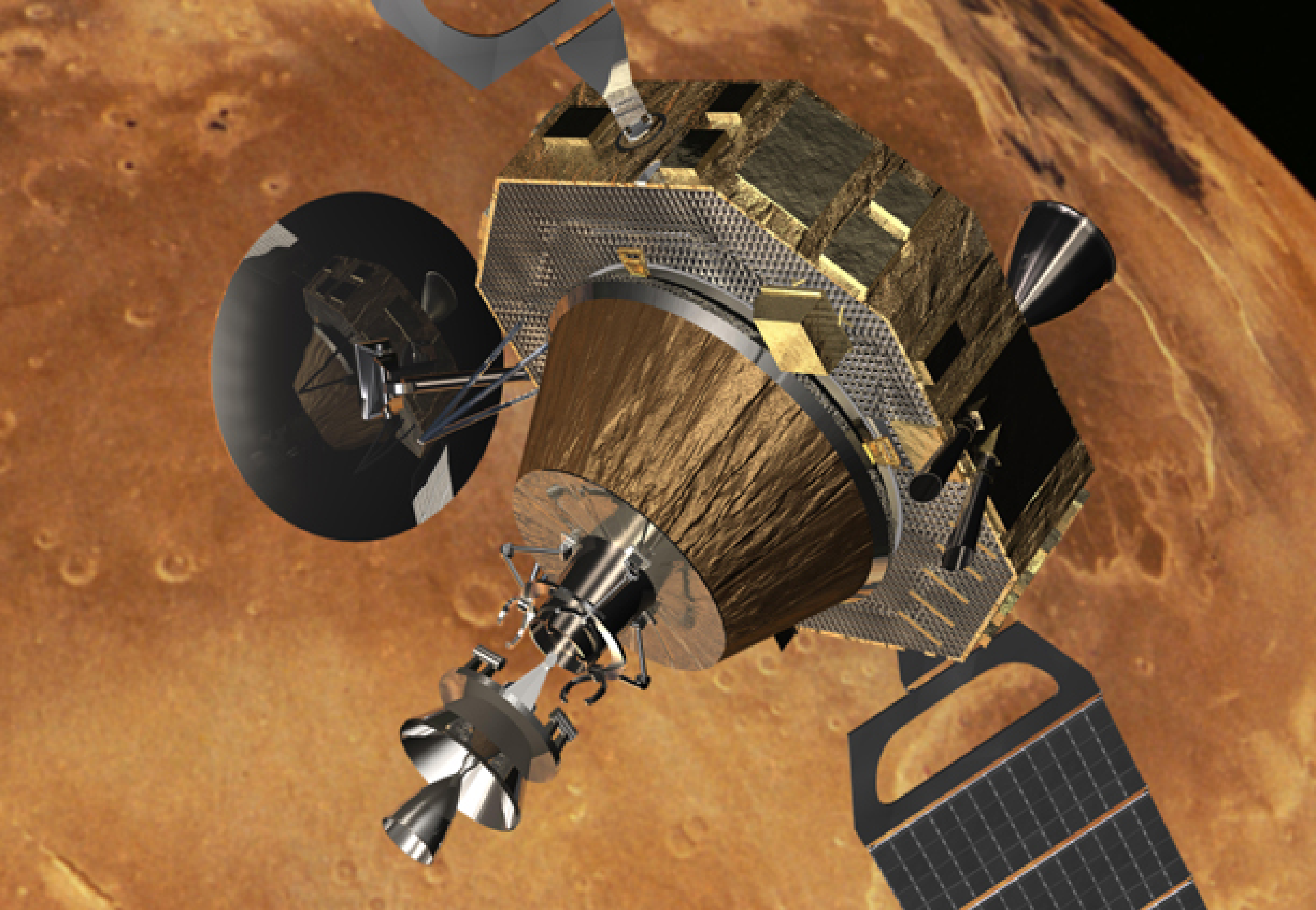

Future and Planned Spacecraft Missions to Mars

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Chapter- 1

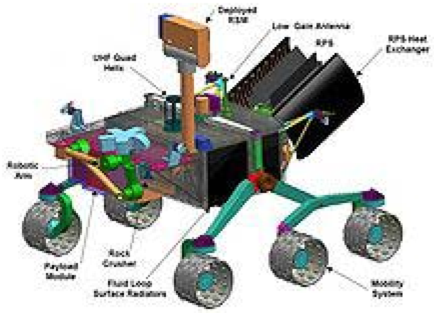
Mars Science Laboratory

Mars Science Laboratory mission

2007 concept artwork

Operator	NASA
Major contractors	Boeing, Lockheed Martin
Mission type	Rover
Orbital insertion date	lands between August 6 and August 20, 2012
Launch date	between November 25 and December 18, 2011
Launch vehicle	Atlas V 541
Mission duration	668 Martian sols (686 Earth days)
COSPAR ID	MARSCILAB
Homepage	Mars Science Laboratory
Mass	900 kg (2,000 lb)

Power	Radioisotope Thermoelectric Generator (RTG)



Schematic diagram of the planned rover components.

The **Mars Science Laboratory** (**MSL**) is a United States space agency (NASA) mission with the aim to land and operate a rover named ***Curiosity*** on the surface of Mars. It is scheduled to be launched in November 2011 and land on Mars in August 2012. It would perform the first-ever precision landing on Mars. The Curiosity rover will help assess whether Mars ever was, or is still today, an environment able to support microbial life. In other words, its mission is to determine the planet's habitability. It will also analyze samples scooped up from the soil and drilled powders from rocks.

The Curiosity rover will be over five times as heavy as and carry over ten times the weight of scientific instruments as the rovers *Spirit* or *Opportunity*. The MSL Curiosity rover will be launched by an Atlas V 541 rocket and will be expected to operate for at least 1 Martian year (668 Martian sols/686 Earth days) as it explores with greater range than any previous Mars rover.

Mars Science Laboratory mission is part of NASA's Mars Exploration Program, a long-term effort of robotic exploration of Mars, and is a project managed by the Jet Propulsion Laboratory of California Institute of Technology for NASA. The total cost of the MSL project is about US$2.3 billion.

Goals and objectives

The MSL mission has four goals: To determine if life ever arose on Mars, to characterize the climate of Mars, to characterize the geology of Mars, and to prepare for human exploration. To contribute to the four science goals and meet its specific goal of determining Mars' habitability, Mars Science Laboratory has eight scientific objectives:

1. Determine the nature and inventory of organic carbon compounds.
2. Inventory the chemical building blocks of life as we know it: carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur.
3. Identify features that may represent the effects of metabolism or biosignatures.

4. Investigate the chemical, isotopic, and mineralogical composition of the Martian surface and near-surface geological materials.
5. Interpret the processes that have formed and modified rocks and soils.
6. Assess long-timescale (i.e., 4-billion-year) Martian atmospheric evolution processes.
7. Determine present state, distribution, and cycling of water and carbon dioxide.
8. Characterize the broad spectrum of surface radiation, including galactic radiation, cosmic radiation, solar proton events and secondary neutrons.

