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Technical Readiness of Japanese lunar penetrator and its application to the future planetary exploration

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Abstract

We have developed a hard landing probe "penetrator" for the investigation of lunar interior. In these years, we have been continuing to make an effort to improve the reliability and robustness. In this paper, we report the technical readiness of lunar penetrator and future prospect for the planetary exploration.

1. Introduction

Remote-sensing observations by past and recent orbital planetary spacecrafts have mainly provided surface elemental abundances, mineral assemblages and geodetic data (gravity field and topography map). Knowledge of bulk composition of terrestrial planets has been gleaned from remote sensing data and determination of orbital dynamics, as well as returned lunar samples and a variety of meteorites, but it remains to be poorly known. Investigation of the internal structure of a planet is needed to determine the bulk composition, which is closely associated with accretion process, early thermal state, core formation, dissipation style of internal heat, differentiation of silicate portion into mantle and crust, styles and extent of volcanism, etc.

Geophysical observations such as seismometry and heat-flow measurement can provide important constraints on the internal structure and the abundance of major elements. Therefore, geophysical network science will become very important in the future planetary explorations. However, significant technological advances or innovative approaches will be necessary to achieve the above objectives. That is, network science requires an establishment of multiple surface stations operating concurrently on a planet.

A hard landing probe "penetrator" has been thought to be a very useful tool for constitution of network stations on the planetary surfaces and subsurface, because it provides light-weight and cost-effective capabilities of deploying scientific instruments. A long-lived network science by penetrators gives unique possibilities for monitoring the global scale phenomena and for studies requiring simultaneous measurements (seismic, geodetic, magnetic, and meteorological observations) from several sites in one mission. In addition, utilization of penetrators for planetary explorations has some advantages over soft landing probes. The penetrator will make it possible to deliver scientific instruments into the planetary subsurface for in situ chemical analysis and/or heat-flow measurements; otherwise those measurements would require drilling holes from the surface. In situ geochemical measurements with higher resolution can also provide ground truth of remotely sensed data. For the reasons cited above several planetary missions to use penetrator system have been proposed and developed.

2. Lunar Penetrator

The scientific objective of the former LUNAR-A penetrator mission was to explore the lunar interior by seismic and heat-flow experiments. And also, it is the first demonstration to implement the geophysical network as an unmanned space probe. Two identical penetrators containing two-component seismometer and heat-flow probes would be deployed from a spacecraft onto the lunar surface, one on the nearside and the other on the farside of the moon. The data obtained by the penetrators would be transmitted to the ground station by way of the LUNAR-A mother spacecraft orbiting at an altitude of about 200 km. The seismic observations could be expected to provide key data on the size of the lunar core, as well as data on the deep mantle structure. The heat flow measurements at two different sites would also provide important data on the thermal structure and bulk concentrations of heat-generating elements inside the Moon. The details of the penetrator instruments onboard and their observations are described in references [1-3]. Since the initiation of the development of LUNAR-A penetrator, a large number of impact experiments had been conducted using scale models and full-size models. To apply a penetrator system for planetary explorations, the most significant technical issue is an achievement of the shock-durability of the onboard instruments at the high-speed impact process. In addition, we need the new technology of separation mechanism, de-orbit motor and attitude control system for an on-target impact on the Moon.

3. Technical Readiness and Future Prospect

The LUNAR-A mission was started in 1993 and we had been continuing the development of penetrator system and the carrier spacecraft. However, it was announced that the LUNAR-A mission was officially cancelled in February, 2007. The main reason is that the reliability would be questioned because of no more than two penetrators available, compared to the present confidence level of JAXA (Japan Aerospace Exploration Agency). Another reason of the cancellation lies in the deterioration in the quality of the instruments onboard the mother spacecraft due to the long-term storage since it has been manufactured [2]. The internal review board of ISAS/JAXA for launch readiness was made in 2004 and the review board recommended that the improvement of the communication link between the penetrator and the orbiting spacecraft should be made, based on lessons learned from the US Deep Space-2 and European Beagle-2 failure of their communication link. Furthermore, the LUNAR-A project had been reviewed by both the internal and external review boards of JAXA from the viewpoint of technological assessment and project management. From recommendations of the review boards, we determined to focus our attention on the improvement of the penetrator system, following a suspension of development of the orbiting spacecraft. A revival program to solve the penetrator technology issues was initiated in 2005 for the validation of a high degree of redundancy and robustness, and then, four times impact load tests with low-temperature thermal stress were conducted using both mock-up and fully-integrated models. Finally, the program has been completed in 2010. The follow-on mission to utilize the penetrator technology is under consideration for the future program of the Japanese lunar program and/or within the framework of international collaborations. We also plan to broaden the applications of penetrator technology, such as Martian and Asteroid missions.

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