

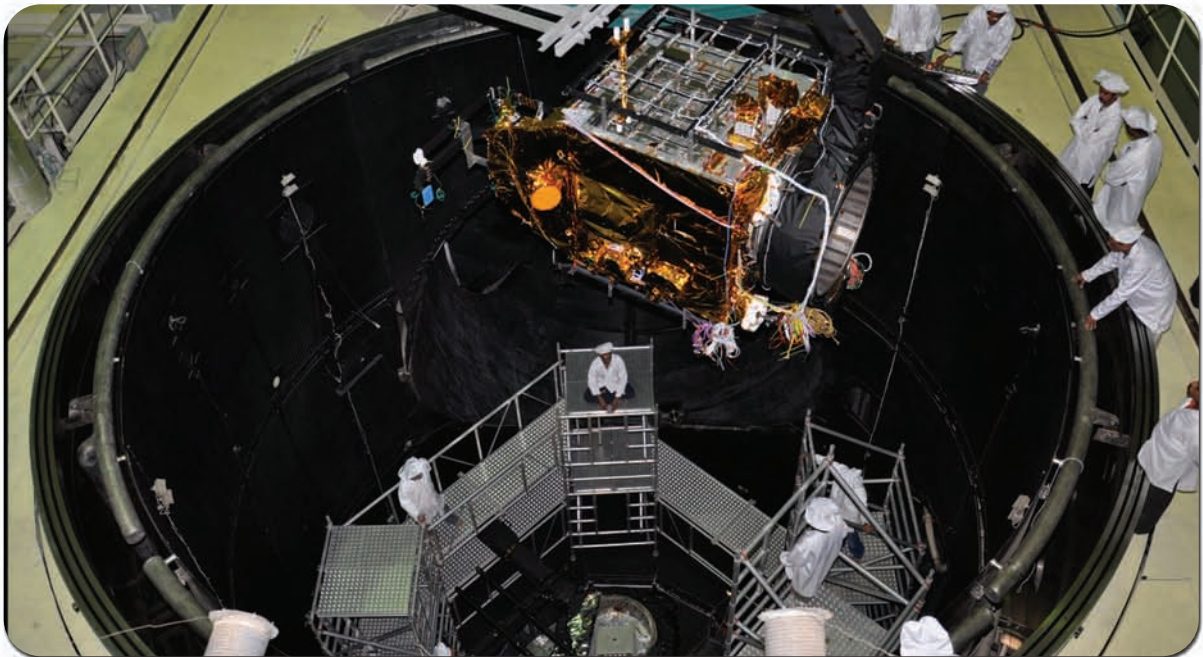
Mars Orbiter Mission

Indian Space Research Organisation

MARS ORBITER MISSION



Chairman ISRO Visiting Mars Orbiter Mission Spacecraft Clean Room



Mars Orbiter Mission Spacecraft getting in to Large Space Simulation Chamber for Testing

The Planet Mars

"In more than one respect, the exploring of the Solar System and homesteading other worlds constitutes the beginning, much more than the end, of history."

-- Carl Sagan

Mars tugs at the human imagination like no other planet. 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 revolution around the axis. Mars takes 24 hours and 37 minutes to complete a revolution around its axis. While Earth takes approximately 365 days to orbit round the sun, Mars takes 687 days for an orbit around sun. The gravity of Mars is roughly one- third of Earth's gravity and it has a thin atmosphere with a pressure of 1 % that of Earth. The atmosphere, water, ice and geology interact with each other to produce a dynamic Martian environment as in Earth. Mars has surface features reminiscent of both the impact craters of the Moon and volcanoes, deserts and polar ice of Earth. It inspires visions of an approachable world. 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 sustained.