If no organic compounds are found, that is useful information, as evidence about life on Mars may not be near the surface. It would also aid understanding of the environmental conditions that remove organics.

History

Jet Propulsion Laboratory engineers test and assemble Curiosity in a large clean room on June 29, 2010 in preparation for a late 2011 launch

In April 2008, it was reported that the project was $235 million USD, or 24% over budget and that the money to compensate this overrun may have to come from other NASA Mars missions.

In October 2008, MSL was getting closer to a 30% cost overrun.

As of November 2008, development is essentially finished, much of MSL hardware and software are complete and testing is ongoing.

On December 3, 2008, NASA announced that the MSL launch will be delayed until the fall of 2011 because of inadequate test time. The technical and budgetary reasons behind the delay were explained to the Planetary Science Community in a January 2009 meeting at NASA Headquarters.

From March 23–29, 2009, the general public had an opportunity to rank nine finalist names through a public poll on the NASA website as additional input for judges to consider the MSL rover name. On 27 May 27 2009, the winning name of *Curiosity* was selected, which was submitted by a sixth-grader, Clara Ma, from Kansas.

In late June 2010, engineers completed the installation of the suspension and wheel assembles on the rover body. The six-wheeled rocker-bogie suspension is similar to the design found on Mars Exploration Rovers and Mars Pathfinder rover. Engineers began testing the integrated suspension system which will also serve as landing gear for the vehicle, unlike its smaller predecessors.

Specifications

MSL mockup compared with the Mars Exploration Rover and Sojourner rover by the Jet Propulsion Laboratory on May 12, 2008

A comparison of sizes for the Sojourner rover, the Mars Exploration Rovers, the Phoenix

Lander and the Mars Science Laboratory.

The MSL Assembly, Test and Launch Operations (ATLO) in the Jet Propulsion Laboratory

Wheel size comparison: Sojourner, Mars Exploration Rover, Mars Science Laboratory

Length/weight

The Curiosity rover will have a length of 9 feet (2.7 m) and weigh 1,984 pounds (900 kg) including 176 pounds (80 kg) of scientific instruments. It will be the same size as a Mini Cooper automobile. This compares to the Mars Exploration Rovers which have a length of 5 feet 2 inches (1.57 m) and weigh 384 pounds (174 kg) including 15 pounds (6.8 kg) of scientific instruments.

Speed

Once on the surface, the Curiosity rover will be able to roll over obstacles approaching 75 centimeters (30 in) high. Maximum terrain-traverse speed is estimated to be 90 meters (300 ft) per hour via automatic navigation, however, average traverse speeds will likely be about 30 meters (100 ft) per hour, based on variables including power levels, difficulty of the terrain, slippage, and visibility. MSL is expected to traverse a minimum of 12 miles (19 km) in its two-year mission.

Power source

The Curiosity rover will be powered by radioisotope thermoelectric generators (RTGs), as used by the successful Mars landers Viking 1 and Viking 2 in 1976. Radioisotope power systems are generators that produce electricity from the natural decay of plutonium-238, which is a non-weapons-grade form of that radioisotope used in power systems for NASA spacecraft. Heat given off by the natural decay of this isotope is converted into electricity, providing constant power during all seasons and through the day and night, and waste heat can be used via pipes to warm systems, freeing electrical power for the operation of the vehicle and instruments.

The Curiosity power source will use the latest RTG generation built by Boeing, called the "Multi-Mission Radioisotope Thermoelectric Generator" (MMRTG). The MMRTG is a flexible and compact power system under development that is based on conventional

RTGs. The MMRTG is designed to produce 125 watts of electrical power at the start of the mission and 100 watts after 14 years. The MSL will generate 2.5 kilowatt hours per day compared to the Mars Exploration Rovers which can generate about 0.6 kilowatt hours per day. Although the primary mission is planned to last about 2 Earth years, the MMRTG will have a minimum lifetime of 14 years.

Heat rejection system

The temperatures in the potential areas at which the Curiosity rover may land can vary from +30 to −127°C (+86°F to −197°F). Therefore, the Heat rejection system (HRS) uses fluid pumped through 60 m (200 ft) of tubing in the MSL body so that sensitive components are kept at optimal temperatures. Other methods of heating the internal components include using radiated heat generated from the components in the craft itself, as well as excess heat from the MMRTG unit. The HRS also has the ability to cool components if necessary.

Computers

The two identical on-board rover computers, called "Rover Electronics Module" (REM), contain radiation hardened memory to tolerate the extreme radiation environment from space and to safeguard against power-off cycles. Each computer's memory includes 256 kB of EEPROM, 256 MB of DRAM, and 2 GB of flash memory. This compares to 3 MB of EEPROM, 128 MB of DRAM, and 256 MB of flash memory used in the Mars Exploration Rovers.

The REM computers use the RAD750 CPU which is a successor to the RAD6000 CPU used in the Mars Exploration Rovers. The RAD750 CPU is capable of up to 400 MIPS while the RAD6000 CPU is capable of up to 35 MIPS.

The rover has an Inertial Measurement Unit (IMU) that provides 3-axis information on its position which is used in rover navigation. The rover's computers are constantly self-monitoring to keep the rover operational, such as by regulating the rover's temperature. Activities such as taking pictures, driving, and operating the instruments are performed in a command sequence that is sent from the flight team to the rover. In the event of problems with the main computer, the backup computer will take over.

Proposed payload

At present, 10 instruments have been selected for development or production for the MLS Curiosity rover:

Cameras

The MastCam, MAHLI, and MARDI cameras are being developed by Malin Space Science Systems and they all share common design components, such as on-board electronic imaging processing boxes, 1600x1200 CCDs, and a RGB Bayer pattern filter.

- **MastCam**: This system will provide multiple spectra and true color imaging with two cameras. The cameras can take true color images at 1200x1200 pixels and up to 10 frames per second hardware-compressed, high-definition video at 720p (1280x720). One camera will be the Medium Angle Camera (MAC) which has a 34 mm focal length, a 15 degree field of view, and can yield 22 cm/pixel scale at 1 km. The other camera will be the Narrow Angle Camera (NAC) which has a 100 mm focal length, a 5.1-degree field of view, and can yield 7.4 cm/pixel scale at 1 km. Malin is also developing a pair of Mastcams with zoom lens, which NASA may choose to fly instead of the fixed focal length cameras. Each camera will have 8 GB of flash memory, which is capable of storing over 5,500 raw images, and can apply real time lossless or JPEG compression. The cameras have an autofocus capability which allows them to focus on objects from 2.1 meters (6.9 ft) to infinity. Each camera will also have a RGB Bayer pattern filter with 8 filter positions. In comparison to the 1024x1024 black & white panoramic cameras used on the Mars Exploration Rover (MER) the MAC MastCam will have 1.25X higher spatial resolution and the NAC MastCam will have 3.67X higher spatial resolution.
- **Mars Hand Lens Imager (MAHLI)**: This system will consist of a camera mounted to a robotic arm on the rover. It will be used to acquire microscopic images of rock and soil. MAHLI can take true color images at 1600x1200 pixels with a resolution as high as 14.5 micrometers per pixel. MAHLI has a 18.3 mm to 21.3 mm focal length and a 33.8 to 38.5 degree field of view. MAHLI will have both white and UV LED illumination for imaging in darkness or imaging fluorescence. MAHLI will also have mechanical focusing in a range from infinite to mm distances. MAHLI can store either the raw images or do real time lossless predictive or JPEG compression.
- **MSL Mars Descent Imager (MARDI)**: During the descent to the Martian surface, MARDI will take color images at 1600x1200 pixels with a 1.3 millisecond exposure time starting at distances of about 3.7 km to near 5 meters from the ground and will take images at a rate of 5 frames per second for about 2 minutes. MARDI has a pixel scale of 1.5 meters at 2 km to 1.5 millimeters at 2 meters and has a 90 degree circular field of view. MARDI will have 8 GB of internal buffer memory which is capable of storing over 4,000 raw images. MARDI imaging will allow the mapping of surrounding terrain and the location of landing. JunoCam, for another spacecraft, is based on MARDI.

