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Development of China's New Generation Launch Vehicles

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Abstract

In the past 2 years, China's new generation Launch vehicles, such as the LM-6, LM-7, LM-5 and LM-11 launch vehicles, successfully made the maiden flights, which marking Chinese Long March series launch vehicles having many achievements such as the diameter of launch vehicles increased from 3.35 meters to 5meters and the toxic propellants replaced with non-toxic and pollution-free propellants. This paper will introduce the features and new technologies of LM-7, LM-5 and LM-11 launch vehicles, which are China's new typical generation Launch vehicles.

Key words

New generation, Launch vehicle, LM-7, LM-5, LM-11

1. Introduction of New Generation Launch Vehicles

From 1970 to December 2017, the Long March launch vehicle series completed 260 launch missions, sending many spacecrafts into their target orbits with a success rate of more than 95%, indicating increasing effectiveness and high-frequency launching capability of carrier rockets. However, the Long March launch vehicle series still had the problems of capability deficiency and technical drawbacks.

China's new generation Launch vehicles which have been developed since 2006 are preparing to replace the old Long March launch vehicle series (LM-2, LM-3 and LM-4) and will become the main force of Long March launch vehicle series in the future.

The Long March 5 (LM-5), China's newest generation of carrier rockets with the maximum carrying capacity, made its maiden flight, and increased the diameter of liquid fuel rocket from 3.35 m to 5 m, with a maximum payload capacity of about 25 tons to low earth orbit and about 14 tons to geostationary transfer orbit, significantly improves the carrying capacity of the Long March rocket family and becomes a symbol of the upgrading of China's carrier rockets. The 120-ton liquid oxygen and kerosene engines were firing tested, which powered Long March 6 and Long March 7 on their maiden flights. The Long March 11, a solid-fuel carrier rocket, also made a successful maiden launch, further enriching the Long March rocket family. In this report, we will introduce the general schemes and technology innovations of LM-7, LM-5 and LM-11 launch vehicles and provide the future plan of China's new generation launch vehicles.

2. LM-7 Launch Vehicle

2.1 General Scheme

The LM-7 and its family are expected to be the workhorse of the fleet, eventually will account for around 70% of all Chinese launches. It will also play a crucial role in the Chinese Space Station. It will initially be send to launch the Tianzhou robotic cargo spacecraft, and will eventually replace the Long March 2F as China's crew-rated launch vehicle.

It is a two stage launch vehicle with four 2.25 m diameter liquid strap-on boosters, capable of delivering a payload of 14.0 tons to LEO. The LM-7 is 53.1 m long

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with a lift-mass of 597 tons and uses a fairing that is 12.718 m long with a diameter of 4.2 m. It uses cryogenic and environment-friendly propellant (see Figure 1). The basic LM-7 has 4 boosters using RP-1/LOX as propellant. Booster is powered by a single oxidizer-rich staged combustion YF-100 engine. Each module has its own single axis thrust vector control, and thus it required a special design in the control system of the rocket to coordinate all the rocket's nozzles. It is 2.25 m in width, but due to the increased thrust of the YF-100, the boosters are almost twice as long as the traditional boosters, at 27 m. The first stage has same propulsion elements as the boosters, but the engines can gimbal in two axes. The second stage also shares the first 3.35 m diameter tanks and propellant. It is powered by four oxidizer-rich staged combustions YF-115 engines.

Fig. 1 LM-7 launch vehicle

2.2 Technology Innovation of The LM-7

By using LOX/RP-1 as propellants, the LM-7 is the first medium generation launch vehicle in China. Its maiden flight accomplished the goal of high reliability, non-toxic, non-polluting. Its perfect performance is not only the prelude to the upgrading of China launch vehicle and the mission of manned space laboratory, but also the high reliable configuration for large satellites in low orbit mission. Innovative and breakthrough points can be summarized in the following five aspects.

(1) The LM-7 adopts modular design concept, using two new types of LOX/RP-1 engines. It overcomes the challenges of high slenderness ratio booster separation with hyper-static strap-on structures, achieves the parallel layouts of engines in Stage-1 and Stage-2, suppresses the longitudinal coupling vibration in the engine system, fulfills the large thrust final stage orbit injection with high accuracy, and also develops the light weight structures, environment friendly manufacturing techniques and 3D digital design. The success of LM-7 signals the launch capacity of China rises from 8.6 tons to 14 tons in low orbit.

(2) In the full spectrum of China launch vehicles, the LM-7 initiates joint swing control of the boosters and Stages, by involving boosters in launch vehicle attitude control. Also, active load shedding technique is first in use in booster launch vehicle with an effect of 15% reduction of aerodynamic-induced torque. The application of hyper-static strap-on technique solves the modal frequency coupling of the boosters while the thrust transmission improves significantly.

