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CHANG'E-2 SATELLITE LAGRANGE L2 POINT MISSION

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Chang'e-2 is the second lunar probe of China. It was launched on Oct 1st 2010. It has successfully finished the nominal mission before April 1st 2011. In its extended mission, on June 9th 2011, Chang'e-2 escaped from lunar orbit, and transferred to the Sun-Earth Lagrange L2 Point. After nearly 3 months journey, the probe successfully entered into the L2 point Lissajous orbit on August 25th 2011. Chang'e-2 was the first Sun-Earth Lagrange L2 point mission of China. And it was also the first probe in the world, which escaped from the lunar orbit and transferred to the Lagrange L2 Point.

In this paper, the design and implementation of Chang'e-2 Sun-Earth Lagrange L2 point mission is introduced. Firstly, lunar mission of the Chang'e-2 is introduced briefly, and the probe's subsystem and status in the extend mission phase are also introduced. Secondly, the goals of the extend mission are discussed, the background of the mission and the alternative plans are also introduced. Thirdly, two kinds of libration point orbits (Halo orbit and Lissajous orbit) are discussed. Mission analysis and design are introduced, including how to design libration transfer orbit when considering the probe circling in the lunar orbit, cruise attitude, space environment, thermal control, telecommunication link budget, ΔV budget and so on. Fourthly, the Sun-Earth Lagrange L2 point mission profile is introduced. The Chang'e-2 escaped from the lunar orbit after two maneuvers. In the cruise phase, only two mid-course maneuvers were executed, the other 3 planned maneuvers were cancelled for accurately orbit determination and orbit control. Finally, the current status and the future mission of Chang'e-2 are discussed.

I. INTRODUCTION

Since the success of Chang'e-1, the technical modification for Chang'e-2 has been completed for the new mission goals. Chang'e-2 was developed as a technical demonstration probe for the second phase of China's Lunar Exploration Program. Chang'e-2 was successfully launched on Oct.1st, 2010 from Xichang Satellite Launch Center. It was inserted into lunar orbit on Oct 6th 2010, and entered in mission orbit on Oct 9th 2010. Chang'e-2 finished the nominal mission goals before April 1st 2011, including six key technologies for lunar exploration, high resolution 3D image and datum about the elements and distribution of different materials on lunar surface. In the extended mission phase, Chang'e-2 finished the first Lagrange L2 point mission of China. This paper involves the mission analysis, mission profile, mission implementation and so on.

The extended mission was taken into account before Chang'e-2 was launched. Chang'e-2 was launched by LM-3C instead of LM-3A, the probe was launched directly into the Earth-Lunar transfer orbit. Chang'e-2 took more propellant than Chang'e-1, the launch mass was increased from 2350kg to 2480kg. At the end of the mission, there was still almost 500kg propellant for extended mission.

	Chang'e-1	Chang'e-2
Launch Vehicle	LM-3A	LM-3C
Launch Mass	2350kg	2480kg
Launch Trajectory	S-GTO	Earth-Lunar transfer orbit
i (deg)	1.85	1.30
T (years)	1.88	11.86

Table 1: differences between Chang'e-1 and Chang'e-2 on Launch

II. MISSION OBJECTIVES

After Chang'e-2 finished the nominal mission on the lunar orbit, the scientists and engineers began to discuss the mission objects of chang'e-2 in the extended stage seriously. Several mission objects were mentioned and discussed:

- (1) Guided to crash the Moon
- (2) Trying to get the image of the Chang'e-1 crashing site
- (3) Return to the Earth
- (4) Near Earth asteroid exploration
- (5) Sun-Earth Lagrange L2 point exploration

At last, as we all know, the "Sun-Earth Lagrange L2 point exploration" was confirmed as the mission objective of chang'e-2 in the extended mission.

The main technique objective for the new mission is transferring from lunar orbit to Sun-Earth Lagrange L2 point. Another target is helping assess the capability of two large deep space telecommunications ground antennas in China. One ground antenna, 115 feet (35 meters) in diameter, is being built at Kashgar in the northwest. The second antenna is nearly twice the size, with a diameter of nearly 210 feet (64 meters), and is being built at Jiamusi in the northeast. These antennas will be part of China's deep space network.

In scientific exploration, Chang'e-2 new position allows it tackle two scientific objectives: observing the Earth's magneto tail on Sun-Earth Lagrange L2 point, charting Solar X-ray Burst and Gamma Ray Burst.

III. MISSION ANALYSIS AND DESIGN

III.1 Mission Orbit

For the restricted three-body system, there are five libration points to be found in the vicinity of two orbiting masses. The term "restricted" refers to the condition that two of the masses are very much heavier than the third. So in the Sun-Earth system there are also five libration points as show in Fig1.

