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by

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DEVELOPMENT OF CHINA'S RECOVERABLE SATELLITES

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ABSTRACT

From 1975 to 1994 China has successfully developed three models of recoverable satellites - the FSW-0, FSW-1 and FSW-2. Nine FSW-0 satellites have been successfully launched and recovered. Five FSW-1 satellites were all successfully launched and recovered with the exception of FSW-1-5 which was not successfully recovered. Two FSW-2 satellites were successfully launched and recovered. Launch weight of these satellites has increased from 1,970 kilograms of the FSW-0-1 to 2,760 kilograms of the FSW-2-2. Duration ranged from three days of the FSW-0-1 to 16 days of the FSW-2-1. The service missions of these satellites has constantly increased. The FSW-2 is a multiple applications satellite, with space science experiments and technology experiments.

1. Introduction

The space activities of mankind can be divided into two major categories. The first category includes activities aimed at the exploration and knowledge of outer space. The other category is the development and application of this space datal. Within this first category, in addition to sending back all sorts of information collected for processing, analysis and study, under many conditions, it also includes sampling in space and the transport of experimental objects into space for experiments and the recovery of samples and test objects for analysis and study. In Within the activities of development and application of space data, in addition to the collection, transmission and relay of information, objects used in space experiments, preparation and production must all be recovered in order to be of real value. When large amounts of information are collected and it is not possible to transmit or receive this information, information is often stored on some medium (film, magnetic disk, or laser disk), and the information medium is returned from space to the surface where it can be removed. Whether it be recovery of samples from space, bringing back tested objects, recovering tested, prepared and produced objects or recovering information mediums, they all require the use of recoverable satellites. Therefore, recoverable satellites have an important place in space science and technology and in promoting advances in science and technology.

In the sixties China recognized this importance of recoverable satellites, and in 1966 began development space recovery technology and recoverable satellites. In 1975 China successfully launched its first recoverable satellite, becoming the third nation after the former Soviet Union and the United States to launch a recoverable satellite (at the present time, these three nations are still the only three with this capability). By 1993 na had launched three models of recoverable satellites, the FSW-0, FSW-1 and FSW-2 satellites. between 1975 and 1994 it launched a total of 16 recoverable satellites (see Table 1). These 16 satellites, with the exception of FSW-1-5 which is still in an orbit higher than the planned orbit because of an abnormal attitude, the other 15 satellites have all been recovered, with a success rate of 94 percent.

Table 1. Primary parameters of China's recoverable satellites

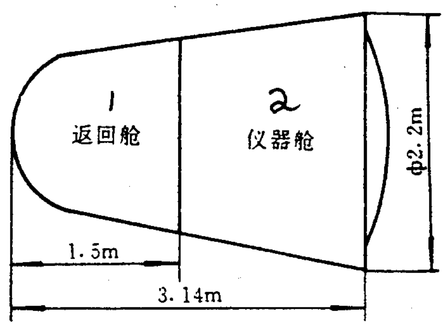
1 卫星序号	2 发射日期	3 返回日期	起飞质量 4/kg	返回质量 5/kg	近地点 6/km	远地点 7/km	周 期 8/min	倾角 9/(°)
FSW-0-1	1975-11-26	1975-11-29	1790	600	181	495	91.2	63.0
FSW-0-2	1976-12-07	1976-12-10	1790	600	172	492	91.2	59.5
FSW-0-3	1978-01-26	1978-01-29	1810	650	169	488	91.0	57.0
FSW-0-4	1982-09-09	1982-09-14	1780	610	177	407	90.2	63.0
FSW-0-5	1983-08-19	1983-08-24	1840	630	175	404	90.2	63.3
FSW-0-6	1984-09-12	1984-09-17	1810	620	178	415	90.3	68.0
FSW-0-7	1985-10-21	1985-10-26	1810	620	175	409	90.2	63.0
FSW-0-8	1986-10-06	1986-10-11	1770	610	176	402	90.2	57.0
FSW-0-9	1987-08-05	1987-08-10	1810	650	172	410	90.2	63.0
FSW-1-1	1987-09-09	1987-09-17	2070	610	208	323	89.7	63.0
FSW-1-2	1988-08-05	1988-08-13	2130	640	208	326	89.7	62.8
FSW-1-3	1990-10-05	1990-10-13	2080	650	206	308	89.6	57.1
FSW-2-1	1992-08-09	1992-08-25	2590	640	175	353	89.1	63.1
FSW-1-4	1992-10-06	1992-10-13	2060	600	211	315	89.8	63.0
FSW-1-5	1993-10-08	未返回	2100	(应) 650	214	317	89.6	56.9
FSW-2-2	1994-07-03	1994-07-18	2760	770	178	333	89.5	62.9

1. Satellite number. 2. Date launched. 3. Date recovered. 4. Launch weight (kg). 4. Recovery weight (kg). 5. Recovery weight. 6. Perigee (km). 7. Apogee (km). 8. Time of orbit (min). 9. Angle of inclination (°).

