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Research Article

AN OVERVIEW OF MARS ORBITER MISSION (MOM) AND OTHER SCIENTIFIC PAYLOADS ON MARS

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A B S T R A C T

The Planetary scientists are always interested in exploration of Mars because of habitation conditions might have prevailing in the red planet. The experience gained from Chandrayaan-1 by the Indian scientist encouraged that to develop the concept of Mars Orbiter Mission (MOM) or otherwise called Mangalyaan feasibility report sending MOM to Mars was finalized during 2010 and that project was sanctioned on August 03, 2012. The total project cost is about Rs 454 crore for satellite cost and established facilities for ground station. The MOM was successfully launched on November 05, 2013, from Sriharikota using the PSLV rocket C25. After several manoeuvres and trans-Mars injection it reached Mars on September 24, 2014. With this achievement India became the first nation to reach the Mars orbit in its first attempt. Currently, the MOM spacecraft is orbiting Mars just 421.7 km at its closest point and about 76,993.6 km at the farthest point in an elliptical orbit. The MOM has five scientific instruments on board to study the surface of Mars for water, methane and its mineral and chemical composition. The payloads are Methane Sensor for Mars (MSM), Thermal Infrared Imaging Spectrometer (TIS), Mars Color Camera (MCC), Lyman Alpha Photometer (LAP), Mars Exospheric Neutral Composition Analyser (MENCA), High Resolution Imaging Science Experiment (HiRISE), MAVEN and Mars Orbiter Laser Altimeter (MOLA) specifications and objectives of payloads are discussed in the papers.

INTRODUCTION

In comparing several terrestrial planets in the solar system, Mars has sparked the greatest human interest. The conditions in Mars are believed to be hospitable since the planet is similar to Earth in many ways. Mars and Earth have almost equal period of rotation around their axes. Mars takes one day, five hours and five minutes to complete a rotation around its axis compared to one day for Earth. While Earth takes approximately 365 days to orbit round the Sun, Mars takes 687 days for a revolution around the Sun. The gravity of Mars is roughly one-third of Earth's gravity and it has a thin atmosphere with a pressure of 1 per cent of that of Earth. The atmosphere, water, ice and geology interact with each other to produce a dynamic Martian environment similar to as Earth. Mars has surface features like impact craters, fluvial landforms of the Moon and volcanoes, deserts and polar ice of Earth. For ages humans have been speculating about life on Mars. But, the question that is to be still answered is whether Mars has a biosphere or ever had an environment in which life could have evolved and been sustained. Mars Orbiter Mission is ISRO's first interplanetary mission to the planet Mars with an orbiter craft designed to orbit Mars in an elliptical orbit. The mission is primarily a technological mission on considering the critical mission operations and stringent requirements of propulsion and other bus systems of the spacecraft. It has been configured to carry out observation of physical features of the planet and also limited study of its atmosphere with five payloads.

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Mission Objectives

The technological objectives on MOM are design and realization of Mars orbiter with a capability to survive and perform Earth-bound manoeuvres; a cruise phase of 300 days of travel; Mars orbit insertion/capture and on-orbit phase around Mars. Deep space communication, navigation, mission planning and management. In addition, the main scientific objectives are the exploration of Mars surface features, morphology, topography, mineralogy and its atmosphere by indigenously developed scientific instruments.

Overview of Mars Orbiter

The spacecraft configuration is derived from Chandrayaan-1, which is a balanced mix of design from flight-proven IRS/INSAT bus. Because of redundant features, the Mars orbiter bus is more reliable than that of Chandrayaan. Modifications required for Mars mission are in the areas of communication and power, propulsion system, mainly related to liquid engine [LE], and mechanisms which is called the Mars Orbit Insertion (MOI) manoeuvre. The Earth–Mars trajectory is shown in **Figure 1.**

