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SUPERENGINEERING

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The “Tiangong” Chinese Space Station project

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1 Introduction

The overall plan of the Chinese Space Station (CSS) project focuses on the grand goal of building a space station with Chinese characteristics, and adheres to the following basic principles: conforming to China’s national conditions; building a station with modest scale and leaving room for extension; constructing a station with outstanding Chinese elements and core connotations; embodying the strategic goals of national development and driving innovation and development; pursuing technological advancement by employing modern advanced technologies to build and operate the CSS and mastering the construction and operation technology of large space facilities; focusing on the application efficiency for major innovation and technological achievements in the space application field; pursuing economical operations; and taking the road of sustainable development.

The CSS is a manned space station, which will be operating in near-Earth orbit for the long-term. The station is named “Tiangong.” It consists of three modules: the core module (CM), experimental module I (EM I), and experimental module II (EM II). It provides three docking ports and can support the docking and berthing of manned spacecraft, cargo ships, and other visiting spacecraft (Fig. 1). Its running orbit is a nearly circular orbit with an inclination of 42°–43° and a height of 340–450 km. The three-module combination configuration has a mass of about 66 t and a crew of three persons for the long-term but only six persons during crew rotation for the short-term. The installation and support capabilities of payloads are more than 10 t. The design lifetime is not less than 10 years, with the ability to extend service life through maintenance and repair and the ability to expand. The three modules are all launched by the Long March 5B launch vehicle at the Hainan launch site.

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The transportation of crew to the station and back to the ground is completed by the Shenzhou manned spacecraft which is launched at the Jiuquan launch site using Long March 2F launch vehicle, with a transportation ability of three astronauts each time. The cargo transportation is completed by the Tianzhou-1 cargo ship, which is launched at the Hainan launch site using the Long March 7 launch vehicle. It can deliver supplies for astronauts, propellants, payload equipment, and other materials and destroy the station’s wastes through re-entry (Fig. 2).

An optical module is designed for common-orbit flight with the station, with the ability to implement astronomical observations and ground observations. It can dock to the space station for maintenance and propellant refueling for a short time period.

2 Basic design of the “Tiangong” Chinese Space Station

2.1 Overall configuration

The basic configuration of the space station is a T-shape configuration consisting of three modules: the CM, EM I, and EM II. The CM is in the center, whereas the EM I and EM II are permanently berthed on each side of the CM. The manned spaceship and cargo ship will dock to the front and back ports of the CM, respectively (Fig. 3).

The CM, named “Tianhe,” is the management and control center of the station. It is responsible for the unified management and control of the space station. It is used for rendezvous and docking of spacecraft such as EMs, manned spacecraft, and cargo ships. It accepts the astronaut’s long-term visits and payload supplies, and it is equipped with a robotic arm to support the astronaut’s extravehicular activity (EVA).

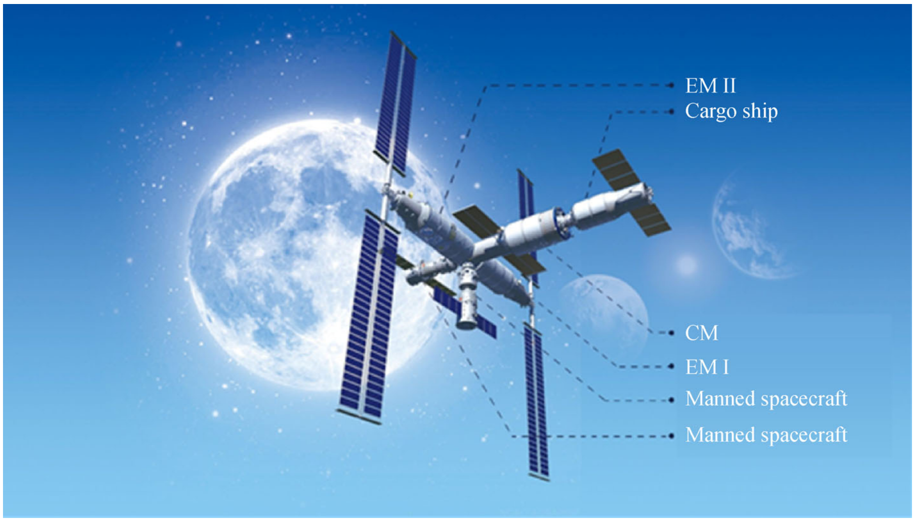

Fig. 1 "Tiangong" Chinese Space Station

Fig. 2 Tianzhou-1 cargo ship was launched using LM 7 rocket at Hainan launch site on April 20, 2017

