999, the LM-2F launch vehicle launched the Shenzhou spacecraft successfully, which established the foundation for China's manned spaceflight. The successful launch made China become the third country in the world to launch a manned spacecraft independently and consolidated the international status of China's aerospace industry. In October 2003, China completed its first manned spaceflight mission successfully. In June 2012, China completed its first manned spacecraft orbital rendezvous mission successfully.

In October 2007, a LM-3A rocket successfully launched China's first lunar probe, Chang'e 1, into a pre-selected orbit. This represented a new area of achievement for China's aerospace industry step and realized an age-old Chinese dream—flying to the Moon.

Launch vehicles have enabled Chinese aerospace development to realize three of its major milestones: launching a manmade earth satellite, a manned spacecraft, and a lunar probe.

Development History of Chinese Launch Vehicles

In considering the development of Chinese launch vehicles, analyzing the standard of overall performance, product performance, reliability and security, environmental suitability, usability and maintainability, and affordability, Chinese launch vehicles can be divided into four generations:

China's first generation launch vehicles are the LM-1 and -2. As China had no prior launch vehicles, its first-generation launch vehicles were derived from ballistic missiles.

The second generation of launch vehicles includes the LM-2C series, LM-2D, LM-2E, and LM-3. This generation of launch vehicles was developed to meet specific engineering requirements.

The third generation of launch vehicles include the LM-2F, LM-3A series, and LM-4B series. The principal launch vehicles currently in service are from this generation.

China's fourth generation of launch vehicles includes the LM-5 and -6. This generation of launch vehicles is intended to greatly enhance the comprehensive technology level and ability of China's aerospace industry. Still in the development and demonstration stage, his generation of vehicles will utilize new non-toxic, non-polluting propellant.

The First Generation of Launch Vehicles

Long March-1 (CZ-1)

CZ -1 was the first modern Chinese launch vehicle. It consists of three stages, with a liquid propellant booster as the first and second stage, and a solid propellant rocket as the third stage. Its diameter is 2.25 meters and it has an overall length of 29.45 meters, a takeoff weight of 81.6 tons and a liftoff thrust of 1100 kN. Given these parameters, it is able to launch a payload of 300 kilograms into a 440-kilometer circular orbit.

On 24 April 1970, the LM-1 launch vehicle was successfully launched and sent China's first manmade satellite into the orbit. In 1971, LM-1 sent the scientific experimental satellite SJ-1 into the orbit. Chinese launch vehicles subsequently entered the international space activity arena.

Long March-2 (CZ-2)

The LM-2 is a basic type of Chinese launch vehicle, whose development began in 1970. The CZ-2C variant is a two-stage liquid launch vehicle 3.35 meters in diameter. It has an overall length of 31.17 meters, a takeoff weight of 192 tons and a liftoff thrust of 2786 kN, with a launch capability of 1.8 tons (200~470 km circular orbit).

On 5 December 1974, LM-2's first launch of China's first recoverable satellite (FSW) failed due to the fracture of a conductor in the launch vehicle control system. In 1975 LM-2 successfully launched the second and the third FSW satellites. It was retired in 1979.

The Second Generation of Launch Vehicles

LM-2C Series

LM-2C is a two-stage liquid-fueled launch vehicle. Based on LM-2, LM-2C it used a modified second-stage motor. A propellant regulating function and some additional hardware were added. This variant has a diameter of 3.35 meters, a length of 43 meters, a takeoff weight of 242 tons and takeoff thrust of 2926 kN. This launch vehicle is mainly used to send payloads into SSO. The launch capability of LM-2C is 1.6 tons for 600 km SSO, and it has dual-satellite parallel launching and upper stage multiple-ignition capability. LM-2C's first flight occurred on 26 December 1975.

Mainly developed for launching Iridium satellites, LM-2C/FP is mainly used for launching LEO and MEO satellites. It can launch 1.9 tons into SSO. It recorded its first flight on 1 September 1997.

Launched successfully in December 2003, LM-2C/SM consists of a two-stage LM-2C and a solid spin stabilization upper stage. LM-2C/SMA consists of the two-stage LM-2C and a solid three-axis stabilization upper stage. It was launched successfully in September 2008.

In September 1987, LM-2C lofted the micro-gravity apparatus for Matra Datavision successfully, thereby initiating the era of international cooperation for Chinese aerospace.

LM-4A and LM-2D

Based on LM-2C, LM-4A was given a more powerful first-stage motor and a conventional third stage. The diameter of the first and second stage is 3.35 meters, and that of the third stage is 2.9 meters, while the fairing is 2.9 meters in diameter. LM-4A has an overall length of 42 meters, a takeoff weight of 241 tons and a liftoff thrust of 2962 kN. This type of launch vehicle is used for launching earth observation satellites; the launch capability is 1.5 tons for a 900-km SSO orbit. In September 1988, LM-4A conducted its first launch successfully.