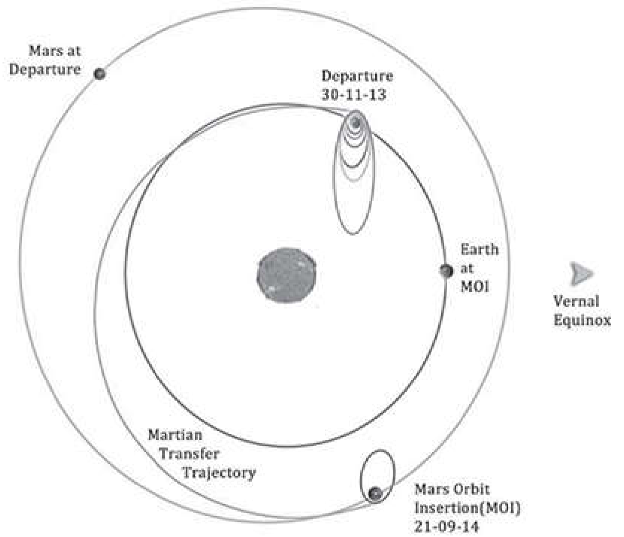

Figure 1 The Earth–Mars Trajectory Design (Note: The actual date of Mars Orbit Insertion was 24 September 2014). (ISRO Annual Report 2016-2017).

All the primary structure, equipment panels and special brackets are fabricated as per ISRO design in the dedicated facilities established for ISRO at Hindustan Aeronautics Ltd, Bangalore. The 390 litre capacity propellant tanks used for Chandrayaan-1 can accommodate a maximum of 850 kg of propellant which is adequate for the proposed Mars mission. A liquid engine of 440 N thrust is planned to be used for orbit raising and Martian Orbit Insertion (MOI). Additional flow lines and valves have been incorporated to ensure the engine's restart after 300 days of Martian Transfer Trajectory (MTT) cruise and to take care of fuel migration issues. Eight 22 N thrusters are used for reaction wheel desaturation and attitude control during manoeuvres. Accelerometers are used for measuring the precise incremental velocity and for precise burn termination. Star sensors and gyros provide the attitude control signals in all phases of the mission.

Chandrayaan-1 required a single solar panel of size 1,800×2,150 mm. However, to compensate for the lower solar irradiance (50 per cent compared to that of Earth), the Mars orbiter would require three solar panels of size 1,400×1,800 mm. Single 36 Ampere Hour (AH) lithium-ion battery (similar to those in Chandrayaan-1) is sufficient to take care of eclipses encountered during the Earth-bound phase and in Mars orbit. The communication dish antenna is fixed to the spacecraft body. The antenna diameter is 2.2 m, which is arrived after the trade-off study between antenna diameter and accommodation within the PSLV-XL envelope. On-board autonomy functions are planned as the large Earth–Mars distance does not permit real-time interventions. This will also take care of on-board contingencies. The spacecraft bus system weighs about 500 kg.

Communication Systems

The large distances between the orbiter and the Earth (200–400 km), communication between them becomes a challenging task. Communication consists of Telemetry, Tracking and Command (TT&C) systems and data transmission systems in S band and a Δ-DOR (Delta Differential One-way Ranging) transmitter for ranging. The TT&C system comprises coherent TT&C transponders, Travelling Wave Tube Amplifiers (TWTAs), a near-omni-coverage antenna system, a High Gain Antenna (HGA) system, Medium Gain Antenna (MGA) and corresponding feed networks. The HGA system is based on a single 2.2 m reflector illuminated by a feed at S band.

Low Gain Antenna (LGA) consists of two pairs of hemispherical coverage antennas mounted suitably on the spacecraft. Near-spherical radiation coverage is obtained by placing two hemispherical coverage antennas with orthogonal circular polarizations. LGA provides mission support up to a distance of about 25 million kilometers.

Medium Gain Antenna (MGA) is needed when the distance between Earth and orbiter exceeds 20 million kilometers. This antenna with half power beam width of ±40° can be used to support the TT&C up to the injection of the spacecraft into Mars orbit.

High Gain Antenna (HGA) in Mars orbit is required to transmit/receive the TT&C or data to/from the Indian Deep Space Network (IDSN). Offset reflector geometry with 2.2 m diameter has been chosen for this application. Conical horn antenna with in-built septum polariser is configured as feed for this reflector system. The dual, circularly polarized feed enables this antenna to cater to both transmit and receive functions of TT&C system. Data transmission is also planned using HGA.