ChemCam

ChemCam is a suite of remote sensing instruments, including the first laser-induced breakdown spectroscopy (LIBS) system to be used for planetary science and a remote micro-imager (RMI). The LIBS instrument can target a rock or soil sample from up to 7 meters away, vaporizing a small amount of it and then collecting a spectrum of the light emitted by the vaporized rock. An infrared laser with 1067 nm wavelength and a 5 nanosecond pulse will focus on a sub-millimeter spot with a power in excess of 10 megawatts, depositing 15mJ of energy. Detection of the ball of luminous plasma will be done in the visible and near-UV and near-IR range, between 240 nm and 800 nm. Using the same collection optics, the RMI provides context images of the LIBS analysis spots. The RMI resolves 1 mm objects at 10 m distance, and has a field of view covering 20 cm at that distance. The ChemCam instrument suite is being developed by the Los Alamos National Laboratory and the French CESR laboratory. NASA's cost for ChemCam is approximately $10M, including an overrun of about $1.5M, which is about 4% of the total mission costs. The flight model of the Mast Unit was delivered from the French CNES to Los Alamos National Laboratory and was able to deliver the engineering model to JPL in February 2008.

Alpha-particle X-ray spectrometer (APXS)

This device will irradiate samples with alpha particles and map the spectra of X-rays that are reemitted for determining the elemental composition of samples. It is being developed by the Canadian Space Agency. The APXS is a form of particle-induced X-ray emission (PIXE), which has previously been used by the Mars Pathfinder and the Mars Exploration Rovers.

CheMin

Chemin stands for "Chemistry and Mineralogy" and is a X-Ray diffraction/X-Ray fluorescence instrument that will quantify minerals and mineral structure of samples. It is being developed by Dr. David Blake at NASA Ames Research Center and the NASA's Jet Propulsion Laboratory.

Sample Analysis at Mars (SAM)

The SAM instrument suite will analyze organics and gases from both atmospheric and solid samples. It is being developed by the NASA Goddard Space Flight Center, the Laboratoire Inter-Universitaire des Systèmes Atmosphériques (LISA) of France's CNRS and Honeybee Robotics, along with many additional external partners. The SAM suite consists of three instruments:

- Quadrupole Mass Spectrometer (QMS)
- Gas Chromatograph (GC)
- Tunable Laser Spectrometer (TLS)

The Quadrupole Mass Spectrometer (**QMS**) will detect gases sampled from the atmosphere or those released from solid samples by heating. The Gas Chromatograph (**GC**) will be used to separate out individual gases from a complex mixture into molecular components with a mass range of 2–235 u. The Tunable Laser Spectrometer

(**TLS**) will perform precision measurements of oxygen and carbon isotope ratios in carbon dioxide (CO_2) and methane (CH_4) in the atmosphere of Mars in order to distinguish between a geochemical and a biological origin.

The SAM also has three subsystems: The Chemical Separation and Processing Laboratory (**CSPL**), for enrichment and derivatization of the organic molecules of the sample; the Sample Manipulation System (**SMS**) for transporting powder delivered from the MSL drill to a SAM inlet and into one of 74 sample cups. The SMS then moves the sample to the SAM oven to release gases by heating to up to 1000 ^oC; and the Wide Range Pumps (**WRP**) subsystem to purge the QMS, TLS, and the CPSL.

Radiation Assessment Detector (RAD)

This instrument will characterize the broad spectrum of radiation found near the surface of Mars for purposes of determining the viability and shielding needs for human explorers. Funded by the Exploration Systems Mission Directorate at NASA Headquarters and the German space agency, DLR, RAD was developed by Southwest Research Institute (SwRI) and the extraterrestrial physics group at Christian-Albrechts-Universität zu Kiel, Germany.

Dynamic Albedo of Neutrons (DAN)

A pulsed neutron source and detector for measuring hydrogen or ice and water at or near the Martian surface, provided by the Russian Federal Space Agency.

Rover Environmental Monitoring Station (REMS)

Meteorological package and an ultraviolet sensor provided by the Spanish Ministry of Education and Science. It will be mounted on the camera mast and measure atmospheric pressure, humidity, wind currents and direction, air and ground temperature and ultraviolet radiation levels.

MSL Entry Descent and Landing Instrumentation (MEDLI)

The MEDLI project's main objective is to measure aerothermal environments, sub-surface heat shield material response, vehicle orientation, and atmospheric density for the atmospheric entry through the sensible atmosphere down to heat shield separation of the Mars Science Laboratory entry vehicle. The MEDLI instrumentation suite will be installed in the heatshield of the MSL entry vehicle. The acquired data will support future Mars missions by providing measured atmospheric data to validate Mars atmosphere models and clarify the design margins on future Mars missions. MEDLI instrumentation consists of three main subsystems: MEDLI Integrated Sensor Plugs (MISP), Mars Entry Atmospheric Data System (MEADS) and the Sensor Support Electronics (SSE).

Hazard Avoidance Cameras (Hazcams)

The MSL will use two pairs of black and white navigation cameras located on the front left and right and rear left and right of the rover. The Hazard Avoidance Cameras (also called Hazcams) are used for autonomous hazard avoidance during rover drives and for safe positioning of the robotic arm on rocks and soils. The cameras will use visible light to capture stereoscopic three-dimensional (3-D) imagery. The cameras have a 120 degree field of view and map the terrain at up to 10 feet (3 meters) in front of the rover. This imagery safeguards against the rover inadvertently crashing into unexpected obstacles, and works in tandem with software that allows the rover to make its own safety choices.

