Mars Orbiter Mission: An Overview

Introduction:

Over millennia, human beings are fascinated and inspired by what happens across the universe. We wonder at the infinite glory and beauty of the cosmic panorama. Through technological developments, we began, only recently, to comprehend the complexity and challenges of probing a little beyond our own planet. The initial discoveries, which are the result of these new technological endeavors, point to the vast potential that exists for boundless knowledge and immense resource around our own solar system and beyond. After the successful Moon mission with Chandrayaan 1, it is natural for ISRO to think about planetary exploration beyond the Moon. In the quest for planetary exploration, Mars holds a very special position in view of the many similarities it has with Earth and because it holds the secrets of our past and the possibilities of our future.

Mars Mission Study Team:

In ISRO, the Advisory Committee for Space Science (ADCOS) has taken up the formulation of the vision document for planetary exploration programme of ISRO. The ADCOS Science panel, ASP-3, has identified missions to Mars as one important component of this vision. In order to concretize these concepts into an integrated and viable blueprint for undertaking systematic and planned missions to Mars, a Mars Mission Study Team was constituted by Chairman, ISRO with experts from all Major Centers and Units; like PRL, SAC, SPL, ISAC, VSSC, LPSC, ISTRAC, LEOS, IIST and ISRO- HQ. During the intense deliberations of the Study Team, it was discovered that we can have a highly elliptic orbital mission around Mars even using our proven PSLV launch system.

Mars Mission (2013) Launch Opportunity:

Mars mission opportunities with minimum energy occur every 26 months as the required conjunction-like geometry (Earth at spacecraft departure from Earth; Sun; and Mars at spacecraft arrival at Mars are in a line) occur every 26 months. For a parking orbit around Earth of 250 x 23500 km and for a parking orbit around Mars of 500 x 80000 km the typical velocity impulses are given in Table 1. The required Argument of Perigee (AOP) and Right Ascension of Ascending node (RAAN) for the Earth parking orbit are also given. These angles ensure the required direction of velocity vector of Trans-Mars cruise phase. The Mars mission in 2013 becomes very important for two reasons: (i) if we miss this opportunity we have to wait for another 26 months for next opportunity (ii) additionally, the velocity impulse requirement for the next opportunity in Jan. 2016 is more by about 400 m/s and will require heavier vehicle.

Launch Strategy:

In an interplanetary mission design, the Earth parking orbit characteristics are so chosen to minimize the energy requirement for Trans-Mars injection and for Mars Orbit Insertion operations. Apart from selecting the minimum energy opportunity, optimal utilization of the existing launch vehicle system is a main driving factor for the Mars Orbiter Mission Design. In an interplanetary mission, placing the spacecraft in the parking orbit around Earth is achieved by a launch vehicle. With twenty three consecutive successes since 1993, PSLV is a reliable and proven work horse of ISRO. PSLV, a four stage vehicle, is developed primarily for launching remote sensing satellites of 1200 kg class in Sun-Synchronous Polar Orbit. It had also carried out Geosynchronous Transfer Orbit (GTO) missions. With its excellent track record, Polar satellite Launch Vehicle (PSLV) is found to be a suitable and viable option for placing the Mars Orbiter Mission spacecraft in an initial orbit around the Earth.

In its regular GTO missions, PSLV achieves about 178 deg. of Argument of Perigee for suitable maximum payload. But Mars Orbiter Mission opportunity demands an AOP of 299 deg at the time of Trans-Mars Injection. In Mars Orbiter Mission, the Trans-Mars injection is executed after several phasing orbits. Due to the perturbing forces from non uniform gravity field, the moon and the Sun, the initial Earth parking orbit characteristics keep changing. Accounting for these changes in AOP, the initial Earth parking orbit AOP is fixed. These phasing orbits are determined depending on a chosen Lift-off Date. This implies that the launch vehicle is expected to achieve different AOPs for different Lift-off dates. Values of required launch AOP, for one typical phasing orbit sequence, range from 275 deg to 288 for Lift-off dates between Oct. 28, 2013 and Nov. 14, 2013. Such large AOP, which is very much different from values of AOP of usual PSLV launches, is achieved by introducing a long coasting between the third stage (PS3) separation and the fourth stage (PS4) ignition that shifts the perigee location to the desired slot.

