Mars Orbiter Mission

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Abstract

Mars Orbiter Mission is India's first interplanetary mission to planet Mars. The objectives of this mission are primarily technological and include design, realisation and launch of a Mars Orbiter spacecraft capable of operating with sufficient autonomy during the journey phase of 300 days; Mars orbit insertion / capture and in-orbit phase around Mars. The scientific objectives of the mission are to study the Martian surface features, morphology, mineralogy and Martian atmosphere. The major challenges involved in the design of spacecraft are in radiation environment, thermal environment, communication systems, power systems, on-board autonomy and propulsion systems.

Introduction

Exploration of Space to advance our knowledge of the Universe we live in has always been an important component of ISRO's Space Science Program. India's solar system exploration program was initiated in a major way in October 2008 with the launch of Chandrayaan-1, the first lunar mission of India. Nationally and internationally, Chandrayaan-1 (Ch-1) generated unprecedented enthusiasm and pride among the public. The confirmation of water on Moon was one major result from the Ch-1 mission. In particular, it created excitement in the young minds of this country and firmly established that India can take on any technological challenge. It established a new sense of confidence in our ability to address new frontiers of space exploration. Data from Ch-1 is still being analysed. After the first lunar mission, ISRO is presently working on Chandrayaan-2, an indigenous lunar landing mission.

Beyond the Earth's vicinity, Mars is a natural target of study in India's solar system exploration program. Of all the planets in the solar system, Mars has sparked the greatest human interest. Its orbit lies between the asteroid belt and the Earth. For ages humans have been speculating about life on Mars. The conditions on Mars are believed to be hospitable since the planet is similar to Earth in many ways. Like Earth, it has an atmosphere, though less dense and different in composition. Mars has surface features reminiscent of both the impact craters of the Moon and volcanoes, deserts and polar ice of Earth. 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 sustained.

The Indian Mars Orbiter Mission (MOM) was undertaken primarily to demonstrate India's capability to venture into interplanetary space and make independent exploration of the red planet. All aspects of MOM project, including scientific, technical and managerial, were handled extremely well and it was executed with a tight time schedule of about 2 years. This paper gives primarily the details of the Mars Orbiter spacecraft operations and its challenges.

Mars Missions – Global Scenario

Prior to Indian Mars Mission, there were 51 missions all over the world in the form of fly-bys, orbiters, landers, rovers and a sample return mission. Out of the 51 missions, only 21 missions were successful, which put the success rate at 42%. In this backdrop, it is very pertinent to note that India has been successful, in the very first attempt, to place the Mars Orbiter spacecraft into orbit on September 24, 2014 and thereby has secured a unique place among the space faring nations.

Scientific payloads

Mars continues to be an object of keen interest to scientists in the context of planetary evolution and extra-terrestrial life. Based on our current understanding of Mars, which was thought to be probably a warm and wet planet earlier, is now seen to be dry with a thin atmosphere. How this evolution has taken place is still a topic of research. Properties of the older versus the younger Martian terrains indicate that chemical changes have also occurred in the soil. In the coming decade, Mars is the promising target where search for life can be addressed realistically. It can be visited frequently by robotic spacecrafts paving way for sample return and human exploration. In this backdrop, the Indian Mars Orbiter Mission carried five scientific payloads, as given below:

(a) ***Mars Color Camera (MCC)*** to provide images and information about the surface features and composition of Martian surface.

(b) ***Thermal Infrared Imaging Spectrometer (TIS)*** to map the surface composition and mineralogy of Mars.

(c) ***Methane Sensor for Mars (MSM)*** is designed to measure Methane (CH_4) in the Martian atmosphere. These measurements will trigger further studies to understand the origin of methane.

(d) ***Mars Exospheric Neutral Composition Analyser (MENCA)*** to study the composition of Martian upper Atmosphere.

(e) ***Lyman Alpha Photometer (LAP)*** to measure the relative abundance of deuterium (D) and hydrogen (H) which allows us to understand the process of the loss of water from the Mars planet.

Major challenges of MOM spacecraft

Mars Orbiter Spacecraft was launched onboard PSLV-C25 on November 05, 2013 from Satish Dhawan Space Centre, Sriharikota. After Earth-bound Orbit raising manoeuvres (Fig.1), the Trans Mars Injection manoeuvre was successfully conducted on December 01, 2013 to set the course of the spacecraft towards Planet Mars through a Sun-centric trajectory. Enroute to Mars, three Trajectory Correction Manoeuvres were carried out on December 11, 2013, June 11, 2014 and September 22, 2014 to achieve the precise path towards Mars Orbit. The spacecraft traversed 666 million kilometres of inter planetary space to reach close to Mars.