2. FSW-0 recoverable satellites

The primary missions of the FSW-0 satellites were earth surveillance and space science and technology experiments. Only the recovery module was recovered, and the remaining portions remained in orbit. The satellite is shown in Figure 1.

Fig. 1. The FSW-0 satellite

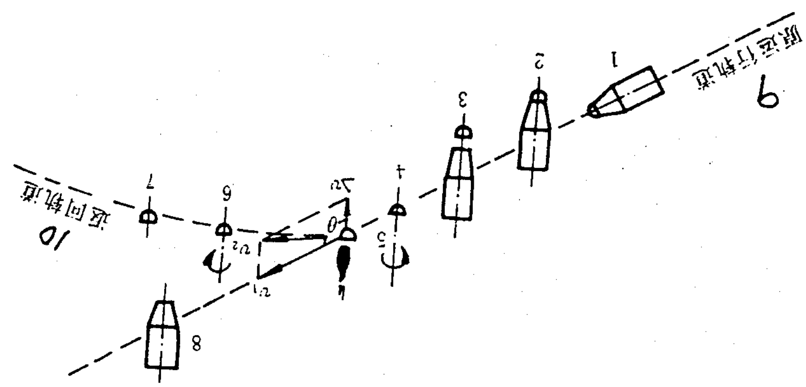


1. Recovery capsule. 2. Instrument capsule.

After the satellites completed their orbital earth survey and experiment missions, the instrument capsule separated from the recovery capsule, and the recovery capsule which contained the observation information medium and experimental objects used retro rockets to generate braking velocity Δv to alter its orbit, leaving its original operating orbit and entering a recovery orbit for reentry into the atmosphere and toward the surface of the earth, as shown in Figure 2.

The FSW-0 satellite was composed of 13 subsystems including the satellite structural platform, the earth survey effective load, the science and technology experiment effective load, the heat control, the attitude control, the sequence control, the remote control instructions, the capsule pressure control, the telemetry, the tracking and metering, the electrical power source and distribution, the recovery and parachute. A total of nine of these satellites were launched, and all nine were recovered. The primary parameters of these satellites are provided in Table 2.

Fig. 2. Recovery capsule leaving its orbit.



1. Satellite travelling along its orbit. 2. Adjustment to recovery attitude. 3. Separation of recovery capsule and instrument capsule. 4. Recovery capsule stabilized attitude. 5. Retro rockets operate. 6. Self spinning stabilization. 7. Recovery capsule descends along recovery orbit. 8. Instrument capsule along original orbit. 9. Original orbit. 10. Recovery orbit.

Table 2. Primary parameters of FSW-0, FSW-1 and FSW-2

1 项 目		FSW-0	FSW-1	FSW-2
2 卫星质量/kg		1800	2100	2800～3100
3 卫星容积/m^3		7.6	7.6	12.8
4 卫星有效载荷质量	5 返回有效载荷/kg	260	260	400
	6 不返回有效载荷/kg	340	450	500～600
7 轨道运行时间/d		3～5	8	15～17
8 微重力量级/g_0		$10^{-3}\sim10^{-5}$	$10^{-3}\sim10^{-5}$	$10^{-3}\sim10^{-5}$
9 轨道倾角/(°)		57～68	57～70	57～70
10 近地点高度/km		172～180	200～210	175～200
11 远地点高度/km		400～500	300～400	300～400
12 轨道周期/min		～90	～90	～90

1. Item. 2. Weight. 3. Volume. 4. Effective load weight. 5. Recovery load. 6. Non-recovery load. 7. Time in orbit (days). 8. Magnitude of low gravity. 9. Orbit angle. 10. Perigee. 11. Apogee. 12. Length of orbit (min).

The FSW-0 satellites were launched using a Changzheng-2C (CZ-2C) rocket from the launch site at Jiuquan in northwest China. The CZ-2C is a two stage liquid fuel rocket. It uses N_2O_4 and UDMH as the oxidizing agent and fuel. The primary parameters of the CZ-2C rocket are shown in Table 3.

