

CHAPTER 1

CZ Series Part 1





Text A The Long March 2 (CZ-2)/The Long March 3 (CZ-3)/ The Long March 4(CZ-4)

Long March 2 Series (CZ-2)

Long March 2 (CZ-2) is China's first generation of two-stage liquid launch vehicles developed in the mid-1970s. It successfully launched China's first recoverable satellite, making China the third country in the world, after the United States and the Soviet Union, to master the technology of developing and launching recoverable artificial satellites.

In the 1950s and 1960s, the Soviet Union and the United States launched many recoverable satellites for space reconnaissance. These satellites weighed between 500 to 2500 kilograms, posing new requirements for rocket payload capabilities. After successfully launching China's first artificial Earth satellite, Dong Fang Hong 1, with the Long March 1, China aimed to enhance its space observation capabilities. The task of launching heavy low-orbit satellites was included in the space development plan. In 1970, to launch heavy recoverable satellites (FSW) in low orbits, China began developing the Long March 2 (CZ-2) rocket, based on long-range rocket technology. On November 5, 1974, the first launch attempt of CZ-2 failed due to a broken wire. After more than a year of improvements, on November 26, 1975, the second launch successfully sent China's first recoverable satellite into orbit. By January 1978, the CZ-2 had conducted four launches, three of which were successful.

Based on the requirements for satellite launches, the China Academy of Launch Vehicle Technology modified the CZ-2 to improve its technical performance and payload capacity from 1800 to 2400 kilograms. This improved version was named the Long March 2C (CZ-2C). The Long March 2C rocket has both two-stage and three-stage configurations, with a diameter of 3.35 meters and a length of 40 to 43 meters. The first and second stages use conventional propellants, while the upper stage uses a solid engine.

The main control equipment of the Long March 2C is installed in the instrument cabin at the front of the rocket, with some control equipment also installed in the interstage and intertank sections. To position the rocket's center of mass as far forward as possible to improve static stability, the oxidizer tanks, which contain a denser substance, are placed at the front, while the fuel tanks, containing a less dense substance, are placed at the rear. The interstage section consists of shell and truss structures, with the truss structure facilitating the smooth discharge of gas from the second stage engine during thermal separation of the first and second stages. Two types of fairings with different docking parts are available to accommodate various payload requirements. The launch support



point is located at the foremost end of the first stage engine frame to ensure stable launch support and reasonable use of the force transmission structure. The interstage separation surface between the first and second stages is located at the connection between the second stage frame and the shell to minimize the structural mass of the second stage and enhance payload capacity.

In 1975, the Long March 2C rocket conducted its first launch. From 1982, it achieved 11 consecutive successful launches at the Jiuquan Satellite Launch Center. On August 5, 1987, the Long March 2C launched China's ninth recoverable satellite, successfully carrying two microgravity experimental devices from France's Matra Company, which safely returned on August 10. This was the first time that China Great Wall Industry Corporation provided satellite payload services to foreign customers.

In 1993, the CZ-2C was modified with an extended second stage and an "intelligent distributor" based on mission needs, resulting in the CZ-2CSD variant. The CZ-2CSD successfully launched two simulated Iridium satellites into their designated orbits on September 1, 1997. Over the following three years, it launched 12 Iridium global communication satellites for Motorola using dual-satellite launch configurations at the Taiyuan Satellite Launch Center. In 2003, the improved Long March 2C model rocket was used for China's European double-star project. The CZ-2C rocket continues to be used, although a launch on August 18, 2011, failed to deliver the Shijian 11-04 satellite into orbit due to a connection failure between the servo mechanism and the second stage YF-20B engine during the later ascent phase.

To launch a new generation of communication satellites and participate actively in the international commercial launch market, the CZ-2E, using advanced bundling technology, was developed starting in 1986. This rocket comprises a core stage and four liquid rocket boosters. The core stage's first and second stages were extended by 4.6 meters and 5.2 meters, respectively, based on the CZ-2C rocket. The Long March 2E rocket is 51.2 meters long, with a core diameter of 3.35 meters. Each booster is 2.25 meters in diameter and 15 meters high. The entire rocket has a lift-off mass of 462 tons and a lift-off thrust of 640 tons, capable of placing a 9.2-ton payload into a 200-kilometer circular orbit. The rocket's upper end is equipped with a fairing with a maximum diameter of 4.2 meters, accommodating large satellites or other payloads. If equipped with a solid engine upper stage, it can place 2.5 to 4 tons of payload into a Geostationary Transfer Orbit (GTO) 36,000 kilometers above the Earth. On July 16, 1990, the CZ-2E made its maiden flight at the Xichang Satellite Launch Center, successfully launching the Australis-OSCAR and Pakistan satellites into their designated orbits. By December 28, 1995, the CZ-2E had conducted seven international commercial launches, five of which were successful, and two failed.

