The Moon Impact Probe on Chandrayaan-1

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A unique, stand alone micro satellite called the Moon Impact Probe (MIP), designed to impact at a pre-decided location near the South Pole of the moon was a part of the Chandrayaan-1 mission. The MIP has two technology and one scientific experiments, viz. a Moon Imaging System (MIS) for surface photography along its path, a Radar Altimeter for terrain topography at close distance (<5 km) and a Mass Spectrometer, CHACE (Chandra's Altitudinal Composition Explorer), for measuring the neutral composition on the sunlit side of the moon. A description of the various sub-systems of the MIP and of the instruments is presented in this article.

Keywords: Altimeter, Chandrayaan, impact probe, imager, mass spectrometer, moon.

Introduction

THE Chandrayaan-1 mission placed a 600 kg class satellite around the Moon in a 100 km circular polar orbit for detail remote sensing studies of the Moon at various wavelengths across the electromagnetic spectrum and using a variety of techniques. The nearly 34 kilogram Moon Impact Probe (MIP) with the features of a mini spacecraft has been designed to be a piggyback on the main orbiter and released for descent on the Moon at a predetermined location. MIP is equipped to take photographs of the lunar surface and perform radar altimetry during the final phase of descent (<5 km from the lunar surface) that may be necessary for possible soft landing missions in future. Scientific studies of the Moon involving *in situ* measurements of neutral composition were also planned. The MIP carries three payloads, viz. (i) the Moon Imaging System (MIS), (ii) a Radar Altimeter and (iii) CHACE (Chandra's Altitudinal Composition Explorer) to achieve these objectives.

The impact probe

The impact probe would be separated from the main orbiter of Chandrayaan-1 using a ball lock release system at an appropriate time and location, after suitably orienting the probe and getting it spin stabilized to meet the mission requirements. A tiny de-orbit solid motor would be fired for about 3 s after ~300 sec of separation in order to reduce the velocity of the probe by about 70 m/s and to bring it down towards the designated region. The probe would take about 25 min to impact on the Moon with a velocity of about 1.7 km/s. From the separation to impact, the data from the MIP would be transmitted to the orbiter using the UHF telemetry link and would be stored in a solid state recorder to be subsequently retransmitted in X-band to the Indian Deep Space Network (DSN) located in Bangalore. Figure 1 schematically depicts the MIP mission profile showing the relative position and orientation of the spacecraft and the MIP at the time of its release and in its subsequent phases. Figure 2 depicts the basic assembly while Figure 3 shows the integrated configuration of MIP with Chandrayaan-1.

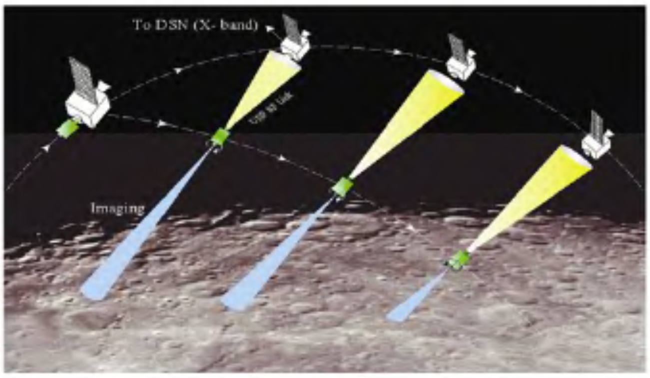

Figure 1. Moon Impact Probe mission profile.

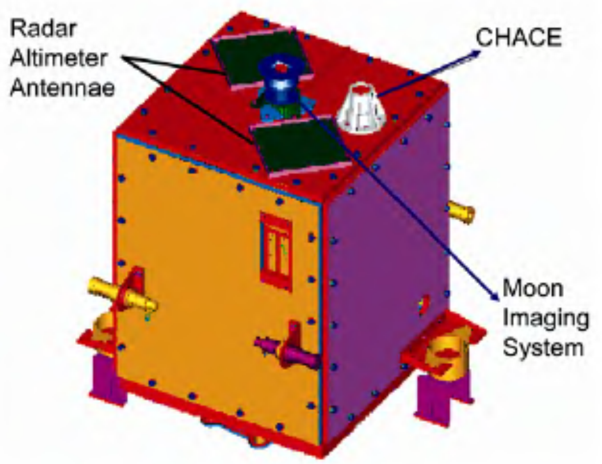

Figure 2. Moon Impact Probe assembly.

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As a part of the mission strategy, a brief rehearsal, excluding the release of MIP is being planned, two orbits before the actual separation. The main orbiter together with the MIP would be oriented at a required angle through orbital manoeuvres and basic health parameters of MIP would be monitored through orbiter telemetry. At the time of actual separation, the Orbiter would issue necessary commands to MIP.