	Mars	Earth
Atmosphere (composition)	Carbon dioxide (95.32%) Nitrogen (2.7%) Argon (1.6%) Oxygen (0.13%) Water vapour (0.03%) Nitric oxide (0.01%)	Nitrogen (77%) Oxygen (21%) Argon (1%) Carbon dioxide (0.038%) Water vapour (1%)
Atmosphere (pressure)	7.5 millibars (average)	1,013 millibars (at sea level)
Deepest Canyon	Valles Marineris 7 km deep 4,000 km wide	Grand Canyon 1.8 km deep 400 km long
Distance from Sun (average)	227,936,637 kilometers	149,597,891 kilometers
Equatorial Radius	3,397 kilometers	6,378 kilometers
Gravity	0.375 that of Earth	2.66 times that of Mars
Largest Volcano	Olympus Mons 26 km high 602 km in diameter	Mauna Loa (Hawaii) 10.1 km high 121 km in diameter
Length of Day	24 hours, 37 minutes	Just slightly under 24 hours
Length of Year	687 Earth days	365 days
Polar Caps	Covered with a mixture of carbon dioxide ice and water ice	Permanently covered with water ice
Surface Temperature (average)	- 63 degrees C	14 degrees C
Tilt of Axis	25 degrees	23.45 degrees
Number of Satellites	2 (Phobos and Deimos)	1 (Moon)



Victoria Crater at Meridiani Planum. The crater is ~800 meters in diameter (NASA/JPL)



Swirling trails left by the earlier passage of dust devils across sand dunes (NASA/JPL)

Mars Orbiter Mission is ISRO's first interplanetary mission to planet Mars with an orbiter craft designed to orbit Mars in an elliptical orbit. The Mission is primarily a technological mission considering the critical mission operations and stringent requirements on propulsion and other bus systems of the spacecraft. It has been configured to carry out observation of physical features of Mars and carry out limited study of Martian atmosphere with five payloads finalised by Advisor Committee on Space Sciences (ADCOS).

Mission Objectives

One of the main objectives of the first Indian mission to Mars is to develop the technologies required for design, planning, management and operations of an interplanetary mission. Following are the major objective of the mission.

Technological objectives

- Design and realisation of a Mars orbiter with a capability to survive and perform Earth bound manoeuvres, cruise phase of 300 days travel, Mars orbit insertion/capture and on-orbit phase around Mars.
- Deep space communication, navigation, mission planning and management.
- Incorporate autonomous features to handle contingency situations

Scientific objectives

- Exploration of Mars surface features, morphology, topography, mineralogy and Martian atmosphere by indigenous scientific instruments.

Mission Plan

Mission planning is done in conjunction with the defined mission objectives. The Mars Mission can be envisaged as a rendezvous problem. The rendezvous mission consists of following three phases:

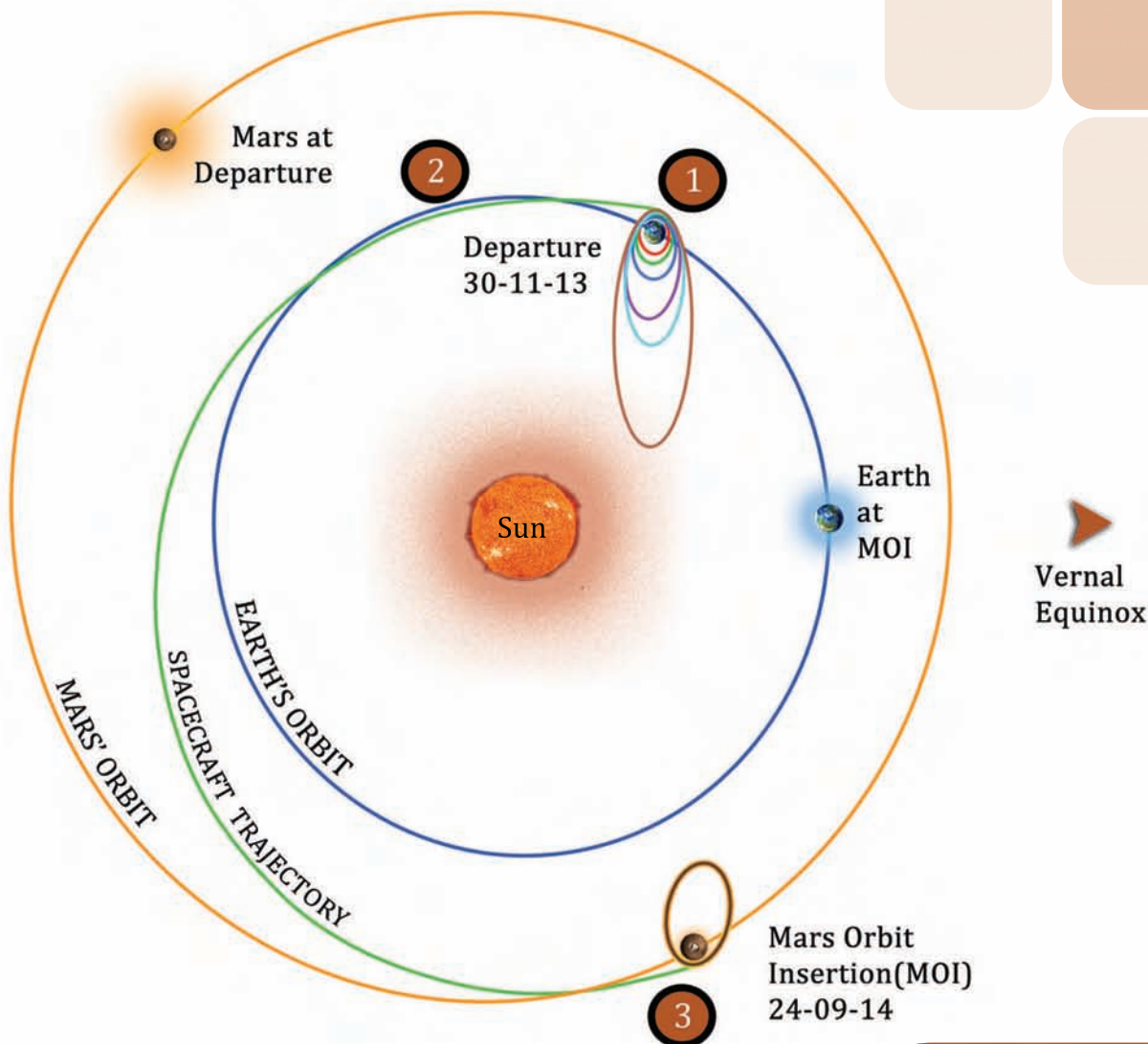
1. Geo Centric Phase

The spacecraft is injected into an Elliptic Parking Orbit by the launcher. With six main engine burns, the spacecraft is gradually maneuvered into a departure hyperbolic trajectory with which it escapes from the Earth's Sphere of Influence (SOI) with Earth's orbital velocity + ΔV boost. The SOI of Earth ends at 918347 km from the surface of the Earth beyond which the perturbing force on the orbiter is due to the Sun only.

One primary concern is how to get the spacecraft to Mars, on the least amount of fuel. ISRO uses a method of travel called a Hohmann Transfer Orbit – or a Minimum Energy Transfer Orbit – to send a spacecraft from Earth to Mars with the least amount of fuel possible.

2. Helio Centric Phase

The spacecraft leaves Earth in a direction tangential to Earth's orbit and encounters Mars tangentially to its orbit. The flight path is roughly one half of an ellipse around Sun. Eventually it will intersect the orbit of Mars at the exact moment that Mars is there too. This trajectory becomes possible with certain allowances when the relative position of Earth, Mars and Sun form an angle of approximately 44° . Such an arrangement recurs periodically at intervals of about 780 days. Minimum energy opportunities for Earth-Mars occur in November 2013, January 2016, May 2018 etc.



