Flight Summary of the Mission of Chang'e 4 Lunar Probe

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Institute of Spacecraft System Engineering
CAST
1. GENERAL MISSION DESIGN
2. SIGNIFICANCE AND CHALLENGES
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4. CONCLUSION
The Chang'e 4 lunar probe is comprised of a lander, a rover and a relay satellite, which were launched separately.

Firstly, the relay satellite was launched and flew into its mission orbit about the Earth-Moon Lagrange point 2.

Secondly, the lander and rover were launched together, flew to the Moon, and landed on the far side of the Moon, later the lander and rover were separated from one another, and started in-situ exploration and patrol survey respectively, with the relay link support from the relay satellite.
Chang'e 4 equipped with 13 scientific payloads.

- Infrared Spectrometer
- Very Low Frequency Radio Spectrometer
- Topographic Camera
- Descent Camera
- Panorama Camera
- Lunar Penetrating Radar
- Popular Scientific Payloads
- Laser Angular Reflector
- Ultra-Long wave Astronomical Detector
- Optical Camera
- Advanced small analyzer for neutrals
- Lunar neutrals and dosimetry detector

Netherlands-China Low-frequency Explorer

Saudi-KLCP

SARAN

German-LND
Separation with rocket
3 times of TCM (Trajectory Correction Maneuver) and 1 time of LOI (Lunar Orbit Insertion) (4 days)
Orbiting the Moon and descent (22 days)
Soft-landing on the Moon
The lunar farside is of great significance on geological evolution study, low-frequency cosmic radio survey, etc. It has unique advantage than the lunar nearside.

On the lunar farside, numerous highland terrains are distributed all over and craters and mountains are widely spread.

The well-known South-Pole Aitken Basin (SPA) is located in the southern part of the farside. This is the largest and eldest impacted basin in the solar system.

- **Latitude:** 40~60 ° S
- **Longitude:** around 180°
- **Diameter:** 2000~2600 km
Challenge #1: Soft-landing on complex terrain

Near side of the Moon: flat Moon seas
Far side of the Moon: Huge impact craters, rugged terrain

Characteristics of landing area (Far side):
Small safe landing area, sharp terrain variation along-track.

Core difficulties:
(1) high precision landing
(2) high reliability landing

Ce-3: 357km × 91km
Ce-4: 50km × 30km

Merely 5% size of Chang’e-3 landing area
Core difficulty #1: high precision landing

(1) Refined orbit design and control

Using the optimal algorithm of joint correction of inclination and phase angle, the precise control of the initial position and time of landing is realized, subjected to the constraint of velocity increment.

(2) Refined engine calibration

The high precision guidance and control in soft-landing process was realized by improving the on-orbit calibration accuracy of 7500N variable thrust engine and optimizing the navigation algorithm.

As a result, a precision landing at the planned time was achieved.
2. SIGNIFICANCE AND CHALLENGES

Core difficulty #2: high reliability landing

- 15km: Primary Deceleration Phase
- 8km: Quick adjustment Phase
- 6km: Approaching Phase
- 100m: Hovering Phase
- 30m: Hazard Avoidance Phase
- 0m: Slow Descent Phase

(1) Optimizing strategy for powered descent
The effect of topography fluctuation along-track was avoided by reasonable design of the control objective and navigation correction strategy for each stage of the descent.

(2) Relay obstacle avoidance
Rough optical obstacle avoidance was first employed at 2km altitude, followed by fine laser obstacle avoidance at 100m hovering altitude.

(3) Improved autonomy
The system is capable of autonomous fault diagnosis and reconstruction, autonomous establishment of the work status after landing. As a result, autonomous and reliable landing was achieved.
Challenge #2: Data relay between Earth and Moon

- Direct communication with the Earth from the far side of the Moon cannot be realized, and data relay is necessary.
- For lunar orbit, the coverage percentage of relay time is low, due to the slow spin of the Moon.
- Earth-Moon L2 orbit has inherent instability and is far from the Moon.

Core difficulties:

1. Full-time relay coverage
2. Design of relay system with multiple constraints
Core difficulty #1: Full-time Relay coverage

(1) Design of Earth-Moon L2 Halo Orbit
Based on the relationship between the Sun, Earth and Moon, the L2 orbit parameters are optimized to achieve full-time relay coverage and reduce orbit shadow time, which helps lower the difficulty of relay satellite design.