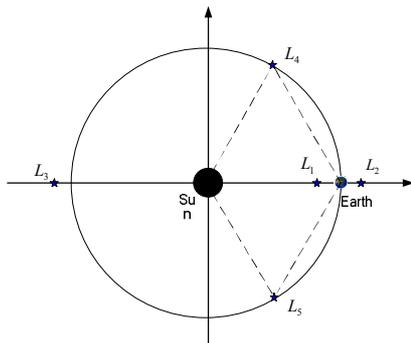


Fig. 1: Position of Sun-Earth Lagrange Point

Chang'e-2 was placed in the orbit about the Sun-Earth L2 libration point located 1.5 millions kilometers from the Earth backward the Sun. And Chang'e-2 was the first probe, which escaped from the lunar orbit and transferred to the Lagrange L2 Point.

The orbit around libration point is generally referred to as halo orbit or Lissajous orbit, and Lissajous orbit is a more common type for libration point. As to Chang'e-2, to avoid the lunar eclipse it should escape from Moon before Jun 16th, 2011. Another restriction, we should take into account, is the deltaV requirement. In the extended mission, decreasing the velocity increments requirement was top-priority. Orbit design result shows that there were only 3~5days escaping windows at the end of May for Halo orbit. However, Lissajous orbit provided more chances. Before Jun 12th, there were several escaping windows satisfying the limited

increments requirement. At last, Lissajous orbit was chosen as the mission orbit about Sun-Earth L2 point.

III.2 Escaping Strategy

To decrease the gravity loss, the escaping progress should be divided into several orbit maneuvers. At the beginning of the orbit design, the escaping progress was divided into three steps. Firstly the probe was accelerated to 3.5 hours orbit; secondly, to 12 hours orbit; lastly escaped from the moon.

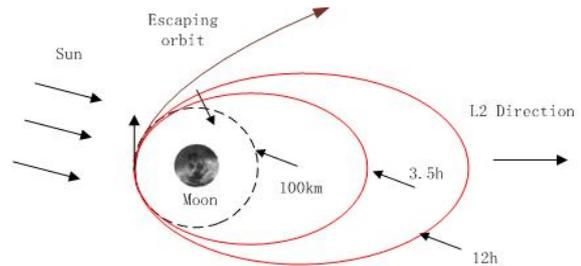


Fig. 2: Escaping Strategy I

After analyzing the escaping strategy mentioned above, the shadow time was unaccepted, and to 12 hours orbit, the shadow time lasted almost 2 hours. The relation between orbit period and shadow time is show in Fig 3.

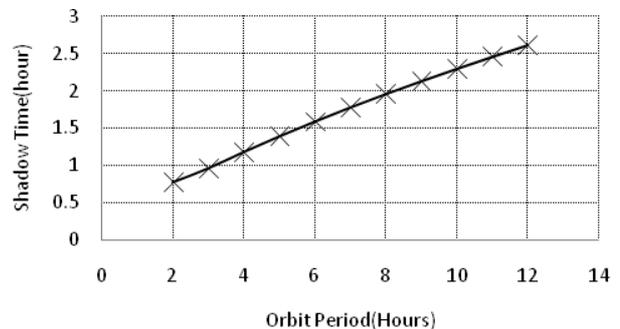


Fig. 3: Relation of phase orbit period and eclipse time

To avoid long-time orbit shadow, the escaping strategy was adjusted from three steps to two steps. At the first step, Chang'e-2 was accelerated to 5.3 hours orbit. Then, the probe was accelerated to escaping orbit directly. The longest orbit shadow was decreased to 1.5 hours.

III.3 Cruise Attitude

Chang'e-2 was equipped with several attitude sensors: gyroscope, digital sun sensor, star tracker, ultraviolet sensor and so on. On the way to the libration point, the ultraviolet sensor is useless, the standard cruise attitude is +X axis pointing to Sun, the same as that of from Earth to Moon. In this attitude mode, the solar panel gets max output, and external heat flux of

the probe is stable. Every status and profile was verified on the way from Earth to Moon.

III. IV Space Environment

Although, Sun-Earth Lagrange L2 point is about 1.5 million kilometers away from the Earth, but 1.5 million kilometers is only 1% of the distance from Earth to Sun. The space charged particle radiation environment almost the same as circling the moon. The radiation effects for L2 point mission is almost the same as that of lunar mission.

III. V Link budget

From moon to Sun-Earth libration point, the distance from probe to Earth increases from 400,000km to 1,500,000km, and the space loss increases about 13dB. The AGC of TT&C transponder decreases 13dB, but the link budget still has enough margin. The data rate of probe around the moon is about 3Mbps, the data rate will decrease to 750kpbs around the libration point.

III. VI Δ V Budget:

For the first libration point mission of China, The capability of orbit determination and orbit maintenance strategy should be verified. To deal with uncertain situation, more propellant was left for TCM and L2 point orbit maintenance.

Maneuver	DV
Escaping From Moon	~700m/s
TCM	~40m/s
L2 point Orbit Maintenance	60~70m/s
Total	800m/s~810m/s

Table 2: ΔV Budge

IV. MISSION PROFILE

Change’-2 Lagrange L2 point mission procedure is divided into 3 phases:

Moon Escaping phase

It was defined as moon escaping phase from lunar orbit to escaping orbit. At the predesigned argument of latitude, the probe accelerated to the ellipse orbit with period of 5.3 hours. After about 26 hours, the probe accelerated at the perilune to the escaping orbit to Sun-Earth libration point.

