Exploration of Planetary Interior

Development of Penetrator System

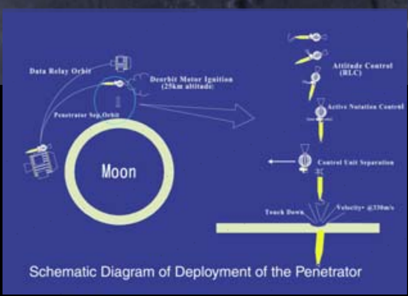
★ Description of LUNAR-A Spacecraft
- Spin-Stabilized Cylindrical Shape
- 2.2 m max. in diameter × 1.7 m in height
- Weight : wet mass 540kg (Fuel 190 kg) including two penetrator modules (45kg ×2)

★ LUNAR-A Mission Objectives
- Technological demonstration of penetrator system and Network Science in Planetary Exploration
- Investigation of lunar internal structure by seismometry and heat-flow experiment on unmanned mission
- Better understanding of bulk composition and early thermal state to clarify the origin and evolution of the Moon

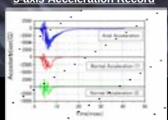
Left figure show the deployment sequence of LUNAR-A penetrator module. Firstly, the penetrator is released from the spinning spacecraft like a Frisbee style. Next, the orbital velocity around the Moon is cancelled by a de-orbit motor ignition. Then, during the free fall, the attitude control system is used to reorient 90 degrees and to align the penetrator module vertical to the lunar surface. Finally, the carrier system is separated and the penetrator will hit on the lunar surface at the velocity of 300 meters per second. At this time, LUNAR-A penetrator will encounter the large impact shock more than five thousands G and penetrate to a depth of 2 or 3 meters.

Middle figure shows a diagonal view of LUNAR-A Penetrator Module. Total length is about one point five meters, and total weight is about forty-five kilograms. Just half of the right in this figure is the penetrator itself, and on the left side, we call carrier system, which consists of de-orbit motor and attitude control system. The right figure shows the inside of penetrator body, its length is seventy-six centimeters, fourteen centimeters in diameter and its weight is about fourteen kilograms. Accelerometer is used to know the impact velocity and penetration depth, by integrating with time and tiltmeter is used to know the attitude of penetrator in the lunar regolith.

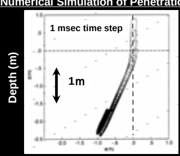
Two-component seismometer and tiltmeter are installed inside gimbals mechanism to adjust their attitude and direction after penetration. Five thermal conductivity sensors and eleven thermocouples are attached to the body surface. On the other hand, seven absolute thermometers are distributed from the nose to the tail. Using these thermo-sensors, we can get the data necessary to estimate the heat-flow value in the lunar regolith. And other supporting instruments, sensor electronics, data processing unit, communication system, 400MHz-UHF antenna, primary batteries are also equipped. The penetrator body is designed to be a combination of a truncated ogive nose and a cylindrical part and it is made from CFRP (Carbon fiber reinforced plastic).

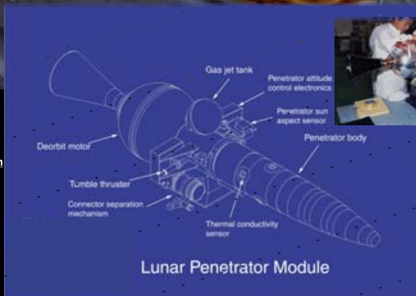


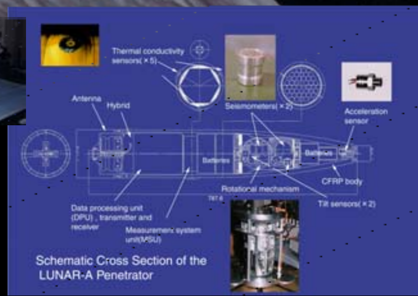
3-axis Acceleration Record



Numerical Simulation of Penetration





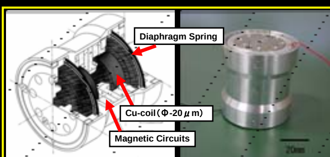


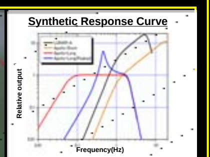
Scientific Objectives

Seismometry
- Determine the meteoroid impact flux on the farside of the Moon
- Determine the seismic activity of the farside of the Moon
- Determine the seismic structure of the deep mantle
- Determine the size and physical properties of the core

Heat-Flow Experiment
- Determine the heat flow values at two different sites on the Moon
- Determine the average heat flow values of whole Moon
- Determine the bulk abundance of the refractory elements

