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China's Recoverable Satellites and Their Onboard Experiments

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Abstract Twenty-three recoverable satellites have been successfully launched in China since 1975. A number of microgravity experiments were successfully performed by utilizing the piggyback capability of the satellite together with other tasks of the previous flights. This paper presents firstly an overview of the recoverable satellite development in China. Main characteristics of Chinese recoverable satellites and the onboard scientific experiments are then discussed. The environment, support, and the interface between the working payload and satellite during different design and manufacture phases are also briefly described, followed by future trends of platform technology and potential applications.

Keywords Recoverable satellite · Satellite platform · Microgravity experiment in space

Historical Development of the Chinese Recoverable Satellite

China's recoverable satellite program was started in the early 1970s. Since then, 23 recoverable satellites have been launched and recovered successfully. Six models of recoverable satellites were developed, they are:

- The first generation recoverable satellites for general land survey (FSW-0);
- The first generation recoverable satellites for space mapping (FSW-1);
- The second generation recoverable satellites for general land survey (FSW-2);
- The second generation recoverable satellites for space mapping (FSW-3);
- The recoverable satellites for detailed domestic land survey (FSW-4);
- ShiJian-8 (SJ-8) satellite for seed breeding and microgravity experiments.

In the past 30 years, China's recoverable satellites were engaged in land survey, river and coast monitoring, and other tasks. The remote sensing data obtained by these missions have been used widely in the city planning, water conservation and geological prospecting. In addition to the main tasks of remote sensing, recoverable satellites have also carried out a series of scientific experiments which successfully utilized the piggyback capability since the late 1980s. Fruitful results of the space microgravity experiments were obtained.

Scientific Experiments on Board the First 17 Recoverable Satellites

Both active and passive space experiments were carried out on board recoverable satellites. There are two types of active experiments: the experiments conducted autonomously without electric interface with satellite platform; and the experiments conducted with power supply, telecommand, and telemetry by satellite platform. The later has more complicated mechanical interface, electrical interface and technology protocol with platform. Active scientific experiments, including space life science experiments, space material science experiments and new technology

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demonstration tests on satellite application, were performed on FSW-0, FSW-1 and FSW-2.

Space Life Science Experiments

Five life science experiments were completed on board the recoverable satellites. Three experiments of them were focused on protein crystal growth in space, and one of them performed on board the FSW-1 in 1988 was devoted by a German team and other two launched by the FSW-2 in 1992 and 1996 respectively were developed by the Chinese Academy of Sciences (CAS). There were two experiments on the cell cultivation and the microbe cultivation respectively in space.

The protein crystal growth experiment was conducted by the Institute of Biophysics, CAS. The space equipment consisted of a protein crystal growth component, an electronic control box and a battery set was developed by the Shanghai Institute of Technical Physics, CAS. The results showed that, better protein crystallizations were achieved in six out of ten sets of protein samples. The crystallization rate was comparably higher than the similar experiments on the ground.

A German payload on board the FSW-1 was provided by MBB. The equipment was calibrated by the German team before the launch. All experiments were conducted automatically in orbit without any intervene from the satellite. The equipments were then handed over to MBB after the recovery, and the results of the experiment were satisfactory.

The cell culture experiment was in charge by the Institute of Zoology, CAS. The equipments consisted of a bioreactor, a control unit and a battery set. The bioreactor and control unit were built by the Shanghai Institute of Technical Physics, CAS. Experimental data showed that, the system worked properly in orbit, and the experiment was successful.

The microbial cultivation experiment was devoted by the Institute of Microbiology, CAS, Institute of Plant Physiology and Ecology, CAS and Institute of Genetics, CAS. The equipments consisted of a microbe cultivation device, an electronic control device and a battery set. The results showed that all microbial samples were alive. Great improvement was obtained after temperature control is implemented in comparison with the previous experiments without enzyme activity.

Space Material Experiment

During this period, two space material experiments were conducted to test the crystal growth of two semiconductors: Gallium Arsenide (GaAs) and HgCdTe. In total seven experiments (one on board the FSW-0, four on FSW-1, 2 on FSW-2) for GaAs and one experiment (on FSW-2) for HgCdTe were conducted. The semiconductor materials were prepared by the Institute of Semiconductors, CAS. The equipments for the experiment consisted of a Crystal Oven, an electronic control device, a storage device and a battery set, was made by the Lanzhou Institute of Physics, CAST (China Aerospace Science and Technology Corporation). All equipment worked properly during orbital flights.

Experiments on Applied Satellite Technology

In total, three microgravity measurement experiments were conducted, one by MATRA company of French (on board the FSW-0 in 1987) and two by Lanzhou Institute of Physics, CAST (on FSW-1, 1990 and FSW-2, 1994). The equipments for the experiments consisted of a microgravity meter, a microgravity telemetry device and a battery set. The microgravity meter was made by Lanzhou Institute of Physics; the microgravity telemetry device was provided by the Institute of Spacecraft System Engineering. Concrete data of the microgravity environment in the FSW-2 were obtained.