The EM I is named "Wentian." It backs up part of the key platform functions of the CM and has the capability of unified management and control of the space station. It is equipped with a special airlock module for EVA. Both internal and external payload experiments are conducted, and the external experimental payloads are operated by the EM I's robotic arm.

The EM II is named "Mengtian," and it is used to carry out internal and external experiments. A cargo airlock is configured for loading in and out payloads of the cabin.

2.2 Construction of the CSS

The basic three-module configuration of the space station is completed by docking and relocating of modules. The EM I and EM II are docked to the front axial port of the node module of the CM and then transferred to the left and right sides of the node module by relocating operations to form the basic three-module configuration.

Without a large transport vehicle such as the space shuttle, the assembly and construction of the space station with a modular and partial truss configuration are completed by RVD and relocation of modules. The overall configuration and construction mode of the CSS is different from that of the Mir and International Space Station (ISS). It has significant Chinese characteristics and utilizes a highly economical and rational construction method for constructing large-scale space facilities.

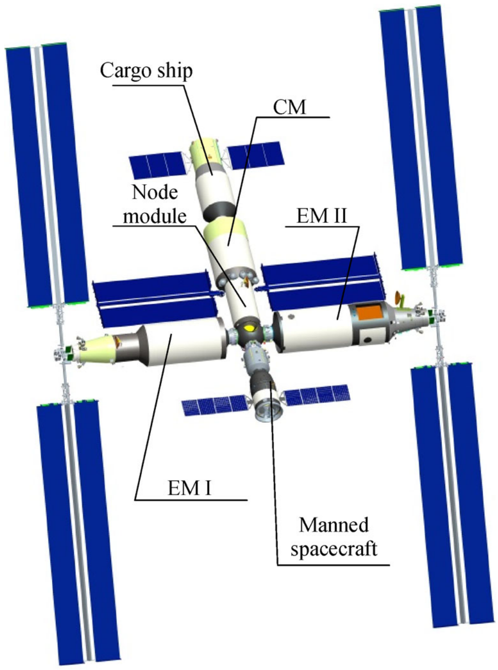

Fig. 3 Basic configuration of the CSS

2.3 Main technologies of the space station

2.3.1 Environmental control and life support of the station

The station adopts a materialized regeneration life support system to realize the recycling of resources. The regenerative life support system includes electrolytic oxygen production, regenerative carbon dioxide removal, trace harmful gas absorption, condensate water collection and treatment, and urine collection and treatment. The unified control of the gas composition, pressure, temperature, and humidity inside the cabin, as well as water recovery management, microbiological control, and waste management, are performed by the CM. The station is also equipped with a certain number of non-recycled life insurance items for emergency maintenance and maintenance. The use of regeneration and health protection technology will realize the recycling of resources and significantly reduce the demand for freight security. During the operation stage, carbon dioxide reduction technologies and waste treatment and reuse technologies will also be developed to further improve the level and efficiency of recycling.

2.3.2 Power supply of the station

The space station's power system uses a three-junction gallium arsenide solar array with a conversion efficiency of more than 30% to generate electricity and employs lithium-ion batteries for power storage. The single degree-of-freedom flexible solar array is used in the CM to provide energy supply during the single-cabin flight. The EMs adopt a two degrees-of-freedom flexible solar array, which is oriented to the sun through a drive mechanism. The solar arrays are maintainable in orbit. The space station uses a 100 V fully adjusted multi-bus system, which is managed by the unified energy management of the CM and provides a certain amount of power to the docked manned spacecraft, cargo ship, and optical module.