The Moon impact probe systems and sub systems have been qualified to meet the anticipated severe environments such as vibration, shock, temperature, radiation, vacuum, Electro Magnetic Interference (EMI), etc. The temperature levels of the MIP systems and subsystems would be maintained to the desired level with both passive and active thermal management systems taking into account the lunar thermal environment.

Moon Imaging System

The Moon Imaging System (MIS) essentially comprises a CCD camera and process electronics and has been designed to acquire images of lunar surface, compress them and then to transmit the compressed data through telemetry link to the orbiting Chandrayaan-1 spacecraft. From the 100 km orbit of the spacecraft, the MIP camera would have a resolution of 70 m with a swath of 34 km. To make the images blur-free, appropriate algorithms have been developed and implemented during data processing. Further, to withstand the stringent environmental conditions including radiation environment encountered during its journey to lunar orbit and its descent to moon, appropriate ruggedization techniques have been employed to make the Moon imaging system space worthy.

For calibration, and for fixing the dynamic range, the extreme cases of maximum illumination from fresh rock surface at equatorial regions and the minimum illumination of matured mare soil over the polar region of the moon have been considered for a single pixel of 7 μm size. Based on this, the camera has been programmed for an auto integration mode with a minimum integration time of 20 microsec. The aperture of the lens has been taken as F2.8 and for this setting, the camera would be operating with ~2 millisec integration time near the poles. A sun illumination test was conducted to study the degradation of CCD pixel elements when exposed to sunlight wherein the camera was exposed to direct sunlight for 2 h keeping the aperture maximum. Images taken after half an hour revealed no degradation in CCD pixel elements ensuring that sudden overexposures might not mar the functioning of the imaging system. Images obtained for typical lunar illumination with auto integration time of 0.25 msec were found to be of excellent quality. Figure 4 shows the schematic of the MIS assembly.

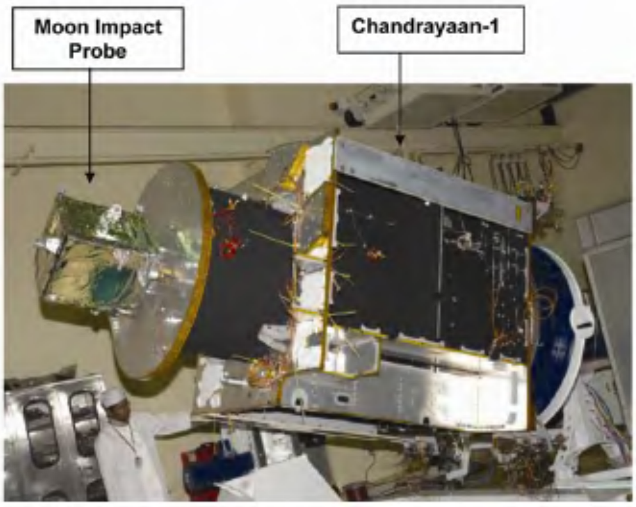

Figure 3. Moon Impact Probe integrated to the Chandrayaan-1 spacecraft.

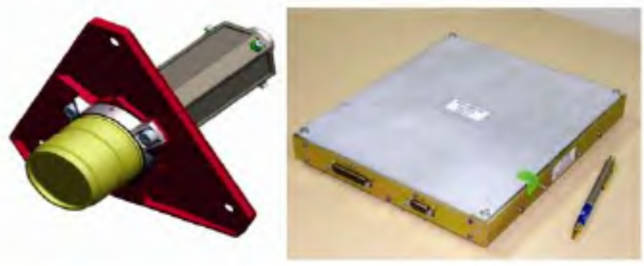

Figure 4. Moon imaging system along with the electronics.

Figure 5. Moon Impact Probe radar altimeter: aircraft test setup.

Figure 6. The Chandra's Altitudinal Composition Explorer payload.

Table 1. Altimeter flight test result

Aircraft location	Radar altimeter	Onboard GPS
Runway	2–4 m	3–7 m
Ascending	98–102 m	96–103 m
Level 500 m	488–516 m	487–514 m
Level 1000 m	968–1032 m	967–1035 m

Table 2. Salient features of CHACE

Mass range	:	1–100 amu
Detector type	:	Electron multiplier
Resolution	:	Unit resolution
Dynamic range	:	10^{10} (considering both the FC and EM)
Min. detectable partial pressure	:	5×10^{-14} torr
Scan rate	:	15 spectra/minute
Sensitivity	:	10^{-1} A/torr (including electron multiplier gain)
Payload mass	:	3.3 kg (excluding mechanical mounts)
Power	:	25 W

Radar altimeter

The C-band radar altimeter will measure the altitude of the probe in the final descent phase from ~5 km till impact. The radar makes use of an FM-CW type transmitter with the centre and modulation frequencies of 4.3 GHz and 100 Hz respectively, and a transmitted output power of 1 W (CW) with a frequency deviation of ±50 MHz. The receiver has a sensitivity of –78 dBm. A data rate of 5 Kbits per second with an update rate of 100 measurements per second are envisaged. The antennae system has been designed to have a gain of +10 dB and a DSP processor has been used for data processing (Figure 5).