The most crucial manoeuvre of Mars Orbit Insertion (MOI) was successfully carried out on September 24, 2014 by firing the 440 Newton thrust Liquid Engine along with eight smaller liquid engines, with which the Mars Orbiter Spacecraft successfully entered into an elliptical orbit of 422 kms by 76,994 kms around planet Mars. With this, ISRO has become the fourth space agency to successfully send a spacecraft to Mars orbit.

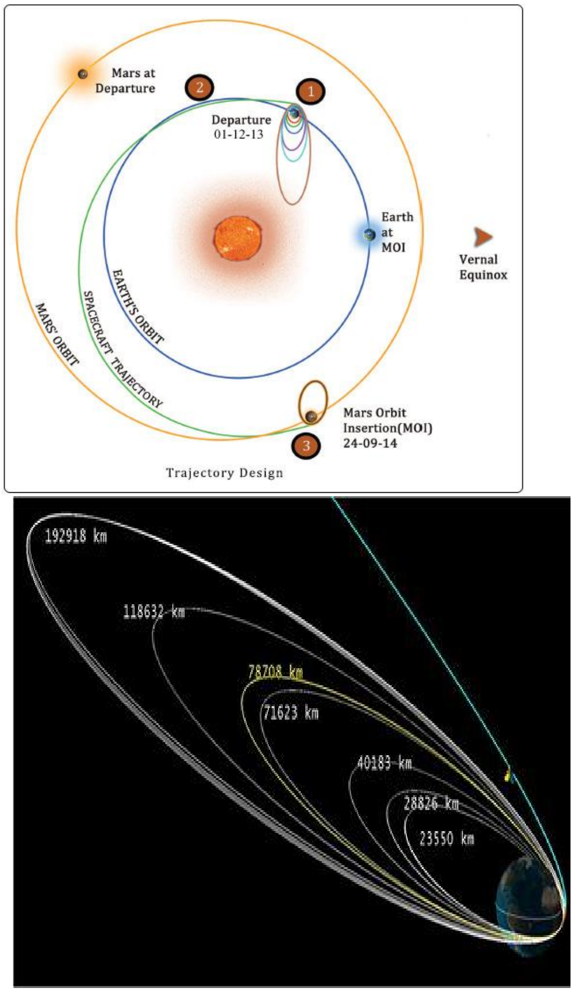

FIG.1: Trajectory design of MOM showing (1) Earth bound orbit, which is zoomed in the right panel (2) Sun-centric trajectory and (3) Mars orbit insertion

ISRO has been continuously monitoring the Spacecraft using its Deep Space Network complemented by that of Jet Propulsion Laboratory of NASA. Mars Orbiter Spacecraft and its five scientific instruments are in good health. All the scientific instruments have been operated and tested successfully. The images of Mars captured by the Mars Colour Camera have been received and are found to be of very good quality. Scientific analysis of the data being received from the Mars Orbiter spacecraft is in progress. Many challenges were involved in the configuration and the subsequent design of the spacecraft (figure 2) which were needed to consider during its mission life. The following subsections details about the major challenges in the design of MOM spacecraft systems / elements.

Mars Orbiter has been technologically a very challenging mission. It has demonstrated technological capabilities of India to reach an interplanetary target like Mars. The spacecraft position prediction and accurate orbit determination with high precision sensors and accurate navigation modelling were critical for successful Mars Orbit Insertion.

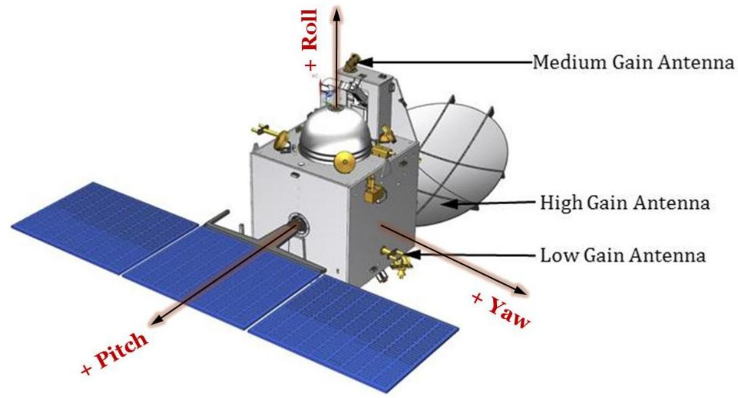

FIG.2: Configuration of MOM spacecraft

Radiation Environment

The main frame bus elements and payloads of MOM are basically designed by considering the radiation environment for the interplanetary missions. The spacecraft bus components were selected pertaining to an accumulated dose of 6 krad for aluminium shielding of standard gauge 22 or below, while the parts have been considered as suitable up to 12 krad with a margin factor of 2.