A Δ-DOR package is introduced to generate ranging tones for distance measurement. The Δ-DOR measurement is used to improve the orbit determination accuracy. It is incorporated as a part of the RF system as the tones generated by Δ-DOR can be down linked along with Telemetry (TM) data. This configuration allows down linking TM data using IDSN while Δ-DOR session is being carried out with JPL (Jet Propulsion Laboratory of NASA) stations in the USA.

On-board Autonomy

On-board autonomy refers to the capability of the orbiter to make its own decisions about its actions. As the distance between the Mars orbiter and Earth increases, the need for autonomy increases dramatically. Given the maximum Earth to Mars Round-trip Light Time (RLT) of forty-two minutes, it would be impractical to micromanage a mission from Earth. Due to this delay in communication, mission support personnel on Earth cannot easily monitor and control all the spacecraft systems in real time. Therefore, it is configured to use on-board autonomy to automatically manage the nominal and non-nominal scenarios on-board the spacecraft. Autonomy is in charge of the spacecraft whenever communication interruptions occur and when the spacecraft is occulted by Mars or Sun. Autonomy also ensures the recovery from safe mode occurrences on-board the spacecraft.

Ground Segment

Operational communications between a control centre and a spacecraft are realised through a ground station. Indian Deep Space Network station (IDSN 32) located in Byalalu, Bangalore, was established with a view to meeting not only the requirements of Chandrayaan-1 mission but also ISRO's future missions to Mercury, Venus and up to Mars. The hallmark of IDSN facility is the 32 m dia Beam Wave Guide (BWG) antenna, with state-of-the-art technology, that had been indigenously designed, developed and installed to support all future deep space missions of ISRO. To manage a deep space mission round the clock, at least two ground stations, one located in the eastern and the other in the western hemispheres is required. Ground support from JPL, NASA, stations is envisaged to complement the efforts of IDSN. The long coasting of PSLV PS-4 stage for 1,644 seconds before PS-4 ignition requires two portable sea-borne S-band terminals to be deployed in the Pacific Ocean to monitor PS-4 performance and satellite separation.

Payloads

The Mars Orbiter Mission is designed to carry five payloads to accomplish its scientific objectives: electro-optical payloads operating in the visible and thermal infrared spectral ranges, and a photometer to sense the Mars atmosphere and surface. The details of the payloads are as follows **(Figure 2)**.

Methane Sensor for Mars (MSM)

This payload intended for atmospheric studies is being developed by the Space Applications Centre (SAC), Ahmedabad. It is designed to measure methane (CH4) in the Martian atmosphere with ppb (parts per billion) accuracy and to map its sources. Data is acquired only over illuminated scene as the sensor measures reflected solar radiation. Methane concentration in the Martian atmosphere undergoes spatial and temporal variations. Hence global data is collected during every orbit.

Methane Sensor for Mars (MSM) for the first time, a Fabry-Perot etalon-based methane measuring instrument has been deployed for an interplanetary mission.

- The MSM has been imaging Mars since 27 September 2014.
- MSM data has been collected during forty-nine orbits out of sixty with twenty-nine apogee imaging sessions and twenty push-broom imaging sessions. •
- About 218 frames have been acquired totaling an imaging time of approximately fifty hours.
- More than 5 GB of data has been collected.
- The MSM has been able to complete full coverage of low and mid-latitude regions (40°S–40°N) whereas high-latitude coverage is very sparse.
- The MSM has been working satisfactorily.

Thermal Infrared Imaging Spectrometer (TIS)

This payload intended for thermal remote sensing is being developed by SAC. It is intended to measure the thermal emission and can be operated during both day and night. Temperature and emissivity are the two basic physical parameters estimated from thermal emission measurement. Many minerals and soil types have characteristic spectra in the Thermal Infrared (TIR) region. TIS can thus map surface composition and mineralogy of Mars. It also monitors atmospheric CO 2 and turbidity (required for the correction of MSM data).

TIS is an imaging spectrometer which measures spectral radiance in the infrared region. This instrument has been deployed by MOM to map surface composition and mineralogy, identifying hot spots, and thereby the underground hydrothermal systems.

- Estimation of differential counts using space-look and Mars-look data has been carried out including normalization of these data sets with varying T case information.
- The performance of the TIS in Mars-bound imaging phase has been found in agreement with the Earth-bound phase and laboratory measurements.