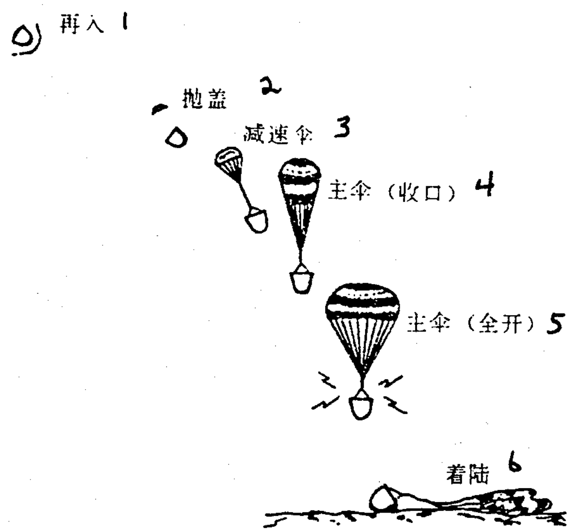
Tab. 3. Primary parameters of the CZ-2C

1 项 目	2 参 数
3 火箭总长/m	34.50
4 火箭直径/m	3.35
5 起飞质量/t	192
6 起飞推力/kN	2747
7 低轨道运载能力/kg	2800
8 燃料剂	UDMH
9 氧化剂	N_2O_4

1. Item. 2. Parameter. 3. Rocket total length (m). 4. Diameter of rocket (m). 5. Launch weight (tons). 6. Launch thrust (kN). 7. Low orbit carrying capacity. 8. Fuel. 7. Oxidizing agent.

While the FSW-0 satellites were operating and during the recovery process, metering and control was carried out at the Xian Control Center.

Fig. 3. Recovery capsule reentry, deceleration and landing



1. Reentry. 2. Hatch ejection. 3. Deceleration chute. 4. Main chute (not fully deployed). 5. Main chute (fully deployed). 6. Landing.

3. The FSW-1 recoverable satellites

China is a very large country, with a land surface of 960X104km_2 and territorial waters of more than 30 million square kilometers with hundreds of islands and a very long sea coast. It borders 15 different countries including Russia. Using traditional manual survey and mapping methods, it would take dozens of years to compile a map of china. Using human methods primarily assisted by aerial surveys, a map of china would take 20 to 30 years. Both these methods require the matching up of many small pieces, and each time a piece is matched up it can cause error. With many of these areas being difficult to enter and cover, mapping has to be done using extrapolation. Therefore, even though human and aerial surveys require a great deal of effort, material and capital, and take a long time and are very difficult, the map of China which is obtained is less than ideal, and cannot meet requirements.

In order to basically solve this problem, China developed the FSW-1 land mapping satellite, applying space technology for orbital mapping of China. The FSW-1 was first successfully launched in September of 1987, allowing China's mapping enterprises to become greatly modernized overnight. The time required to compile a map was reduced by one order of magnitude. The scale and precision were greatly improved. At the same time, this also solved the problem of not being able to enter or cover certain areas by human or aerial surveys.

Compared to the FSW-0 satellite, the primary parameters of the FSW-1 satellite were: The time in orbit was extended from three to five days to eight days. The orbit perigee was increased slightly, and the apogee was reduced, making the orbit more circular. The satellite overall weight was increased from 1800 kilograms to 2100 kilograms. The satellite precision of satellite down-looking and rolling was improved from better than 1° to better than 0.7°. The course deviation attitude was improved from better than 2.2° to better than 1°. There were also improvements in orbital measurement precision and landing point spread. All of these improvements were conducted to meet cartographic requirements.

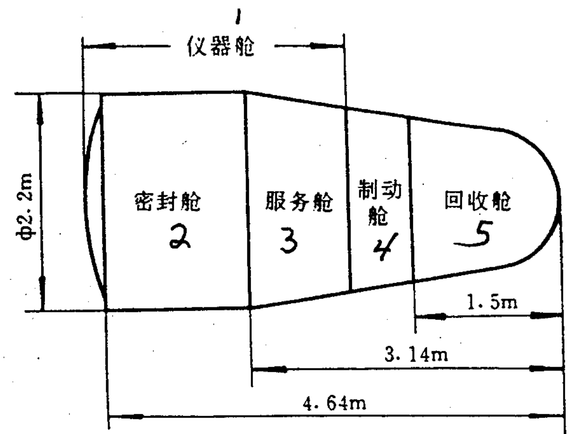
The FSW-1 satellite was first successfully launched in 1987, and a total of five had been launched by 1993. The first four satellites successfully completed their missions, and the final satellite was not recovered because of a malfunction in the attitude control system. All five satellites were launched using he Changzheng-2C rocket from the Jiuquan launch site. The Xian Control Center was responsible for instrumentation and control during operation and recovery.