Fig. 1 depicts the PSLV trajectories for a regular GTO-type elliptic parking orbit mission and for Mars orbiter Mission. As is obvious from the figure the characteristics of the trajectory are entirely different. A coasting of 1600 sec between

Table 1: Mars Mission Launch Opportunities

Departure Date	Flight Duration (days)	Arrival Date	Argument of perigee (deg)	Total velocity impulse (m/s)
30-11-2013	298	24-11-2014	299	2590
10-01-2016	275	11-10-2016	246	2970
17-05-2018	239	11-01-2019	121	2570

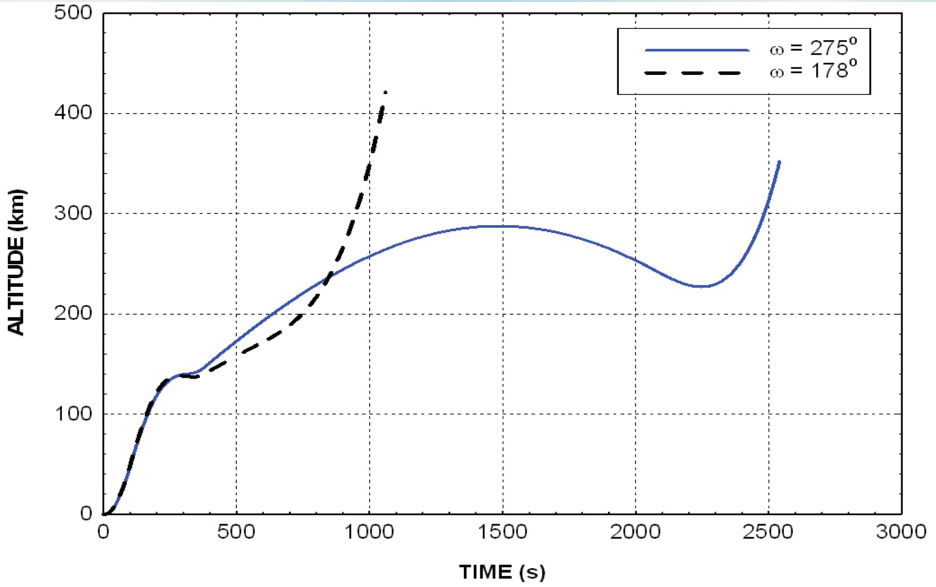

Figure 1: Launch Vehicle Trajectory Design for Different AOPs

PS3 separation and PS4 ignition is introduced. Two shipborne terminals are planned to ensure visibility during PS4 ignition and satellite separation events. For Nov. 5 lift-off, the AOP target for launch vehicle trajectory design is set as 282.7 deg. The payload loss due to long coasting is found to be marginal.

Another parameter that must be ensured by the launch vehicle at the time MOM injection is right ascension of ascending node (RAAN). The parameter RAAN fixes the launch vehicle trajectory/ parking orbit crossing point on the equator with reference to an inertial axis (vernal equinox). The RAAN also undergoes changes due to perturbing forces during phasing orbit evolution. So, RAAN at MOM injection is chosen such that after phasing orbit evolution, it will result in the RAAN required at Trans-Mars injection. As Earth rotates, the launch station also rotates thus changing the trajectory crossing point on the equator with respect to an inertial axis. So, the RAAN required at MOM injection is obtained by setting suitable lift-off time on the day of the launch. The RAAN at MOM injection must be 127 deg to ensure the required RAAN of 115 deg at Trans-Mars injection. For Nov. 5 launch, the lift-off time is 09.08 UTC (14:38 IST) which is demonstrated in Fig. 2. It is because of the requirement of RAAN that the lift off time of the launch vehicle has to be very precise and the launch window available is very narrow (one to five minutes) compared to normal launches (30 to 60 minutes or more).

Trans Mars Injection Strategy:

From the parking orbit a velocity impulse of about 1470 m/s must be added to the existing orbital velocity at perigee to put the spacecraft in Trans-Mars phase / cruise phase. This addition is split into several burns (i) to reduce the finite burn loss (ii) to provide flexibility for lift-off day of the Launch vehicle (iii) To validate the spacecraft systems before Trans-Mars phase (iv) to ensure visibility of the burn events. The details of the maneuvers are given in Table 2. Final burn maneuver on Dec. 1, 2013 sent the spacecraft towards Mars. The arrival is expected on Sep. 24, 2014. Some midcourse maneuvers are also planned, if required, to ensure precise arrival conditions at Mars.

Specific Technological Features of MOM:

Power system - Power generation of the Mars orbiter is reduced to nearly 50% to 35% compared to Earth's orbit due to distance from Sun. To meet this challenge, single Solar Array with 3 panels of 1.8m x 1.4m each to generate 840 W in Mars orbit during sunlit normal incidence is provided. A Lithium ion Battery of 36AH is also provided.

Communication system - To meet the challenging task of managing distance up to 400 million km S-band systems are kept for both TTC and Data transmission. Delta Differential One-way Ranging (D-DOR) Transmitter is provided for ranging to improve Orbit Determination accuracy. Antenna System consists of Low Gain Antenna, Medium Gain antenna and High Gain Antenna.