LUNAR-A Seismometer



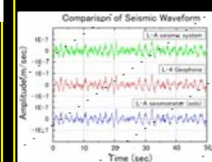


Description of L-A Seismometer
- Short-period electromagnetic type sensor with velocity sensitive
- A moving coil suspended by a pair of three spiral-beam spring
- Natural frequency : 1.0～1.2 Hz
- Generator constant : 10.8 Volt / kine
- Dimensions: Φ50mm×50mm in height
- Weight: 680 g (1 horizontal and 1 vertical components)

Seismic Observation Test

★ Description of Seismic Observation
- Setup on the tunnel of Inuyama Seismic Observatory in Central Japan
- Simultaneous observation by several types of seismometers
- Remote-operation of penetrator system by tele-communication onboard S/C
- Observation Target : Micro-tremor with very small amplitude

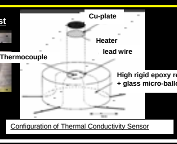
★ Key Items of Evaluation for Seismic System
- Sensor performance before and after impact test
- Noise level of sensor, preamplifier and analog filter system
- Long-term stability of sensor－gimbals system for natural ground motion



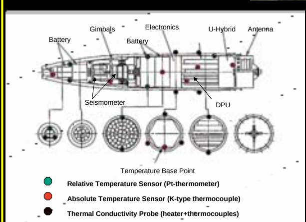
Heat-Flow Probes

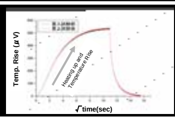
Surface Heat Flow Value

Q = K × dT/dz



Measurement Principle of Thermal Conductivity
⇒Point-heat source method
Dimensions: Φ-12mm×5mm in height
0.025kelvin resolution, 0.01kelvin accuracy





Calibration Profiles before and after Impact Test

Recent Progress

(1) LUNAR-A mission has been suspended and the launch date is not determined since 2004, by the following two reasons.

Mother Spacecraft : Recall and replacement of some thruster bulbs used for Reaction Control System.

Penetrator : A malfunction observed in the qualification level test (QT) performed in November, 2003

(2) LUNAR-A project had been reviewed by both the internal and external review boards from the viewpoint of technology and management in 2004.

Spacecraft and Carrier System :
Suspension of development and safekeeping under purged N_2 gas condition

Penetrator System :
Further improvement and some modifications are required

We have put on a three-year program into effort to solve the penetrator technology issues

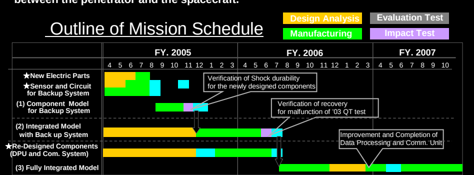
Technical Issues

★A new 3-year program to solve the penetrator technology issues was initiated in 2005, and now half-way complete.

(1) Improvement of electronics design for robustness against ESD, and addition of back up system for possible malfunction which occurred in the QT level experiment in 2003.

(2) Assurance of robustness on communication system and of a sufficient margin on link between the penetrator and the spacecraft.

Outline of Mission Schedule



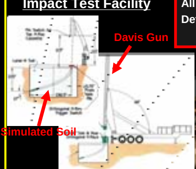
★Final QT level impact test will be fired in FY2007 and we aim for completion of penetrator technology

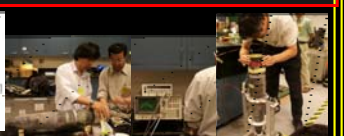
Result of Last Impact Test

★Description of Last QT Level Impact Test
- Almost fully integrated hardware components and FM software are installed.
- Two types of reset sensors and a coupling electronic circuit are equipped for backup system.
- Noise reduction of electronics and partially improvement on the link margin for communication system.
- Careful arrangements for experimental procedure and workmanship in test field to avoid ESD input.

Impact conditions : 330 m/sec, 8.7 deg attack angle
Successfully communicated with the penetrator just after impact
All the functions of instruments work well after impact
Detailed examination of instruments and evaluation of sensor performance were made after return to Japan.

Impact Test Facility





Checkout of Communication System and Seismometer-Gimbals Mechanism

Future Prospect

★ LUNAR-A project was cancelled in Feb. 2007.

(1) There is no redundancy for mission success because of only two penetrators, higher reliability and robustness are required for JAXA confidence level.

(2) More than ten years have passed since the mother S/C was manufactured, the deterioration in the quality of the instruments onboard the mother S/C because of the long-term storage.

★ Utilization of Penetrator System on Follow-on missions
⇒ Luna-Glob mission in collaboration with Russia
★ Application and Modification of Payload Instruments
⇒ Post-SELENE mission in JAXA and other lander missions

Luna-Glob Mission

★ Description of Luna-Glob Satellite
- 3-axis stabilized satellite, 2.3 ton in total weight
- Single launch by Soyuz-Fregat2 rocket in 2012 (TBD)
- 1 Main S/C, 1 Lander, and 4 LUNAR-A penetrators
- Geophysical Network Observation by 5 points (possibly, including seismometer onboard Lander)