(2) Design of Orbit Maintenance Strategy
The orbit maintenance strategy is optimized to reduce velocity increment budget, based on the accuracy of orbit determination and orbit control.
2 SIGNIFICANCE AND CHALLENGES

Core Difficulty #2: Design of relay system with multiple constraints

(1) **Regenerative Data Relay**
Regenerative forwarding scheme is adopted to obtain channel coding gain of backward link and improve data relay capability, which is also beneficial to the unification of ground link and relay link for the probe.

(2) **Relay satellite with small platform and large antenna**
The 4.2m umbrella antenna technology is used to improve the channel gain of forward/backward link; Fault-tolerance strategy of frame synchronization is optimized to improve demodulation capability of low SNR; Reliable simultaneous relay for dual lunar targets is achieved using multi-channel, multi-mode and multi-rate scheme.
Relay Satellite

On 21 May 2018, the relay satellite of Chang’e 4 Queqiao was delivered into an earth-moon transfer trajectory by Long March 4C launch vehicle, lifting from Xichang Satellite Launching Center.

On 14 June 2018, after the third capture maneuver, the Queqiao enters the Halo mission orbit.

Lander and Rover

On 8 Dec 2018, the Lander and Rover of Chang’e 4 was delivered into a earth-moon transfer trajectory by Long March 3B launch vehicle, lifting from Xichang Satellite Launching Center.
3 FLIGHT SUMMARY

Power Descent

- **20190103, 10:14:35**, 7500N Engine fired to decelerate and the spacecraft started to descend
- **20190103, 10:26:02**, Ground-Touching switch is on, namely the spacecraft have safely landed on the lunar surface

<table>
<thead>
<tr>
<th>Height: 100m</th>
<th>Height: 2000m</th>
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<tbody>
<tr>
<td>Precision avoidance: move 8.5m</td>
<td>Coarse avoidance: move 216m</td>
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Image of 3D laser

Image of optical camera
The lander surveillance camera took the first close-up image of the far side of the Moon in human history.

First-ever close-up photo of the far side by lander

Photo of rocks on the far side by rover
The panorama images taken on lunar surface and descent images collected during the descent are used to match the lunar images taken by Chang’e-2 and LRO.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
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</thead>
<tbody>
<tr>
<td>Position</td>
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<td>Longtitude (°)</td>
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<tr>
<td>Latitude (°)</td>
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<td>Altitude (m)</td>
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<td>Attitude</td>
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<td>Pitch Angle (°)</td>
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<tr>
<td>Yaw Angle (°)</td>
<td>4.1639</td>
</tr>
</tbody>
</table>

Localization of Lander

Courtesy of CE-2 image

Courtesy of LRO image

Locate the exact landing site by image matching.
The occlusions at landing site induced by the terrain are analyzed. The altitude angles of Sun and relay satellite are both much higher than terrain occlusion angles. The power and communication of lander is without a break.
• Crater C(Diameter): 25 m
• Crater C(Deep): 2 m

• Crater A(Diameter): 29 m
• Crater A(Deep): 2.6 m

• Crater B(Diameter): 20 m
• Crater B(Deep): 2.4 m
Lander-Rover Separation

Transfer Yutu-2 to the ground

Locomotion of Yutu-2
Take Photos for Each Other

Photo of Lander by Panorama Camera on Yutu-2

Photo of Yutu-2 by Topography Camera on Lander

Photo of Lander by Panorama Camera on Yutu-2
LFS (Low Frequency Radio Spectrometer) deployed 3 antennas with each deployed length of 5m and measured the low-frequency radio waves on the lunar farside.
The lander took panoramic photo of 360° around the landing site.
The lander measured the soils temperature firstly at lunar day and night on the farside of the moon, and the minimum temperature is about -196°C.
Until now (25, Mar., 2020), Chang’e-4 has survived for over 15 lunar days and lunar nights, work well and stable.

Yutu-2 traveled about 400m northwest on the moon from landing site.
The scientific payloads equipped on Chang’e-4 lander and rover work well, and got lots of detection data.
On 4th, Feb., 2019, the landing site and its nearby impact craters, hill and central peak were named by IAU. The site named ‘Statio Tianhe’ is the second Statio on the moon following the ‘Statio Tranquilitatis’ which is the landing site of Apollo 11.
The success of Chang’e-4 mission helps achieve in human history the first soft-landing and patrol survey on the far side of the Moon, the first TT&C and communication between Earth and the far side of the Moon, and also left the first footprint of lunar exploration on the far side of the Moon.

In the future, China will setup Lunar Science Station and deepen the study of the Moon, and carry out widely international cooperation on lunar resource exploitation and application.
Thank You!
谢谢！