2.3.3 Dynamics and control of the station

The attitude of the space station is controlled by using the control moment gyro as the main control method and the propulsion control as the auxiliary control method. The attitude stability is 0.005°/s. After the construction of the station, the attitude control does not consume the propellant in the normal configuration. The space station

Fig. 4 Core module of the CSS

engine nozzles are uniformly configured and coordinated to work together with the docked cargo spacecraft to improve the redundancy, reliability, and longevity of the control system. Electric propulsion technology is used on the space station to compensate for the impact of atmospheric resistance, and the demand for propellant supply maintained by the orbit is substantially reduced.

2.3.4 Information system of the station

The station uses the latest information technology to construct a unified information system. On the basis of network technology, the management and sharing of the information between each module in the space station and visiting spacecraft are realized, and related equipment is used for system reconstruction. Wireless mobile communication networks and video monitoring systems are deployed inside and outside the space station to enhance communication, life, and work, as well as to sense the state of the cabins of the astronauts. The transmission, measurement and control of information adopt a unified design between the space and the ground, and use space-based network as the major communication method. The monitoring and control equipment and the communication equipment in each module are jointly used to ensure the coverage of measurement and control communications under various flight attitudes. The equipment can also enhance the interoperability and efficiency of observation, control, communication, and network interaction between the space and ground.

2.3.5 EVAs of the station

The space station can support two astronauts’ EVAs simultaneously. During the single-cabin flight of the CM, the node module is used as the air lock module. After the EM I is docked, the special-purpose airlock module of the EM I is used, and the CM’s node module is used as backup.

The space station has one large robotic arm in the CM and a small robotic arm in the EM I. The two arms can work independently, or they can work together as a single unit. The robotic arms can complete tasks such as module capture, transfer, equipment installation, maintenance, replacement, load operation, astronaut’s transfer, and external status monitoring. With the support of astronauts, EVA suits, and cargo ships, the station can complete operations of large-scale space facilities and complex external construction tasks.

2.3.6 Resident and work supply for astronauts

The space station is equipped with long-term living facilities for three astronauts. It can support up to six astronauts during the crew rotation period for a short-term, including drinking and eating, bathroom, and collection and disposal of garbage. The free space for astronaut movement is about 110 m^3. The atmosphere inside the cabin is the same oxygen–nitrogen mixed gas and pressure system as the ground. It adopts noise reduction and sound insulation design to reduce cabin noise and provides astronauts with convenient, reliable, and highly automated display, lighting, alarm, and operation systems. The station is equipped with various tool, handrails, and other communication facilities to efficiently ensure that astronauts complete the tasks of station management, construction, maintenance and repair, material transfer, EVA operations, and operation of scientific and technological experiments.

2.3.7 Space station extension

The space station allows module extension, energy extension, and external experiment extension. A new module with a node bay needs to be launched for module extension, and the additional docking ports can be used for extension. A priority plan for the energy extension of the space station is to transfer and install the solar arrays of the CM (covered during assembly) on the trusses of the EM I and II, effectively reusing the space station resources. The CM, EM I, and EM II reserve interfaces for the external experimental platform and load hanging points to extend the external experiments.

The space station can extend three modules and four large-scale external experiment platforms. Moreover, large external payloads can be hung outside. The total mass after extension is 180 t. The space station extension configuration is shown in Fig. 5, where A, B, and C are extended modules.

The extension capability of the CSS leaves a flexible development space for the new needs of space sciences and technologies in the operation phase. It also provides the opportunity for international cooperation and further improves the application efficiency of the space station.

3 Development and mission planning

The assembly and construction tasks of the space station are divided into the key technology verification phase, assembly construction phase, and operation phase.

In the key technology verification phase, the test CM, manned spacecraft, and cargo ships are launched to verify the propellant refueling technology, regenerative life support technology, solar cell and drive mechanisms, controls of a large station, space station assembly and construction technology, EVA technology, in-orbit maintenance technology, and other key technologies. They can also verify the platform’s functions and the ability to