Mars Colour Camera (MCC)

MCC, intended for surface imaging, is another payload being developed by SAC. This tricolour camera gives images and information about the surface features and composition of the Martian surface. They are useful to monitor the dynamic events like dust storms/atmospheric turbidity, and also the weather of Mars. MCC will also be used for probing the two satellites of Mars, Phobos and Deimos. It also provides the context information for other science payloads. MCC images are to be acquired whenever MSM and TIS data is acquired. Seven apoareon (farthest point from Mars) imaging of entire disk and multiple periareon (closest point) images of 540×540 km snaps are planned in every orbit.

Mars Colour Camera (MCC) used for study of Mars's topography (with high geometrical fidelity), surface composition, polar ice caps, dust storms and moons. It has taken nearly 470 images so far out of which nearly 400 were taken after MOI. The collected raw data size has been about 3.7 GB. For the first time, high-fidelity full-disc images of Mars have been captured and analysed. The MCC data has been used for:

- Characterizing the CO2 ice clouds on Mars based on height estimations using MCC images.
- Mapping the 'white-streaks' trailing the obstacle dunes to ascertain the dominant wind directions.
- Imaging Deimos from the far side, which is a rarity among the contemporary Mars orbiters from other missions.

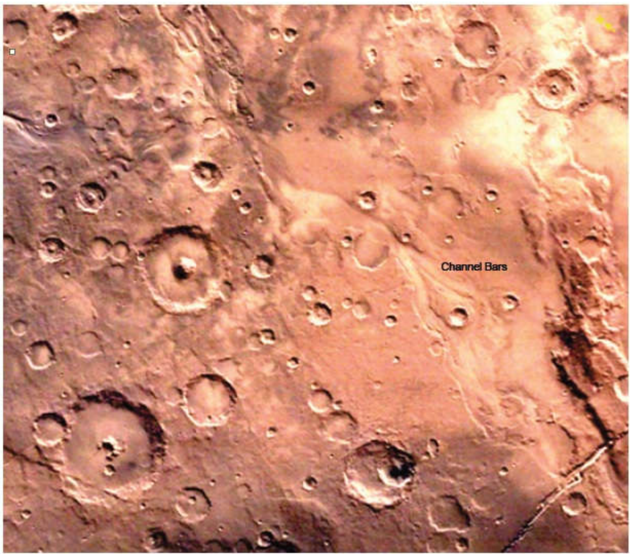

Figure 2, Image of channel bar in Mangala Valles region was taken by Mars Colour Camera (MCC) on 24.11.2014 at a spatial resolution of 380 m from an altitude of 7336 km.

Lyman Alpha Photometer (LAP)

LAP being developed by the Laboratory of Electro-Optics Systems (LEOS), Bangalore, is also meant for atmospheric studies. It is an absorption cell photometer, which measures the relative abundance of deuterium and hydrogen from the Lyman-Alpha emission in the Martian upper atmosphere (typically exosphere and exobase). Measurement of D/H (deuterium to hydrogen) abundance ratio allows us to understand the loss of water from the planet. The instrument has been made operational in the Martian phase since 30 September 2014. So far the instrument has been operated both in photometer and absorption cell modes spread over fifty-three sessions. Nearly 820 MB of data has been acquired using the instrument. The instrument has been calibrated and working satisfactorily. Further analysis of the acquired data is in progress.

The objectives of this instrument are as follows

- Estimation of D/H ratio
- Estimation of escape flux of H 2 corona
- Generation of hydrogen and deuterium coronal profiles
- Nominal plan to operate LAP is between the ranges of approximately 3,000 km before Mars periapsis to 3,000 km after Mars periapsis. Minimum duration of observation required for achieving these goals is sixty minutes per orbit during normal range of operation.

Mars Exospheric Neutral Composition Analyser (MENCA)

MENCA being developed by Vikram Sarabhai Space Centre (VSSC), Trivandrum is meant for the plasma and particle environment studies. It is a quadruple mass spectrometer capable of analysing the neutral composition in the range of 1 to 300 atomic mass unit (amu) with unit mass resolution. The heritage of this payload is from Chandrayaan-1 Altitudinal Composition Experiment (ChACE) payload aboard the Moon Impact Probe (MIP) in Chandrayan-1 mission. MENCA is planned to perform five observations per orbit, one hour per observation. The main objective of MENCA is ‘to measure in-situ the neutral composition and density of the Martian exosphere (at altitudes around 500 km and beyond), and to examine its radial, diurnal and seasonal variations’.

