LM-11— The Main Force in China's Small Launch Vehicles for Commercial Launch

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Abstract: The Long March 11 launch vehicle (LM-11) is the only solid launch vehicle within China's new-generation launch vehicle series, enabling a full spectrum of Chinese launch vehicles. Compared with other China's LM series launch vehicles, it has the shortest launch preparation time. With the characteristics of appropriate launch capability, quick response, easy-to-use, flexible operation, universal interface and strong task adaptability, LM-11 can better meet the launch requirements for various small networking satellite, replacement and for emergency use. After four successful launches, LM-11 has become the main Chinese launch vehicle oriented to the international small satellite commercial launch market.

Key words: LM-11, launch vehicle, technology characteristic
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1 LM-11 LAUNCH VEHICLE BRIEF INTRODUCTION

The Long March 11 launch vehicle (LM-11) is a small solid launch vehicle aiming at quick launch. It is the first solid rocket in China's new-generation launch vehicle family, which fills the gap in the field of solid launch vehicle for China. It can realize the rapid networking and replacement launch of small satellites, satisfying the emergency launch requirement for natural disasters and emergencies. It is of significance in perfecting the Chinese space transportation system, enhancing the quick launch capability and launch efficiency for small launch vehicles, while promoting the scale development of small satellites.

The LM-11 launch vehicle is a four-stage solid rocket, with a total length of 20.8 m. The lift-off weight is about 58 t and the maximum diameter of the rocket is 2 m. The capability of the rocket enables placing a 500 kg satellite into a 500 km sun synchronous orbit. The launch preparation time is less than 24 hours. The launch vehicle is designed for horizontal assembly, horizontal test, horizontal transportation and vertical launching. The LM-11 launch vehicle conducted four multi-satellite launch missions from the Jiuquan Satellite Launch Center in September 2015, November 2016, January 2018 and April 2018 respectively, launching 20 small satellites successfully into space. The launch vehicle is shown in Figure 1.

Figure 1 Artist's concept of the LM-11 launch vehicle

2 LM-11 LAUNCH VEHICLE TECHNOLOGY INNOVATIONS

The LM-11 launch vehicle has standard satellite adapter interfaces and a multi-satellite launching capability. It is the first time for a small solid launch vehicle to be self-contained, with autonomous environmental protection, be efficient while having a rapid launch capability and easy operation. It has the ability for all-weather launch. The main technical features are as follows:

1) Appropriate launch capability. The technical difficulties such as four-stage full solid configuration and entire rocket layout optimization, large thrust solid engines and high-power thrust vector control, multi-task mode and multi-terminal constraint ballistic design, lightweight rocket body structure and electrical equipment, fairing separation have been tackled. The rocket launching coefficient has reached an advanced international level.
2) Quick response. Technical problems related to complete rocket storage, mobile launching platform for a large-tonnage rocket and vertical launch of a large-tonnage solid propellant rocket have been overcome. The electrical system on board the vehicle uses an integrated design to significantly shorten the test and launch time, enabling a quick response and launch ability within hours.
3) Easy operation. The technical problems such as an independent guarantee of the payload environment, pre-packing of propellant, overall optimized design and manufacturing test of a high-power, pre-storage energy servo system have been solved. Propellant filling is no longer needed before launch, hence the support conditions at the launch site are greatly simplified, enabling a simple launch operation and easy of use.
4) Flexible launch. It adopts a vehicle launch mode, space-ground based integrated measurement and control, both remote and local command and control mode. It no longer needs a service tower, diversion channel and other infrastructure support. It has mobile launch ability and all-weather launch ability, and can be quickly and easily adapted for offshore platform launch or air launch.
5) Universal interface and mission adaptability. The high precision orbit control of a solid launch vehicle has been realized, and standardized multi-satellite launch adapters have been designed. The use of a modular multi-satellite separation control device enables dozens of different types of separation timing control. The

standard satellite adapter interface is able to meet the launch requirements for single satellite and multi-satellite networking launch.

In order to meet the technical specifications including launch capacity, quick response and adapter interface, LM-11 has been optimized with new innovations adopted during the development, providing high quality and an efficient service for small satellite users, thus making LM-11 a main Chinese carrier rocket for commercial launch of small satellites.