To support China's manned spaceflight program, the CZ-2E was modified and upgraded to the CZ-2F in 1992. On November 20, 1999, it successfully launched China's



first experimental spacecraft, "Shenzhou 1", into space. The new rocket featured an escape tower. In case of an accident on the launch pad or within the first two minutes of flight, the rocket escape system will activate by deploying the fairing and grid fins, firing the escape tower to rapidly pull away the Shenzhou spacecraft, utilizing the attitude control engine to change angles and escape the danger zone. Once at a certain altitude, the return capsule carrying the astronauts will separate, while the remaining parts continue to fly. If the launch proceeds smoothly, the normal trajectory to orbit takes 586 seconds, after which the Beijing Ground Control Center takes over mission control. The escape tower separates at 120 seconds, the boosters are jettisoned at 160 seconds, and the fairing separates at 212 seconds. To perform the "Tiangong" missions, the CZ-2F's payload capacity was increased to 8.8 tons. The Long March 2F has successfully launched the "Shenzhou" series of spacecraft multiple times, becoming a star rocket in China's Long March series.

Unlike other "Long March 2" variants, the "Long March 2D" (CZ-2D) rocket was developed by the Shanghai Academy of Spaceflight Technology, based on the first and second stages of the "Long March 4" rocket. It is a two-stage liquid rocket with a launch thrust of 300 tons, capable of launching single or multiple satellites into Low Earth Orbit (LEO) and Sun-Synchronous Orbit (SSO). It has a payload capacity of 4 tons to LEO and 1.3 tons to 700-kilometer SSO, characterized by high reliability, high safety, low cost, and short launch cycles. The CZ-2D successfully completed its maiden launch in August 1992. The CZ-2D rocket has undertaken various domestic and international satellite launch missions, with high accuracy and a 100% success rate, making it the fastest-launching liquid rocket model in China's active fleet.

Long March 3 Series (CZ-3)

The Long March 3 (CZ-3) is a three-stage liquid launch vehicle developed by China in the 1970s and 1980s. In 1978, to launch geostationary payloads, China began producing the CZ-3 based on the first and second stages of the CZ-2C, adding a hydrogen-oxygen third stage. The CZ-3 conducted its maiden flight on January 29, 1984, but the satellite failed to reach orbit due to a third-stage malfunction. On April 8 of the same year, the CZ-3 successfully launched China's first communication satellite, Dong Fang Hong 2, into orbit. The CZ-3 is primarily used for launching domestic and international communication and meteorological satellites. The CZ-3 represents a significant milestone in China's rocket development history. It was the first Chinese rocket to use liquid hydrogen and liquid oxygen as propellants for the third stage, achieve multiple rocket ignitions, and send payloads into Geostationary Transfer Orbits. The successful development of the CZ-3 made China the fourth country in the world with the capability to launch geostationary satellites. After completing 13 missions, the rocket was retired in 2000 after launching the



"Fengyun-2" meteorological satellite.

The CZ-3 was later succeeded by the CZ-3A, the powerful CZ-3B, and the latest CZ-3C. The CZ-3A, introduced after 1994, significantly improved performance and could send about 2.6 tons of payload into geostationary orbit. It features an extended first stage and a more powerful third stage, which was completely redesigned with two YF-75 engines (the CZ-3 only had one). The third stage also has 10 small engines for propellant management and attitude control during the coasting phase. The CZ-3A has been used to launch communication and navigation satellites. On October 24, 2007, the CZ-3A successfully launched China's first lunar probe, Chang'e 1, into its intended orbit.