The MENCA instrument has shown interesting features during the observations around the periareon, which are distinctly different from the observations made further away from Mars. These include the effect of the umbra crossing on the total and partial pressures and the enhancement of the mixing ratios of lighter species near the periareon.

The mission is planned in such a way that imaging data of every orbit can be down linked during a single orbital period of seventy-six hours around Mars.

Figure 3 The Mars Orbiter Mission (MOM) payloads

Data Archival, Dissemination and Analysis

Indian Space Science Data Centre (ISSDC), the infrastructure established during Chandrayaan-1, is earmarked for Mars science data processing, archival and dissemination. The data transfer system at ISSDC, with suitable security systems, distributes science data. The communications infrastructure is elaborate and caters to the needs of PIs (Principal Investigators) and POCs (Payload Operation Centres). ISSDC also interfaces with POCs for routing the operational needs of the instrument to the SCC. Level-0 and Level-1 data products of instruments, as applicable, are routinely produced at ISSDC. Automation in the entire chain of data processing is planned. Provision is made to host higher-level data products for any instrument as supplied by the PI teams. ISSDC also provides for data archives in Planetary Data Systems (PDS) format, an international standard. The data dissemination will also follow PDS standard. The computer networking at ISSDC is connected to the IDSN operations facility, ISSDC will also host a website for collecting observations and making them available for an apex committee to review before giving further clearance for operations. ISSDC data archival and distribution functions will follow the data policy guidelines of ISRO.

The ISSDC will be the single nodal agency to distribute scientific data to the global scientific community on demand. The following are the main responsibilities:

- Online monitoring of the scientific payloads data and health parameters.
- Generating necessary feedback and strategies for payload control and navigation.
- Coordinating with potential users.
- Examining the validation and authenticating for scientific use.
- Associating the attributes of different payload data to composite data group for effective data utilization.
- Continuously monitoring the history and trends in space and time.
- Correlating the available data with previous Mars mission observations for validation and identifying new findings.
- Developing new algorithms and techniques for interpreting, analysing and presenting the data based on laboratory simulation of lunar samples and detector characteristics.
- Preparation of comprehensive chemical chemical and mineralogical maps based on all the current and previous observations.
- Planning further missions for more detailed studies.

Other mars missions and payloads
Mars reconnaissance orbiter (mro) – hirise

High Resolution Imaging Science Experiment is a camera on board the Mars Reconnaissance Orbiter (MRO). The 65 kg instrument was built under the direction of University of Arizona’s Lunar and planetary Laboratory. It consists of a 0.5 m aperture reflection telescope, which allows it to take pictures of Mars with resolution of 0.3 m/pixel.

Mars Global Surveyor (MGS) – MOLA

Mars Global Surveyor was launched at 12:00:49 p.m. Eastern Standard Time on November 7, 1996. MGS is the first mission in a sustained program of robotic exploration of Mars. The MGS was a global mapping mission that examined the entire planet, from the ionosphere down through the atmosphere to the surface, Mars Orbiter Laser Altimeter (MOLA) one of the payloads onboard on MGS. The DEM represents data from more than 600 million measurements gathered between 1999 and 2001. This allows it to take elevation data of Mars with resolution of 463 m/pixel.

Maven Mission on Mars

Mars Atmosphere and Volatile EvolutioN Mission (MAVEN) is a space probe developed by NASA designed to study the Martian atmosphere while orbiting Mars. MAVEN was successfully launched aboard an Atlas V launch vehicle at the beginning of the first launch window on November 18, 2013. MAVEN will study Mars' upper atmosphere and its interactions with the solar wind. Its instruments will measure characteristics of Mars' atmospheric gases, upper atmosphere, ionosphere, and the solar wind.

CONCLUSION

Considering all aspects, this maiden Mars mission of ISRO, known as Mars Orbiter Mission (MOM), Mangalyaan has been a resounding success. It has established the professionalism of Team ISRO. Surely, MOM is a precursor to more complex and ambitious interplanetary missions of ISRO.

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