Scientific Experiments on FSW-3, SJ-8

To fully utilize the extra capabilities of payload space, power supply and TT&C in the FSW-3 and SJ-8 satellites, several additional scientific experiments were conducted onboard in addition to fulfil the satellite's main task.

Microgravity Experiments on Board the FSW-3 in 2003

The FSW-3(03) is the 22nd recoverable satellite, launched on August 29, 2005. The following four microgravity scientific experiments were carried out:

- Boiling heat transfer of space pool;
- Thermal capillary transfer of air bubble;
- Characteristic experiment of the interface between liquid and solid and the surface of melt mass in space;
- Cell cultivation experiment in space.

In order to complete above experiments, a common service system was developed by the CAS, including a controller and a recorder. The recorder was used to record the engineering parameters and the image data. The total weight of the experiment equipment is 57 kg and the total power consumption is 1,320 Wh. All of the required scientific experimental data were acquired successfully.

Microgravity Experiments on Board the SJ-8

China's 23rd recoverable satellite SJ-8 is a scientific experiment satellite. It was launched successfully by LM-2C rocket from Jiuquan Satellite Launch Centre (JSLC) on September 9, 2006. The satellite's recovery capsule was ecovered in Sichuan after 15 days in space. In addition to seeds mutation experiments of primary task of the SJ-8 in space, a series of

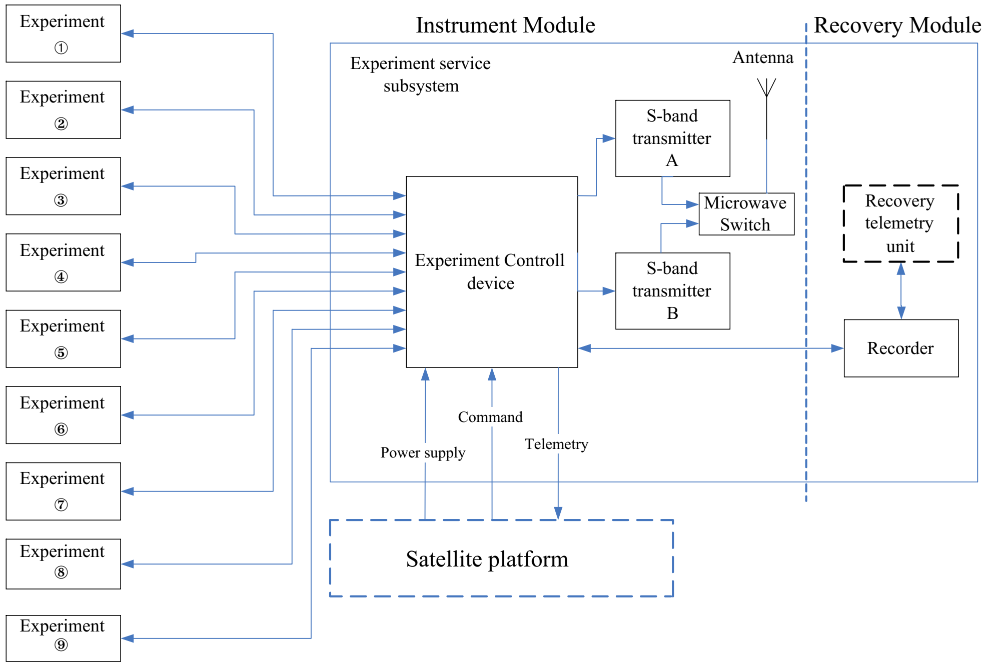

Fig. 1 Block diagram of the microgravity experiment system

piggyback microgravity experiments were also successfully conducted on it. Those experiments were as follows:

① Mass transfer in microgravity environment;
② Embryo cell cultivation;
③ The behavior of granular media in microgravity;
④ Study of surface deformation and volume effect of thermocapillary;
⑤ Study on fire initiation of wire insulation at microgravity;
⑥ Study on pool boiling heat transfer in microgravity;
⑦ Higher plant cultivation on-board;
⑧ Microgravity smoldering combustion experiments;
⑨ Space test of spring accelerometer.

Microgravity experiments consisted of nine payloads and a service component. In total there were 14 pieces of equipment controlled by one central payload controller, which had only one interface with the satellite platform for control and telemetry. Payload power was provided by two platform batteries. All commands for controlling the internal subsystems were issued by the payload control device. Figure 1 is a block diagram of the microgravity experiment system.

The microgravity experiments, conducted onboard during orbit flight, were performed separately in a time sequence as shown in Fig. 2. All nine experiments successfully recorded the output data and were completed according to the schedule.

