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PROGRESS AND DEVELOPMENT OF SPACE TECHNOLOGY IN CHINA†

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Abstract—In this paper, historical progress and development of space technology and its education in China are reviewed. The paper summarizes the progress and development of Chinese space activities, including designs and launches of artificial satellites, and launching vehicles, mainly Chinese Long March vehicle series. Moreover, some principal space organizations and research institutes are briefly described. Finally, universities and colleges of aeronautics and astronautics are introduced. © 2000 Elsevier Science Ltd. All rights reserved

1. INTRODUCTION

Space technology is a synthetical technology of astronautical sciences for the design, manufacture, test, launch, reentry, control and management of spacecraft and their launch vehicles, and is used to explore and utilize space and celestial bodies beyond the earth. From the early 1960s to the present, in the field of space technology, China have been successful not only in developing scientific experimental satellites, earth-observing satellites, communication satellites and meteorological satellites of different kinds and different functions as well as Long March Series launch vehicles but also in developing satellite application system and space medicine engineering experimental research. All these success and developments are initiated under the leadership of the famous scientist Dr. Qian Xuesen.

2. SPACE ACTIVITIES IN CHINA

2.1. *Launch vehicles*

A launch vehicle is a space transportation means composed of multi-stage rockets, and its function is to send the artificial satellite or other payload to a predetermined orbit. China developed the launch vehicle on the basis of ballistic missile. Up to 1989, China had successfully developed and put into use six models of launch vehicles with capacities to send the satellites into near-earth orbit, sun-synchronous orbit and geostationary orbit.

2.1.1. Long March-1 launch vehicle. In order to launch DFH-1 (namely dongfanhong-1) satellite, China began developing Long March-1, namely, Changzheng-1 (CZ-1) launch vehicle in the second half of 1965.

The Long-March-1 (CZ-1) launch vehicle was a tandem three-stage rocket. The first and second stages adopted liquid rocket engines used by the intermediate–long range surface-to-surface missile, while the third stage used the solid rocket motor. The lift-off mass of the entire vehicle was 81.5 ton, the lift-off thrust 1020 kN (104 tonf), the total length 29.4 m, the maximum diameter 2.25 m and the near-earth orbit payload capacity 300 kg. After the second stage was completely separated from the third stage, a spin rocket spanned the third stage to keep it in stable flight. In order to increase the payload capacity of the vehicle and orbit altitude, the vehicle flew in a powerless glide flight phase for over 200 s after the second stage engine had finished its work and before the third stage would start igniting. Corresponding to this, an attitude control system in the gliding phase was added to the second stage to control the vehicle in gravity-free state and with residual liquid propellant.

The development from the ballistic missile to launch vehicle required to solve a series of technical problems due to difference in kinds of payloads and requirements.

In the mid-sixties, technically, China had just finished the whole course of developing miniature solid rocket engines. So, developing the third stage solid rocket motor with diameter of 770 mm, length of about 4 m and charge of 1.8 ton needed by the Long March-1 launch vehicle was a completely new subject. Especially, the requirement that the motor should be ignited reliably in high-altitude and

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worked under the rotating condition of 180 rev/min added more difficulties to the development work.

From May 1969 to January 1970, four full thrust tests of the engine under different states and one flight test of a two-stage rocket composed of the first two stages were carried out successfully one after another for the Long March-1 launch vehicle.

On 24 April, 1970, the Long March-1 launch vehicle carrying the DFH-1 satellite rose slowly from the launching pad and sent China's first satellite into the space. After less than one year, the Long March-1 launch vehicle once again successfully launched the Practice-1 scientific experiment satellite.

2.1.2. Long March-2 launch vehicle. In order to launch recoverable remote sensing satellites, The Chinese Academy of Launching Vehicle Technology, under president Ren Xinmin, started developing Long March-2 launch vehicle on the basis of the intercontinental missile in 1970. This launch vehicle was a tandem two-stage liquid rocket with total length of 32 m, maximum diameter of 3.35 m and lift-off mass of 190 ton. Four sets of liquid rocket engines with swivelling thrust chamber were mounted on the first stage with a total ground thrust of 2746 kN (280 tonf); and one set of main engine with a vacuum thrust of 716 kN (73 tonf) and four sets of vernier engines with swivelling thrust chamber having a total thrust of 46 kN (4.7 tonf) were mounted on the second stage. The control system adopted platform-computer inertial guidance technique. The development personnel under the charge of Tu Shou'e, the chief designer solved a series of problems.