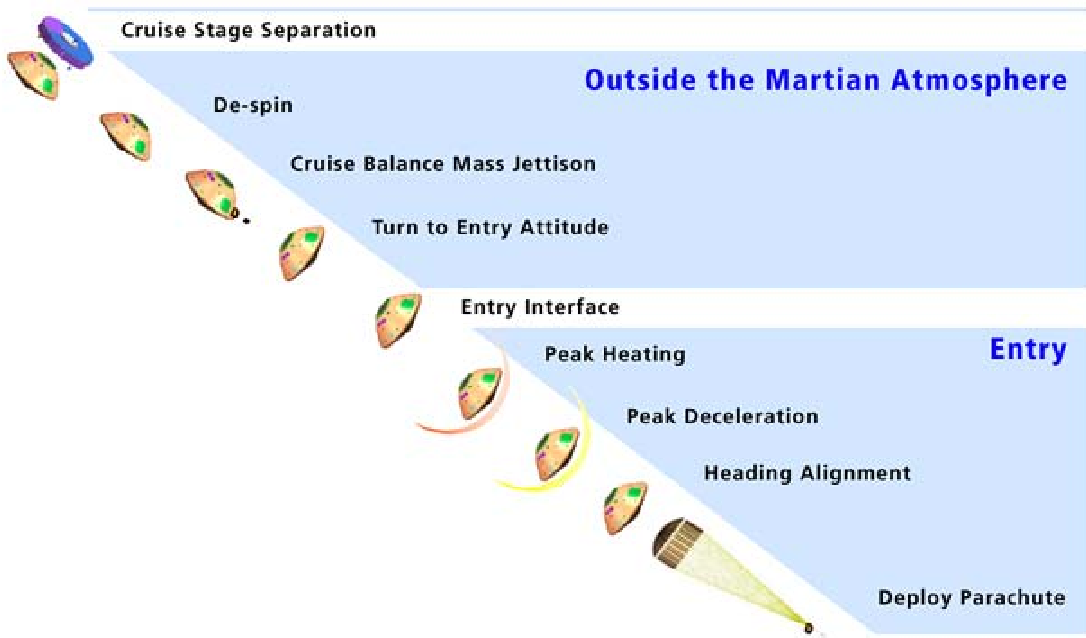
Navigation Cameras (Navcams)

The MSL will use a pair of black and white navigation cameras mounted on the mast to support ground navigation. The cameras will use visible light to capture stereoscopic 3-D imagery. The cameras have a 45 degree field of view.

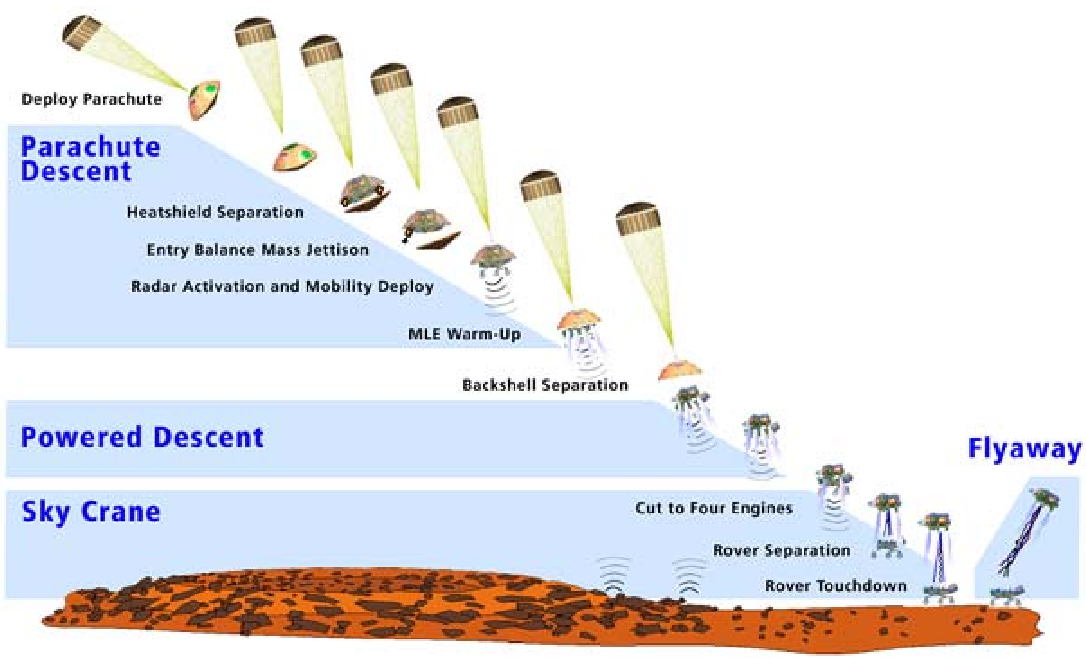
Launch vehicle

The MSL will be launched using the Atlas V 541 which is a two stage rocket capable of launching up to 17,597 pounds (8,672 kg) to geostationary transfer orbit. The Atlas V has also been used to launch the Mars Reconnaissance Orbiter and New Horizons.

Landing system



Curiosity landing diagram for outside Martian atmosphere and for entry.



Curiosity landing diagram for parachute descent, powered descent, and sky crane.

Landing a large mass on Mars is a difficult challenge: the atmosphere is thick enough to prevent rockets being used to provide significant deceleration, but too thin for parachutes and aerobraking alone to be effective. Although some previous missions have used airbags to cushion the shock of landing, the MSL is too large for this to be an option.

Curiosity will be set down on the Martian surface using a new high-precision entry, descent, and landing (EDL) system that will place it in a 20 kilometer (12 mile) landing ellipse, in contrast to the 150 kilometer by 20 kilometer (about 93 miles by 12 miles) landing ellipse of the landing systems used by the Mars Exploration Rovers.

For this, the MSL will employ a combination of several systems in a precise order, where the entry, descent and landing sequence will break down into four parts.

- **Guided entry** - The rover is folded up within an aeroshell which protects it during the travel through space and during the atmospheric entry at Mars. Atmospheric entry is accomplished using a Phenolic Impregnated Carbon Ablator (PICA) heat shield. The 4.5-m (14-ft, 9-in.) diameter heat shield, which will be the largest heat shield ever flown in space, reduces the velocity of the spacecraft by ablation against the Martian atmosphere, from the interplanetary transit velocity of 5.3 to 6 km/sec down to approximately Mach-2, where parachute deployment is possible. Much of the reduction of the landing precision error is accomplished by an entry guidance algorithm, similar to that used by the astronauts returning to Earth in the Apollo space program. This guidance uses the lifting force experienced by the aeroshell to "fly out" any detected error in range and thereby arrive at the targeted landing site. In order for the aeroshell to have lift, its center of mass is offset from the axial centerline which results in an off-center trim angle in atmospheric flight, again similar to the Apollo Command Module. This is accomplished by a series of ejectable ballast masses. The lift vector is controlled by four sets of two Reaction Control System (RCS) thrusters that produce approximately 500 N of thrust per pair. This ability to change the pointing of the direction of lift allows the spacecraft to react to the ambient environment, and steer toward the landing zone.


The MSL test parachute. Note the people in the lower-right corner of the image.