4. The FSW-2 recoverable satellites

The FSW-2 recoverable satellites are a new earth survey and space science and technology experiment satellite. They were developed to meet the expanded needs of advanced technology. This model satellite had improved information collection capacity, expanded space science and technology experiments, increased orbital life, increased earth survey coverage and reduced recovery capsule landing point dispersion in order to meet these increased requirements. Compared to the FSW-0 satellite, this model satellite required the development of new high information collection volume earth survey equipment, increased information carriers, additional orbital control subsystems, more precise positional control subsystems and improved reliability of all subsystems. All of this made demands on increasing the overall weight and dimensions of the satellite and improving the precision of instrumentation and control. The increase in satellite weight also required increased rocket thrust. In this manner, the development of the FSW-2 satellite was not merely a problem of satellite development, but became satellite engineering problem of developing a FSW-2 satellite. That is, while developing the satellite, its rocket and its instrumentation and control system all had to be developed at the same time.

The FSW-2 recoverable satellite was a further development on the basis of the FSW-0 and FSW-1 satellites. Its overall structure was composed of the FSW-0 satellite platform with an additional 2.2m diameter by 1.5 meter cylinder (see Figure 4).

Fig. 4. The FSW-2 satellite

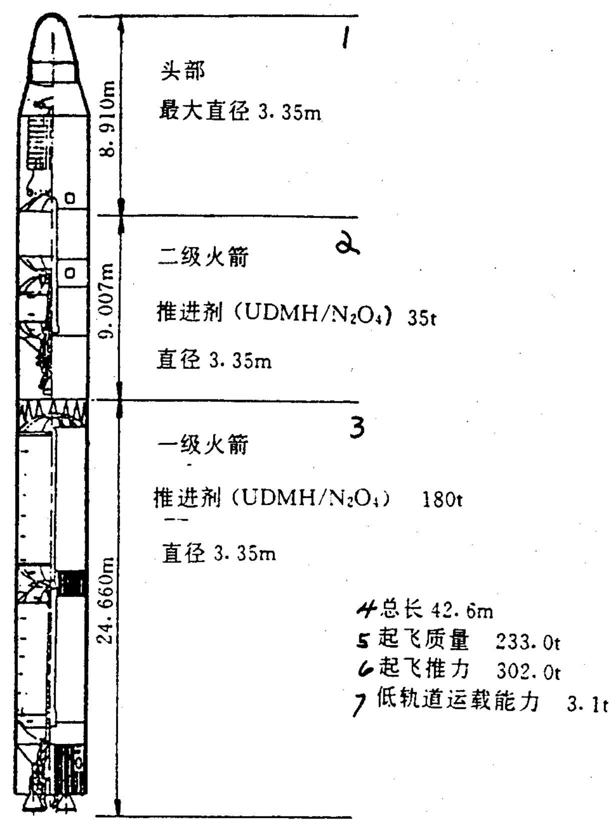


1. Instrument capsule. 2. Sealed capsule. 3. Service capsule. 4. Braking capsule. 5. Recovery capsule.

Compared to the FSW-0 satellite, the primary parameters of the FSW-2 satellite were: The satellite weight was increased from 1800 kilograms to 2800 to 3100 kilograms, and the effective load was also greatly increased. The orbit operational life was twice that of the FSW-1. The landing spread was reduced. In addition, the FSW-2 also had a certain orbital mobility. Its positional control precision, down-look and roll were all improved to better than 0.5°. Course deviation was improved to better than 0.7°.

The rocket for the FSW-2 was the Changzheng-2D (CZ-2D) which was developed on the basis of the Changzheng-2C. Its structure is shown in Figure 5. Figure five also provides the primary parameters of the CZ-2D. The CZ-2D was also launched at the Jiuquan launch site, and could use the launch facilities for the CZ-2C. The instrumentation and control of the FSW-2 satellite during operations and recovery were conducted by the Xian Control Center.

Fig. 5. The Changzheng-2D rocket



1. Nose. Greatest diameter 3.35 Meters. 2. Second stage rocket. Fuel was 35 tons of ($UDMH/N_2O_4$). Diameter 3.35 meters. 3. First stage rocket. Fuel was 180 tons of ($UNMH/N22O_4$). Diameter 3.35 meters. 4. Total length 42.6 meters. 5. Launch weight 233.0 tons. 6. Launch thrust 302.0 tons. 7. Can carry a 3.1 ton payload into low orbit.