After the successful development of the Long March-2 launch vehicle, the development personnel, in accordance with the demand of launching other types of satellite, conducted many adaptive modifications for the configuration of the vehicle. Thus, it evolved into Long March-2C launch vehicle. Both the technical performance and payload capacity of Long March-2C launch vehicle was enhanced in comparison with those of the Long March-2 launch vehicle, and its payload capacity for a near-earth orbit was 2500 kg.

Since its first mission of launching the application recoverable remote sensing satellite on 9 September, 1982 till August 1988, the Long March-2C launch vehicle had successfully sent six application type and two new type recoverable remote sensing satellites into the space in succession.

The Long March-2 and Long March-2C launch vehicles increased the near-earth orbit payload capacity of China's launch vehicles from 300 kg of Long March-1 launch vehicle to 2 ton, so that China's launch vehicle technology reached a new level and a solid foundation for developing Long March series launch vehicles was laid down. Moreover, the Long March-2E, Wang Yongzhi being the Chief designer, with 4-strap on boosters has increased its payload capacity for LEO to 9200 kg.

2.1.3. Long March-3 launch vehicles. The Long March-3 launch vehicle was a tandem three-stage liquid rocket. The surface-to-surface intercontinental ballistic missile was taken as the prototype for developing the first and second stages. The third stage adopted a liquid hydrogen–oxygen engine with a vacuum thrust of 44 kN (4.5 tonf), which might be started twice. The lift-off mass of the vehicle was 202 ton; the total length was 43.25 m; the diameter of the first two stages was 3.35 m and the diameter of the third stage was 2.25 m. The payload capacity of the vehicle was 5000 kg for near-earth orbit, 2900 kg for sun-synchronous orbit at an altitude of 900 km and 1400 kg for transfer orbit of geostationary orbit satellite (transfer orbit inclination: 31.5°, perigee altitude: 200 km, apogee altitude: 35,786 km).

On the road of scaling new heights in space launch technology and marching towards geostationary orbit, the development personnel of the Long March-3 launch vehicle, through indomitable struggle, resolved a series of very difficult technical problems.

The utmost peculiarity of the Long March-3 launch vehicle was that the third stage adopted a liquid hydrogen–oxygen rocket engine. This kind of engine is superior in performance and advanced in technology, its combustion product is safe and non-poisonous, and its vacuum specific thrust is 50% more than that of the conventional propellant engine. But, the boiling points of liquid hydrogen and liquid oxygen are low (−253°C and −183°C respectively) and they are inflammable and explosive. To develop such a kind of engine not only the breakthrough in development technique of the engine itself was necessary, but all special problems caused by low temperature ought to be solved also. Furthermore, it was required that the engine should be started twice under high vacuum environment and microgravitational conditions. Besides, how to suppress the longitudinal coupling vibration was another key problem. These problems were successfully settled under the leadership of chief designer Xie Guanxuan.

On 8 April, 1984, the Long March-3 launch vehicle successfully launched the second experimental communication satellite into the geosynchronous transfer orbit. Afterwards, the Long March-3 launch vehicle successfully launched one practical communication and broadcast satellite and two practical communications satellites in 1986 and 1988 in succession.

The successful development of the Long March-2 and -3 launch vehicles showed that China had the capability to launch geostationary orbit satellites, and the Chinese launch vehicle technology had entered into the World's advanced rank.

2.1.4. Storm-1 and Long March-4 launch vehicles. The Storm-1 was about the same as the Long March-2 launch vehicle in payload capacity and was also a two-stage launch vehicle developed with the intercontinental surface-to-surface missile as prototype.

In the autumn of 1969, in order to unfold the development of Storm-1 launch vehicle, a development team with the Shanghai No. 2 Bureau of Mechanic-Electrical Industry as the backbone was formed. The general system design was started in December the same year.