Thermal Environment

The spacecraft during its journey to Mars undergoes a thermal environment where temperature is highly varying (hot environment at near Earth and cold environment during Earth to Mars cruise). On an average the solar flux at Mars orbit is about 589 W/Sq.m, which is about 42% of solar flux at Earth orbit. Due to the eccentricity of Mars's orbit, the solar flux at Mars varies by +/- 19% over the Martian year and is found to be more than the 3.5% variation compared to Earth. The Albedo fractions at Mars being around 0.25 to 0.28 at the equator and generally increasing toward the poles are similar to that of Earth. The challenges related to varying thermal conditions during different phases of the mission were alleviated to a certain extent by choosing different attitudes.

Power Systems

The spacecraft and payloads during various phases of mission have to be supported by the power system. Power generation, energy storage and power conditioning elements, the essential components of a power system, needs to be carefully designed for an interplanetary mission. The design of power system by considering the power generation under low solar intensity due to the larger distance of the satellite from the Sun is one of the major challenges. The power generation in Mars orbit is reduced to nearly 50% to 35% compared to Earth's orbit. The power generation variation is nearly 15% in a Martian year due to the eccentricity of Mars orbit. The power bus configuration comprises of a single wing of solar array with 7.56 m^2 area generating about 840 W when it is sunlit with normal incidence in Martian orbit, and it is a battery tied single bus of 28-42V.

The single solar array wing consists of three solar panels of size 1.8 m x 1.4 m converts solar energy into electrical energy by photo-voltaic conversion is the power source for the Mars Orbiter Mission. The solar cells convert sunlight to electrical power to operate the spacecraft electrical loads and charge the battery during sun-lit conditions. Design of the solar panels of Mars Orbiter Mission is similar to the earlier IRS missions. The optimized solar array for MOM is designed in such a way to maximise the power generation during extreme environmental conditions (low temperature in the Martian orbit phase and high temperature during earthbound and heliocentric phases).

Mars is away from the Sun as compared to Earth and the distance between Mars and Sun varies from 206 million km (1.38 A.U.) to 249 million km (1.5 A.U.). As a result of it, the solar irradiance near Mars varies from 715 W/m^2 to 470W/m^2 and it leads to a variation in the solar cell operating temperature which varies from 2^oC to -20^oC.

MOM spacecraft is using a single 36 Ah Lithium ion battery in series-parallel configuration and is having a heritage from Chandrayaan-1. The power requirement during launch phase, initial attitude acquisition, during eclipse, liquid engine burns near earth, Mars Orbit Insertion, safe mode and data transmission phases are supported by this battery. Battery charging is done by Taper Charge Regulator and the battery is fully charged before each discharge. Hardware Emergency logic is taking care of battery protection against over discharge. The protection logic opens the Emergency relays to disconnect the battery from the power bus in case of battery emergency.

Communication Systems

One of the challenging tasks is to design the communication systems to meet the requirement for the communication management at a distance of nearly 200 to 400 million km. Communication system consists of Telemetry, Tacking and Commanding (TTC) systems and Data transmission systems in S-band and a Δ-DOR Transmitter for ranging. The TTC system comprises of a near omni coverage antenna system, a High gain antenna system, Medium Gain Antenna, Coherent TTC Transponders, Travelling Wave Tube Amplifiers and feed networks.

Antenna	Beam width	Peak Gain	TM Support (km)/margin (dB)	TC Support (km)/ margin (dB)
LGA	± 90°	0dB	1.4 million /2.4 dB	30 million /2 dB
MGA	± 40°	7dB 3dB @ ±40°	40 million /2.4 dB (with MGA peak pointing to earth)	110 million /2.3 dB (with MGA peak pointing to earth)
HGA	± 2°	31dB	400 million /5.4 dB	400 million /10 dB

Table-1 MOM antennae specifications

Antenna System consists of Low gain Antenna (LGA), Medium Gain Antenna (MGA), and High Gain Antenna (HGA). Coverage details of the antennae are shown in table-1. LGA on the spacecraft consists of two hemispherical coverage antennas with orthogonal circular polarization and provides near spherical radiation coverage. MGA is designed for MOM mission in order to support the TTC up to Mars orbit insertion. HGA is designed on a single 2.2 meter reflector illuminated by a feed at S-band to transmit/receive the TTC or data to/from the Indian Deep Space Network.