3 COMMERCIAL LAUNCH SERVICE INNOVATION

3.1 Diverse Standard Adapter Interfaces

The LM-11 launch vehicle is mainly used for single satellite and multi-satellite networking and supplementary network launching of small spacecraft less than 500 kg. In order to maximize the launch capacity and reduce the cost for individual users, the multi-satellite launch is generally chosen by small spacecraft users. Satellites less than 30 kg are usually launched as piggyback payloads. Up to now, LM-11 has conducted a number of multi-satellite missions. Based upon the actual launch missions of other international launch vehicles, the multi-satellite launch has become the most common launch mode of small launch vehicles.

The "multi-satellite with one vehicle" launch mission features multiple states of adapter interface, complex design of the satellite adapter with long development and test time. The related interface affects the state of the main hardware and software products of the launch vehicle. If the rocket was developed after the determination of the multi-satellite interfaces, it would seriously restrict the LM-11's rapid deployment capability.

Due to the general-purpose and task-based design, the LM-11 launch vehicle implements multi-satellite launch interfaces between the hardware and software products on the vehicle, which isolate the product directly with the adapter interface, and the other products can be produced ahead of time. It not only improves the ability for fast response, but also provides the condition of reducing the cost of mass production.

The design of LM-11 universal adapter interface is mainly composed of a single satellite and multi-satellite layout and installation, satellite connection and separation, satellite separation control, satellite separation measurement and so on. Through the design of remote one to remote four launch tasks, LM-11 has formed a standardized multi-satellite layout and separation scheme adapting from 1 main satellite + multiple cubic satellites, 1 main satellite + 2 microsatellite satellites + multiple cubic satellites, 2 main satellites + multiple cubic stars, multiple main satellites + multiple cubic stars, as shown in Figure 2.

For the satellite connection and separation, the LM-11 rocket can provide various standard vehicle separation devices, such as straps, point connections, cubic star release mechanisms, light straps and so on, as shown in Figure 3.

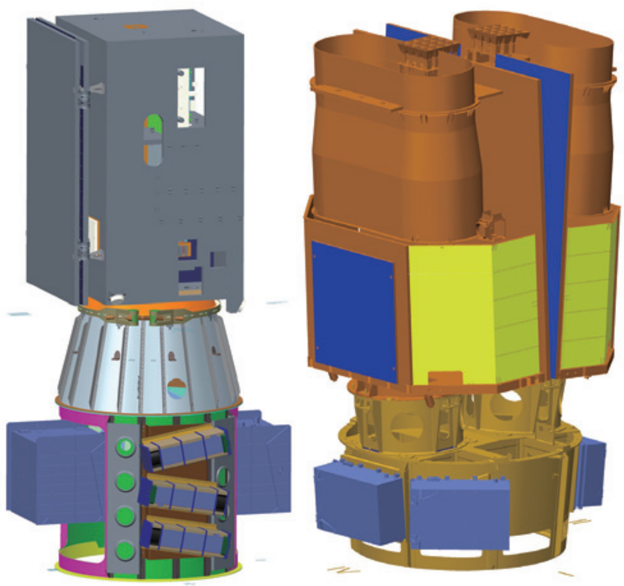

Figure 2 Two typical types of multi-satellite layout

Figure 3 Typical satellite connection and separation devices

For the satellite separation control and measurement, at present, LM-11 has the capability of deploy and release signals for dozens of different types of satellite, as well as satellite and vehicle separation signal measurement channels. The signal for deploying the satellite covers a wide range of currents with a short-time signal that detonates explosive devices, and also satisfies the small current long-time signal required for electromagnetic deployment mechanisms.

Through the design of the universal adapter interface, LM-11 has greatly improved the ability to adapt to the needs of one vehicle with multi-task satellites with high performance. It has realized the reduction in preparation time for the interface in the first 8 months before the launch of the main task interface and 5 months before launching the integration of the standard cube satellite.

3.2 Excellent Interface Environment for Satellites

3.2.1 Independent environmental logistics support

The thermostat cabin and temperature control system located on the test and launch platform of the launch vehicle can provide a controlled temperature and humidity environment within the fairing and guarantee the cleanliness in the fairing.

