

CHANDRAYAAN-1 : AN UPDATE

M. Annadurai* and T.K. Alex**

Background

India has recognized the potential of space science and technology for the socio-economic development of the society during the early days of space era and embarked upon development of an ambitious space program. Over the last three decades, India has achieved significant progress in design, development and operation of space systems, as well as in using the systems for societal applications like telecommunication, television broadcasting, meteorology, disaster warning and natural resources survey and management. The Indian Space Program has become largely self-reliant with capability to design, build and launch its own satellites using indigenously designed and developed launch vehicles, for providing space services to the country.

The state of maturity of spacecraft development at ISRO is amply demonstrated with launch and maintenance of a series of remote sensing satellites in low earth polar orbit and communication satellites in geostationary orbit. Launch Vehicle PSLV has been operationalized through successful demonstration of a series of flights to place spacecraft in low earth polar orbit. The GSLV had its three successful flights to place communication satellites in geostationary orbit. The capability of PSLV to place a satellite in geostationary orbit has been demonstrated in 2002 when meteorological satellite, KALPANA-1 was launched. With these developments, ISRO is in a position to embark on newer missions. Lunar and interplanetary explorations provide such an opportunity.

In the new millenium international scientific community has considered several exciting missions in space science and exploration. These have the prospect of expanding horizons of our knowledge effectively and will provide benefits to the human society at large. In the Indian context, one of the initiatives, which attracted debates and excited the imagination of a large number of people, was the possibility of launching a lunar mission through an Indian launcher. Groups of national scientists and technologists debated this in various fora under the aegis of Indian Academy of Sciences as well as Astronau-

tical Society of India (ASI). Based on these interactions, and further study conducted by a National task team, the Chandrayaan-1 mission came into being.

Mission Objectives

The overall objectives of the mission are summarized as

- Design, develop and launch a spacecraft in a lunar polar orbit using Indian Launch Vehicle.
- Develop expertise for planning and execution of mission and ground systems for sending spacecraft beyond the orbit around the earth for future planetary exploration missions.
- High resolution imaging and chemical and mineralogical mapping of lunar surface to understand the process of formation and chemical evolution of the moon.
- Systematic topographic mapping of the whole surface of the moon.
- To establish capability of planetary data analysis and also data archival and dissemination.
- To create expertise in development of detectors and sensor technology for planetary remote sensing for future planetary exploration programme.
- To enhance India's image in the international scene by being part of a select group having capability to observe planets directly.

Scientific Payloads

Chandrayaan-1 carries the following science instruments developed by ISRO to achieve the science objectives,

- Terrain Mapping stereo Camera (TMC) in the panchromatic band, having 5m spatial resolution (size of the smallest object that can be seen) and 20 km swath (width of the picture).
- A Hyper-spectral camera (HySI) operating in 400-900nm band with a spectral resolution of 15nm and

* Project Director, Chandrayaan-1, ISRO Satellite Centre, Airport Road, Bangalore-560 017, India

** Director, ISRO Satellite Centre, Airport Road, Bangalore-560 017, India

spatial resolution of 80m with a swath of 20km producing data in 64 spectral bands (colors).

- A Laser Ranging Instrument (LLRI) with height resolution of about 10m.
- A Low energy (1-10keV) X-ray Spectrometer (LEX) using for measuring the fluorescent X-rays emanating from the lunar surface having a foot print of approximately 20km. This instrument was realized as a joint effort by ISRO and Rutherford Appellton Laboratory, UK.
- A high energy X-ray (30-270keV) mapping (HEX) employing CdZnTe solid state detector with CSI anti-coincidence system having a foot print of approximately 40km to identify degassing faults or zones on the moon by mapping Rn[222] and its radioactive daughter Pb[210]. This will enable us to understand the transport of volatiles on the moon.
- A Moon Impact Probe (MIP) which will be released to impact the Moons surface during the Mission. MIP in turn carries three instruments, a mass spectrometer, a C-band altimeter and a video camera.

Apart from the five payloads (TMC, HySI, LLRI, LEX and HEX) and MIP discussed above, five additional instruments under international collaboration have been accommodated in Chandrayaan-1. They are,

- Miniature Imaging Radar Instrument (Mini-SAR) from Applied Physics Laboratory USA supported by NASA.
- Sub KeV Atom Reflecting Analyser (SARA) from IRF, Sweden, JAXA, Japan supported by ESA and VSSC, ISRO.
- Moon Mineralogy Mapper (M-3) from Jet Propulsion Laboratory and Brown University, USA, supported by NASA.
- Infra Red Spectrometer-2 (SIR-2) from Max Plank Institute, Germany, supported by ESA.
- Radiation Dose Monitor (RADOM), Bulgarian Academy of Science, Bulgaria.

Table-1 provides the summary of Chandrayaan-1 scientific instruments, their configuration and objectives.

The Spacecraft and Launch Vehicle

Spacecraft for lunar mission has a judicious mix of the technologies of remote sensing satellites and Communication satellites.