The altimeter would have an accuracy of 2 m for heights measured up to 150 m and 3% of the measured height for the range between 150 m and 5 km. A basic field evaluation of the altimeter has been carried out using aircraft sorties and by using an onboard GPS as reference. Table 1 provides a comparison of results obtained by the two systems.

Chandra's Altitudinal Composition Explorer

The total pressure in the lunar environment, as confirmed by the Apollo missions[1], is of the order of 10^{-12} torr during lunar night. During lunar day, the pressure is estimated to be at least two orders higher. However, there are no reliable measurements till this date. Hence any *in situ* experiment must have the sensitivity to explore the extremely thin and tenuous lunar atmosphere. Chandra's Altitudinal Composition Explorer (CHACE), which is a state-of-the-art quadrupole mass spectrometer based system, would explore the lunar atmospheric constituents during lunar daytime, when the solar flux coupling to moon through energetic particles and also electromagnetic radiation would modify lunar surface and its environment (Figure 6). Earlier attempt made during the Apollo17 mission could successfully measure some of the lunar atmospheric constituents during night time and CHACE will be the first *in situ* experiment with the capability of exploring presence of gaseous constituents, ranging in mass from 1 to 100 amu, in the lunar atmosphere (Figure 7).

The CHACE payload consists of a quadrupole mass analyser and an electronic control unit. The probe houses the ionizer, mass analyser and the detectors, while the processing and communication electronics are housed within the electronic unit. The processed and digitized data from the electronic unit is communicated to the MTU (MIP Telemetry Unit) through an RS 232 bus.

Calibration

The instrument has been calibrated in the laboratory environment, with respect to the important residual gases H_2O (18 amu), N_2 (28 amu) and CO_2 (44 amu) and known spectral signatures of certain other species/molecules. The mass calibration of the instrument has been validated by inserting known gases and looking for the capability of the instrument to detect the same. The detection limits in terms of partial pressures had been verified to far exceed 10^{-13} torr, through elaborate laboratory simulations in an ultra high vacuum system. This had become

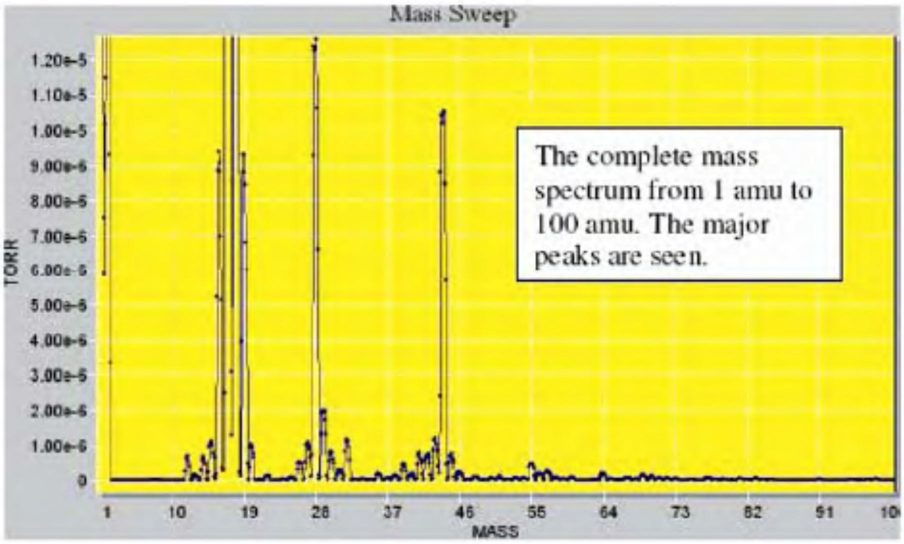

Figure 7. A typical mass spectrum of residual gases as seen by Chandra's Altitudinal Composition Explorer.

possible by the use of an ultra sensitive electron multiplier having a gain of 10^5 at the detector stage.

Conclusion

The MIP is unique in several ways and it is targeted to land in the south polar region of the moon, an area of prime interest, both from lunar science and lunar resource perspectives. It intends to demonstrate technologies useful for future landing mission and will also perform a novel scientific experiment to measure the tenuous composition of the lunar dayside.

1. Alan Stern, S., The lunar atmosphere: History, status, current problems and context. *Rev. Geophys.*, 1999, **37**, 453–491.

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