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Overview and Technical Architecture of India's Chandrayaan-2 Mission to the Moon

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ABSTRACT

The Indian Space Research Organization (ISRO) began India’s planetary exploration program with the successful launch of Chandrayaan-1 orbiter mission to the Moon in 2008. The eleven remote-sensing scientific instruments from ISRO, NASA and ESA onboard Chandrayaan-1 have made significant findings including discovery of water signature, spinel minerals, lunar lava tubes, evidences of recent volcanism, impact-triggered boulder movements and discovery of sputtered atomic oxygen and backscattered helium on the lunar surface.

The first Indian inter-planetary mission, Mars Orbiter Mission (MOM) with five science payloads was successfully launched by a PSLV rocket on November 5, 2013 and entered an elliptical orbit around planet Mars on September 24, 2014. The Mars Orbiter is currently observing Mars surface features, morphology, mineralogy and the Martian atmosphere.

The Chandrayaan-2 spacecraft to the Moon is a composite module consisting of Orbiter, Lander and Rover. Chandrayaan-2 Mission is planned to be launched onboard Geosynchronous Satellite Launch Vehicle (GSLV) during first quarter of 2018. The Orbiter will carry the combined stack up to moon till the Lunar Orbit Insertion (LOI). The combined stack is then inserted into a lunar orbit of 100 km x 100 km. The Lander with the Rover is then planned to be separated from the Orbiter for soft-landing on a site near south polar lunar surface.

This paper presents an overview of the technology and science objectives of India’s Chandrayaan-2 Mission to the Moon, spacecraft architecture, science instruments, launch vehicle, mission design and operations.

I. INTRODUCTION

Indian Space Research Organization (ISRO), established in November 1969, is the implementation arm of the Government of India’s Department of Space (DOS). The Government of India constituted the Space Commission and established the Department of Space (DOS) in June 1972 and brought ISRO under DOS in September 1972. Space Commission formulates the policies and oversees the implementation of the Indian Space Program to promote the development and application of space science and technology for the socio-economic benefit of the country. DOS implements these programs through, mainly, ISRO, Physical Research Laboratory (PRL), National Atmospheric Research Laboratory (NARL), North Eastern-Space Applications Centre (NE-SAC) and Semi-Conductor Laboratory (SCL). Antrix Corporation, incorporated in 1992 as a Government owned company, markets the space products and services.[1]

The establishment of space systems and their applications are coordinated by the national level committees: INSAT Coordination Committee (ICC), Planning Committee on National Natural Resources Management System (PC-NNRMS) and Advisory Committee for Space Sciences (ADCOS).

The Advisory Committee for Space Science (ADCOS) promotes indigenous activities in the field of space science. ADCOS is the planning body responsible for supporting Indian Space Program missions in the following areas: (1) Astronomy & Astrophysics, (2) Space Weather, (3) Planetary Exploration, and (4) Weather & Climate Science.

Chandrayaan-1, India’s first deep space orbiter mission to the Moon, was launched on October 22, 2008 by the PSLV-XL Rocket. The successful launch and operation of the Chandrayaan-1 spacecraft and the significant scientific discoveries from the mission heralds a new phase in the Indian Space Program. ISRO launched its first interplanetary mission, Mars Orbiter Mission (MOM), also known as “Mangalyaan” on November 05, 2013. The Mars Orbiter spacecraft is providing valuable data on Martian surface and atmosphere through its five scientific payloads. Astrosat satellite, India’s first dedicated space observatory, was successfully launched on September 28, 2015 by a PSLV Rocket and is currently providing simultaneous multi-wavelength (optical, UV and X-rays) observations of astronomical objects through its five scientific instruments.[2]

II. CHANDRAYAAN-1 MISSION AND ITS FINDINGS

Chandrayaan-1, India's first deep space orbiter mission to the Moon, was launched on October 22, 2008 by a PSLV-XL Rocket. The spacecraft carried eleven scientific instruments to prepare three-dimensional chemical and mineralogical mapping of the lunar surface. The payloads consisted of five Indian instruments, two from NASA, three from ESA and one from Bulgaria. A secondary mini-satellite carried onboard the Chandrayaan-1 spacecraft, Indian Moon Impact Probe (MIP) was also released from the spacecraft's final lunar polar orbit of 100 KM above the moon's surface on November 14, 2008.

The basic architecture for Chandrayaan-1 was derived from the IRS satellite bus, weighing 1380 kg wet and with a dry mass of 560 kg. The Chandrayaan-1 orbiter spacecraft had the shape of a cuboid with a length of 1.5 meters, a width of 1.53 meters, and a height of 1.56 meters. The structure was designed with a central thrust bearing cylinder extended above the cuboid to a height of 2.18 meters. A single canted solar panel generated 750 W of peak power. A Lithium-Ion battery provided backup power supply.

Chandrayaan-1 spacecraft was in the intended 100 km lunar polar orbit from 12 November 2008 till 19 May 2009, before being raised to a 200 Km orbit to keep the temperature of the orbiter down. This change enabled further studies of orbital perturbations and gravitational field variations and imaging of lunar surface with a wide swath. Though it was originally planned for a two-year period, the mission ended on 29 August 2009 when ISRO lost communications with the satellite, most likely due to a failure of a power converter. The scientific payload data were stored in two solid state recorders and subsequently played back and downlinked in X-band with a 20-MHz bandwidth by a steerable antenna pointing at the Indian Deep Space Network (IDSN).

The Indian baseline science payload consisted of a Terrain Mapping Camera (TMC), a Hyper-Spectral Imager (HySI), a Low **e**nergy **x**-ray **s**pectrometer, a High Energy X- ray Spectrometer (HEX) and a Lunar Laser Ranging Instrument (LLRI). These payloads provided simultaneous mineralogical, chemical and photo-geological remote-sensing data. NASA supplied a miniature imaging radar instrument (Mini-SAR) to explore the polar regions of the moon and the Moon Mineralogy Mapper (M^3) for high resolution chemical mapping. ESA provided a Sub-keV Atom Reflecting Analyser (SARA) for studying solar wind–lunar surface interactions and lunar surface magnetic anomalies. Bulgaria supplied the Radiation Dose Monitor (RADOM) for monitoring cosmic energetic particle flux en route to the moon and in the lunar environment.[3] The scientific payloads of Chandrayaan-1 spacecraft had a mass of about 55 kg. Below is the list of the various Indian and foreign payloads carried onboard Chandrayaan-1 to achieve the scientific objectives:

Science Objective	Payload	Agency
Chemical Mapping	HEX - High Energy X-ray Spectrometer	Indian Space Research Organization (ISRO)
	C1XS - Chandrayaan-1 X-ray Spectrometer	European Space Agency (ESA)
Mineralogical Mapping	HySI - Hyper Spectral Imaging Camera	Indian Space Research Organization (ISRO)
	SIR-2 - Near Infrared Spectrometer	European Space Agency (ESA)
	M3 - Moon Mineralogy Mapper	National Aeronautics and Space Administration (NASA), USA.
Map and characterize nature of polar region	Mini-SAR Synthetic Aperture Radar	National Aeronautics and Space Administration (NASA), USA.
Topography Mapping	LLRI - Lunar Laser Ranging Instrument	Indian Space Research Organization (ISRO)
	TMC - Terrain Mapping stereo Camera	Indian Space Research Organization (ISRO)
Radiation Environment	RADOM - Radiation Dose Monitor Experiment	Bulgarian Academy of Sciences
Magnetic Field Mapping	SARA - Sub KeV Atom Reflecting Analyzer	European Space Agency (ESA)
Lunar Atmospheric Constituent	MIP - Moon Impact Probe	Indian Space Research Organization (ISRO)

NASA's Moon Mineralogy Mapper (M3) instrument discovered surficial water in the Moon, linked to abundance of OH/ H_20 involving solar-wind interaction with lunar surface.[4] ISRO's Chandra's Altitudinal Composition Explorer (CHACE) mass spectrometer payload onboard the Moon Impact Probe (MIP) made a direct detection of H_2O in the tenuous lunar ambience through *in situ* measurements. These two (CHACE and M3) complementary experiments are shown to collectively provide unambiguous signatures for the distribution of water in solid and gaseous phases in Earth's moon.[5]

The Terrain Mapping Camera (TMC) instrument has provided unprecedented details on lunar topography including those for Apollo 15 and 17 sites. ESA provided SARA payload onboard Chandrayaan-1 had found that solar wind protons impinging on the lunar surface are reflected back to space as neutral hydrogen atoms.

The Mini-SAR imaging instrument from NASA mapped more than 95% of the areas polewards of 80° latitude at a resolution of 150 meters. A new study found that the signature of water is present nearly everywhere on the lunar surface, not limited to the polar regions with a maximum water concentration average of around 500 to 750 parts per million in the higher latitudes.[6]

III. CHANDRAYAAN-2 MISSION OVERVIEW

The Chandrayaan-2 ("चन्द्रयान-२" in Sanskrit) spacecraft is an advanced version of the flight proven Chandrayaan-1 orbiter spacecraft. Chandrayaan-2 is a two-module configuration spacecraft comprising of the 'Orbiter Craft' and the 'Lander Craft'. The Orbiter Craft Module structure is a three-metric ton category bus structure made of a central composite cylinder, shear webs and deck panels. It was developed by Hindustan Aeronautics Limited (HAL) and delivered in June 2015 to ISRO Satellite Center where the other spacecraft subsystems and payloads were built onto the structure.[7] The Chandrayaan-2 mission is aimed at placing an Orbiter around the moon and sending a Lander module with a Rover to the surface of the moon. Chandrayaan-2 will be launched by a Geo-Stationary Satellite Launch Vehicle (GSLV-MKII) during the first quarter of 2018.

The primary objectives of Chandrayaan-2 mission are to design, realize and deploy a Lunar Lander module capable of soft landing on a specified lunar site and deploy a Rover to carry out in-situ analysis and to carry out remote sensing analysis of lunar surface to enhance the scientific objectives of Chandrayaan-1 with improved resolution through the orbiter science payloads observation. The Lander module with the Rover is to be de-orbited from 100 km circular orbit and has to descent to the moon surface at the identified site using the liquid engines for braking. Chandrayaan-2 orbiter is planned to be operational for two years while the Lander-Rover module is expected to be operational for only 14 Earth days.

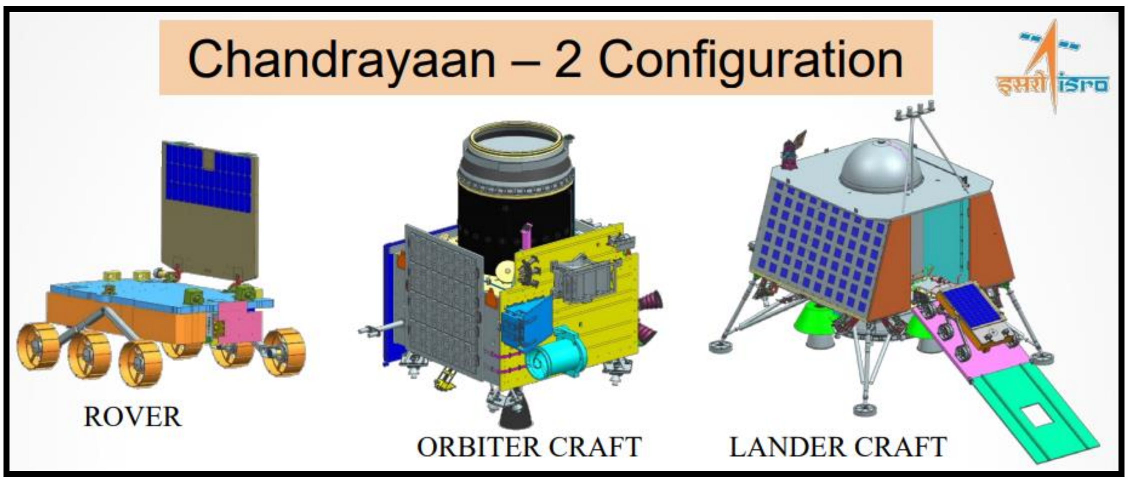

Fig. 1: Chandrayaan-2 Configuration (Credit: ISRO)

ISRO identified the following as advanced technology elements needed for this mission: High Resolution Camera, Altimeter, Velocity meter, Throttleable Liquid engines and attitude thrusters, Navigation Camera, Accelerometer, Hazard avoidance camera and related software.[7] The Systems Reliability Group, a part of the ISRO Space Application Centre (SAC**),** based in Ahmedabad, is responsible for development and testing of the camera module on the Rover. The same facility is also responsible for creation of the software to be used on the rover to operate in a semi-autonomous fashion.

The Chandrayaan-2 Orbiter and the Lander will be stacked together and will be injected into an "Earth Parking Orbit". After going around the Earth several times, the Orbiter will be inserted into an extremely elliptical Lunar orbit, which will be reduced to 100 km over the surface of the moon after a few Earth Bound Maneuver (EBN) orbits. The orbiter will carry the Lander, with the Rover on board, from Earth orbit to Moon orbit. The orbiter will survey the landing site before deploying the lander.