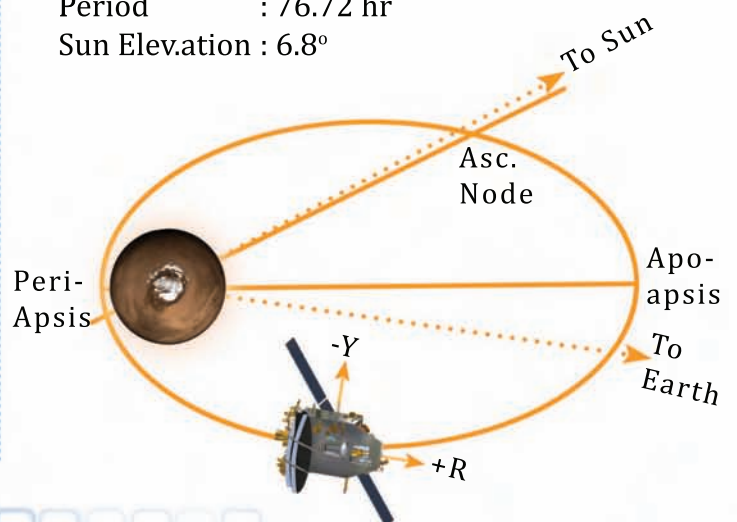
Trajectory Design

Martian Orbit

3. Martian Phase

The spacecraft arrives at the Mars Sphere of Influence (around 573473 km from the surface of Mars) in a hyperbolic trajectory. At the time the spacecraft reaches the closest approach to Mars (Periapsis), it is captured into planned orbit around Mars by imparting ΔV retro which is called the Mars Orbit Insertion (MOI) manoeuvre. The Earth-Mars trajectory is shown in the above figure. ISRO plans to launch the Mars Orbiter Mission during the November 2013 window utilizing minimum energy transfer opportunity.

MOI Epoch	: 24-09-2014, 02:34
Periapsis	: 365.3 km
Apo-apsis	: 80000 km
Inclination	: 150.0°
AOP	: 203.5°
RAAN	: 61.4°
Period	: 76.72 hr
Sun Elevation	: 6.8°



Payloads



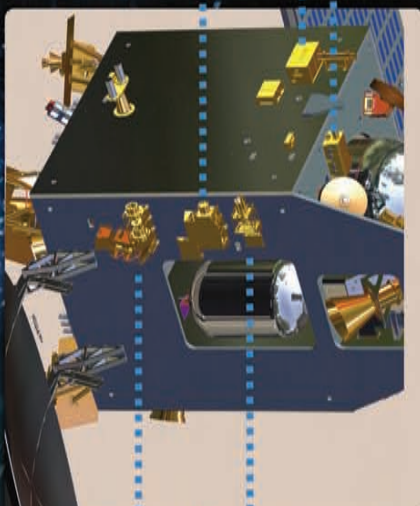
Lyman Alpha Photometer (LAP)

Lyman Alpha Photometer (LAP) is an absorption cell photometer. It measures the relative abundance of deuterium and hydrogen from 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 especially the loss process of water from the planet.



Methane Sensor for Mars (MSM)

MSM is designed to measure Methane (CH_4) in the Martian atmosphere with PPB accuracy and 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.



Mars Exospheric Neutral Composition Analyser (MENCA)

MENCA is a quadrupole mass spectrometer capable of analysing the neutral composition in the range of 1 to 300 amu with unit mass resolution. The heritage of this payload is from Chandra's Altitudinal Composition Explorer (CHACE) payload



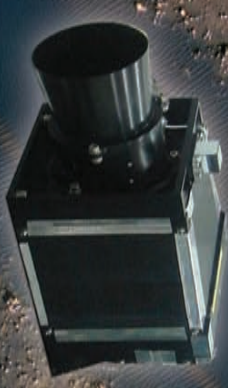
Thermal Infrared Imaging Spectrometer (TIS)

TIS 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 TIR region. TIS can map surface composition and mineralogy of Mars.



Mars Color Camera (MCC)

This tri-color Mars Color camera gives images & information about the surface features and composition of Martian surface. They are useful to monitor the dynamic events and weather of Mars. MCC will also be used for probing the two satellites of Mars – Phobos & Deimos. It also provides the context information for other science payloads.



Mainframe Elements

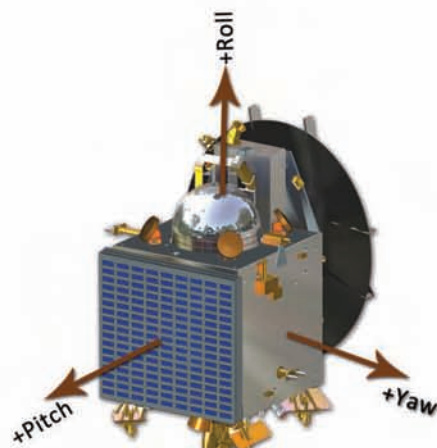
The spacecraft configuration is a balanced mix of design from flight proven IRS/INSAT/ Chandrayaan-1 bus. Improvisations required for Mars mission are in the areas of Communication, Power, Propulsion (for liquid engine restart after nearly a year) Systems and On board Autonomy.