After the successful development of Storm-1 launch vehicle, the Shanghai Administration of Astronautics satisfactorily fulfilled the development of Long March-4 launch vehicle in cooperation with departments concerned.

The Long March-4 launch vehicle, Sun Jingliang being the chief designer, was a tandem three-stage liquid launch vehicle used mainly for launching sun-synchronous orbit satellites and for launching geostationary orbit satellites, too. Its configuration of the first two stages was close to that of the Long March-3 launch vehicle. The third stage adopted two sets of newly developed conventional propellant rocket engine of bidirectional swing with a vacuum thrust of 50 kN (5.1 tonf). The total length of the vehicle was 41.9 m, maximum diameter 3.35 m, lift-off mass 240 ton and lift-off thrust 2942 kN (300 tonf). It could send a satellite of 1400 kg into a sun-synchronous orbit of 900 km altitude. The Long March-4 launch vehicle started its conceptional design in 1978; it was assigned to be the launch vehicle of Fengyun-1 meteorological satellite in March 1982, and its development work was started in the Shanghai Administration of Astronautics and the liquid rocket engine bases of the Ministry of Aerospace Industry.

On 7 September, 1988, the first launching of the Long March-4 launch vehicle was a success with single action. It exactly sent Fengyun-1 meteorological satellite into 901 km high sun-synchronous orbit. The successful development of the Long March-4 launch vehicle added a carrier of sun-synchronous orbit satellite to the launch vehicle series of China and made a new contribution to the development of China's space carrier technology.

2.2. Artificial satellite

In 1968, the Chinese Academy of Space Technology (CAST) which was in charge of developing satellites was set up.

The scientific experimental satellite is an artificial earth satellite used for scientific exploration and research. China, from 1970 to 1981, successfully launched five scientific experimental satellites, i.e. DFH-1, Practice-1, Practice-2, Practice-2A and Practice-2B.

DFH-1 satellite is the first artificial satellite successfully sent into orbit on 24 April, 1970 by Long March vehicle CZ-1 from Jiuquan. It was composed of seven systems, i.e. the structure, thermal control, power supply, "The East Is Red" melody generating device, short wave telemetery, tracking and radio systems, and attitude measuring subassembly. The total mass of the satellite was 173 kg and its appearance was a seventy-two-face polyhedron approximate to a sphere of 1 m diameter. The satellite adopted the method of spin stabilization during its flight in space.

In order to guarantee successful launching of the satellite around 1970, the research development personnel of CAST, headed by Min Guiyong made great efforts to tackle a series of technical problems, e.g. thermal vacuum stimulation test.

On 3 March, 1971, the Practice-1 satellite was launched successfully. The design life of the satellite was 1 year, but actually, it operated in space for more than 8 years. On 11 June, 1979, the satellite fell down due to end of its orbit life. During the 8 years, the performance of solar power supply system, thermal control system and long-term telemetering system kept normal all the time.

On 26 November, 1975, the experimental satellite was, for the first time, sent into the predetermined orbit by the Long March-2 (CZ-2) launch vehicle. Three days after, the satellite returned to the ground on schedule, obtaining the data for the predetermined region. This flight test revealed also that the skirt of the return capsule, some wires and instruments were burnt during reentry into the atmosphere and that the deviation of landing point of the return capsule was relatively large. The Chinese Academy of Space Technology organized the development personnel to find out the cause, and some relevant improvement measures were put forward. In December 1976 and January 1978, two improved experimental satellites were launched respectively by Long March-2 launch vehicle. The flight test was successful and the return and recovery of the return capsule were fully realized.

The successful development of the experimental satellite made China the third country that mastered the technology of satellite recovery in the World following the United States and the Soviet Union.

On the basis of the experimental satellite, China developed and launched the recoverable application remote sensing satellites (called application satellites for short) and new type recoverable remote sensing satellites (called new type satellites for short) in succession.

In the summer of 1977, China decided to use Storm-1 (namely, Fengbao-1, or FB-1) launch vehicle to launch the Practice-2 satellite. As Storm-1 launch vehicle had a payload capacity of more than 1 ton for the near-earth orbit, it was decided to use one Storm-1 launch vehicle to launch 3 satellites, i.e.