The Aerial Services & Digital Mapping Area (AS&DMA**)**, a division of National Remote Sensing Centre (NRSC) of ISRO has conducted airborne tests of sensors included onboard the Chandrayaan-2 Lander in the Chitradurga district of Karnataka state with simulated lunar terrain and artificial craters. The details of the potential lunar south pole landing sites are provided in the table below.[8]

L.S.	Name	Lat.	Long.	Area (Sq. km)	Hmin (m)	Hmax (m)	Havg (m)	Crater Density (> 4m)
1	Cabeus Crater Rim	-86.793	-25.805	16 X 10	62	5685	2685	502
2	Malapert West	-85.480	-16.098	16 X 10	-624	4683	2243	434
3	Leibnitz β Plateau South	-85.090	26.505	16 X 10	8857	11004	10031	354
4	Leibnitz β Plateau North	-84.918	35.924	16 X 10	9392	13792	12408	300

IV. CHANDRAYAAN-2 SPACECRAFT ARCHITECTURE

Chandrayaan-2 Orbiter Craft is built around a cuboidal structure and houses the propulsion tanks and the separation mechanism of the launch vehicle at one end and lander at the other end. The Orbiter decks have the different housekeeping systems of the Spacecraft. The Solar array consists of two solar panels which are stowed in the launch configuration and deployed on separation to provide the power required for the Orbiter Craft during different phases around the earth and the moon. Lithium Ion battery provides the power support during eclipse and peak power requirements of the spacecraft. Orbiter is a three-axis body stabilized spacecraft with reaction wheels which provide a stable platform for imaging. Thrusters are present for momentum dumping and attitude corrections. A bipropellant liquid engine is used to raise the orbit of the composite from earth parking orbit to 100km lunar orbit. The attitude and orbit control electronics receive the attitude data from the star sensors and the body rates from the Gyro's for S/C control. The other sensors used for spacecraft control are Sun sensors and accelerometers. The telemetry system provides health information of the spacecraft while the tele-command system handles the command execution and distribution. The different payloads on the Orbiter are interfaced to the base band data handling system for formatting and recording in solid state recorder for play back later. The RF system consists of a S band TTC transponder and X band transmitter for Payload data transmission to Indian Deep Space Network (IDSN) station. The payload data is transmitted through a X-band dual gimbal antenna which will be pointed to the ground station.[9]

Chandrayaan-2 Lander structure is a truncated pyramid around a cylinder which houses the propellant tank and the interface for the separation mechanism of Orbiter. The vertical panels have solar cells while the stiffener panels house all the electronic systems. The lander leg mechanism (four nos.) provides stability upon landing on different terrains. The body mounted solar panels provide the power for the different systems during the mission in all phases. In addition, lithium ion battery supports the power requirements during eclipse and the lander descent. The Control electronics provide the interface to all the sensors and the actuator drives. The sensors are configured for inertial navigation from separation to the end of rough braking and the absolute sensors determine the position and velocity with respect to the landing site to guide the lander beyond the rough braking phase to the identified site. The lander Navigation guidance and control will be autonomous from separation onwards and must ensure a precise, safe and soft landing on the lunar surface. The braking thrust for decelerating the lander is provided by four nos. of liquid engines. The attitude of the lander is maintained with eight nos. of thrusters. The lander leg mechanism ensures that the energy at touch down is absorbed and all the lander systems are integral and stable for further conduct of payload deployments and science on moon. Each leg consists of a telescopic leg assembly with crushable damper material in the leg and foot pad. Extensive analysis and tests are done for the lander leg mechanism to ensure stability under extreme terrain conditions and terminal velocity. The TTC communication between the Lander – IDSN is in S band and the payload data is transmitted by a high torque dual gimbal antenna. The Lander has a TM-TC data handling system with inbuilt storage. The Chandrayaan-2 Rover is stowed in the lander during launch and upon landing the ramps are deployed and Rover starts its journey on the lunar surface. The Lander payloads will be deployed on landing.[9]

Chandrayaan-2 Rover is a six-wheeled mobility system with the objective of performing mobility on the low gravity & vacuum of moon and in addition conduct science for understanding the lunar resources. The design of the Rover is based on the well-proven space rover "Sojourner" that was deployed by NASA for the exploration of Mars in July 1997. Rover chassis houses all the electronics and has two navigation cameras to generate stereo images for path planning. The deployed solar panel provides the power during the mission. The rocker bogie mechanism along with the six wheels ensure a rugged mobility system over obstacles and slopes along the identified path for exploration of the region. The Rover communicates to the IDSN via the Lander. The two Rover payloads conduct science on the lunar surface.[9]

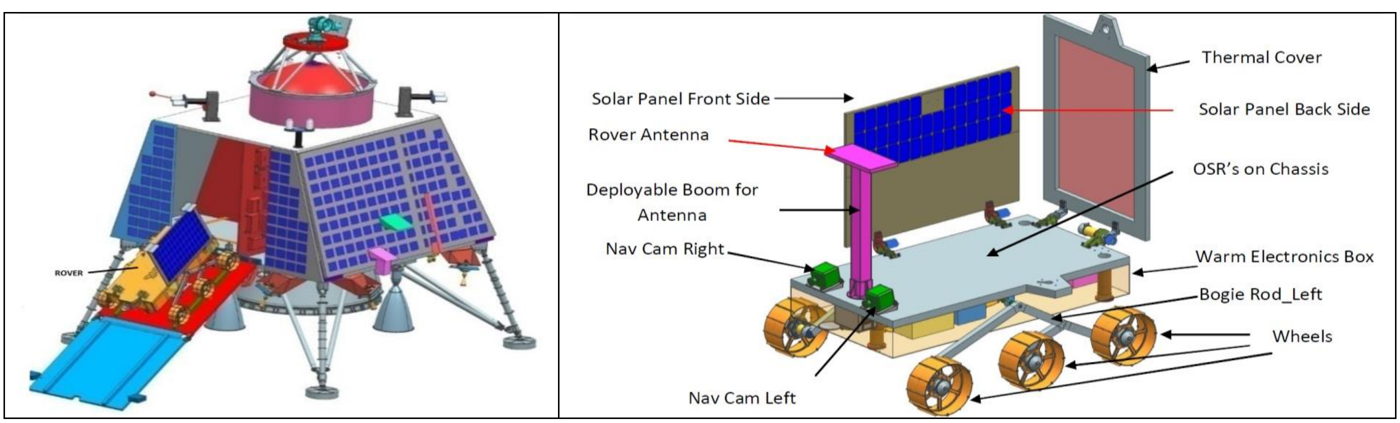

Fig. 2: Schematic of Chandrayaan-2 Lander-Rover Module and Rover in deployed configuration

The Chandrayaan-2 mission profile starts with the GSLV MKII launch vehicle injecting the combined stack of lunar orbiter and lander modules (wet mass ~ 3320 kg) into a Transfer Orbit. The orbiter and lander are injected to a 170 x 18500 km transfer orbit by the launch vehicle. A series of mid-course orbit raising maneuvers and the final insertion maneuver are performed to place the spacecraft in a 100 x 100 km circular lunar orbit. Based on mission planning, after achieving the desired initial conditions, the lander is separated from orbiter and a short burn de-boost is carried out to reduce the peri-lune to 6 km. After a long coast phase, the lander will reach the peri-lune. Near the peri-lune, a second longer de-boost burn is carried out for horizontal braking. The objective of the braking phase is to efficiently kill the horizontal velocity to 0 at desired altitude. The lander will then follow a vertical descent, during which periodic firing shall be done to reduce the vertical velocity and achieve 0 m/s velocity, at 4 m height where the thrust will be cut off. The final phase is the free fall from 4 m to impact point with touch down velocity < 5 m/s.