In 1993, the CZ-3B was developed using the CZ-3A rocket as its core stage, with four liquid rocket boosters strapped around the first stage. This increased the payload capacity to Geostationary Transfer Orbit to 4.8-5.5 tons, making it the most powerful Chinese rocket at the time. The CZ-3B's maiden flight in 1996, intended to launch the International 708 communications satellite, failed due to a component failure that caused the inertial reference to tilt, leading to incorrect attitude correction and resulting in the rocket crashing 22 seconds after liftoff. After this failure, the China Academy of Launch Vehicle Technology spent more than six months investigating the failure, and conducting verification tests, to improve the rocket. In 1997, the second CZ-3B successfully launched the Mabuhay satellite for the Philippines, manufactured by the American company Loral, into a high orbit far from Earth. On April 25, 2008, it successfully launched the Tianlian data relay satellite, later used for the Beidou and Chang'e-2 lunar missions. The CZ-3B has since become China's main workforce for commercial launches.

Building on the CZ-3B, China developed a new upper stage called the "Yuanzheng" (YZ), which successfully launched the Beidou navigation satellite on March 30, 2015. It performed a series of maneuvers over six hours, allowing multiple payloads to be deployed and multiple restarts. The YZ upper stage comes in four versions: standard, upgraded, enhanced, and commercial. The initial YZ-1 upper stage, although capable of only two starts, could reduce the time from launch to operational orbit from several days to just over five hours without using the satellite's fuel. The YZ-1A, based on the mature technology of the YZ-1 upper stage, is fully upgraded, capable of 20 restarts, completing multiple satellite deployments in different orbits with a working time of more than 40 hours. It successfully flew for the first time on June 25, 2016. The YZ-2, another series of the Yuanzheng family, with a diameter of 3.8 meters and two engines, has a higher carrying capacity for direct multi-satellite high orbit missions, successfully flying for the first time on November 3, 2016. The YZ-1S commercial upper stage, optimized from the YZ-1 upper stage, completes its mission in less than an hour after separation from the primary stage with significantly reduced weight and cost, making it more competitive in the market.

At the end of 2016, another new model, the Yuanzheng-3 (YZ-3) upper stage, was



developed based on the CZ-2D. It has the capability for more than 20 independent rapid orbit maneuvers and deployments. On December 29, 2018, after entering a 190-kilometer parking orbit, the YZ-3 maneuvered to 515-525 kilometers, 50 degrees inclination, where it deployed the "Hongyan" communication test satellite and three "Yunhai-2" meteorological satellites. It then performed two more burns, maneuvering to 1090-1100 kilometers, 50 degrees inclination, where it deployed three more "Yunhai-2" satellites.

The CZ-3C is based on the Long March 3A (CZ-3A) and the Long March 2E (CZ-2E) rockets, using the CZ-3A as its core stage, with four 2.25-meter diameter liquid boosters attached, similar to the CZ-2E. The core stage is 1.5 meters longer than the CZ-3A, and it has a payload capacity of 3.9 tons to Geostationary Transfer Orbit.

Long March 4 Series (CZ-4)

The CZ-4 is a three-stage conventional liquid launch vehicle developed by the Shanghai Academy of Spaceflight Technology in 1979, based on the "Storm-1" rocket, for launching geostationary satellites. Feasibility studies began in 1982. After the CZ-3 successfully launched the Dong Fang Hong 2 communications satellite on April 8, 1984, the CZ-4 adjusted its development plan and launch target, switching to launching Sun-Synchronous Orbit satellites.

The CZ-4 rocket was developed by improving the first and second stages of the CZ-3 rocket and adding a new third stage. All stages use nitrogen tetroxide and unsymmetrical dimethylhydrazine as propellants. The second stage is identical to the CZ-3's second stage, while the first stage's propellant tank is extended by 4 meters, adding 40 tons of propellant. The total ground thrust of the four first-stage engines increased from 2746 kN to 2942 kN. The third stage engine, composed of two independently operating single engines in parallel, is the first high-performance conventional propellant upper stage engine developed in China, with a single engine thrust of 49 kN, and a specific impulse of 2971 m/s. Each engine is capable of swinging along two mutually perpendicular directions with a maximum swing angle of 4.5 degrees, allowing two starts in a vacuum. The third stage engine uses a radiation-cooled niobium alloy nozzle extension, leading in specific impulse and thrust-to-weight ratio among Chinese conventional propellant engines. The third stage propulsion system employs a full-time constant pressure helium pressurization and main and auxiliary pressurization pipeline schemes. The third stage propellant tank uses a high-strength aluminum single-layer thin-wall common-bottom structure, with the fuel tank at the front and the oxidizer tank at the rear, and a common bottom convex towards the fuel tank. The attitude control engine system uses a surface tension tank, with anhydrous hydrazine as the propellant, for velocity correction and attitude control during coasting after engine shutdown.