- **Parachute descent** - Like Viking, Mars Pathfinder and the Mars Exploration Rovers, the Mars Science Laboratory will be slowed by a large parachute. After the entry phase is complete and the capsule has slowed to Mach 2, a supersonic parachute is deployed. The entry vehicle must first eject the ballast mass such that the center of gravity offset is removed. In March and April 2009 the parachute for the MSL was tested in the world's largest wind tunnel and passed flight-qualification testing. The parachute has 80 suspension lines, is over 165 feet (50 meters) long, and is about 51 feet (16 meters) in diameter. The parachute is capable of being deployed at Mach 2.2 and can generate up to 289 kN (65,000 pounds) of drag force in the Martian atmosphere.
- **Powered descent** - Following the parachute braking, the rover and descent stage drop out of the aeroshell. The descent stage is a platform above the rover with

variable thrust mono propellant hydrazine rocket thrusters on arms extending around this platform to slow the descent. Each of the 8 rockets on this stage produce up to 3.1 kN (700 pounds) of thrust and were derived from those used on the Viking landers. Meanwhile, the rover will transform from its stowed flight configuration to a landing configuration while being lowered beneath the descent stage by the "Sky Crane" system.

- **Sky Crane** - The Sky Crane system will lower the rover to a "soft landing" – wheels down– on the surface of Mars. This consists of 3 bridles lowering the rover and an umbilical cable carrying electrical signals between the descent stage and rover. At roughly 7.5 meters below the descent stage the "sky crane" system slows to a halt and the rover touches down. After the rover touches down it waits 2 seconds to confirm that it is on solid ground and fires several pyros (small explosive devices) activating cable cutters on the bridle and umbilical cords to free itself from the descent stage. The descent stage promptly flies away to a crash landing, and the rover gets ready to roam Mars. The planned "Sky Crane" powered descent landing system has never been used in actual missions before.

Proposed landing sites

The essential issue when selecting an optimum landing site is to identify a particular geologic environment, or set of environments, that would support microbial life. To mitigate the risk of disappointment and ensure the greatest chance for science success, interest is placed at the greatest number of possible science objectives at a chosen landing site. Thus, a landing site with morphologic and mineralogic evidence for past water, is better than a site with just one of these criteria. Furthermore, a site with spectra indicating multiple hydrated minerals is preferred; clay minerals and sulfate salts would constitute a rich site. Hematite, other iron oxides, sulfate minerals, silicate minerals, silica, and possibly chloride minerals have all been suggested as possible substrates for fossil preservation. Indeed, all are known to facilitate the preservation of fossil morphologies and molecules on Earth. Difficult terrain is the best candidate for finding evidence of livable conditions, and engineers must be sure the rover can safely reach the site and drive within it.

Current engineering constraints call for a landing site less than 45° from the Martian equator, and less than 1 km above the reference datum. At the first MSL Landing Site workshop, 33 potential landing sites were identified. By the second workshop in late 2007, the list had grown to include almost 50 sites, and by the end of the workshop, the list was reduced to six; in November 2008, project leaders at a third workshop reduced the list to four landing sites.

On August 20, 2009, NASA sent out a call for additional landing site proposals and issued another request for proposals on November 16, 2010. A fourth landing site workshop was held in late September 2010. A fifth and final workshop is planned for March 2011.

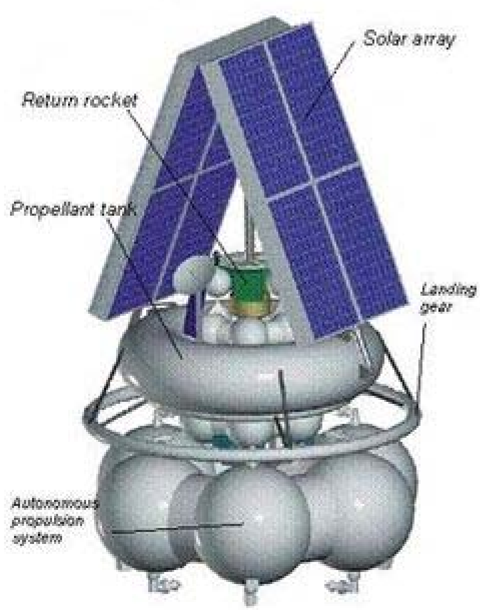
Current prospective landing sites

Name	Location	Elevation
Eberswalde Crater Delta	23.86°S, 326.73°E	−1450 m
Holden Crater Fan	26.37°S, 325.10°E	−1940 m
Gale Crater	4.49°S, 137.42°E	−4451 m
Mawrth Vallis Site 2	24.01°N, 341.03°E	−2246 m

Chapter- 2

Fobos-Grunt

Fobos-Grunt



Operator	Russian Federal Space Agency
Mission type	Orbiter, lander, sample return
Flyby of	**Phobos**
Satellite of	**Mars**
Launch date	November 2011
Launch vehicle	Zenit rocket

Mission duration	Three years
Mass	11,100 kg with fuel

Fobos-Grunt (Russian: **Фобос-Грунт** meaning "Phobos Ground") is a planned Russian sample return mission to Phobos, one of the moons of Mars. The Chinese Mars orbiter Yinghuo-1 will be sent together with the mission. Scheduled for launch late 2011 or early 2012, Fobos-Grunt will be the first Russian interplanetary mission since the failed *Mars 96* mission. If successful, this will be the first macroscopic extraterrestrial sample from a planetary body brought back to Earth since the last sample return mission by Luna 24 in 1976. (The Japanese Hayabusa probe has returned with a sample from 25143 Itokawa in June 2010, but the sample only consisted of some particles of dust.)

Overview

Fobos-Grunt is an unmanned lander that will study Phobos and then return a soil sample to Earth. It will also study Mars from orbit, including its atmosphere and dust storms, plasma and radiation. It is currently scheduled to be launched in November 2011 on a Zenit rocket launcher with a Fregat upper stage. The return vehicle is scheduled back to Earth on August 2014.

The Mission Control Center will be in the Center for Deep Space Communications (Yevpatoria RT-70 radio telescope), near Yevpatoria in Ukraine.

Schedule

The mission was originally scheduled for launch in October 2009. During the year, officials admitted that the schedule was very tight, but still hoped until the last moment that a launch could be made. On 21 September, it was officially announced that the mission would be delayed to the next launch window in 2011.

Mission objectives and studies

- Collect soil samples from Phobos and return them to Earth for scientific research on Phobos, Mars, and Martian space.
- In situ and remote studies of Phobos (to include analysis of soil samples)
- Monitoring the atmospheric behavior of Mars, including the dynamics of dust storms
- Studies of the vicinity of Mars, to include its radiation environment and plasma and dust
- Study of the origin of the Martian satellites and their relation to Mars
- Study of the role played by asteroid impacts in the formation of terrestrial planets
- Search for possible past or present life

- Sending select extremophile microorganisms on a three-year interplanetary round-trip in a small sealed capsule (LIFE experiment).

Mission description

The spacecraft's journey to Mars is scheduled to take about ten months. It will then spend several months studying the planet and its moons from orbit, before landing on Phobos. The current timeline is for arrival in October 2012 and landing in February 2013.