LM-2D is a two-stage liquid launch vehicle, which was built based on LM-4A but without the third stage. It has a diameter of 3.35 meters with a 3.35-meter diameter fairing. It has an overall length of 41 meters, a takeoff weight of 250 tons and a liftoff thrust of 2962 kN. This type of launch vehicle is used for launch the satellites into SSO; the launch capability is 1.35 tons for a 600 km SSO. LM-2D was first launched successfully in August 1992.

LM-2E

LM-2E is the first Chinese-developed strap-on launch vehicle. Four liquid propellant boosters are attached to an extended LM-2C launch vehicle. The core stage measures 3.35 meters in diameter, the booster 2.25 meters. It has an overall length of 49.7 meters, a takeoff weight of 460 tons and a liftoff thrust of 5923 kN, with a 4.2-meter diameter fairing. This type of launch vehicle is used for launching LEO satellites. After adding a liquid propellant booster upper stage, it could be used for launching satellites into MEO and HEO. The launch capability is 9.2 tons for a 28.5° 600-km circular orbit. With the addition of a liquid propellant booster upper stage, the GTO capability is 3.5 tons. First launched successful in July 1990, LM-2E has since been retired.

LM-3

Based on LM-2C, LM-3 is a new type of launch vehicle that utilizes liquid hydrogen/liquid oxygen propellant in its third stage. It is a multipurpose heavy lift launch vehicle mainly used for launching GTO satellites, with a payload of up to 1.6 tons. It has an overall length of 45 meters. The first and the second stages measure 3.35 meters in diameter, the third stage 2.25 meters. LM-3 is the first Chinese-developed launch vehicle to use liquid hydrogen/liquid oxygen propellant, achieves multiple-ignition, and send payloads into GTO. Its successful launch represents a milestone in the development history of Chinese launch vehicles and shows that China has reached a world-class level in launch vehicle technology.

The Third Generation of Launch Vehicles

LM-2F

LM-2F is a high-reliability launch vehicle designed for China's manned spaceflight program. Developed from LM-2E, LM-2F incorporates redundancy technology in its control and utilization system, improved engine design and testing reliability, an escape system, and a malfunction detection system.

LM-2F has variants for launching both manned spacecraft and target spacecraft. With a diameter of 3.35 meters and total length of 58.3 meters, the variant for launching manned spacecraft consists of four liquid boosters, first and second stages, a fairing, and an escape tower. First launched in 1999, LM-2F can launch a 8.1-ton payload into LEO.

On 15 October 2003, LM-2F successfully carried Chinese astronaut Yang Liwei into space, making China become the third country to achieve manned spaceflight independently, and marking the operationalization of China's manned spaceflight project for practical use. As of July 2013, LM-2F had completed 11 successful launches, including five unmanned spacecraft, five manned spacecraft, and one target spacecraft.

LM-3A Family

The LM-3A family of launch vehicles consists of three versions, LM-3A, LM-3B, and LM-3C.

LM-3A incorporated the mature technologies of the LM-3 and a redesigned cryogenic third stage. It also draws on four key breakthrough technologies: four-axis inertial platform-computer guidance, a YF-75 LOX/LH2 liquid engine, a cryogenic helium-pressurized propellant tank, and cryogenic hydrogen as primary energy sources for a servo actuator with a double pendulum. It also adopted other advanced technologies, such as a digital miniaturized control system and a cryogenic propellant utilization system. LM-3A has a total length of 52 meters. The first and the second stages are 3.35 meters in diameter, while the third is 3 meters. LM-3's launch capability for GTO missions is 2.6 tons. It conducted its maiden flight successfully in February 1994.

LM-3B is a three stage liquid launch vehicle, based on LM-3A as its core stage with four liquid strap-on boosters. It is 54 meters in length, while the booster's diameter is 3 meters. At present, LM-3B has three versions. The standard GTO capacity is from 5.1 tons to 5.6 tons, making it China's most powerful launch vehicle to date. First flown in 1996, LM-3B is dedicated for international commercial launch service. In the coming years, LM-3B will support the second stage of China's lunar probe program, completing the launch of the Chang'e-3 and -4 lunar probes.

LM-3C utilizes LM-3A as its core stage with two strap-on boosters on the first stage. It is 54.84 meters in length, with a 3.35-meter diameter booster. LM-3C's first and the second stage have a diameter of 3.35 meters, the third stage 3 meters. It has a standard GTO capacity of up to 3.8 tons. LM-3C made its first launch in April 2008.