Scientific Experiments on Board SJ-10 Satellite

According to China's space science program, the SJ-10 recoverable satellite will be launched in 2010. The mission of the launch is for space scientific experiments, including microgravity experiments and life science experiments. Twenty research projects will be chosen in the field of

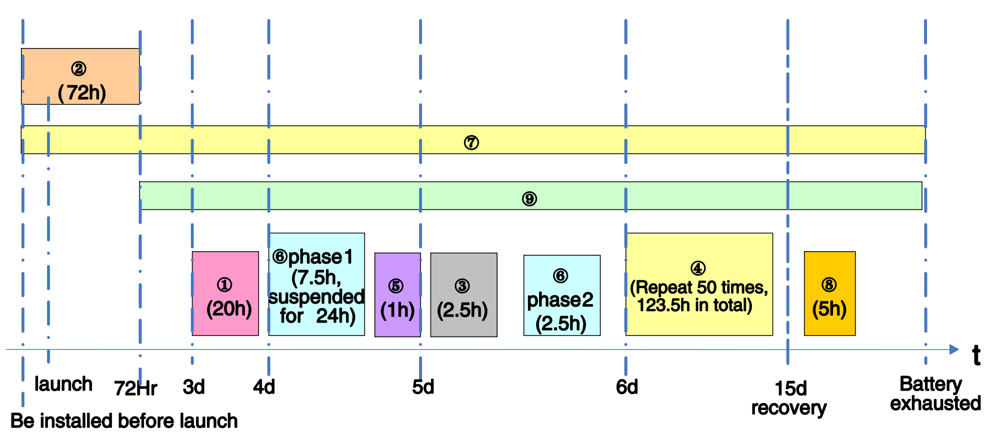

Fig. 2 Task sequence for microgravity experiment, where mass transfer in microgravity environment, embryo cell cultivation, the behavior of granular media in microgravity, surface deformation and volume effect of thermocapillary, fire initiation of wire insulation at microgravity, pool boiling heat transfer in microgravity, higher plant cultivation on-board, microgravity smoldering combustion experiments, space test of spring accelerometer

microgravity fluid physics, microgravity combustion, space materials science, fundamental space physics, space biotechnology, biological effect of gravity and biological effects of radiation. The research projects will be chosen according to their impact in their own fields.

Capability of Recoverable Satellite

Performing scientific experiment onboard recoverable satellite platform is a mature technology. Compatibility between the satellite and the experiment equipments can be achieved by modifications to the design of the original satellite platform to meet the scientific experiment requirements. The following data are based on SJ-8.

General Performance and Parameters

- Flight duration: 15 days;
- Total mass of the satellite: <3,600 kg;
- Launch vehicle: CZ-2;
- Launch sites: Jiuquan, Gansu Province;
- Recover site: Suining, Sichuan Province;
- Perigee altitude: 170~200 km;
- Apogee altitude: 350~400 km;
- Inclination: 63°~65°;
- Period: about 90 min;
- Microgravity level: 10^{-3}~10^{-5} g;
- Earth oriented, three-axis altitude stabilized.

Satellite System Configuration

The satellite comprises two modules: pressurized module (sealed) and recovery capsule (non-sealed). Payloads can be fixed in recovery module or pressurized module based on its requirements of recovery. Figure 3 is the typical configuration of a recoverable satellite.

After completing in-orbit scheduled tasks, the satellite conducts attitude adjustment, and separates the recovery capsule and pressurized module; the recovery capsule escapes from original operation orbit and enters atmosphere; and the pressurized module continues to be in-orbit and carries on the other experiments.

Interface of Satellite and Payload

System Capability

- Volume and weight requirements to payload
  Pressurized module has a volume capacity of 0.9 m^3 and has a weight capacity of 600 kg (including battery set); Recovery capsule can hold payload of 0.45 m^3 in volume and 250 kg in weight.

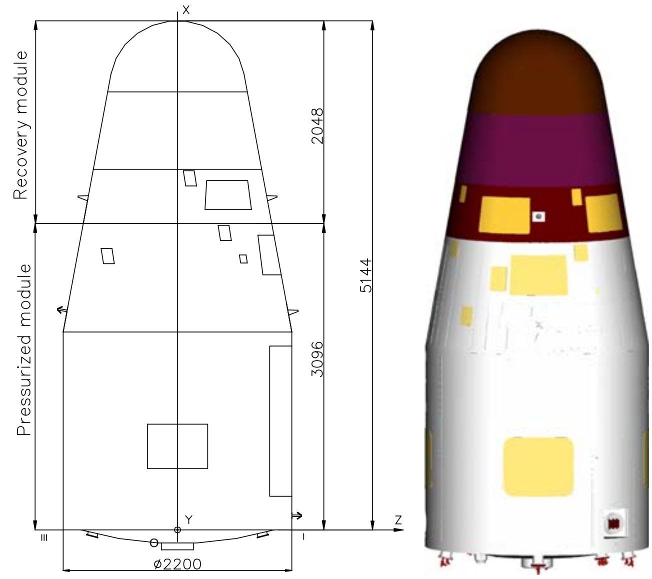

Fig. 3 Satellite configuration

- Flight duration
  Projects to be recovered are usually required to be finished within 15 days, though certain degree of freedom can be arranged upon the requirement by customer. Projects which only need to use the pressurized module can last until the pressurized module battery runs out, which usually takes about 18 days.