(3) An innovative work flow in launch site is proposed and applied, which is call "Three vertical modes". The launch pad, umbilical tower and launching pendulum bars are integrated on one active launch platform. Th platform with a mass of 1800 tons can achieve turning movement, load shedding and water spraying when lift-off takes place. The platform resolves the difficulties induced by natural environment like high humidity, high temperature, salt mist, shallow wind and thunderstorm in Hainan Province. Among the entire medium and large China launch vehicle family, the LM-7 utilizes the least time in launch campaign.

(4) Based on new thermal and mechanical design, light weight and insulating structures, materials and coating are invented and introduced to overcome the influence of thermal and mechaical environment induced by multiple engines.

(5) The applications of three 1553B bus control scheme, robust control of autogenous pressurization system, gas-liquid sealing design of redundancy enhances the product reliability. During the development of the LM-7, the reliability enhancement test and reliability growth test is integrated to improve the robustness and reliability of the product. The index of flight reliability is evaluated to be 0.98 while the index of maiden flight reliability is evaluated to be 0.9.

3. LM-5 Launch Vehicle

3.1 General Scheme

In the evening of November 3, 2016, the new generation launch vehicle Long March 5 (LM-5) blasted off from Wenchang Satellite Launch Center in Hainan Island (see Figure 2), taking YZ-2 (Yuanzheng 2) upper stage and SJ-17 (Shijian 17) satellite into the destination orbit after 1821s' flight, achieving a successful maiden flight. The success symbolized that China's launch vehicle entered into the club of heavy-lift rockets, and China's solid step towards a major power in space.

Fig. 2 LM-5′s maiden flight

Designed with the ideas of generalization, serialization and modularization, LM-5 series have two types of engines and three types of modules. It is planned to target the urgent demand of China′s space industry, instead of certain particular payloads. The LM-5 series are built based on the 5 diameter module with 6 sub-types (see Figure 3). The maiden flight tested the largest sub-type, which has a two stage structure with strap on 3.35m diameter boosters (namely 2.5 stage). The target GTO carrying capacity reaches 14 tons. LM-5B is designed to launch the core modules of manned space-station, and is the largest sub-type for 1.5 stage types. The LEO capability of LM-5B reaches 25 tons. The medium and small size of China′s new generation launch vehicles are built on the basis of 3.35m and 2.25m diameter modules, known as LM-7 and LM-6 respectively (see Figure 3).