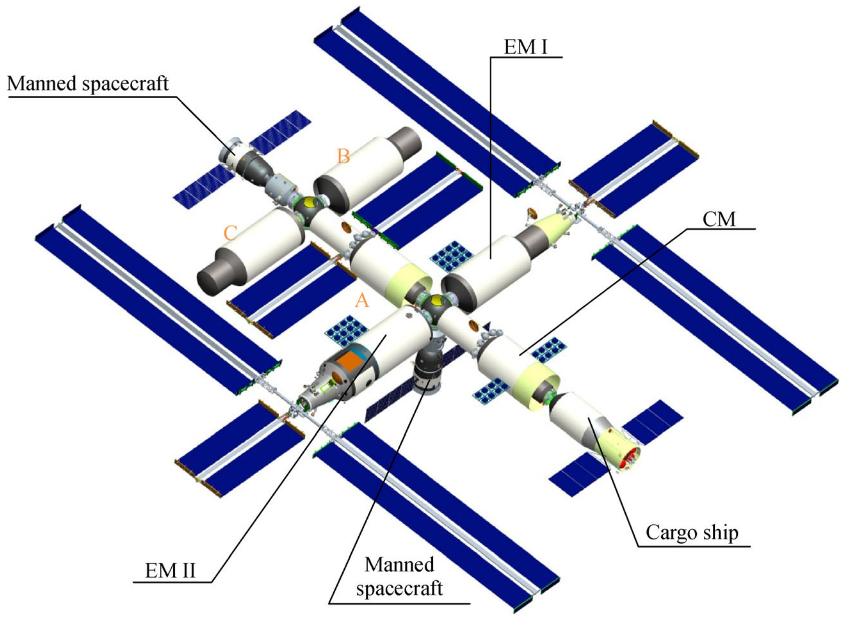

Fig. 5 Extended configuration of CSS

support the long-term residence of astronauts.

In the construction phase, the EM I and EM II are respectively launched and docked to complete the construction of the space station. During this period, the Shenzhou manned spacecrafts and cargo ships will be launched to support the completion of construction tasks. Scientific and technological experiments will be conducted simultaneously.

After the construction phase of the space station is completed, it enters the long-term operation and management phase. The astronaut crew will live and work in the station for a long time period and carry out scientific and technological research and exploration activities. The extension of the station and replacement of application payloads will be conducted when necessary.

4 Space station features

Except for scale, the CSS's payload weight ratio is 17.7%, which is higher than ISS's 7.9%. The load power supply ratio is 44.4%, which is comparable with the ISS. The station can supply power to the manned spaceship, cargo ship, and optical module. The power provided by the space station platform to other spacecraft is 63%, whereas the power consumption of the platform itself is only 37%, which is better than that of the ISS. The power/weight ratio is 0.41 kW/t, which exceeds that of the ISS (0.26 kW/t). The station provides 10 Gb network transmission between modules for scientific experimental payloads. The total downlink rate is 1.2 Gbps, of which 1.1 Gbps is used for scientific experiments, which is far more than the 100 Mbps downstream data transmission rate of the ISS. Therefore, the support capacity of scientific experiments will be maximized on the CSS which is smaller than the ISS.

All the spacecrafts and module sections are developed by Chinese companies independently, which adopt a standardized, modular, and integrated design scheme. The generalization rate of equipment in each module section is 80%, with all the components and raw materials self-controllable. Advanced information technology can be used to achieve system reconstruction between modules, which greatly improves the reliability and safety of the space station. The use of intelligent control technology and independent health management system improves the level of space station health management and reduces the workload of astronauts and ground controls. The use of physical and biological regenerative technology will better realize the recycling of resources and greatly reduce the costs of supplements and operations.

The CSS has also established a "space home port" mode. The space station is used as a homeport in space, and it is in common orbit with the optical module. The optical module will dock to the space station for replenishment and maintenance when needed, giving full play to people's advantages in space and extending the in-orbit service of high-value space facilities by the astronauts and the space station. In the future, more spacecraft will be developed to operate in the common orbit with the space station to form a Chinese in-orbit formation flight model, which will lead the future development of space-based on-orbit service technology.

In summary, after the completion of the CSS, all aspects of control, information, power supply, resource recycling, material supply requirements, operating costs, and application efficiency will reach the level of contemporary international advanced level and surpass it in some aspects. The station will become economical and reasonable to operate.

The space station aims to build a national space laboratory. It will provide scientists in China and around the world with an advanced space science, technology research, and experimental platform and create favorable conditions for major achievements in space science and applications. It is expected to obtain research results with major scientific value and strategic significance in scientific fields such as physics, astronomy, materials, biology, earth observation, information, and aerospace.