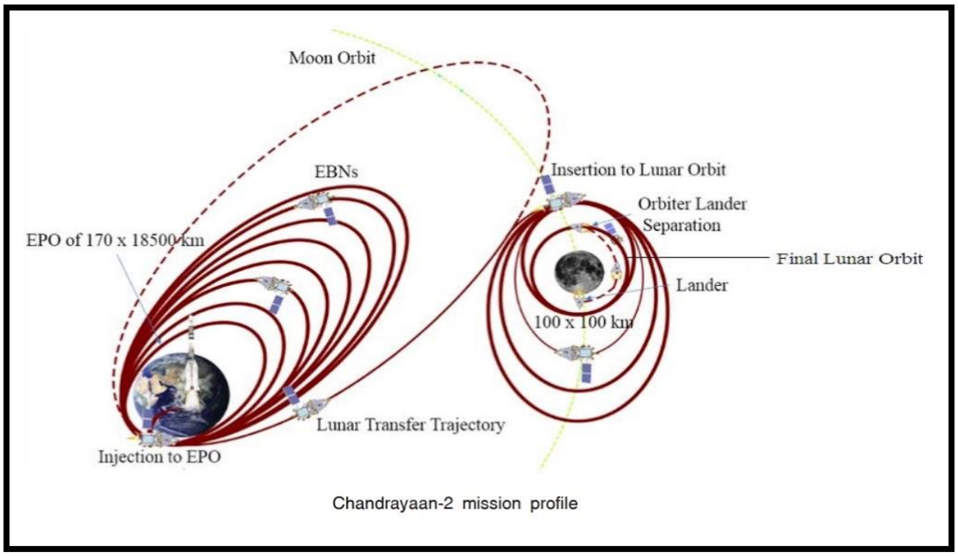

Fig. 3: Chandrayaan-2 Mission Profile (Credit: ISRO)

The Lander module operations from separation to touch down shall be carried out by a closed loop NGC system. The Inertial Navigation System (INS) alone will not be able to meet the stringent touchdown requirement of < 5 m/s in vertical and horizontal velocity. The unbounded error growth in the INS with time is corrected with the help of other absolute external measurements. An integrated navigation system consisting of an INS, star tracker (2), altimeter (2), velocimeter (2) and image sensor (2) will be utilized. The initial attitude of IMU at de-boost is determined using star tracker. The accelerometer and gyro drifts are also updated before the first burn. The state vectors are established using Deep Space Network (DSN), Orbit Determination and ground uplink and transferred to the INS system. The lander NGC will be active before the separation from orbiter itself. The INS after updating the state vector is used for the first burn. During the long coast phase also, the attitude and gyro drifts are updated using star tracker. The accelerometer bias also is updated during the long coast phase. The INS state vector is used during the second burn. During the vertical descent phase, radar altimeter is used for the height information. Doppler velocity sensor is primarily used to measure the horizontal velocity in the terminal landing phase to ensure safe landing with a touch down velocity of < 5 m/s. Vision aiding or terrain sensor using CCD camera is used to get the image of lunar surface to avoid the obstacles and re-targeting the landing surface.[10]

Chandrayaan-2 Lander will employ a clustered configuration of four 800N engines along with 50N attitude control thrusters placed at the bottom of spacecraft, to decelerate the spacecraft for braking and soft landing on lunar surface. The lander-craft will be released from lunar orbit, which will further undergo various lunar bound phases like de-boosting, rough braking, precision braking, and vertical descent. The engines will be operated together in different phases to reduce spacecraft's velocity to move from 100 km North Pole to 6 km South Pole lunar altitude location. The Lander will have on board a radio altimeter, a pattern detection camera and a laser inertial reference and accelerometer package (LIRAP). The thermal protection system has been designed to maintain the temperature of lander-craft systems within the safe limits during this phase.[11]

The Proportional Flow Control Valve (PFCV) is the heart of the system which uses a movable pintle based design as a valving element, which moves in and out of the valve flow area thus closing and opening the valve in the process. This movement is controlled by a stepper motor based actuator which will provide stroke proportional to command and thereby provide smooth and continuous flow control.[12]

The Lander-Rover module weighing about 1250 kg will be soft landed on the specific lunar south polar site. The Lander will deploy a Lunar Rover (~ mass 20 kg) to carry out in-situ analysis. The Rover comprises of six independently driven wheels that are connected to the body of the rover using a rocker-bogie mechanism with 10 degrees of freedom (DOF). Rover chassis houses all electronics and has two cameras for generating stereo images for path planning. The deployed solar panel provides all the power during the mission. Rover is the integration of locomotion, navigation system, communication system, manipulator and science equipment. An onboard software will allow the Rover to roam the surface of the Moon in a semi-autonomous manner. ISRO will provide partial command and control instructions from the ground.

As per a memorandum of understanding signed with ISRO, IIT Kanpur has designed, developed and validated two software algorithms (a) kinematic control algorithm for the rover motion on an uneven terrain and (b) algorithms for computer vision based autonomous navigation system for mobile robots for the lunar rover mission. The vision based system would provide the 3D map of the terrain based on which the traction control algorithm would give the safest path for the rover. The path tracking control (PTC) is based on the kinematics and dynamics model of the Rover undergoing 3D motion with slips. A slip estimator for the rover would be used in the feedback for the path tracking controller.[13]

All the six wheels of the Rover are driven by DC brushless servo motors. The front and the rear wheels also have steering motors. The rover has two rocker arms connected to the rover body through a differential. Each rocker has a rear wheel connected to one end, and a bogie connected to the other end. The bogie is connected to the rocker with a free pivoting joint. The wheels are spherical in shape and this ensures that the normal force at the terrain contact passes through the wheel center to reduce the wheel torque requirement. The maximum allowable gradient that the rover can safely climb is 35', and it can move in a terrain with a maximum of 35' sidewise slope.[14]

The inertial navigation of the lander is carried out by LIRAP (Laser gyro based Inertial Reference Unit and Accelerometer Package). The LIRAP consists of four ILG (ISRO Laser Gyro) and four CSA (Ceramic Servo Accelerometer) sensors. This sensor provides attitude referencing for the lander after it separates from the orbiter till landing. The accelerometers provide velocity increment for the liquid engine cutoff during orbit maneuvers. It also provides inertial navigation information (position, velocity & quaternions) from lander separation to touchdown. One of the key elements essential for safe landing is the Hazard Detection and Avoidance (HDA) system. The HDA system comprises of several sensors like Orbiter High Resolution Camera (OHRC) for characterization of landing Site, Cameras for Horizontal velocity calculation, Camera for pattern matching and position estimation, Microwave and Laser altimeter, Laser Doppler velocimeter. All these sensors provide information like lander's horizontal velocity, vertical velocity, height above moon's surface, relative position of the lander w.r.t moon's surface, hazard/safe zone around the landing site. The HDA system onboard the lander processes the inputs from the various sensors, compares the data collected with the information already stored in the lander and provides the required inputs to the Navigation and Guidance system in real time to correct the trajectory at the end of rough braking to enable a safe and soft landing.[9]