5. The science and technology experiments of China's recoverable satellites

Using recoverable satellites to conduct space science and technology experiments not only collects experimental data, but can also recover the equipment and objects of the experiment after the experiment is over. This special capability is of great value for science and technology experiments. China's recoverable satellites naturally generated a low gravity environment in orbit, of the magnitude of $10^{-3}g_0$ and $10^{-5}g_0$. This environment can be viewed as a valuable space resource. Since the satellite recovery capsule can bring back to earth the objects tested, prepared and manufactured in low gravity experiments. Therefore, China's recoverable satellites are a highly valuable space science and technology experiment tool. The use of recoverable satellites for space science and technology experiments in order to promote the development of space science and technology is a major reason for China making the early development of this type of satellite a high priority.

Space science and technology experiments are one of the two major missions of China's recoverable satellites. The science and technology experiment payload and the earth observation payload were separated. Each was an individual payload subsystem. The science and technology experiment mission was further divided into two types. In the first type, the experimental equipment and the objects of the experiments were both carried aboard as effective payload. In this type, the effective payloads were independent systems, and as long as they fit within the weight, dimension and mechanics and heat environment limitations, they could be loaded aboard the satellite for experiments. The space science experiments and new technology, new equipment and new instrument experiments mostly used this type. The other type was isolated. When using this type for space experiments, the effective payload of the experiments were added to the overall design of the satellite as subsystems, with the ports and connections with their related systems.

Since 1975, China has conducted hundreds of space science and technology experiments on recoverable satellites, achieving a number of successes in many areas. Below we will merely list the space experiments conducted on the FSW-1-1 in September of 1987. Table 4 shows the low gravity materials scientific experiments conducted on this satellite. The dimensions and property parameters of the materials experiment equipment (crystal oven) are given in Table 5. In addition to space materials experiments, this satellite also carried about 30 objects of experiments including plant seeds, microorganisms, bugs and high energy ion detectors.

Table 4. Space materials equipment experiments on the FSW-1-1

1 试验项目	2 用户单位	3 样品尺寸 mm	4 要求温度 ℃	5 冷却速度 ℃/mm	6 试验种类
7 砷化镓	8 中科院	φ17×130	1250	0.2	9 微重力下定向生长单晶
10 碲镉汞	11 航天部	φ13×18	830	0.2	
12 锑化铟	13 兰州大学	φ10×60	580	0.5	
14 钇钡铜	11 航天部	φ10×50	900～800	15 慢冷	16 微重力下固气反应
17 钇钡铜	11 航天部	φ10×50	780～800	15 慢冷	
试验项目	用户单位	样品尺寸 mm	要求温度 ℃	冷却速度 ℃/mm	试验种类
18 铝—铌	8 中科院	φ9×45	730	19 快冷	20 微重力下的合金重熔凝固
21 铋—镓	8 中科院	φ9×45	400	19 快冷	
22 锂—铝	11 航空部	φ9×45	730	23 无要求	
24 铝—铅 锌—铅	11 航天部	φ10×50	680	23 无要求	
25 镉—铟	11 航天部	φ10×50	30	15 慢冷	26 液/液界面

1. Experiment. 2. Customer. 3. Sample dimensions. 4. Required temperature. 5. Cooling rate. 6. Category of experiment. 7. Gallium arsenide. 8. China Academy of Science. 9. Directional crystal growth under conditions of low gravity. 10. Mercury cadmium terruride. 11. Ministry of Space. 12. Indium Antimonide. 13. Lanzhou University. 14. Yttrium-barium-copper. 15. Slow cooling. 16. Solid-gas reaction under conditions of low gravity. 17. Yttrium-barium-copper. 18. Aluminum-niobium. 19. Rapid cooling. 20. Low gravity remelting and solidification of alloys. 21. Bismuth-gallium. 22. Lithium-aluminum. 23. No requirements. 24. Aluminum-lead, Zinc-lead. 25. Cadmium-Indium.

Table 5. Parameters of the crystal furnace aboard the FSW-1-1

1 炉体性能	2 数 值
3 炉膛中心最高温度/C	1300
4 生长速率/(cm/h)	1.2
5 有效容积/mm	ф164×200
6 最大加热电流/A	5.6
7 平均加热功率/W	120
8 能耗/(A·h)	6.7
9 工作时间/min	90
10 炉外壳最高温度/C	36
11 外形尺寸/mm	250×230×275
12 安装尺寸/mm	218×110×ф9
13 质量/kg	11

1. Furnace property. 2. Numerical value. 3. Highest temperature at center of chamber (C). 4. Growth rate (cm/h). 5. Effective volume (mm). 6. Maximum heating current (A). 7. Average heating power (W). 8. Energy consumption (A•h). 9. Operating time (min). 10. Maximum temperature of outside of furnace (C). 11. Outside dimensions (mm). 12. Installed dimensions (mm). 13. Weight (kg).

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