The soil sample collection will begin immediately after the lander has touched down on Phobos. Normal collection will last 2–7 days. An emergency mode exists for the case of communications breakdown, which enables the lander to automatically launch the return rocket to deliver the samples to Earth. The samples, which can be up to 0.5 inches (1.3 cm) in diameter, will be collected by a robotic arm. At the end of the arm, there is a pipe-shaped tool which splits to form a claw. The tool contains a piston which will push the sample into a cylindrical container. A light-sensitive photo-diode will confirm whether material collection was successful and will also allow visual inspection of the digging area. The sample extraction device should perform 15 to 20 scoops yielding a total of 3 to 5.5 ounces (85 to 160 g) of soil.

The return rocket is situated on top of the lander. It will need to accelerate to 35 km/h (22 mph) to escape Phobos' gravity. In order to avoid harming the experiments remaining at the lander, the return vehicle will only ignite its engine once the vehicle has been vaulted to a safe height by springs. It will then begin maneuvers for the eventual trip to Earth, where it is expected to arrive in August 2014.

After the departure of the return vehicle, the lander's experiments will continue in-situ on Phobos' surface for a year. To conserve power, mission control will turn these on and off in a precise sequence. The robotic arm will place more samples in a chamber that will heat it and analyze its spectra. This analysis might determine the presence of easily vaporized substances, such as water.

The landing site that has been chosen is a region from 5°S to 5°N, 230° to 235°W.

Instruments

- TV system for navigation and guidance
- Gamma ray spectrometer
- Neutron spectrometer
- Alpha X spectrometer
- Mass spectrometer
- Seismometer
- Long-wave radar
- Visual and near-infrared spectrometer
- Dust counter

- Ion spectrometer
- Optical solar sensor

Partners

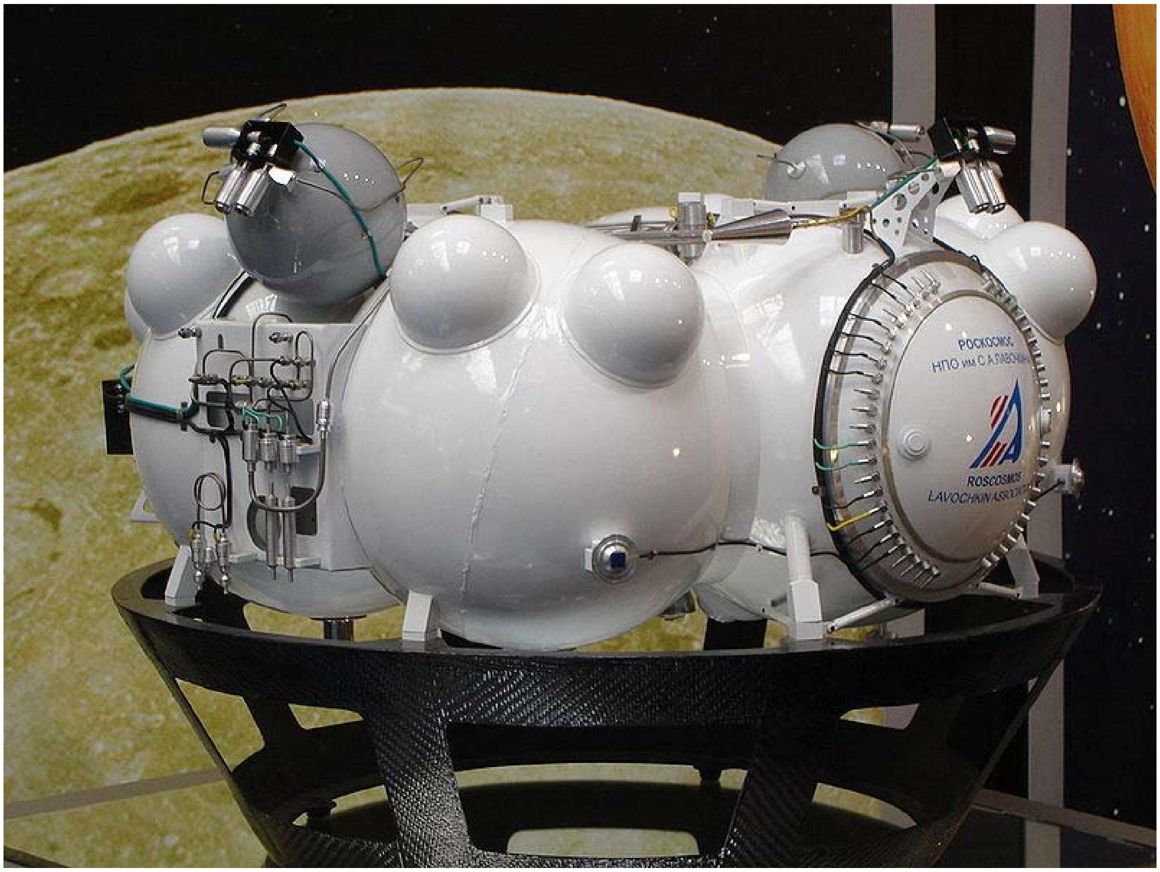
The Chinese Mars probe Yinghuo-1 will be sent together with Fobos-Grunt. In late 2012, after a 10 – 11.5 months cruise, Yinghuo-1 separates and enters a 800 x 80,000 km three day equatorial orbit (5° inclination). The spacecraft is expected to remain on Martian orbit for one year. Yinghuo-1 will focus mainly on the study of the external environment of Mars. Space center researchers will use photographs and data to study the magnetic field of Mars and the interaction between ionospheres, escape particles and solar wind.

A second Chinese payload, the Soil Offloading and Preparation System (SOPSYS), is to be integrated into the instruments of the lander. SOPSYS is a microgravity grinding tool developed by the Hong Kong Polytechnic University.

Another payload on the Fobos-Grunt is an experiment from the Planetary Society called Living Interplanetary Flight Experiment, or LIFE, which will send 10 types of microorganisms and a natural soil colony of microbes on the three-year round trip. The results may fuel the debate about whether meteorite-riding organisms can spread life throughout the solar system.

Furthermore, two MetNet Mars landers, developed by the Finnish Meteorological Institute, are planned to be included as a payload to the Fobos-Grunt mission. Due to delays in MetNet development, the landers were not ready for the previous launch date of Fobos-Grunt, 2009. However, since Fobos-Grunt was delayed to 2011, MetNet is expected to be included.

Development



Model of the cruise-stage spacecraft bus that will carry the lander to Phobos

The space mission component development is led by the company NPO Lavochkin. Phobos soil sampling and downloading have been assigned to the GEOHI RAN Institute of the Russian Academy of Science (Vernadski Institute of Geochemistry and Analytical chemistry) and the integrated scientific studies of Phobos and Mars by remote and contact methods are being developed by the Russian Space Research Institute.

Development started in 2001 and the preliminary design was completed in 2004. The cost of the spacecraft is 1.5 billion rubles ($64.4 million). Total project funding for the timeframe 2009-2012 is about 2.4 billion rubles. If successful, Fobos-Grunt could pave way to a number of Russian interplanetary missions, including missions to the moons of Jupiter, Saturn and Uranus, and asteroid and comet sample return missions.

ESA's info page on the mission from 2004 states, that the mission may be propelled by controllable electric jet propulsion due to its capability for smooth changing of the propulsion output parameters along the flight trajectory.