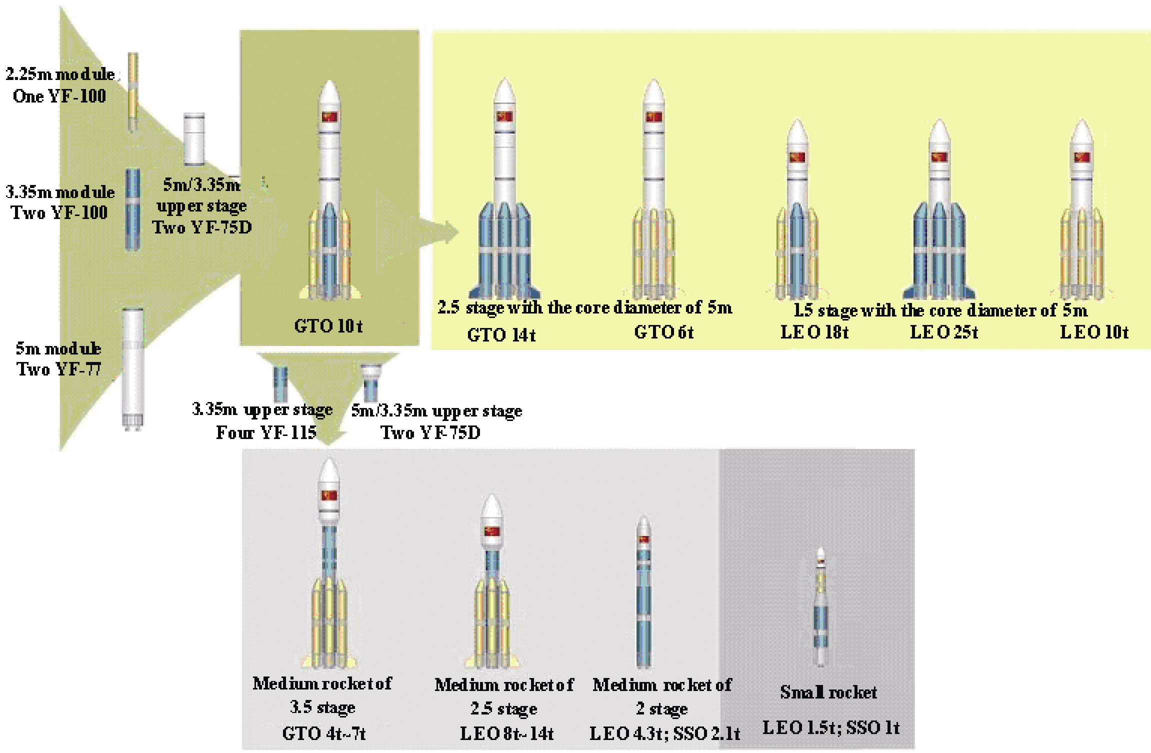


Fig. 3 Sub-types of Long March 5 series

The height of LM-5 is about 57 m, and the lift-off weight is around 878 t. It consists of 6 sub-systems, including the rocket body structure, propulsion, control, telemetry and measurement, command and monitor, together with launch support.

3.2 Technology Innovation of The LM-5

The research and development of LM-5 takes 10 years, targeting at new demands, practicing new concepts, applying new technologies, and realizing new breakthroughs. The general technology of LM-5 reaches the international advanced level. Its main features can be concluded in 12 aspects as ′new developing ideas, new system design, new carry capacity, new general configuration, new environment protection, new body structure, new propulsion system, new electrical system, new launch mode, new design methods, new production and launch base, together with new transportation methods′. During the development of LM-5, 247 key technologies from 12 major aspects are achieved. The main technical innovation can be concluded as follows.

(1) Optimized scheme of the structure design. For LM-5′s configurations, the sub-type with kerosene/LOX boosters and 5 m diameter LH2/LOX core stage has advantages of smaller scale, minimum number of engines and increasing launch efficiency. LM-5 is the only rocket with the kerosene/LOX boosters and 5m diameter LH2/LOX core stage structure among the current launch vehicles worldwide, and this help the rocket to take advantage of both the high density specific impulse, high thrust from kerosene/LOX engines and the high specific impulse from LH2/LOX engines. The overall performance of LM-5 reaches the advanced level worldwide.

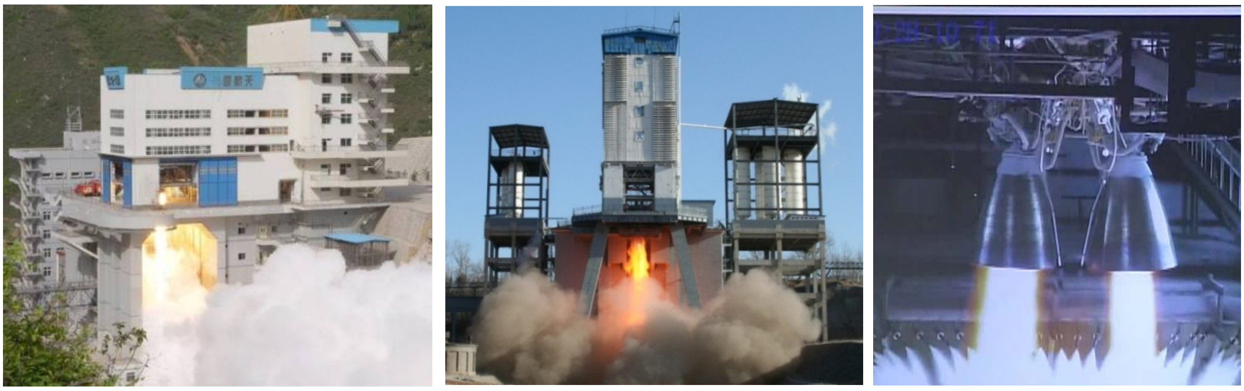
(2) Brand new aerodynamic configuration and load-transfer scheme. The Von Karman shape is used for LM-5′s fairing, and the structure of oblique nose cone is used in the boosters. With optimizations including the radius of fairing and the length of Karman curve, fluctuation pressures under transonic speed conditions are decreased. For the load-transfer scheme, in the traditional scheme, the load is transferred by the bottom strap on structures and supported by core stages, however, in the adopted scheme, the load will be transferred by the top strap on structures and supported by four boosters, thus improving the structural efficiency of core stages, the stiffness and partial modes of rockets, and lowering the designing difficulty of the stabilization system.

(3) Large diameter rocket body structure. The first use of 5 m diameter as the core stage of LM-5 rocket is a breakthrough from conventional rockets designed within 3.35 m diameter. It is the foundation to meet the requirements of higher carrying capacity and larger payload volume for domestic rockets. With the technical study of design, manufacture and testing of large diameter structures, the nation′s largest lightweight cryogenic tank is developed. With the research and development of 5 m diameter rocket body structure, the technologies of large diameter and large concentrated load thin-shell structure achieved a leapfrog breakthrough. Researches in large-scale structure have promoted the development of machining, hot processing, welding, testing, tooling and other equipment (see Figure 4).