PSLV, with enhanced performance, is chosen for the Chandrayaan-1 mission to place the spacecraft in 260km X 22,860km orbit around earth. 440 N liquid fuel motor similar to that used in INSAT series of satellites is used for further orbit raising. The spacecraft is cuboids in shape of approximately 1.50m side, weighing about 625kg at lunar orbit. The spacecraft structure used in Kalpana satellite was adopted with minor modifications for extending the thrust cylinder and incorporating an upper payload deck to accommodate MIP and few other scientific instruments. The high gain antenna used for downloading the scientific data to the Indian Deep Space Network (IDSN) is a dual gimbaled system.

The spacecraft is a 3-axis stabilized. The orientation of the spacecraft orbit is precisely determined using star trackers and gyroscopes. Chandrayaan-1 has a canted (inclined) solar array to maximize the solar power for the orbit around the moon, which is inertially fixed. It generates about 750W of peak power and is supported by Li-Ion batteries for eclipse operations. The spacecraft carries a bipropellant propulsion system to carry it from EPO through lunar orbit, including orbit and attitude (direction) maintenance in lunar orbit. The propulsion system would carry required propellant for a mission life of 2 years, with adequate margin. The TTC (Telemetry, Tracking and Tracking) system uses microwave in the S-band and the scientific payload data transmission is in X-band. Fig 1 provides the spacecraft configuration with payloads. Fig.2 gives the configuration of the Polar Satellite Launch Vehicle with its capability.

The Mission Sequence

Chandrayaan-1 was launched by PSLV- XL, a variant of flight proven PSLV, from Satish Dawan Space Centre, (SDSC), Shar. The spacecraft was injected into 260 Km X 22,860Km orbit. After separation from the launcher solar panel was deployed. The spacecraft was be raised to moon rendezvous orbit by five consecutive in-plane maneuvers at the perigee (closest location to the earth) to achieve the required 379,500km apogee. After the fifth perigee burn, the achieved Lunar Transfer Trajectory (LTT) orbit was computed using tracking data received by the IDSN and a mid-course correction was imparted 24 hrs after the last perigee burn. The spacecraft coasted for about 5 days in this trajectory prior to the lunar encounter. During the coasting phase the spacecraft was staying mostly in the sun-pointed mode and at the same time ensuring good communication link to ground. The major maneuver of the mission, called Lunar Orbit Insertion (LOI) leading to

Table-1 : Chandrayaan-1 Scientific Instruments and their Configurations				
Payload	Sensor Configuration	Wavelength/Energy Range	Spatial Resolution	Objective
Hyperspectral imager (HySI)	Wedge filter and Silicon Detector Array	0.4-.95 micrometer with 15 nanometer resolution	80 m	Mineral mapping
Infra red Spectrometer (SIR-2)	Grating Spectrometer	0.90 - 2.60 micrometer	100 m	Mineral mapping
Moon Mineral Mapper (M-3)	Grating Spectrometer and HgCdTe Detector	0.4 - 3.0 micrometer with 10 nanometer resolution	30 m	Mineral mapping and resource identification
Terrain Mapping Camera (TMC)	Three stereo cameras using silicon Detector Array	Panchromatic	5 m	Topographic mapping
Laser Ranging (LLRI)	Pulsed Nd-Yag laser with optical system	1064nm	10 m (Height)	Topography
X-ray Fluorescence Spectrometer (LEX)	Swept charged CCD	1 - 10 keV	20 km	Chemical mapping (Mg-Fe)
Solar X-ray Monitor (XSM)	Si pin diode	2 - 10 keV	---	Solar X-ray spectrum
High Energy X-ray Spectrometer (HEX)	CdZnTe Detector	20 - 250 keV	40 km	Th, Pb[210]
Synthetic Aperture Radar (mini SAR)	Radar, Scatterometer and Altimeter	2.4 GHz	100 m	Soil Topography, altimetry, detection of polar ice
Sub KeV Neutral Atom Analyzer (SARA)	Mass Spectrometer and Solar Wind Monitor	10eV - 2keV	100 m	atmospheric neutrals (H-Fe) composition, magnetic anomalies
Radiation Dose Monitor (RADOM)	Si Semiconductor	> 8 keV	---	Radiation dose

lunar capture, was carried out at the peri-selene (nearest point to the moon) part of the trajectory. The maneuver ensured successful lunar capture in a polar elliptical orbit of 500km X 7500km orbit around the moon. After successful capture and health checks, the altitude was lowered through a series of in-plane corrections to 100km near circular orbit. Fig.3 details Chandrayaan-1 Mission Sequence from launch to final orbit acquisition.

Payload Commissioning

Moon Impact Probe was released on 14 Nov 2008. All the three instruments of MIP namely video camera, altimeter and the mass spectrometer have provided good data.

Subsequently all other instruments of Chandrayaan-1 were commissioned one by one as given below:

RADOM	: 23 Oct 2008, one day after launch
TMC	: 13 Nov 2008 (in the moon orbit)
MIP	: 14 Nov 2008
HySI	: 16 Nov 2008
LLRI	: 16 Nov 2008
MiniSAR	: 17 Nov 2008
M3	: 18 Nov 2008
SIR-2	: 19 Nov 2008
CIXS	: 20 Nov 2008
HEX	: 05 Dec 2008
SARA	: 08 Dec 2008

(Low Voltage Commissioning)

All the instruments are functioning satisfactorily and refer Fig.4 for the initial data of some of the instruments. Fig.4a, the close up pictures of the Moon's surface taken by Moon Impact Probe (MIP) on November 14, 2008 as it approached it after separating from Chandrayaan-1 Spacecraft, that these pictures are reproduced as received.