During the transportation to the launch pad and the launch preparation at the launch pad, a special air-conditioning system for the fairing is adopted to provide a controlled temperature and humidity environment, which provides, cooling, dehumidification in a high-temperature environment, or heating, and humidification in a low-temperature environment. This can guarantee the clean requirements, and provide good pre-launch environment for spacecraft.

3.2.2 Better flight environment

Solid rockets have higher accelerations. LM-11 meets the flight overload demands for various small satellites through reasonable inter stage mass distribution and an optimized design of engine thrust at all stages. Taking the actual measurements through LM-11's four missions, the noise in the fairing and the interface vibration between spacecraft and launch vehicle were found to be at a comparative order of magnitude as those of the traditional liquid rockets. LM-11 provided good flight environment for the spacecraft in those missions.

3.2.3 Shock reduction design of the separation between satellite and launch vehicle

For the satellite, the shock caused by pyrotechnic devices when satellite and launch vehicle separate is one of the harshest environments the satellite experiences on the launch vehicle, especially for micro-satellite. Due to their limited structures, fragile payloads, such as those of cameras, are usually close to the interfaces between spacecraft and launch vehicle. Such payloads are particularly sensitive to interface shock environments. Thus a higher requirement is required for the interface shock environment between spacecraft and launch vehicle.

By selecting adaptive energy absorption materials and structures, LM-11 vehicle converts the kinetic energy generated by the pyrotechnic explosion to the movement of separation structures, so as to reduce the impact. Through a series of optimization tests, a method was determined optimizing the shock reduction effect enabling a feasible satisfactory assembly. The shock response spectrum at the typical position of the interface between satellite and launch vehicle was reduced to 2000 g.

3.3 Short Test Launch Preparation Time

In order to realize a short test and launch in 24 hours, for the LM-11 vehicle, adoption of key technologies enabling fast assembly integration and test launch based on the three aspects

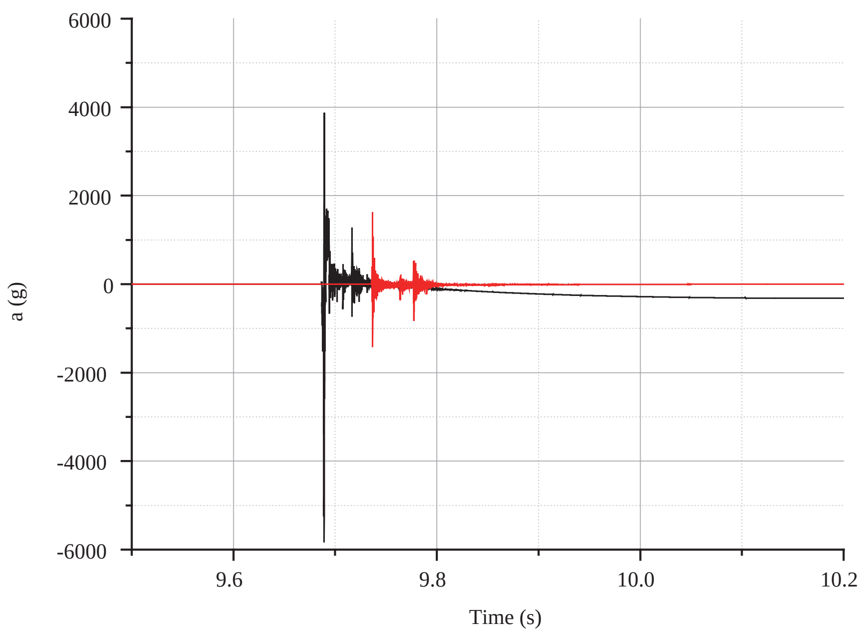

Figure 4 Shock environment schematic diagram at the interface between satellite and launch vehicle

of assembly, process and electrical system.

Vehicle structure designs assumed the need for fast assembly integration operation, which resulted in "two-horizontal" techniques of rapid mating technology for the satellite and launch vehicle mating and fairing encapsulation. It simplifies assembly operating processes and simplifies assembly programs resulting in considerable reduction in preparation time. Also work on the rockets and satellites can be carried out in parallel to further shorten the preparation time.