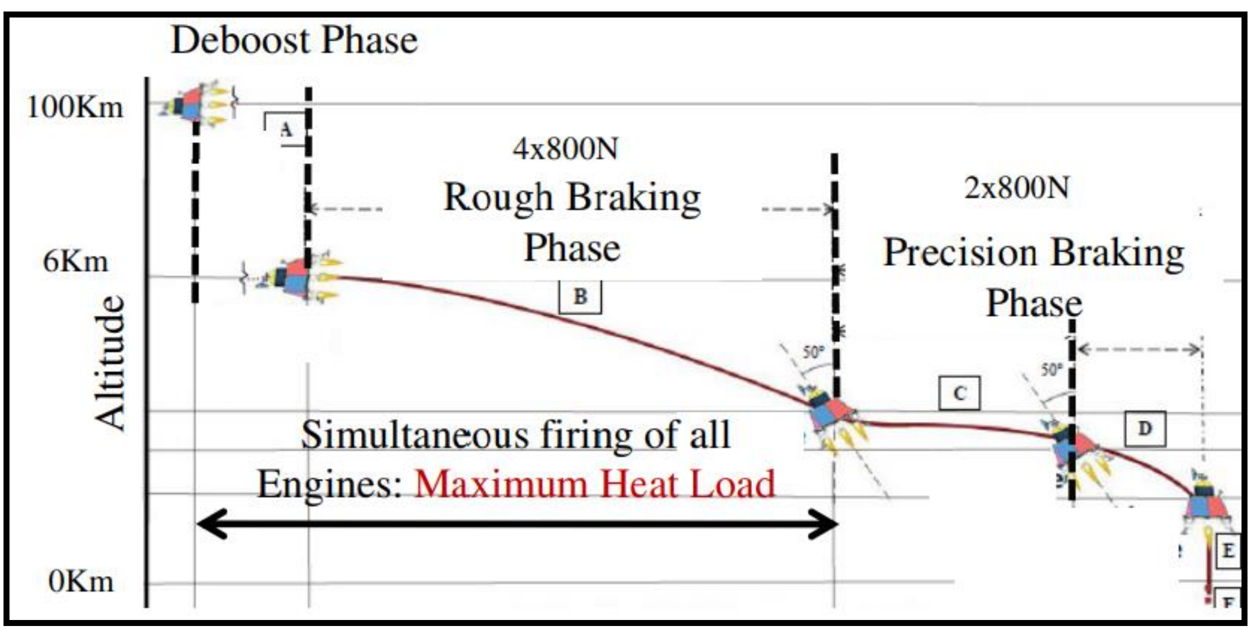

Fig. 4: Chandrayaan-2 Lunar Lander (with Rover) Soft Landing Sequence (Credit: ISRO)

V. CHANDRAYAAN-2 SPACECRAFT SCIENCE PAYLOADS

Chandrayaan-2 mission aims at understanding the origin and evolution of the Moon using instruments onboard Orbiter and in-situ analysis of lunar surface using instruments on the Lander and Rover.

The instruments on the Orbiter and their science objectives are as follows:

Science Objective	Payload	Provider
Chemical Mapping	CLASS: Large Area Soft X-ray Spectrometer	ISRO Satellite Center, Bengaluru
	XSM: Solar X-ray Monitor	Physical Research Laboratory, Ahmedabad
Mineralogical Mapping	IIRS: Imaging IR Spectrometer	Space Applications Center (SAC), Ahmedabad
Map Lunar Exosphere	ChACE-2: Neutral Mass Spectrometer	Space Physics Laboratory, Thiruvananthapuram
Topography Mapping	TMC-2: Terrain Mapping stereo Camera	Space Applications Center (SAC), Ahmedabad
Probe Lunar Surface for Water Ice, constituents	SAR: L and S band Synthetic Aperture Radar	Space Applications Center (SAC), Ahmedabad

1) **CLASS: Large Area Soft x-ray Spectrometer** - aims to map the abundance of the major rock forming elements on the lunar surface using the technique of X-ray fluorescence during solar flare events. CLASS is a continuation of the successful C1XS XRF experiment on Chandrayaan-1. CLASS is designed to provide lunar mapping of elemental abundances with a nominal spatial resolution of 25 km (FWHM) from a 200 Km polar, circular orbit of Chandrayaan-2. The science objectives of CLASS are to make global studies on the diversity and distribution of lunar lithologies, quantitative estimate of Mg abundance, essential for determining the distribution of Mg suite rocks, bulk composition of the crust, abundance patterns in the major crustal provinces and mare basalt diversity. CLASS is expected to provide global maps of major elements from Na to Fe at resolutions of a few tens of kilometers. Together with mineralogical data this would provide a comprehensive picture of lunar surface chemistry.[15]

2) **XSM: Solar X-ray Monitor** - XSM instrument will have two packages namely, XSM sensor package and XSM electronics package. XSM will accurately measure spectrum of Solar X-rays in the energy range of 1–15 keV with energy resolution ~200 eV @ 5.9 keV. This will be achieved by using state-of-the-art Silicon Drift Detector (SDD), which has a unique capability of maintaining high energy resolution at very high incident count rate expected from Solar X-rays. XSM onboard Chandrayaan-2 will be the first experiment to use such detector for Solar X-ray monitoring. [16]

3) **IIRS: Imaging IR Spectrometer** – Coverage in the 0.8 to 5μm for lunar mineralogy and trace signatures of hydroxyl (OH) and water (H_20) molecules in polar regions. Study of mare volcanism, variations in basaltic compositions, mantle hetereogenity at basin and local scale.[17]

4) **ChACE-2: Neutral Mass Spectrometer** – To carry out a detailed study of the lunar exosphere. CHACE-2 mass spectrometer aboard the Chandrayaan-2 orbiter will study the lunar exosphere from 100 km polar orbit in the range of 1 to 300 amu with 1 amu mass resolution. CHACE- 2 will cover the polar regions of the moon including the permanently shadowed regions (PSR), which are believed to be pristine enough to retain the history of the inner solar system. Taking advantage of the axial rotation of the Moon and the polar orbit of Chandrayaan-2, the CHACE-2 will be useful to study the global distribution of the lunar exosphere. It will also study the day-night variation of the lunar neutral exosphere as well as the variation during the passage through the geomagnetic tail.[18]

5) **TMC-2: Terrain Mapping stereo Camera** – To prepare a detailed three dimensional map of the lunar surface essential for studying the lunar mineralogy and geology.

6) **SAR: L and S band Synthetic Aperture Radar** - The S-band SAR will provide continuity to the Chandrayaan-1 MiniSAR data, whereas L-band is expected to provide deeper penetration of the lunar regolith. The system will have a selectable slant-range resolution from 2 m to 75 m, along with standalone (L or S) and simultaneous (L and S) modes of imaging. Various features of the instrument like hybrid and full-polarimetry, a wide range of imaging incidence angles (~10° to ~35°) and the high spatial resolution will greatly enhance our understanding of surface properties especially in the polar regions of the Moon. The system will also help in resolving some of the ambiguities in interpreting high values of Circular Polarization Ratio (CPR) observed in MiniSAR data. The added information from full-polarimetric data will allow greater confidence in the results derived particularly in detecting the presence (and estimating the quantity) of water–ice in the polar craters.[19]

The following are the scientific instruments selected for the Chandrayaan-2 Lander.