Practice-2, Practice-2A and Practice-2B, so as to obtain results in many respects with single launch.

On 20 September, 1981, the one rocket with three satellites was launched successfully. This achievement made China the fourth country that could use one rocket to launch multi-satellites in the world following the Soviet Union, the United States and the European Space Agency.

On 29 January, 1984, the experimental communications satellite was launched for the first time. The satellite had not been pushed into the predetermined orbit but parked in a near-earth orbit. The Weinan Satellite TT&C (tracking, telemetering and command) Center adopted some measurement and control measures to save the satellite. As a result, after the apogee engine of the satellite was ignited, the satellite was transferred from the parking orbit to an elliptic orbit with apogee at 6480 km, so that many tests such as satellite data communication, TV and telephone retransmission were successfully conducted.

On 8 April, 1984, the second experimental communications satellite was successfully launched. On 16 April, the satellite was positioned at 125°E over the equator. Up to now, this was the first Chinese communications satellite on the geostationary orbit, which was a great breakthrough in development of space technology in China. This success made China the fifth country that could launch the geostationary satellite in the world.

On 7 September, 1988, Fengyun-1 sun-synchronous meteorological satellite was successfully launched by Long March-4 (CZ-4) launch vehicle for the first time. The satellite entered into the predetermined orbit and the satellite onboard instruments all worked normally. On that day, China Central Television broadcast the pictures of cloud charts obtained by Fengyun-1 satellite in a weather broadcasting program. The pictures were clear in images. This test fulfilled the task of verifying the performances of the satellite onboard instruments and equipment and proved that the general system design scheme of the satellite was correct.

The Fengyun-1 satellite worked normally in space only for 39 days due to failures in the control system. The development personnel adopted improvement measures for the second Fengyun-1 satellite according to the problems discovered in the test.

On 14 August, 1992, China launched a US-made Australian telecommunications satellite with a Long March-2E launch vehicle successfully. The launch took place at the Xichang Satellite Launch Center (XSLC) in Sichuan Province, Southwest China. It was the second attempt to send the Aussat B1 satellite into orbit. The first abortive attempt was on 22 March, that year, when a fault in the booster rockets ignition system caused an emergency shutdown of the rocket engines. Eleven minutes after the liftoff, the satellite was successfully separated from the rocket to begin its 10-day journey to a geostationary orbit 36,000 km above the Earth.

On 21 December, 1992, the second Australian communications satellite Aussat B2 was blasted into its planned initial orbit successfully by Chinese launch vehicle Long March-2E at the Xichang Satellite Launch Center. The successful launch means the contract signed by the China Great Wall Industry Corp., the US Hughes Aircraft Corp. and the Australian Aussat Pty Ltd in 1988 has been fully honoured. But it is a pity that the onward signal from the satellite was lost. Investigation concluded that the failure had nothing to do with any design, manufacture and assembly flaw of the launch vehicle and nothing on the satellite had been found to be responsible for the explosion.

On 8 February, 1994, Long March-3A, a powerful launch vehicle newly developed by China, successfully launched a scientific satellite and a simulated satellite into space at Xichang Satellite Launch Center. Based on LM-3, LM-3A is designed to launch large communications satellites and has a capability of launching a 2.5-ton satellite into geosynchronous transfer orbit. The scientific satellite launched by the LM-3A, named Shijian (Practice) 4, with six detectors onboard, is designed for space environment monitoring and environmental effect testing.

Again Long March-3 launch vehicle successfully launched a communications satellite. Apstar-1, at 18:31, 21 July, 1994, from Xichang Satellite Launch Center.

Xi'an Satellite Control Center, Yuanwang Instrumentation Ship and other control centers, which monitored and controlled the satellite's flight, said the satellite separated from the LM-3 launch vehicle 24 min after launching, and entered into a geosynchronous transfer orbit, which has a perigee of 205.96 km, and apogee of 42,261.2 km and an inclination of 26.8°.

The Apstar-1 satellite, weighing about 1.4 tons and owned by the APT Satellite Company, is a HS376 model made by Hughes Space and Communications Co. of the United States. It is equipped with 24 C-band transponders and has a service life of 10 years. The satellite was positioned at longitude 131° east over the equator, and operated by the APT Satellite Company.