The optimization of launch site process based on simulation analysis, can simulate and analyze key projects such as rocket test, mating of satellite and launch vehicle, transition transportation, and launch pad test during the launch process, hence optimizing the design plan, and reducing process time.

Adopting an integrated design concept, the integration of rocket with the ground system is achieved based on use of high-speed data bus technology. The integration of ground test and launch system is realized by SDH transmission technology. Through intelligent single device design, the integration of a single device function on the rocket is achieved, thereby significantly reduces the test data, and transmits data more rapidly. The reliability of the information transmission is greatly improved. At the same time, a closed-loop design technology for the electrical system test projects based on test coverage analysis. On the one hand to optimize test items, and on the other hand to drive system design changes. It eliminates or reduces the risk of test coverage programs, in order to achieve the balance between speed and test coverage with as few programs as possible.

Through the above technical means, the LM-11 launch vehicle can complete small satellite launch missions in 30 days and if needed in 24 hours in an emergency, which greatly expands the networking application of small satellites.

3.4 Reduced Test Launch Support and Launch Cost

Through the function of integrated test control and failure diagnosis, LM-11 vehicle achieves one-button ground test tasks and meets the requirements for automatic, rapid test and automatic interpretation.

The testing process function accomplishes the design and plan for switches, processes and logic in each pre-launch period by command and control software and embedded measurement and control software in ground front-end equipment.

Failure diagnosis is composed of the monitoring and diagnosis module in the front-end information control system and in the back-end failure diagnosis software platform. It completes the whole test process of monitoring and diagnosis, provides monitoring status on the rocket, status testing of the ground test equipments, the real-time monitoring and diagnosis of the whole rocket during the test process, using a pre-arranged plan for faults, and ensures that the testing process is safe, correct, and reliable. At the same time, with the automatic analysis function of test results, it applies a knowledge base integration function in the failure diagnosis module to automatically analyze the test results, and exports the test results. Functional components of the failure diagnosis module are shown in Figure 5.

The LM-11 solid propellant launch vehicle adopts an information management platform suitable for rapid test launch, realizing real-time processing, interpretation and quick analysis of the post-test information. The front-end and back-end switches and SDH undertake the front-end and back-end information exchange function of the LM-11 solid launch vehicle, hence their functions are mainly divided into uplink and downlink categories. The uplink is used to receive the commands, status, parameters and other signals issued by back-end ground equipments. After photoelectric conversion, signals are sent to the rocket master control module through the backplane bus of the front-end ground equipment. The downlink is used to receive the monitoring status, drive instruction, parameters and other signals issued by front-end ground equipments. After photoelectric