Science Objective	Payload	Provider
Measure near surface plasma density and its changes with time	RAMBHA: Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere	Space Physics Laboratory, Thiruvananthapuram
Measure thermal properties of lunar regolith near polar region	ChaSTE: Chandra's Surface Thermo Physical Experiment	Physical Research Laboratory, Ahmedabad Space Physics Laboratory, Thiruvananthapuram
Measure Lunar Seismicity around the landing site	ILSA: Instrument for Lunar Seismic Activity	Indian Space Research Organization

1) **RAMBHA: Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere** - a unique payload package that would provide a comprehensive exploration of Lunar plasma environment. RAMBHA consists of a suite of three experiments, a Langmuir Probe (LP) and a dual frequency radio science (DFRS) experiment to measure the density of the lunar near-surface plasma and how it changes over time.[20] DFRS will measure the total electron content of lunar ionosphere.

2) **ChaSTE: Chandra's Surface Thermo Physical Experiment** - ChaSTE will help measure the vertical temperature gradient and thermal conductivity within the top 10 cm of the regolith. The experiment contains a thermal probe which will be deployed up to ~10 cm into the lunar regolith at the landing site. Harness running from the probe will connect the probe to the electronics placed inside the lander. An important aspect of the payload is the design of a precise and wide-range temperature measurement front-end (FE) and the selection of a custom developed Platinum RTD, PT1000 as a sensing element.[21]

3) **ILSA: Instrument for Lunar Seismic Activity** - which measures seismicity around the landing site.

The following are the scientific instruments selected for the Chandrayaan-2 Rover.

Science Objective	Payload	Provider
Study the elemental composition of lunar rock and soil	APXS: Alpha Particle X-ray Spectroscope	Physical Research Laboratory, Ahmedabad
Elemental analysis of lunar regolith	LIBS: Laser Induced Breakdown Spectroscope	Laboratory for Electro-Optic Systems, Bengaluru

1) **APXS: Alpha Particle X-ray Spectroscope** - to study the elemental composition of Lunar rock and soil onboard Chandrayaan-2 rover by irradiation the lunar surface with alpha particles and X-rays using radio-active alpha source. The working principle of APXS involves measuring the intensity of characteristic X-rays emitted from the sample due to Alpha Particle Induced X-ray Emission (PIXE) and X-ray florescence (XRF) processes using ^{241}Am alpha source which allows us to determine of elements from Na to Br, spanning the energy range of 0.9 to 16 keV. The electronics design of the APXS experiment has been completed and shown that the developed system provides energy resolution of ~150 eV @ 5.9 keV which is comparable to off-the-shelf Silicon Drift Detector (SDD) based X-ray spectrometers.[21] APXS instrument consists of two packages namely APXS sensor head and APXS backend electronics. APXS sensor head will be mounted on a robotic arm. On command, the robotic arm brings the sensor head close to the lunar surface (without touching it) and after the measurement, the sensor head is taken back to the parking position. APXS sensor head assembly contains SDD, six alpha sources and front end electronic circuits such as charge sensitive preamplifier (CSPA), shaper and filter circuits associated with the detector. Sensor head contains a circular disc which holds 6 alpha sources symmetrically around the disc and the detector at the center.[22]

2) **LIBS: Laser Induced Breakdown Spectroscope** – for performing simultaneous multi-element determination of matter in any of its diverse forms, namely, solid, liquid or gas using an intense nanosecond pulse duration of laser beam of lunar regolith from an in-situ distance of 200mm from the surface. The plasma emission emanating from the target surface is collected by a chromatic aberration corrected Collection-Optics-Unit (COU) and spectra are acquired using an aberration corrected concave holographic grating and linear-CCD based spectrograph. The spectrograph supports variable time delay in range of 1µs to 5µs and integration time of 8µs to 1ms. The LIBS instrument is realized with the weight of 1.2kg, power consumption of <5W and a footprint of 180mm x 150mm x 80mm.[23]

VI. CHANDRAYAAN-2 MISSION OPERATIONS

India's Chandrayaan-2 spacecraft consisting of an Orbiter module and a Lander (with Rover) module is expected to be launched during the first quarter of 2018 by the Geostationary Satellite Launch Vehicle MKII (GSLV – F10) from the Satish Dhawan Space Center (SDSC) in Sriharikota Island located in the state of Andhra Pradesh. The GSLV MKII Rocket will place the Chandrayaan-2 spacecraft in a highly elliptical Earth parking orbit (EPO) of 170 km x 18,500 km. The Chandrayaan-2 spacecraft's Orbiter propulsion system raises the orbit around the earth through a number of earth burn maneuvers and propels the composite to a Lunar transfer trajectory. Further, the Orbiter gets captured into a Moon orbit through a precise maneuver by the propulsion system of the Orbiter. Further, maneuvers around the moon are planned such that the orbital path of the composite in the 100 Km circular polar orbit will be over the landing site at the identified day.[9]

The day of launch / day and position of insertion into the Lunar Orbit will be timed so as to maximize the life of the Lander and Rover missions. This constraint will be met by proper planning of the Launch vehicle insertion parameters, orbit raising maneuvers and Lunar capture geometry with respect to Sun and Earth. The Orbital parameter of the Chandrayaan-2 spacecraft composite when around the moon will have to be precisely determined and corrections made so as to ensure that the composite is at the separation point at the pre-determined time. Once at this point, the Orbiter / Lander separation system will separate the two modules. The Chandrayaan-2 Orbiter will continue to orbit around the Moon and will perform the science over the moon.

On separation, a de-boost maneuver at 100km altitude, causes a free fall of Lander to 18km altitude. Powered descent to the designated landing site is initiated using a closed loop Navigation, Guidance and Control (NGC) system to ensure a precise soft landing at touchdown. The Lander which will be travelling at 1.7 km/sec at 100km, on separation, will be de-orbited [by a Hohmann transfer] by firing its braking engines to reach a periapsis of 18 Km. The Lander module will be precisely navigated as per plan with the onboard Inertial Navigation System. Once at the periapsis the rough braking phase is initiated. During this powered descent phase the attitude of the Lander will be precisely controlled and the Navigation Guidance and Control System with the help of the Inertial sensors will provide the closed loop feedback for the actuator Systems. At the end of the rough braking phase [~7 km], the Hazard avoidance sensors will sense the position and velocity of the Lander with reference to the landing site. Based on the relative position and velocity with respect to the pre-determined landing site on the moon surface, the further trajectory is planned on board and the sensors along with actuators will guide the Lander to a position over the landing site [~100 m]. At this point, the Lander hovers over the site and the hazard avoidance sensor will determine the safest landing point in the near vicinity and the Lander will be maneuvered to this point. At a height of 2m, upon ensuring that the relative velocity with reference to moon surface is zero, the braking engines are cut off. The Lander freely falls to the surface and the landing leg mechanism will absorb the impact loads and ensure the integrity of the Lander for further operations. The entire operation from separation to touch down is fully autonomous and must be performed by the onboard computers in the Lander without any intervention from ground.