On September 7, 1988, the CZ-4 rocket successfully launched China's first



experimental meteorological satellite, "Fengyun-1," into a Sun-Synchronous Orbit from the Taiyuan Satellite Launch Center. Subsequently, the CZ-4 was used for launching the China-Brazil Earth Resources Satellite (CBERS) and resource satellites. After 1998, the CZ-4 was replaced by the improved CZ-4B rocket with higher carrying capacity, which sent the third polar meteorological satellite (Fengyun 1-3) into orbit and carried the small scientific satellite "Shijian-5". It has a carrying capacity of 4.2 tons to Low Earth Orbit, 2.8 tons to polar orbit, and Sun-Synchronous Orbit (SSO) capacity increased from 1.5 tons to 1.9 tons. The CZ-4C, based on the CZ-4B, added a secondary restart capability to the third stage, increasing the Sun-Synchronous Transfer Orbit capacity to 2.8 tons. The CZ-4C made its maiden flight on April 27, 2006, successfully launching China's first remote sensing satellite into its intended orbit from the Taiyuan Satellite Launch Center.

The CZ-4 series rockets have high reliability, better cost-effectiveness, and extensive applications, suitable for launching sun-synchronous and polar orbit payloads, and can also undertake Geostationary Transfer Orbit payload launches from any of China's satellite launch centers. They are the main vehicles for launching various application satellites into sun-synchronous and polar orbits in China. The CZ-4 rockets have two different diameter fairings to accommodate different payload sizes and masses. They also have multi-satellite launch technology, allowing one rocket to launch multiple satellites.

Words and Expressions

reconnaissance	侦察
configuration	构型
interstage	级间段
intertank section	箱间段
recoverable satellite	返回卫星
modified	改造
Iridium satellite	铱星
servo mechanism	伺服系统
booster	助推器
lift-off mass	起飞质量
fairing	整流罩
escape tower	逃逸塔
launch pad	发射台
flame-retardant panel	阻燃板
trajectory	轨道
Low Earth Orbit	低地球轨道
Sun-Synchronous Orbit	太阳同步轨道
Geostationary Transfer Orbit	地球同步转移轨道
inertial reference to tilt	惯性基准倾斜
maneuver	机动



Nitrogen Tetroxide	四氧化二氮
Unsymmetrical Dimethylhydrazine	偏二甲肼
perpendicular	垂直
radiation-cooled	辐射冷却
niobium alloy nozzle	铌合金喷管
helium pressurization	氦气增压
pressurization pipeline	增压管
high-strength	高强度
aluminum single-layer	铝单层
common-bottom structure	共底结构
convex toward	凸面朝向
surface tension tank	表面张力贮箱

Terms

1. China Academy of Launch Vehicle Technology 中国运载火箭技术研究院
2. Shanghai Academy of Spaceflight Technology 上海航天技术研究院

Discussion Suggestions

1. Searching more information on Dongfeng I-IV and present your understanding of them in class.
2. How does the Dongfeng IV finally evolve into CZ-2? Please draw a map to demonstrate your understanding.
3. One of the principles of developing launch vehicles is modularization design. You are required to use CZ-2, CZ-3, CZ-4 as a case to illustrate your understanding of the modularization design.



Text B Rocket Governing Laws^{*}

The operation of rocket engines and motors and the vehicles that they propel are primarily governed by Newton's laws of motion.

Newton's first law, often called the law of inertia, states that there is no change in the motion of a body unless a resultant force acts on it. A number of forces act on a launch vehicle throughout its flight. The gravitational force (weight of the vehicle), lift, drag, and the thrust of the rocket engine all act on the vehicle to cause the resultant motion. The net amount of the resultant force and its direction determine the acceleration of the vehicle and the path of the flight trajectory, in accordance with Newton's second law.