Fig.4b, the picture of Moon's surface taken from lunar orbit by Chandrayaan-1 spacecraft's Terrain Mapping Camera (TMC) on November 15, 2008. The bright terrain on the lower left is the rim of 117 km wide moretus crater.

Fig.4c, Radom Data and Fig.4d, CIXS - First Lunar Spectrum. Fig.4e, Lunar craterlet (BARROW H) imaged by Chandrayaan-1 HySI camera (64 Bands) on November 16, 2008. Fig.4f, M3 composing image of the Orientale region. The image strip on the left is a color composite of data from 28 separate wavelengths of light reflected from the moon. The blue to red tones reveal changes in rock and mineral composition, and the green color is an indication of the abundance of iron-bearing minerals such as pyroxene. The image strip on the right is from a single wavelength of light that contains thermal emission, providing a new level of detail on the form and structure of the region's surface.

Indian Deep Space Network (IDSN)

Establishment of IDSN is a vital element not only for Chandrayaan-1, but also to cater to future planetary missions. The existing ISTRAC/TTC and external S-band network supported slant range up to 100,000km during journey towards moon orbit. Beyond this range during the mission profile and at lunar distance of approximately 400,000 km, IDSN was used both for TTC and payload data reception. The spacecraft position in orbit was determined using radio frequency ranging technique and computation of orbital parameters based on the measurement of range and rate of change of range. Two ground terminals one with 18m antenna and another with 32 m antenna have been established at Byalalu village near Bangalore as a part of IDSN. Though 18m terminal is sufficient for Chandrayaan-1, 32m antenna provides further margins and would cater to the futuristic needs also. Electronics Corporation of India Limited, Hyderabad had the prime responsibility of realizing 32m antenna with the technical contributions from ISTRAC, ISAC, BARC and others. Fig.5 depicts IDSN antenna.

Compared to the International Deep Space Network stations of, Goldstone California, USA, the Bangalore IDSN has 180° longitudinal shift with respect to longitude and is centrally located with respect to the other two DSNs, viz., Villa Franca, Spain and Perth, Australia. Establishing IDSN at Bangalore has the potential of commercial benefit since it may be useful to international space agencies for their planetary missions.

Indian Space Science Data Centre (ISSDC)

The IDSN in Bangalore receives the payload data. The data in its raw form along with auxiliary data is sent to Indian Space Science Data Centre (ISSDC) that has been set up in Bangalore. ISSDC would process the raw data and convert it into user-friendly form. The data centre also archives all the payload data and is the focal point for foreign payload teams as well.

Present Status and the Road Ahead

Chandrayaan-1 Spacecraft along with all 11 science instruments is fully functional in its targeted 100km Lunar Polar Orbit. All the newly built ground systems are fully operational. In a few weeks from now, the science outputs as derived from Chandrayaan-1 instruments data will be released after due reviews by Chandrayaan-1 science team. The experience gained in realizing Chandrayaan-1 mission will be fully utilized for the upcoming Chandrayaan-2 mission along with the mission specific updates.

Conclusion

The technical objectives of the mission namely, a) to design, develop and launch a spacecraft in a Lunar Polar Orbit using Indian launch vehicle and b) to develop expertise for planning and execution of mission and ground systems for sending spacecraft beyond the orbit around the earth for future planetary exploration missions have been fully accomplished.

The scientific objectives of higher resolution topographic mapping of the Moon and imaging in X-rays identified for the present mission are unique experiments in many ways and would provide insight into the chemical composition of the moon and frequency of small impactors. A comprehensive image and topography of the moon will be generated using data from Chandrayaan-1 instruments in the coming months. Such a topography database would be valuable for onward research, by both Indian and the International Science Teams. It will also enable us to

understand the lunar surface features for a more systematic planning of future missions.

The Indian mission to the moon should be seen beyond the scientific results it produces. Studies have shown that the moon could serve as a source of economic benefit to mankind and could be of strategic importance. The moon can be both, a beacon and a focus for the next generation of space exploration which will accrue new and important benefits, to the people of all nations and the earth.

Just a few decades back, man never imagined that he would set foot on the moon. Decades from now, human colonies on the moon could become a reality. India should also be in the forefront of this challenging and exciting endeavor. Chandrayaan-1 mission is a well thought out mission in this direction and has lived up to the expectations paving the way for future lunar missions.

Fig.1 Chandrayaan-1 Spacecraft configuration with payloads

Fig.2 PSLV-XL and its payload capability

Fig.3 Chandrayaan-1 Mission sequence

Fig. 4a

Fig.4b

Fig.4c Radom Data

Fig.4d CIXS First lunar spectrum

Fig.4f M3 composing image of the Orientale region

Fig.4e

Fig.5 Bangalore IDS