The onboard guidance algorithm takes current position and velocity from Navigation (at every guidance cycle) and generates steering profile in real time by considering the end target states. The steering profile decides the magnitude of the thrust for each engine and the required attitude for the lander. The attitude controller tracks the reference attitude while ensuring closed loop stability. Inertial Navigation is prone to errors due to factors such as error in initial states, propagation errors and inherent inaccuracies. This needs to be corrected with updates from Absolute Navigation sensors. When the lander is at a height of 7kms from moon's surface, the absolute position of the lander with respect to the landing site is determined using Lander position detection camera. In addition, at this instance the horizontal and vertical velocity, absolute height with respect to moon's surface are derived from the onboard instruments and provided to the closed loop Navigation Guidance and Control (NGC) system for further refinement of trajectory.

Given the absence of atmosphere on moon, active deceleration by thrusting utilizing a bipropellant system with four 800N engines will be performed. Eight 50N thrusters are used to ensure the required orientation during the entire phase of the descent. The error ellipse at separation (100km) which is due to composite state uncertainty, increases with time in view of the inertial navigation errors. To correct the same, at 7 km it is required to have controllability in the engine thrust and the same is obtained by providing throttlability in all the four engines. This variability in the engine thrust ensures a safe and soft landing at the identified site irrespective of the accumulated errors at the end of rough braking phase. The lander follows the descent trajectory and after a short hovering phase at 100m for reconfirmation of the safe landing site lands at the identified site. Once the Lander has landed on the surface, the Rover is deployed, and the Rover commences its journey on the moon surface.

Semi-autonomous navigation of the Rover is enabled by a pair of navigation cameras mounted on the Rover that are capable of taking images of the moon's surface in front of the Rover. These images are sent to the ground control center where the Digital Elevation Model of these images are created. Based on this data, the path in which the Rover can move is decided and the same is uplinked to the Rover (via lander). The slope that the Rover can navigate, the size of the boulder that the Rover can climb, the sinkage/ slippage are the basic inputs that are considered while planning the path for Rover movement. An inclinometer mounted on the chassis of the Rover computes the slope being navigated on the moon's surface and the same is used for safety reasons to terminate the motion in case the safe limits are exceeded. Other similar autonomous safety parameters like motor wheel current, communication feasibility with Lander and power generation from solar panel in view of shadows are monitored to ensure safety of the Rover during mobility.

The Chandrayaan-2 Mission will utilize the ISRO ground segment consisting of the following four main entities: [24]

- Mission Operations Complex (MOX),
- Indian Deep Space Network (IDSN),
- Indian Space Science Data Centre (ISSDC), and
- Payload Operations Centre (POC).

ISRO Mission Operations Complex (MOX) is located at Peenya campus of ISTRAC near Bangalore in the state of Karnataka. MOX has facilities such as the Main Control Room, the Mission Analysis Room, Mission Planning and Flight Dynamics, the Mission Scheduling and Payload Scheduling Facility. Mission and spacecraft specialists along with the operations crew from ISTRAC carry out operations from the MOX.

Indian Deep Space Network (IDSN) consisting of 11-m, 18-m and a 32-m antenna were established at the IDSN campus in Byalalu near Bangalore as part of the Chandrayaan-1 mission ground segment. The IDSN station will receive the Chandrayaan-2 spacecraft health data as well as the payload data. For the orbit raising phase, the TTC functions will be executed by ground stations at ISTRAC network (Bangalore, Mauritius, Port Blair, Brunei, Biak, Trivandrum). JPL DSN (Goldstone, Canberra, and Madrid) will provide deep space communication with Chandrayaan-2 Orbiter as requisitioned.

Indian Space Science Data Center (ISSDC) is a new facility established by ISRO for the Chandrayaan-1 and future deep space missions, as the primary data center for the payload data archives of Indian Space Science Missions. This data center, located at the Indian Deep Space Network (IDSN) campus in Bangalore, is responsible for the ingestion, archive, and dissemination of the payload data and related ancillary data for the Space Science missions. ISSDC interfaces with Mission Operations Complex (MOX) through dedicated communication links, Data reception centers, Payload designers, Payload operations centers, Principal investigators, Mission software developers and Science data users.

Payload Operation Centres (POCs) focus on the higher levels of science data processing, planning of payload operations, performance assessment of the payload and payload calibration. These centers are co-located with the institutions/laboratories of the Instrument designers, Principal Investigators and will be processing and analyzing data from a specific payload. POCs will pull relevant payload (level 0 and level 1) and ancillary data sets from the ISSDC dissemination server and process the data to generate higher level products. These products will be archived in ISSDC after qualification.

Fig. 5: 18-m and 32-m Antennas of the Indian Deep Space Network (IDSN) (Credit: ISRO)

VII. FINDINGS AND CONCLUSION

- The Indian Space Research Organization (ISRO) was founded in 1969 and was brought under the Department of Space (DOS) in 1972. ISRO is the implementation arm of the DOS.

- The vision of the Indian Space Program (ISP) is harnessing space technology for national development while pursuing space science research and planetary exploration.

- ISRO carries out the vision of ISP through the following programs: (a) Earth Observation – Indian Remote Sensing (IRS) Satellites, (b) Telecommunications & Weather – Indian National Satellites (INSAT), (c) Navigation – Indian Regional Navigational Satellite System (IRNSS) and (d) Planetary Exploration & Space Science missions.

- The success of India's first deep space mission to Moon, Chandrayaan-1 launched in 2008 that carried five Indian and six international scientific instruments heralded a new era in Indian Space Program (ISP) with dedicated Planetary Exploration and Space Science missions as key components of the Indian Space Vision.

- ISRO also learned several lessons from the premature demise of the Chandrayaan-1 spacecraft within 312 days of the intended two years of lunar operations. These were mainly in the areas of high radiation tolerance for electronic components, thermal management systems, importance of redundant and miniaturized sensors.

- The Indian Mars Orbiter Mission ("*Mangalyaan*") was launched on November 05, 2013 by an uprated PSLV rocket (PSLV-XL). The 1,350 Kg mass spacecraft carried five scientific payloads weighing 15 kg. The Mars mission is currently performing scientific observations from an elliptical orbit of 372 km x 80,000 km above the surface of Mars.

- A dedicated multi-wavelength space observatory mission, ASTROSAT-1 was successfully launched on September 28, 2015 by a PSLV Rocket and is currently performing scientific observations of distant celestial objects in the Optical, Ultraviolet, low and high energy X-ray regions of the electromagnetic spectrum.

- Chandrayaan-2 Mission is a two-module configuration spacecraft comprising of the 'Orbiter Craft' and the 'Lander Craft'. The Chandrayaan-2 mission is aimed at placing an Orbiter around the moon and sending a Lander module with a Rover to the surface of the moon. Chandrayaan-2 will be launched by a three-stage Geo-Stationary Satellite Launch Vehicle (GSLV-MKII) during the first quarter of 2018.