Propulsion - Unified bipropellant system is used for orbit raising and attitude control. The propulsion system consists of a 440N Liquid Engine and 8 numbers of 22N thrusters. Additional safety and redundancy features for

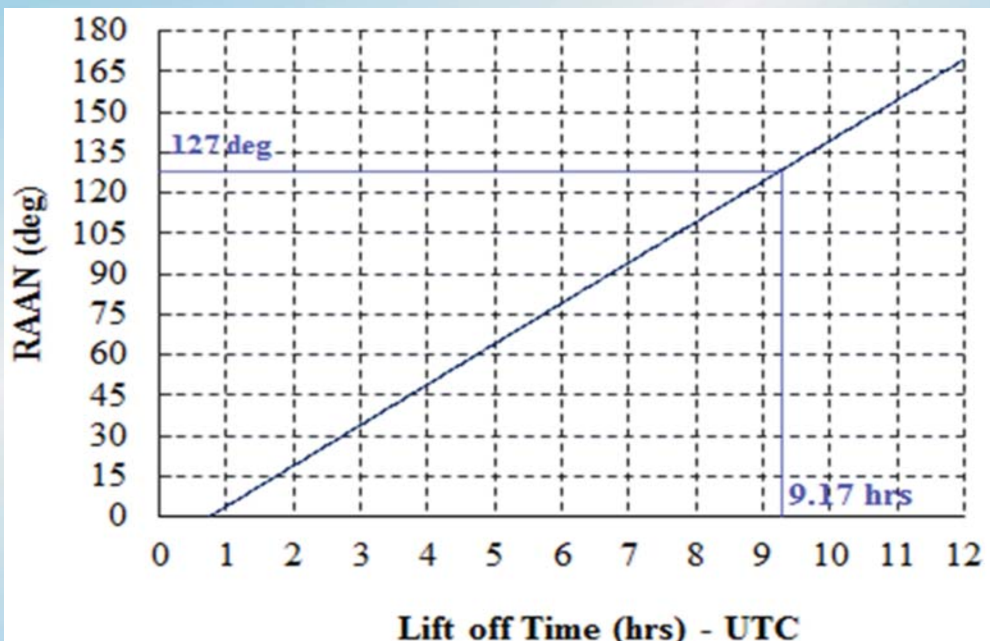

Figure 2: Lift off Time to achieve RAAN

Table 2 : Trans-Mars Injection Burn maneuvers

Burn Epoch	Apogee after Burn (km)	Velocity Impulse (m/s)	Period (hrs)
05-11-13 : 15:22 IST	23560	PSLV XL	6.83
07-11-13 : 01 : 17 IST	28786	138	8.35
08-11-13 : 02 : 19 IST	40186	202	11.99
09-11-13 : 02 :11 IST	71636	268	24.07
11 & 12-11-13	118642	159	46.60
16-11-13 : 01:27 IST	192874	102	91.30
01-12-13 : 00:49 IST	TMI	647	-

Source: www.isro.org

Mars Orbit Insertion [MOI] are included to ensure ignition of the thruster after a long duration of 300 days.

Thermal system is designed to cope with a range of thermal environment considering that average solar flux at Mars is 589 W/m^2 (42% of flux at Earth orbit).

On-board autonomy is provided because communication may take a duration between 6 to 43 minutes and real time interventions are not possible due to large distances. Autonomy logic manages the spacecraft when occulted by Mars, Whiteouts /Blackouts due to Sun, and when S/C enters safe mode.

Science Objectives:

The science objectives of the Mars Orbiter Mission are:

- Exploration of Mars surface features morphology, topography, mineralogy.
- Study of constituents of Martian atmosphere , dynamics of upper atmosphere.
- To detect emanation of gaseous constituents from surface/subsurface looking for clues on petrogenic or biogenic activities.

Accordingly there are five payloads, all indigenously developed. They are :

- ***Lyman Alpha Photometer (LAP)*** to study the escape processes of Mars upper atmosphere through Deuterium / Hydrogen
- ***Methane Sensor for Mars (MSM)*** to detect Methane presence
- ***Martian Exospheric Composition Explorer (MENCA)*** to study the neutral composition of Martian upper atmosphere
- ***Mars Colour Camera (MCC)*** for optical imaging
- ***TIR Imaging Spectrometer (TIS)*** to map surface composition and mineralogy

Details of each of these science payloads describing the objectives and operations are given in separate articles in this issue.

Beyond MOM: The Future of Mars Exploration

For the future missions to Mars involving landers, rovers and sample return experiments, the most important development needed is efficient aero-assist technology for descent. Mars entry, descent and landing are fraught with many new engineering challenges. One of the important challenges emanate from an atmosphere, which is thick enough for substantial heating, but not sufficiently dense enough for providing low terminal descent velocity. Also the surface environment is made of complex terrain patterns with rocks, craters, and dust.

At this juncture, the initial journeys for Mars settlement are conceived another 25 years into the future, beginning from 2035. Radiation in space is a major issue to contend with. From the standpoint of humans in interplanetary space, the two important sources of radiation for the Mars expedition are, the heavy ions (atomic nuclei with all electrons removed) of galactic cosmic ray and sporadic production of energetic protons from large solar particle events. Another important factor for the Mars expedition is absence of gravity during Mars transfer trajectory. One of the major effects of prolonged weightlessness seen in long-duration space flights has been an extended loss of bone mass. So, there are many interesting challenges ahead for the next generation of young scientists in the coming decades.

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