Fig. 4 5 m diameter lightweight cryogenic tank

(4) Advanced propulsion system scheme. The propulsion system of the LM-5 rocket has adopted all cryogenic engines, and the scale of its LH2/LOX propulsion system is 11 times of that of the LM-3A series launch vehicles, which makes the research and development much more difficult. In order to meet the requirements of high reliability, strong adaptability of the rocket, the advanced precooling technology is adopted. As a result, the restriction of launch adaptability caused by the fast temperature re-rise of cryogenic engines is solved, the pre-launch process is simplified, and the emergency disposal ability is greatly improved. The new outflow structure is developed to reduce the amount of propellant that are not applicable, and achieve a larger carrying capacity for large diameter tanks. What is more, in order to improve the reliability of the pressurization transportation system of tanks, the single location invalidation of sensors and magnetic valves are solved, and the redundancy control scheme for pressurization, based on digital pressure sensor signals, is adopted. Figure 5 shows the firing test of the rocket engine.

(5) Highly reliable electric system scheme. The redundancy strategy of dynamic isolation is adopted in the control system. Moreover, the system-level redundant scheme is adopted for the first time, solving technological problems of redundant judgment and fault isolation. The real-time uninstall, active guidance and shut down estimation technologies are adopted in the guidance control system, which noticeably improves the accuracy of guidance control and the carrying capacity of rockets. The telemetry data transfer and integration technology with 10 Mbps+5M bps high bit rate is adopted in the telemetry and measurement system, raising China′s telemetry technology to the international advanced level. What is more, key technologies are tackled, including the transfer of telemetry data, bit rate and visual image from the rocket, together with the combination of space-based TT&C and ground-based TT&C modes. As a result, the problems including wire



YF-100　　YF-77　　YF-75D

Fig. 5 Firing test of the rocket engine

4. LM-11

4.1 General Scheme

LM-11 launch vehicle, being the first solid propellant launch vehicle in Long March family, characterized with simple configuration and rapid launch, facilitates the construction and replacement of small satellite networks, by breaking into the area of sold launch vehicles in China. Meeting the emergency requirements posed by disasters and accidents, it significantly enhances the Chinese astronautic transportation system, shortens the response time, improves the launch efficiency, and promotes the developments of small satellites.

LM-11 launch vehicle adopts a four-stage configuration with a length of 20.8 m, a lift-off mass of 58 t (in maiden flight) and a maximum diameter of 2.0 m. LM-11 launch vehicle can be used to send 420 kg payloads into 700 km SSO orbits, or 500 kg payloads into 500 km SSO orbits, with a launch preparation time no more than 24 hours. The LM-11 launch vehicle is assembled, tested and transported horizontally, then entirely transported and erected, and finally launched vertically, as shown in Figure 6. It finished its virgin launch successfully in September, 2015.

4.2 Features

LM-11 provides standard satellite interfaces and can launch multiple satellites in one single mission. Being stored in assembly and equipped with autonomous environment conditioner, it features rapid launch ability, easy launch operation, and can be launched in all weather conditions.

(1) High launch ability. By implementing the four solid stage configuration, the system optimizing technique, high trust solid motors, high power vector control servos, the multiple constraint ballistic design technique, the horizontal separation of fairing, and low weight structure and avionics, the launch coefficient is significantly improved to the leading position in the world.

Fig. 6 LM-11 launch vehicle

(2) Rapid response to requirements. By solving the problems of the assembly storage, the packaging of ultra-high pressured gas, heavy launch platform with erection mechanic, and high integration avionic, the launch time is scientifically shortened to the order of hours.

(3) Easy usages. By implementing the technique of payload environment conditioning, propellant packaging, high power energy-storing servo, no filling process is needed before launch, which has greatly simplified the requirements to launch sites.

(4) Versatile launch platform. With the moveable launch platform, command and control system and satellite-based telemetry, few launch facilities such as launch towers, are required. It can not only be launched in all-weather condition and even on highways, but also can be launched on boats.

(5) Standard interfaces. While achieving high accu-

racy orbit injection, it can provide various standardized multiple satellite adapters. The modular multiple-satellite separation controller can provide the timing control for tens of satellite separations, meeting the requirements for satellite networks.

5. Summary and Perspective

The successful maiden flights of China's new generation Launch vehicles mark the upgrading of the overall level and capacity of the Chinese aerospace industry. In the future, we will develop and launch medium-lift launch vehicles which are non-toxic and pollution-free, improve the new-generation launch vehicle family, and enhance their reliability. In addition, China will also conduct research into the technologies for low-cost launch vehicles, new upper stage and the reusable space transportation system between the earth and low-earth orbit. Meanwhile, China's new generation Launch vehicles will participate in commercial launch, piggy-back launch, sea launch etc. We believe the development of China's new generation Launch vehicles will support China to become a main space power.

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