LM-4B Family

The LM-4B family is composed of two versions, LM-4B and -4C.

LM-4B is derived from LM-4A. The major improvements it contains include: a newly designed rotary separation fairing in its major diameter; and, for the second stage, both a high-specific-impulse engine and a residual propellant venting system. Its first and the second stages measure 3.35 meters in diameter, the third stage 2.9 meters. LM-4B has an overall length of 48 meters, and a 2.9-meter diameter fairing. With a takeoff weight of 249 tons and a liftoff thrust of 2962 kN, LM-4B can send different types of satellites into a variety of orbits (SSO, LEO, GTO). For a 600-km SSO orbit, its payload capacity is 2.65 tons. It made its maiden flight in May 1999.

LM-4C was developed from LM-4B. Its principal improvement is a restartable third-stage engine. Mainly used to conduct SSO missions, it can send a payload of 3.1 tons into a 600-km SSO orbit. LM-4C first flew in April 2006.

The Fourth Generation of Launch Vehicles

China is working hard to develop its space transportation system, to improve the capability and diversity of its launch vehicles, and to strengthen its ability to explore space. It is developing next-generation upper stages and launch vehicles, such as LM-5, -6 and -7. LM-5 uses nontoxic, non-polluting propellants. LM-5's payload capability is 25 tons for LEO and 14 tons for GTO. LM-6 is a new fast-response launch vehicle. It will be capable of placing a payload of at least 1 ton into a 700-km SSO orbit.

LM-5

LM-5 is a family of heavy-lift space launch vehicle systems. Measuring 57 meters in length, LM-5 utilizes four 3.35-meter diameter strap-on boosters. Its development follows the roadmap of "One-Family, Two Engines, Three Modules." "Three Modules" refers to its use of a 5-meter diameter module with LOX/LH2 propellant, a 3.35-meter diameter module with LOX/Kerosene propellant, and a 2.25-meter diameter module. "Two Engines" refers to two types of newly designed engines: 50-ton engines using LOX/LH2 propellant, and 120-ton engines that burn LOX/RP-1 propellant. Following the design principal of generalization, serialization, and modularization, based on the three newly designed modules, LM-5 has six variants of heavy-lift launch vehicles with a core vehicle whose first and second stages measure 5m in diameter. The launch vehicle is capable of delivering a 6–14-ton payload to GTO, or a 10–25-ton payload to LEO. The LM-5 variant performing the maiden flight for the family had four 3.35-meter diameter strap-on boosters.

Adopting new engines, new heavy-lift launch vehicle technology, and advanced control systems and digital technology, LM-5 has significantly improved the overall level of China's launch vehicles and its capability to explore and utilize space resources.

LM-6

As a member of the new-generation small-lift liquid launch vehicle family, Long March 6 is designed to be a light-weight-payload, "high-speed response" rocket. CZ-6 is shipped to a simple launch site (one lacking a fixed tower) by transporter-erector-launcher to complete erecting, fueling and launching integrally. It has an overall length of 29.9 meters, a takeoff weight of 102 tons and a liftoff thrust of 1200 kN, a diameter of 3.35 meters. This three-stage launch vehicle uses non-toxic, non-polluting propellants such as liquid oxygen and kerosene. Under "the limitation of observe and control," it is capable of placing a payload of roughly 500 kg into a 700-km SSO. While without the limitation, it can deliver a payload of roughly 1,000 kg into a 700-km SSO.

LM-7

LM-7 is the medium-lift variant in China's new-generation launch vehicle family. Using a 3.35-meter diameter module as its core vehicle, LM-7 has an overall length of 53.1 meters, a takeoff weight of 595 tons, and a liftoff thrust of 735 tons. Four 2.25-meter diameter strap-on boosters may be attached to the vehicle. It will be capable of delivering a 13.5-ton payload to a 400 x 200 km LEO inclined at 42°.

The Launch Plans of the Long March Launch Vehicle

By the end of 2012, China's Long March family launch vehicle had conducted a total of 174 missions, launching more than 203 spacecraft into orbit with a 95.4 percent success rate. It took China launch vehicle 28 years to complete the first 50 launches, but only another 12 years for the subsequent 124 launches. During the latter period, the workhorse CZ-3A vehicle completed its 50th launch. All these statistics and benchmarks have demonstrated the reliability of Chinese launch vehicles, while documenting the industrialization of China's launch vehicle industry.