Power Supply

All onboard power comes from battery. The onboard battery outputs are rated at 28 or 12 V in voltage. The voltage and current supplied to the payload can also be adjusted according to customer requirements. Electrical interface is provided by the satellite manufacture. The technical details must be approved by both parties to accommodate the experiment requirements.

Onboard Environment in Orbit

The satellite can sustain a temperature range between 10~30°C to payload. Factors such as payload energy consumption, working time duration and the thermal character of payload all affect the actual temperature. The pressure normally falls into the range of 30~60 kPa in pressurized module and 10^{-9}~10^{-5} Pa in recovery capsule.

Capability of TT&C and Communication

- Telemetry service
  Real-time or delayed telemetry to parameters such as electrical voltage, current, temperature air pressure, on-off status, and digital parameters can be provided to

customers. These services are available to customers six orbit circles per day.

▪ Data transmission service

The satellite provides high speed digital data download capability to customers who need large amount of experiment data (such as video footages and images). Data is transmitted in S band and the bit rate is 8 Mbps. The downloading time available to customers is 20–30 min per day.

▪ Remote manipulation

During satellite in-orbit operation, remote manipulation can be conducted through two modes: direct command and program control command.

When the satellite enters observation arc of domestic TT&C station, real-time telecommand is available for onboard payloads; no real-time telecommand is available outside this observation arc. However, the uplink data, including the commands and the sequence can be transmitted to the satellite when the satellite is within observation arc, and the commands can be implemented when the satellite is outside the observation arc.

Satellite Development and Manufacture Procedures

A satellite development and manufacture normally consists of the following phases:

1. Preliminary definition phase
   During this phase, both parties need to submit:
   - Technical requirement to satellite for payload;
   - Interface specification between satellite and payload;
   - Technical plan for loading payload.
2. Subsystem Design and Manufacture Phase
   Customer should complete all the design, manufacturing, and unit tests of the payload equipments.
3. Satellite assembly phase
   During this phase, customer should deliver on time the payload equipments to participate satellite assembly and integration.
4. Factory integration test phase
   The satellite is tested with the payload as an integral part of the entire system.
5. Launching site integration and test phase
   Complete the payload equipment test in satellite level and pre-launch preparation
6. Satellite launching/in-orbit operation/recovery phases

During orbit flight, monitoring and control of onboard experiments are done jointly by the customer and satellite monitoring and control team. Upon landing, after satellite team finishing processing the landing scene, the experiment sample is taken out from recovery capsule and signed out to customer.

Prospect for Future Scientific Experiment Satellite

Capability of Satellite Platform

To fulfil the need of the scientific research community, the new generation of recoverable satellite systems is designed to have vastly increased capability in the aspects of energy supply, control, data management, structure and thermal control. The goal is to carry more payloads, maintain a better microgravity environment and provide longer flight time in order to obtain more and better results for the scientific research community.

International Collaboration

Currently, microgravity environment can be achieved using a number of methods such as tower dropping, parabolic aircraft flights, sounding rocket, satellite, space ship and space station. Among these methods, tower dropping can only provide a microgravity period of several seconds; parabolic flight airplane can provide about 10 min; space orbital vehicle such as satellite, space ship and space station is the ideal provider of longer microgravity period since it can maintain microgravity environment for weeks or months. As a satellite is of relatively low cost, has a relatively higher microgravity level and simple to launch, the prospect for international collaboration on using the recoverable satellite in microgravity scientific experiment is very promising and suitable.

Conclusions

China's effort on conducting scientific experiments through either piggyback payload or special designed scientific experimental satellite has been a great success.

1. The needs for scientific experiment are taken into consideration in all areas of satellite design such as general satellite configuration, components assembly, control command, telemetry channel, electrical test, launching and landing.
2. The design guideline is "one satellite for multiple purposes and customers", which ensures that the utilization of the satellite onboard resources and flight time is optimal. In many times, conducting multiple scientific experiments in a piggyback manner, while the satellite continues to finish its main task, achieves the same results as launching separate satellites.
3. Improving technical capability, conducting microgravity science and technology experiment and international collaboration are the focal points for future recoverable satellites.