The 390 litres capacity propellant tanks accommodate a maximum of 852 kg of propellant is adequate with sufficient margins. A Liquid Engine of 440N thrust is used for orbit raising and Martian Orbit Insertion (MOI). Additional flow lines and valves have been incorporated to ensure LE 440N engine restart after 300 days of Martian Transfer Trajectory (MTT) cruise and to take care of fuel migration issues.

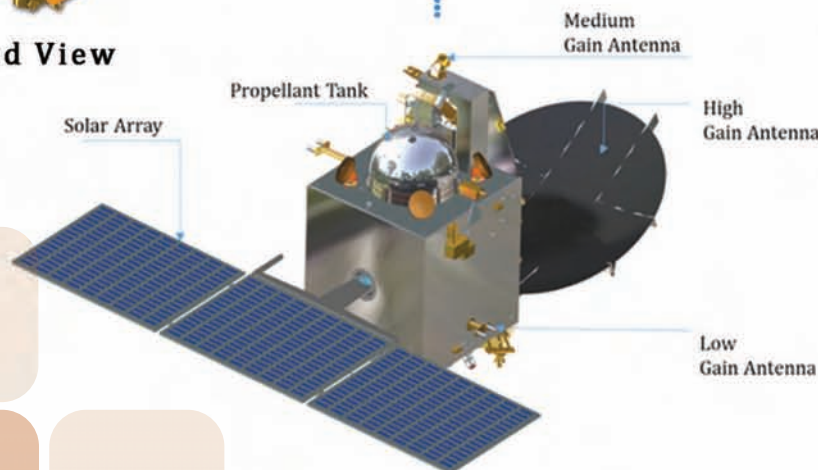
Eight numbers of 22N thrusters are used for wheel desaturation and attitude control during manoeuvres. Accelerometer is used for measuring the precise incremental velocity (ΔV) and for precise burn termination. Star sensors and gyros provide the attitude control signals inputs in all phases of mission.

To compensate for the lower solar irradiance (50% to 35% compared to Earth), the Mars orbiter requires three solar panels of size 1800 X 1400mm. Single 36AH Li-Ion battery is sufficient to take care of eclipses encountered during Earth bound phase and in Mars orbit.

The communication dish antenna is fixed to spacecraft body. The antenna diameter is 2.2m is arrived after the trade-off study between antenna diameter and accommodation within the PSLV-XL envelope. On-board autonomy functions are incorporated as the large Earth-Mars distance does not permit real time interventions. This will also take care of on-board contingencies.



Stowed View



Deployed View



Launch Configuration

Salient features of the Space Segment

Features	Specifications
Mass	1340 -3/+0 kg
Structures	Aluminum and Composite Fiber Reinforced Plastic (CFRP) sandwich construction-modified I-1 K Bus
Mechanism	Solar Panel Drive Mechanism (SPDM), Reflector & Solar panel deployment
Propulsion	Bi propellant system (MMH + N ₂ O ₄) with additional safety and redundancy features for MOI. Propellant mass: 852 kg
Thermal System	Passive thermal control system
Power System	Single Solar Array-1.8m X 1.4 m - 3 panels - 840 W Generation (in Martian orbit), Battery: 36AH Li- ion
Attitude and Orbit Control System	AOCE (Attitude and Orbit Control Electronics): with MAR31750 Processor Sensors: Star sensor (2Nos), Solar Panel Sun Sensor (SPSS)-1No, Coarse Analogue Sun Sensor (CASS)-9 Heads, and Inertial Reference Unit and Accelerometer Package (IRAP) Actuators: Reaction Wheels (5Nms, 4Nos), Thrusters (22N-8Nos), 440N Liquid Engine
TTC Baseband and RF System	Telemetry (TM) and Telecommand (TC): CCSDS Compatible Baseband Data Handling (BDH) and Solid State Recorder (SSR) - 16+16 Gb Communication (RF) Systems: S-Band for both TTC and Data Antennae: Low Gain Antenna (LGA), Mid Gain Antenna (MGA) and High Gain Antenna (HGA)