Criticism

Barry E. DiGregorio, the director of the International Committee Against Mars Sample Return, citicised the LIFE experiment on the Fobos-Grunt mission as a violation of the Outer Space Treaty of 1967 due to its risk of contaminating Phobos or Mars with the microbial spores and live bacteria it contains. While the mission lands and returns from Phobos, a moon of Mars, the risk to Mars itself is from the possibility of Fobos-Grunt losing control and crash landing on the planet. It is speculated that the heat-resistant extremophile bacteria would be particularly able to survive such a crash, on the basis that heat resistant bacteria Microbispora survived the Space Shuttle Columbia disaster.

Chapter- 3

Yinghuo 1 & MetNet

Yinghuo 1

Yinghuo 1（YH-1） 萤火一号 Mars 1 or Firefly 1	
Operator	CNSA
Mission type	Orbiter
Satellite of	**Mars**
Launch date	2011
Launch vehicle	Zenit rocket
Mission duration	1 year in Mars orbit
Mass	110 kg
Orbital elements	
Inclination	5°
Apoapsis	800 km
Periapsis	80,000 km
Orbital period	3 days

Yinghuo 1 is a joint Russian-Chinese Mars-exploration space probe scheduled for launch in 2013. On March 26, 2007, the director of the China National Space Administration,

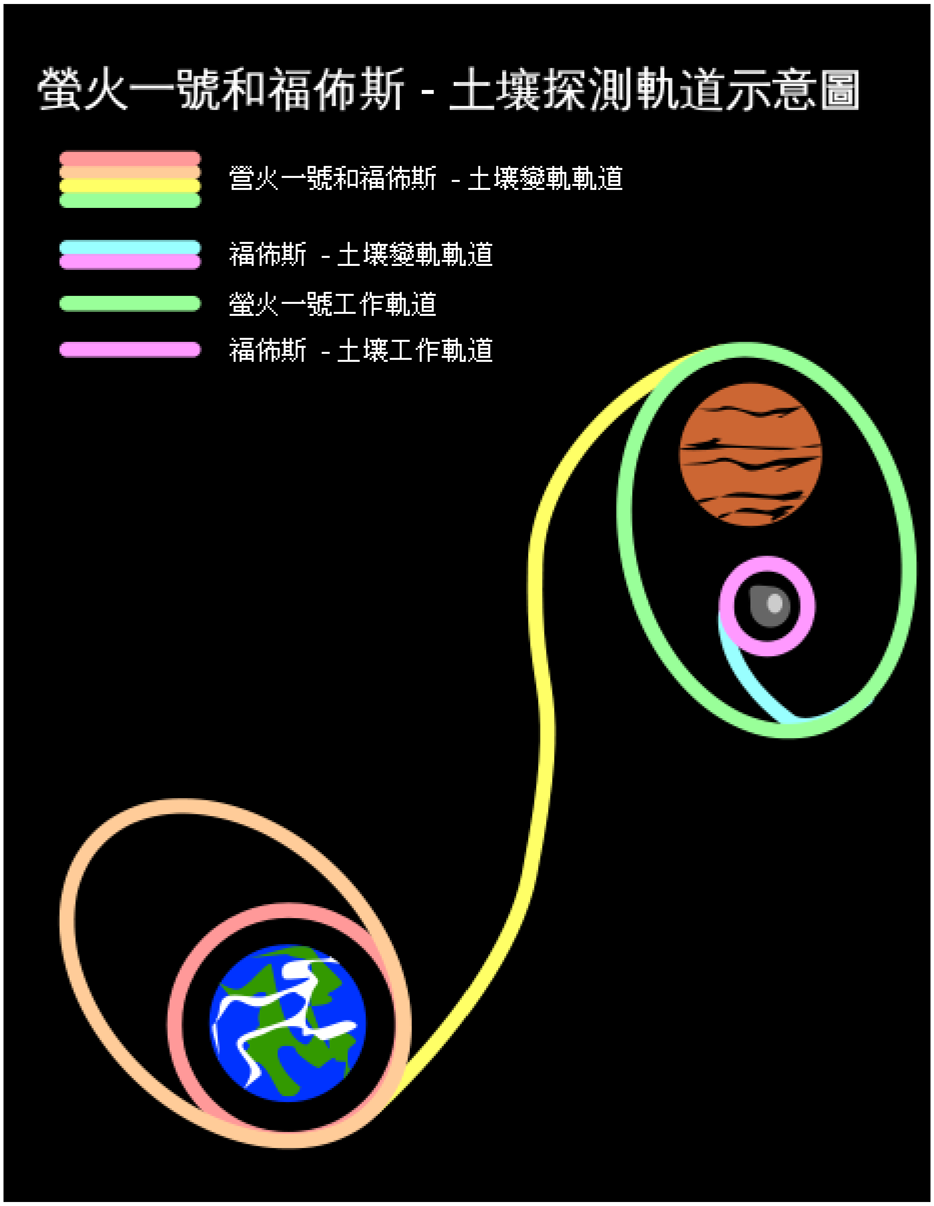
Sun Laiyan, and the head of the Russian Space Agency, Anatoly Perminov signed the "Cooperative Agreement between the China National Space Administration and the Russian Space Agency on joint Chinese-Russian exploration of Mars", one facet of which is the construction of the Yinghuo probe. The probe will be 75 cm long, 75 cm wide and 60 cm high. Weighing 110 kg, it is designed for a two-year mission, according to Chen Changya, a researcher at the Shanghai Institute of Satellite Engineering.

The name *Yinghuo* (simplified Chinese: 萤火; traditional Chinese: 螢火; pinyin: *yínghuǒ*), which means "firefly" (literally "luminous fire"), is a tribute to the homophone *yinghuo* (simplified Chinese: 荧惑; traditional Chinese: 熒惑; pinyin: *yínghuò*), an ancient Chinese name for Mars (literally "shimmering bewilderment").

China's Yinghuo 1 and the Russian **Phobos-Grunt** spacecraft was to be sent together to Mars by a Russian Zenit rocket with a Fregat upper stage from Baikonur Cosmodrome on 6 to 16 October 2009. Originally, in August–September 2010, after a voyage lasting between 10 and 11.5 months, Yinghuo 1 was to have separated and entered an 800 × 80,000 km three-day equatorial orbit at 5° inclination. The spacecraft is expected to remain in Martian orbit for one year. Phobos-Grunt and Yinghuo 1 will conduct Mars ionosphere occultation experiments. The probe will experience seven periods of 8.8 hours in darkness while the sun is obscured by the red planet.

The main scientific objectives include: (1) detailed investigation of the plasma environment and magnetic field; (2) study of Martian ion escape processes and possible mechanisms; (3) ionosphere occultation measurements between Yinghou 1 and Phobos-Grunt, focusing on the sub-solar and midnight regions; and (4) observation of sand storms.

The scientific payload consists of a five-instrument payload including a plasma package (consisting of an electron analyzer and an ion analyzer and mass spectrometer), fluxgate magnetometer, radio-occultation sounder and an optical imager camera with 200 m resolution at best to take pictures of Mars.