Newton's second law of motion states that whenever a net (unbalanced) force acts on a body, it will produce an acceleration in the direction of the force; the acceleration is directly proportional to the force and inversely proportional to the mass of the body:

$$a = F/m \quad (1-1)$$

This relationship is more typically seen in the form

$$F = ma \quad (1-2)$$

As stated in the definition, a rocket develops its thrust by expelling a mass rearward. Examining this in the context of this equation, a mass is accelerated rearward by some means that accelerates its velocity from near zero to thousands of meters per second. The force for this acceleration is proportional to the mass of the exhaust gases and the acceleration per Newton's second law. The force acting on the exhaust gases is in the direction of the accelerating mass, but produces a thrust in accordance with Newton's third law, which states that for every acting force, there is a reacting force that is equal in magnitude but opposite in direction. Therefore, the force of accelerating the fluid internal to the rocket has an equal but opposite external force which is the thrust produced by the rocket.

The magnitude of this force (thrust) can be determined by examining the change of momentum in the device and the sum of the forces that act on a closed duct or control volume, as shown in Figure 1.1. The flow internal to the rocket experiences a change of momentum that is equal to the mass flow rate times the change in velocity of the gases:

$$\Delta_{\text{momentum}} = \dot{m} (V_{\text{exit}} - V_{\text{inlet}}) \quad (1-3)$$

Assuming that the inlet velocity into the device is low, the momentum at the inlet can be considered negligible. Thus, the momentum change is

$$\Delta_{\text{momentum}} = \dot{m} V_{\text{exit}} \quad (1-4)$$

The sum of all pressures on the surfaces perpendicular to the flow axis of the device

^{*} This text is adapted from the book: MARK H. Encyclopedia of space science and technology[M]. New Jersey: John Wiley & Sons, 2003:359-366.

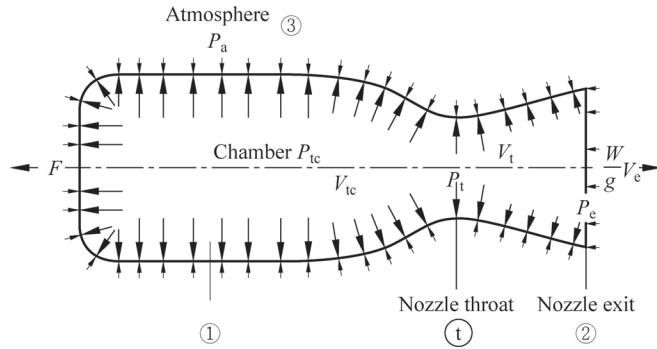


Figure 1.1 Pressure balance on the rocket chamber and nozzle wall

reduces to a resultant force due to the pressure differential between the pressure at the nozzle exit plane and the ambient pressure that acts on the exit area of the nozzle:

$$\text{Net pressure force} = (p_{\text{exit}} - p_{\text{amb}})A_{\text{exit}} \quad (1-5)$$

The sum of the forces that act on a rocket is equal to the change of momentum in accordance with Newton's second law. By combining Equations (1-4) and (1-5) and rearranging the terms, we develop the following expression for the thrust of a rocket:

$$\text{Thrust} = \dot{m}V_{\text{exit}} + (p_{\text{exit}} - p_{\text{amb}})A_{\text{exit}} \quad (1-6)$$

When p_{exit} equals p_{amb} , expansion is optimum and performance best. When the nozzle exit pressure is less than ambient, the nozzle is said to be over-expanded. If exit pressure is greater than ambient, the nozzle is said to be under-expanded. Because the rocket, generally, flies through the atmosphere, it experiences variations in the ambient pressure, so it operates at optimum expansion at only one altitude. The choice of the rocket exit area ratio then becomes the result of trading off a number of design and flight considerations.

Newton's laws are applied to analyze the acceleration of a vehicle propelled by a rocket as well. Examining vehicle flight in a vacuum free of gravitational forces, the rocket produces an unbalanced force and a resultant acceleration in accordance with Newton's second law. Here, it is written in a way slightly different from that in Equation (1-2). The thrust is the net accelerating force that is equal to the instantaneous mass of the vehicle, and its instantaneous acceleration is written as the time rate of change of the velocity:

$$F = M \frac{dV}{dt} \quad (1-7)$$

The thrust of the rocket F can also be expressed in terms of the mass flow rate $\dot{m}$ from the rocket and its effective exhaust velocity V_e assuming that nozzle exit pressure equals the ambient from Equation(1-6):

$$F = \dot{m}V_e \quad (1-8)$$

where