- The primary objectives of Chandrayaan-2 mission are to design, realize and deploy a Lunar Lander module capable of soft landing on a specified south polar lunar site and deploy a Rover to carry out in-situ analysis and to carry out remote sensing analysis of lunar surface to enhance the scientific objectives of Chandrayaan-1 with improved resolution through the orbiter science payloads observation.

- Chandrayaan-2 Mission is expected to further consolidate the findings from the first mission and add new ones with *in situ* analysis of the lunar surface and ionosphere. The Chandrayaan-2 Lander will take the first on-site thermal measurements on the lunar surface near a polar region.[25]

- ISRO has identified the following as advanced technology elements needed for the Chandrayaan-2 mission: High Resolution Camera, Altimeter, Velocity meter, Throttleable Liquid engines and attitude thrusters, Navigation Camera, Accelerometer, Hazard avoidance camera and related software.

- *Chandrayaan-2 Lander* structure is a truncated pyramid around a cylinder which houses the propellant tank and the interface for the separation mechanism of Orbiter. The vertical panels have solar cells while the stiffener panels house all the electronic systems. The lander leg mechanism (four nos.) provides stability upon landing on different terrains. The body mounted solar panels provide the power for the different systems during the mission in all phases. In addition, lithium ion battery supports the power requirements during eclipse and the lander descent. The lander Navigation guidance and control (NGC) will be autonomous from separation onwards and must ensure a precise, safe and soft landing on the lunar surface. The braking thrust for decelerating the lander is provided by four nos. of liquid engines.

- *Chandrayaan-2 Rover* is a six-wheeled mobility system with the objective of performing mobility on the low gravity & vacuum of moon and in addition conduct science for understanding the lunar resources. The Rover communicates to the IDSN via the Lander. The two Rover payloads conduct science on the lunar surface.

REFERENCES

[1]Department of Space, Government of India, "*About ISRO*", URL: https://www.dos.gov.in/about-isro [accessed December 04, 2017].

[2]Niruj Mohan Ramanujam, et.al, "*ASTROSAT: The Indian Astronomy Mission*", URL: https://www.isro.gov.in/sites/default/files/article-files/node/7356/astrosat-book-final.pdf [accessed December 04, 2017].

[3]Jayati Datta and S.C. Chakravarty, "*Chandrayaan-1: India's First Scientific Mission to the Moon*", URL: https://solarsystem.nasa.gov/docs/Chandra_book.pdf [accessed December 04, 2017].

[4]C.M. Pieters, et.al., "Character and Spatial Distribution of OH/H_2O on the surface of the Moon seen by M3 on Chandrayaan-1", *Science*, Vol. 326, Issue 5952, pp. 568-572, October 2009.

[5]R. Sridharan, et.al., "Direct Evidence of water (H_20) in the sunlit lunar ambience from CHACE on MIP on Chandrayaan-1", *Journal of Planetary and Space Science*, Vol. 58, Issue 6, May 2010.

[6]Shuai Li and Ralph E. Milliken, "Water on the surface of the Moon as seen by the Moon Mineralogy mapper: Distribution, abundance and origins", *Science Advances*, Vol. 3, No. 9, September 2017.

[7]Hindustan Aeronautics Limited, "HAL delivered 'Orbital Craft Module Structure' to ISRO Satellite Center", June 22, 2015.

[8]Amitabh, et.at., "Study of Potential Landing Sites on Lunar South Polar area for Chandrayaan-2 Lander", *46th Lunar and Planetary Science Conference*, The Woodlands, Texas, March 2015.

[9]M. Annadurai, "Chandrayaan-2: Lunar Orbiter & Lander Mission", *10th IAA Symposium on The Future of Space Exploration: Towards the Moon Village and Beyond*, Torino, Italy, June 2017.

[10]A.R. Rekha, et.al., "Challenges in Navigation System design for Lunar Soft Landing", *ISRO Inertial Systems – Thiruvananthapuram Conference*, 2011.

[11]Abhishek Sharma, et.al, "Plume Flow Field Analysis for Lander Propulsion System of Chandrayaan-2 Mission, *68th International Astronautical Congress (IAC)*, Adelaide, Australia, September 2017.

[12]Chinmoy Mondal, et.al., "Development of a Proportional Flow Control Valve for the 800N Engine Test", *9th National symposium and Exhibition on Aerospace and related Mechanisms (ARMS 2015)*, Bengaluru, January 2015.

[13]K.S. Venkatesh and Ashish Dutta, "Lunar Rover for Chandrayaan-II Lunar Mission: 3D Map Generation using Structured Light, Kinematics, and Path Planning, *IITK Directions*, Vol. 15, No. 1, 2015.

[14]M. Gunasekaran, R. Potluri and A. Dutta, "Path Tracking Control of a Moon Rover", *Indian Control Conference, IIT Madras*, Chennai, India, 2015.

[15]V. Radhakrishna, et.al., "The Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS)", *42nd Lunar and Planetary Science Conference*, The Woodlands, Texas, March 2011.

[16]S.V. Vadawale, et.al., "Solar X-ray Monitor (XSM) on-board Chandrayaan-2 Orbiter", *Advances in Space Research*, Vol. 54, Issue 10, November 2014.

[17]M. Annadurai, "Future Exploration Missions of ISRO", *60th Session of the UN COPUOS*, Vienna, June 2017.

[18]Anil Bhardwaj, et.al., "CHACE-2 mass spectrometer aboard Chandrayaan-2 orbiter to study the lunar neutral exosphere", *19th National Space Science Symposium (NSSS-2016)*, Thiruvananthapuram, India, February 2016.

[19]Deepak Putrevu, et.al., "Chandrayaan-2 dual frequency SAR: Further Investigation into lunar water and regolith", *Advances in Space Research*, Vol. 57, Issue. 2, January 2016.

[20]G. Manju, et.al., "RAMBHA Langmuir Probe (LP) Payload onboard Chandrayaan-2 Lander: Design and Development", *19th National Space Science Symposium (NSSS-2016)*, Thiruvananthapuram, India, February 2016.

[21]K. Durga Prasad, et.al., "Front-End Electronics Development for ChaSTE Payload onboard Chandrayaan-2 Lander", *Physical Research Laboratory – Annual Report 2015-16*, India, 2016.

[22]M. Shanmugam, et.al., "Alpha Particle X-ray Spectrometer (APXS) on-board Chandrayaan-2 rover", *Advances in Space Research*, Vol. 54, Issue 10, November 2014.

23A.S. Laxmiprasad, et.al., "An in-situ laser induced breakdown spectroscope (LIBS) for Chandrayaan-2 rover: Ablation kinetics and emissivity", *Advances in Space Research*, Vol. 52, Issue 2, July 2013.

[24]GR Hathwar, "Indian Deep Space Network: Mars Not Too Far", *Notion Press*, Chennai, India, 2016.

[25]T.V. Padma, "India gears up for second Moon mission", *Nature*, October 2017.