The Australian Optus-B3 communications satellite was successfully sent into space by a Long March launch vehicle from Xichang Satellite Launch Center. The 49.7 m high LM-2E was launched at 7:10 am, 28 August, 1994, and put the satellite into a near earth orbit accurately and precisely after an 11-min flight. The satellite was then handed over to Hughes who would control the transfer of the satellite into the final geosynchronous orbit.

Optus-B3 is built to replace the B2, which exploded and was lost during a launch by LM-2E in December 1992, as stated above.

The Lockheed Martin EchoStar-1 communications satellite was successfully sent into orbit by a Chinese LM-2E booster. The satellite went into an orbit with a perigee of 185.34 km, an apogee of 306.71 km and an inclination of 28 degrees after a launch from Xichang Satellite Launch Center on 7:50, 28 December, 1995.

The LM-3B, a new version in the Long March family, lifted off at 3:01, 15 February, 1996, with the Intelsat 708 but began to experience an anomaly in attitude about 2 s later, pitching down and yawing to the right side of the launching direction. It touched down with its nose at about T+22 s and exploded violently, leaving basically no major debris of the launcher and its payload. The Chief-Designer System for the launch vehicle organized an analysis team on the same day of the accident. Interpretation and analysis of the telemetered data have shown that the crash was caused by a change in the inertial reference, which is to be confirmed through further analysis and demonstration. XSLC has done its best to rescue the wounded after the explosion, which killed six and injured 57. Of the killed two were senior engineers with CASC.

On 3 July, 1996, an Asia-Pacific-IA communication satellite was successfully sent to the predetermined orbit by LM-3, this is the 41st launching of Long March series, collaborated by Chinese Academy of Space Vehicle Technology and Shanghai of Bureau Astronautics.

3. PRINCIPAL SPACE ORGANISATIONS

The national space programme falls under the aegis of Ministry of Aerospace Industry, now called China Aerospace Corporation (CASC), since 1993. CASC performs the action of government department when dealing with foreign affairs in the name of China National Space Administration (CNSA). But commercial activities are directed by China Great Wall Industry Corporation.

There are five main Research Academies under CASE: Chinese Academy of Launch Vehicles Technology (CALVT) in charge of designs and manufactures of Long March series, Chinese Academy of Space Technology in charge of designs and manufactures of satellites, Academy of Solid Rockets, Academy of Tactical Missiles Technology, and Academy of Cruise Missiles Technology.

China Great Wall Industry Corporation (CGWIC), a foreign trade company under the Ministry of Aero Space Industry of China, is an exclusive organization in China, responsible for the launch service, marketing, commercial negotiation, contract execution and performance with a legal person status.

CGWIC has established the business relations with a number of companies and research institutes in the United States, Sweden, Germany, France, Australia, Britain, Brazil, and with many international organizations throughout the world, as well as International Communication Satellites Organization and International Marine Satellites Organization contracts and agreements signed for satellite launch and piggyback payload service.

CGWIC will extend its friendly exchanges and cooperation with the people of all circles in all the countries and regions in the World in wider fields so as to make a greater contribution to the development of the space cause and the promotion of the economic prosperity in the World.

4. COLLEGES AND UNIVERSITIES OF AERONAUTICS AND ASTRONAUTICS

Early, around 1940, Tsing Hua University, Shanghai Chao-Tang University, Central University and Zhejiang University established departments of Aeronautics. Around 1958, Beijing Aeronautical Institute, Northwestern Polytechnical University, Xarbin Polytechnical University, Xarbin Military Institute of Technology and others established their departments of astronautics. Among these departments of astronautics, Northwestern Polytechnical University is uninterrupted since 1958. Thus far, it has graduated more than 5000 Bachelors, 500 masters and 80 PhD. Most of the others were interrupted, and only after 1985, did they resume. In these departments, there are specialities: Flight Vehicle Design, Rocket Engine, Control Engineering, Flight Mechanics, Electronics, Avionics, Computer Sciences. These departments of Astronautics are now called colleges of Astronautics.

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