Moon- L2 Transfer phase

From escaping from the moon to L2 point orbit insert was defined as Moon- L2 Transfer phase, this phase lasts about 85 days. In the transfer phase, four trajectory correction maneuvers (TCM) was predefined.

The first trajectory correction maneuver planed to execute 1~2 days after the probe escaping moon; the second trajectory correction maneuver planed to execute 10days after the probe escaping moon; the third maneuver planed to execute about 40days before Lissajous orbit insertion(LOI), the fourth and the last maneuver planed to execute 30 days before LOI.

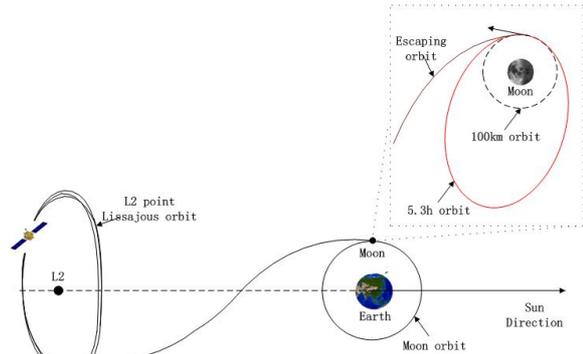


Fig. 4: Flight profile of CE-2 Lagrange L2 Point Mission

Orbit keeping phase

The Lissajous orbit with $A_x = \sim 292,000\text{km}$, $A_y = \sim 918,000\text{km}$, $A_z = \sim 212,000\text{km}$ has been selected as the nominal mission orbit for chang’e-2 Lagrange L2 Point Mission. Period orbit control was planned at one-month interval.

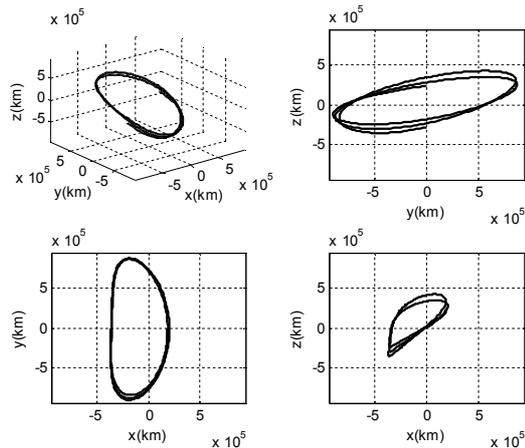


Fig. 5: nominal mission orbit

On June 8th 2011, Chang’e-2 was accelerated to 100km×3580km phase orbit, one day later, the probe escaped from the lunar orbit. On Aug 25th 2011, Chang’e-2 entered into the Lissajous orbit.

Maneuver date	Maneuver
2011-6-8	Accelerate to 100km×3580km phase orbit
2011-6-9	Escaping to Moon-L2 Transfer orbit
2011-6-20	Trajectory correction maneuver(TCM)
2011-8-25	Lissajous orbit insert(LOI)

Table 3: Sun-Earth L2 point mission maneuver

In the cruise phase, only two mid-course maneuvers were executed; the other 3 planned maneuvers were canceled for orbit determination and control.

	Time	Design	Actual
TCM-1	6-11	~10m/s	Cancelled
TCM-2	6-20	~10m/s	~3m/s
TCM-3	7-23	~10m/s	Cancelled
TCM-4	8-2	~10m/s	Cancelled
LOI	8-25	-	~4m/s
Total		~40m/s	~7m/s

Table 4: ΔV of trajectory correction maneuvers

V. CURRENT STATUS AND FUTURE PROSPECT

Chang'e-2 is working around the Sun-Earth Lagrange L2 point, the +X axis of the probe pointing to the Sun and slow spin; The thrusters, propellant tank and high pressure vessel are all in good condition; Solar panel output is about 2400W; The AGC of TT&C transponder decreases 13dB, but uplink & downlink have still enough margin. Several payloads such as γ / X-Ray Radiometer, Solar High Energy Particle Detector,

Low Energy Ionic Detector are in working for scientific target.

How about the future of Chang'e-2? The scientists and engineers are facing the same question at the beginning of Sun-Earth Lagrange L2 point mission. Several choices were mentioned and discussed, including:

- (1) Stay at Sun-Earth Lagrange L2 point?
- (2) Transfer to Sun-Earth Lagrange L1 point?
- (3) Near Earth asteroid exploration?
- (4) Return to the Earth?
- (5) Return to the Moon?

VI. SUMMARY

After the Success of Sun-Earth Lagrange L2 mission, Chang'e-2 is not only a lunar probe, but also a libration point probe. Chang'e-2 provides important technical basis for the successful implementation of China's future deep-space exploration, especially trajectory design, deep space tracking and telecommunication. Chang'e-2 is the farthest probe of China at present. It maybe goes farther.