Delta Differential One-way Ranging (Δ-DOR)

Delta Differential One-way Ranging (Δ-DOR) is a powerful accurate technique for finding the accurate position of the spacecraft. The pointing direction of the ground station antenna directly gives the angular location of the spacecraft.

However, the accuracy one can achieve using the above technique is insufficient for interplanetary missions with stringent navigation requirements.

Radio signals sent from MOM are received at two different widely separated ground stations at different instances. This time difference corresponds to the angle difference between the lines joining the two ground stations to the spacecraft.

Subsequently the two antennae are pointed towards another standard reference radio source (a 'visually' adjacent quasar) whose angular locations are precisely known. The difference between the measured and known angular position of the reference radio source is the correction required to be made on the angular position of MOM to make it accurate. Delta-DOR measurement is used to improve the Orbit determination accuracy. It is incorporated as a part of RF system as Δ-DOR tones can be down-linked along with TM data.

Propulsion Systems

The propulsion system consists of one 440N Liquid Engine (LE-440) and 8 numbers of 22N thrusters similar to conventional GEOSAT missions. The unified bipropellant system is used for orbit raising and attitude control. The most challenging and critical task in the design of the propulsion system is to restart the main liquid propulsion engine for Mars Orbit Insertion on September 24, 2014 after a dormant period of 300 days (since the Trans-Mars insertion on Dec 01, 2013) and perform to the required stringent/exact specifications. The propellants are stored in Titanium propellant tanks each with a capacity of 390 litres. The tanks have combined storage capacity up to 852 kg propellant. The 67 litre helium pressurant tank is used to pressurize the propellant.

After the Earth bound liquid engine operations are completed the main engine was closed using pyro valves and were successfully made open after about 300 days for propellant supply for Martian Orbit Insertion maneuvers.

On-board Autonomy

It takes about 28 minutes for a radio signal to reach Mars Orbiter Spacecraft and return to Ground Station on Earth. This makes real-time control and communications (as done in earth orbiting satellites) impractical. Therefore, Mars Orbiter had to be built with its own autonomy and intelligence to manage crucial manoeuvres, fault detection, isolation & reconfiguration of systems and operations & controls during non-visible period.

Extended life span of MOM

The designed lifespan of MOM was six months. On completion of six months the lifespan was extended for a further period of six months from March 24, 2015. MOM successfully completed one year in its orbit on 24th September 2015. Normally for a healthy spacecraft, the life limiting parameter under nominal orbital conditions is the availability of propellant to maintain its orbit around the planet. In case of MOM, a reserve of about 35 kg of propellant was available in the satellite. In view of the health parameters of all critical systems of the satellite and the availability of propellant, MOM can survive many years and continues to provide very useful data in the years to come.

The details of the overall mission can be obtained from the special section of Mars Orbiter Mission published in Current Science, Vol.109, No.6, 25 September 2015.

Public Outreach

Mars Orbiter Mission is a mission of national pride which has attracted the attention of students, general public, media and international science/ technical community. Importantly, Mars Orbiter Mission has created enthusiasm among the younger generation in the country, provoked their curiosity to understand and discuss space related techniques and is maintaining the tempo throughout the mission. The Mars Orbiter Mission would go long way in building the scientific human resources in the country in the years to come.

ISRO has been utilizing its website and social media to update and popularise its activities and programmes to the general public. ISRO has made an Announcement of Opportunity (AO) for utilizing the MOM in ISRO website (www.isro.gov.in). The last date for submission of proposals is 10th October 2015. On the occasion of the first anniversary of MOM, ISRO has released a Mars Atlas comprising of images taken by MCC (pdf version is available in ISRO website). Atlas also provides preliminary scientific outputs from MSM and TIS payloads.

Chandrayan-1 data is already available in ISSDC website (www.issdc.gov.in).

ISRO conducts National Space Science Symposium (NSSS) every alternate year to provide a scientific forum for the presentation of new results and to discuss recent developments in space science, planetary exploration and space & ground based astronomy programmes/projects in India. The next NSSS-2016 will be held at Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram during 9-12 February, 2016. All participants have to pre-register. Last date for submission of abstract is on 30th October 2015.

Details are provided in NSSS-2016 website (http://spl.gov.in/nsss2016)

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