Ground Segment



Features	Specifications
S- band sea-borne terminals	Located in Pacific Ocean to monitor PS4 and satellite separation
JPL(Jet Propulsion Laboratory) Deep Space Network	Located at Canberra, Goldstone, and Madrid with 34m & 70m (200kW) antennae network
ISTRAC Ground Network	TTC Operations during Geo-centric phase
Indian Deep Space Network (IDSN)	Located in Bangalore with 18m & 32 m antenna, up linking at 20KW power
Indian Space Science Data Centre (ISSDC)	For archiving and dissemination of payload data

PSLV-XL Launch Vehicle



- Launch Vehicle composition : S139+ 6S12 + PL40 + S7 + L2.5 + ϕ 3.2 meter aluminum fairing.
- Meets the required AOP for Mars Trajectory by extended coasting of ~1600 s

- Launch azimuth : 104 deg
- Spacecraft mass at lift-off : 1340 (-3/+0) kg

EPO Parameter	Specification
Perigee Height (km)	250
Apogee Height (km)	23500
Inclination (deg)	19.2
Argument of Perigee (AOP, deg)	Function of Launch Time
Right Ascension of Ascending Node (RAAN, deg)	Function of Launch Time

Major Challenges

Radiation Environment

Main frame bus elements and payloads are basically designed for interplanetary missions capable of operating in EBN, MTT and MO environments.

The bus unit components are selected with respect to a cumulated dose of 6 krads below 22 AWG aluminium shielding. Parts have been considered as directly suitable if they have been evaluated successfully up to 12 krads (margin factor of 2).

Bus parts are latch up immune with a Minimum threshold value LET

- For Single Event Upset (SEU) $LET > 40 \text{ MeV.cm}^2.\text{mg}^{-1}$
- For Single Event Latch ups (SEL) $LET > 80 \text{ MeV.cm}^2.\text{mg}^{-1}$

Thermal Environment

The bus needs to cope with a wide range of thermal environment, from Near Earth conditions with Sun and Earth contributions (hot case) to Mars conditions where eventually eclipses and reduced solar flux give rise to cold case issues.

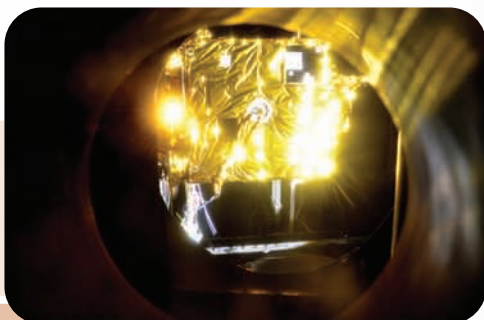
The average solar flux at Mars orbit is 589 W/Sq.m , or about 42% of what is experienced by an Earth-orbiting spacecraft.

As a result of the eccentricity of Mars's orbit, however, the solar flux at Mars varies by $\pm 19\%$ over the Martian year, which is considerably more than the 3.5% variation at Earth.

Albedo fractions are similar to Earth's, being around 0.25 to 0.28 at the equator and generally increasing toward the poles.

The effect of albedo and Mars IR loads are negligible due to the eccentricity of orbit around Mars.

Thermal Balance Tests simulated Mars flux conditions and validated thermal model



MOM Spacecraft under Thermal balance test

Propulsion System

- > Liquid Engine to be restarted after 10 months for Martian Orbit Insertion (MOI) manoeuvre.
- > To improve safety and redundancy second LVG is provided.
- > Additional pyros provided for MOI manoeuvres.
- > Component heritage maintained from GEOSAT and Chandrayaan-1 missions.
- > Heaters on gas lines incorporated.
- > Two Liquid Engines are subjected to mission simulation tests in High Altitude Test Facility.
- > LAM injector tests at TERLS test stand under sea level conditions conducted



Liquid Engine undergoing sea level hot test at TERLS

Power System

- > Reduction in Solar power generation due to lower solar irradiance (50% to 35% as compared to earth).
- > Very low temperature of solar panels during eclipse periods (-185°C).
- > The array designed for maximum performance at Martian solar flux conditions ensuring 840 W generation.
- > Coupon level test carried out at -200°C to qualify solar cells and bonding process.