Since the Chinese government announced that Long March-series launch vehicles were granted access to the commercial launch market in 1985, and several foreign satellites were soon placed into orbit successfully, China has played an important role in the commercial launch market. By 31 December 2012, Long March vehicles had logged 37 international commercial launches and seven carrying services, sent 43 international commercial satellites into space and completed the domestic satellites in-orbit delivery four times. Chinese aerospace is achieving a good reputation as a high-class brand. In the future, China will expand communication with international customers concerning such areas as product development, system construction, satellite applications, resource sharing, personal exchanges, manned space flight, in order to achieve the goal of benefiting mankind by using space technology.

Chinese launch vehicle will maintain a rapid launch rate. Twelfth Five-Year Guideline (2011–2015), China plans to complete 100 launch missions, at a rate of 20 each year.

Development Characteristics of Long March-Series Launch Vehicles

Integral to China's Overall Development Strategy

Outer space is the common heritage of humankind, exploration therein its perpetual pursuit. Currently, international space activities are flourishing, with the main spacefaring nations implementing or adjusting their space development strategy, objectives, and programs, and space activities propelling social and civilization advancement. Within this larger context, the role of China's space industry is becoming increasingly prominent in its overall development strategy.

China has long taken space industry development as an important part of the nation's overall development strategy. It always adheres the principle of exploring space and using its space industry solely for peaceful purposes. In recent years, space activities have played a more important role to China's economic and social development than ever before. The development of China's aerospace industry has allowed it to lead the world in some fields of technology.

In the future, China's space industry will closely reflect and support overall national strategic goals, strengthen the independent innovation ability, and finally approach or achieve an international advanced level comprehensively. Meanwhile, China remains willing to jointly maintain the peace, freedom, and environmental conditions of outer space, and to promote peace and development for all mankind.

Insisting on Technology Innovation and Breakthroughs

The development of the Long March series of launch vehicle has always followed the principle of technological innovation. In doing so, the LM-series has at last approached or achieved international advanced levels, particularly in the following respects: (1) both tandem construction and parallel construction are used, (2) both solid and liquid rockets have been developed, (3) both liquid propellant and cryogenic propellants are used, (4) rocket motors have both single-ignition and multiple-ignition capability, (5) both single- and multiple-launch missions can be executed, and (6) LM-series vehicles have world-class orbit injection accuracy, payload factors, launching capacity and adaptability.

Starting from the beginning and gradually improving from there, Long March launcher development has always been informed by the goals of independent innovation and keeping up with international advanced levels. Development has proceeded in accordance with Chinese characteristics, including an emphasis on using domestic raw materials and components. In developing the escape and failure detection system, for example, without any prior experience for reference, Chinese designers worked through problems and ran over 10,000 programs and massive calculations on a capacity-limited computer. More than 300 failure models were considered and several hundred simulation experiments were conducted. This enabled the determination of reasonable criteria the development of systems that reached international advanced levels.

Quality Control Is the Key

Adhering to the following principles has been essential to the successful development of China's Long March launcher series: (1) Putting a "zero defect" approach into practice, "doing things right at the first time," and taking risk reduction as the goal of quality control. (2) Always employ risk management in practical work by factoring in technical risk, design risk, product quality risk, and work risk. (3) Carry out comprehensive model technical risk analysis and overall-process and total element quantized control [quantization involves reducing a continuous set of values to a relatively small discrete subset.] (4) Conduct design goal margin quantization and design margin and process margin verification. (5) Execute a top-down quantitative process, including interface and requirements with respect to the general system, subsystems, components, and parts. (5) Then check from top to bottom to verify the mechanism of data quantization control.

Meanwhile, during the vehicle quality control, quality management methods such as software engineering, reliability and safety management, and test coverage requirements, were generated. Implementing such practices broadly on various vehicles has assured a high success rate for China in space.

Conclusion

During half a century of development, China space payload delivery technology has made remarkable achievements. China's development of launch vehicles has been driven by both a need to enhance national capacity to ensure access to space, and by the requirements of specific launch missions In doing so, it has followed a path of "self-reliance and independent innovation." Over more than four decades, China's launch vehicle development progressed from research tests to flight application to industrialization. During this time, China successfully developed more than ten models of launch vehicles. Such development has promoted the development of satellites, satellite application technology, and manned space technology. It has strongly supported the successful implementation of major projects in China, with the "manned space project" and "lunar exploration project" as leading examples.

Chinese launch vehicle development has thus contributed significantly to space exploration technology. All countries enjoy the right to explore, develop, and utilize outer space and its celestial bodies. Countries' outer space activities should contribute to national economic development, social progress, human security, survival, and development. China advocates equality and mutual benefit, peaceful utilization and common development of space exploration, and the strengthening of international exchanges and cooperation.