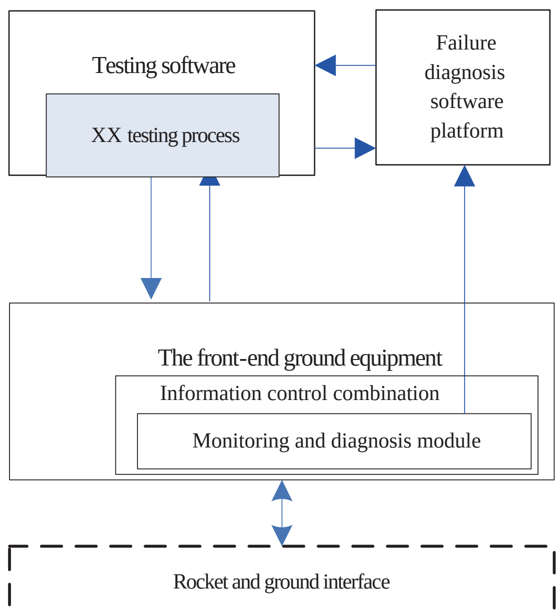

Figure 5 Functional components diagram of the failure diagnosis module

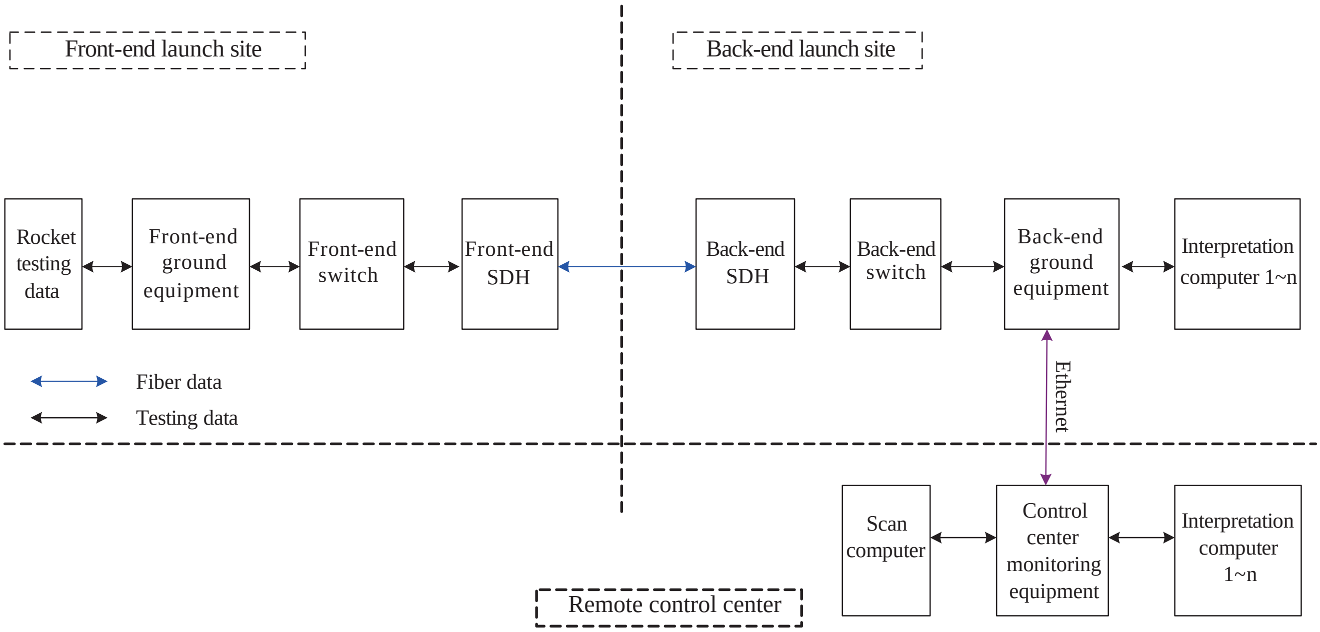

Figure 6 Mode diagram of remote rapid test launch

conversion, signals are sent to the back-end through an optical fiber cable. The LM-11 solid rocket realizes the technical support for remote rapid test launch by unifying system resources and adopting an improved network. The main architecture of the system is shown in Figure 6.

3.5 Good Regional Adaptability

The LM-11 launch vehicle has the benefit of not requiring propellant filling at launch site, erection and launch of the large-tonnage rocket. The rocket does not require the support of traditional liquid rockets, a maintenance service tower or ground additional support facilities. It has a high degree of system integration and has the technological advantage of being modified for sea launch or air launch.

The rocket ground test equipment adopts a square cabin design. The launch support equipment of the rocket can be independently transferred to a sea launch platform. The sea launch platform does not need additional large-scale ground facilities such as launch platforms or flame deflector. The rocket can be transported by sea to lower latitude areas at sea to enable launch of low-angle satellites, optimizing the rocket payload lift capacity, and to avoid the difficulty in selecting suitable land launch sites. After modifications, the LM-11 rocket could also be adopted for airborne air-launch, which would provide an optimized launch environment free from regional or topographic limitations thus enabling launch modes for small satellites more flexible, and providing more convenient launch services for small satellites.

4 CONCLUSIONS

The LM-11 launch vehicle is a new member of the LM launch vehicle family. It fills the gap in the field of solid launch vehicles. It is of great significance in improving the space transportation system and the rapid launch capability of launch vehicles, increasing launch efficiency, and promoting the development of small satellite. The LM-11 launch vehicle lays a sound foundation for the production serialization and enhances the spectrum of the Chinese solid propellant launch vehicle. With the characteristics of simple operation, short preparation time, low launch cost, and broad application prospects, it has become the main force among small launch vehicles for commercial launches.

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