Communication System

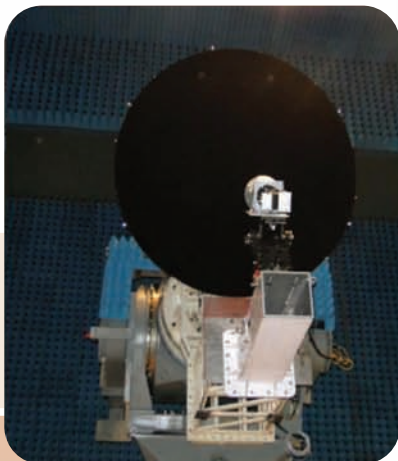
- > Communication management at distances from 214 million (range at Mars capture) to 375 million Km (Range of Mars after 6 months)
- > S-Band deep space frequencies for both TTC and Data transfer.
- > With two 230 W TWTAs and two coherent transponders
- > Sensitive receiver with -135 dBm carrier acquisition threshold
- > Selectable data rates of 5/10/20/40 kbps (without turbo coding)
- > S-Band Δ -DOR transmitters for improving the Orbit Determination accuracy



Receiver Package

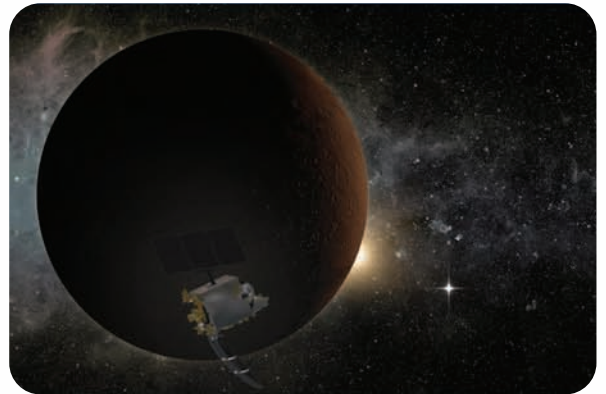
- > Qualification model of the receiver is subjected to full scale environmental tests and performance demonstrated.
- > The results are verified jointly by JPL and ISRO and they meet the mission requirements.
- > Doppler accuracy of 1mm/s and Ranging accuracy of 3m and Δ -DOR accuracy of 30nano radians per measurement is estimated for MOM RF system performance for the purpose of Orbit
- > Determination. The target plane (B-plane) is achievable within +/- 50 kms (3 sigma)

High Gain
Antenna
in High Power
Testing



Spacecraft Autonomy

- > Maximum Earth to Mars Round-trip Light Time (RLT) 42 minutes during the mission. Impractical to Micromanage the mission from Earth with ground intervention.
- > On-board autonomy is implemented through autonomous Fault Detection, Isolation and Reconfiguration (FDIR) logics and executed by AOCE and TMTC packages.
- > Continuous Watch, Fault Detection, Isolation and Reconfiguration without disturbing the Earth Pointing attitude
- > Essential during Communication Interruptions during eclipse, whiteouts, blackouts.
- > Safeguard the spacecraft during MOI, TWTAs duty cycling and sun pointing safe mode.



- > The mission requirements resulted in development of 22 software modules, modification of 42 modules and usage of 19 existing modules.
- > These modules were extensively tested using simulation and flight hardware in OILS and HILS tests from November 2012.
- > Incorporation of a Sodern make star sensor with interplanetary mission heritage to improve reliability of the mission.
- > Usage of MAR31750 processor which has heritage of Mars mission.

Navigation

Design, development testing and evaluation of navigation software included all planetary models and force models and validated through thread test.

Mars Orbiter Mission



Mars Orbiter Mission Project
ISRO Satellite Centre, Bangalore
Design: Shamsudheen T, shams@isac.gov.in