Zenit 2 Rocket pathway for Yinghuo-1

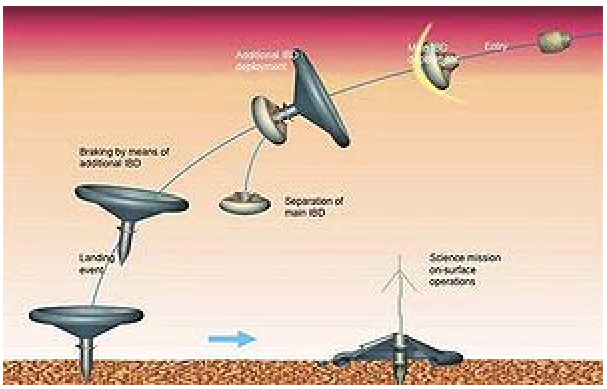
Design

- 110 kg
- Power: 90 W (averaged), 180 W (peak)
- HGA 950 mm antenna dish (S-band), 12 W transmitter in two frequencies (8.4 and 7.17 GHz), data rate between 8 bps and 16 kbps
- LGA: 80 bit/s (up/down link),
- 2×3 section solar array, total length 5.6 m
- 3-axis stabilized, solar array perpendicular to the Sun

- Direct communication with Earth - use of ESA and Russian deep space antennae, use of VLBI for localization
- Two imaging cameras (square 20 degree and 38 degree fields)

MetNet

MetNet



Operator	Finnish Meteorological Institute
Mission type	Multi-lander network
Launch date	2011-2019
Launch vehicle	Zenit launch vehicle / Volna

MetNet is an atmospheric science mission to Mars, initiated and defined by the Finnish Meteorological Institute. The mission includes sending several tens of MetNet landers on the Martian surface. The objective is to establish a widespread surface observation network on Mars to investigate the planet's atmospheric structure, physics and meteorology.

Concept and goals

The fact that both meteorology in particular and climatology in general vary both temporally and spatially means that the most effective means of monitoring these is to make simultaneous measurements at multiple locations and over a sufficiently long period of time. Bearing this in mind, MetNet includes both a global-scale, multi-point network of surface probes supplemented by a supporting satellite in orbit, for a projected duration of two Martian years. Somewhere in the range of ten to twenty observation points is seen as a minimum to get a good picture of atmospheric phenomena on a planet-wide scale.

Lander concept

The MetNet Lander vehicle will use inflatable entry and descent systems instead of rigid heat shields and parachutes as earlier semi-hard landing devices have used. This way the ratio of the payload mass to the overall mass is optimized, and more mass and volume resources are spared for the science payload. The MetNet Lander's atmospheric descent process can be partitioned into two phases: the primary aerodynamic or the Inflatable Braking Unit deceleration phase and the secondary aerodynamic or the Additional Inflatable Braking Unit deceleration phase. The operational lifetime of a lander on the Martian surface will be seven years.

Status

The descent vehicle has been fully qualified for Martian environment. Development of a precursory mission is under way and its launch is planned for 2011. The precursory mission will consist of one lander and is intended as a technology and science demonstration mission. More landers will be deployed in the following launch windows extending up to 2019.

Precursory mission

The Precursory Mission plans to send one or two MetNet demonstration landers to Mars in 2012. Two delivery concepts were being considered:

1. Piggyback delivery attached to the Russian Phobos Grunt Sample Return mission.
2. Dedicated launch using the Russian Volna — a converted Submarine/Sea-Launched Ballistic Missile (SLBM).

The FMI announced it would launch the demonstration lander onboard the Phobos Grunt mission on 2012.

The key contribution of the precursory mission is:

- Availability of new and high-quality resolution atmospheric vertical structures as well as long-duration (of the order of a Martian year) in situ meteorological and imaging observations at a single or few landing site(s)
- Demonstrated feasibility of the lander concept for a meteorological network mission.

Development

MetNet is a "successor" of the NetLander Mission's atmospheric leg. It is also continuance of the Russian Mars 96 mission. MetNet development has been going on since 2001.

MetNet is being developed by a consortium consisting of the Finnish Meteorological Institute (Mission Lead), Babakin Space Center (Systems Lead) and Russian Space Research Institute (Payload Lead, in cooperation with the FMI).

Chapter- 4

Northern Light (Spacecraft)

Northern Light

Northern Light Lander on Mars
(artist's impression)

Operator	Northern Light Consortium
Major contractors	Thoth Technology Inc.
Mission type	Lander and rover
Launch date	early 2012
Homepage	marsrocks.ca
Mass	6 kg rover; 35 kg lander
Power	Solar power

Northern Light is a proposed unmanned mission to Mars that would consist of a lander and a rover, being planned by a consortium of Canadian universities, companies and organisations. If enough private investment goals are reached, the mission could land as early as 2012. The primary contractor for the spacecraft is Thoth Technology Inc., based in Kettleby, Ontario.

The spacecraft consists of four parts: An apogee kick engine provides orbital injection for a cruise vehicle that carries the Northern Light lander and the Beaver Rover to a direct rendezvous with Mars using a Hohmann transfer orbit. Atmospheric entry is achieved by a heat shield, parachute and airbag deployment system. The descent system avoids recoil in order to enable Northern Light to be targeted at a specific landing site. The lander will transfer the rover to the Martian surface. Once deployed on the Martian surface, the lander contacts Earth directly utilizing the 46m parabolic antenna located at the Algonquin Radio Observatory.

The Beaver Rover is designed to have a maximum range of 1000 metres (0.62 mile) from the landing site. It operates under its own power utilizing tools and sensors to investigate surface rocks that may contain the presence of photosynthetic life.

History

The project got started officially on 2001, and its project leader is Ben Quine, from York University, Canada. York University has enjoyed a strong participation in the Canadian Space Program and has designed several space research instruments and applications currently used by NASA, including the meteorological station on board the Phoenix Mars lander.

Partners in this Mars project are York University, University of Alberta, University of Toronto, University of Waterloo, University of Winnipeg, University of Western Ontario, University of Saskatchewan, University of New Brunswick, McGill University and Simon Fraser University. The mission control for the period after it lands on Mars, would be headquartered at York University.

Much of the hardware is based on the British Beagle 2 lander. The cost will be an estimated $20 million dollars, or possibly less if another country shares the rocket. So far, the Canadian Space Agency confirmed it knows of the project, but has no involvement in it.

Scientific goals

There are four primary goals for the mission:

1. Search for life on Mars.
2. Search for water on Mars.
3. Investigate Martian electromagnetic radiation environment and atmospheric properties.
4. Prepare for the international effort of a Mars sample return mission and a manned mission to Mars.

Payload of the Beaver Rover

The rover system is required for geological surface exploration and for subsurface imaging. With a mass of approximately 6 kg (13.2 lb), the rover will operate under its own power and will have a range of roughly 1 km (0.62 mile). The rover will be equipped with a visible camera for manoeuvering and surface exploration, as well as a Point Spectrometer and microscope camera for geological survey. A ground-penetrating radar will explore the Martian subsurface and will look for water; an active vibrator and receiver will use short, sub-millisecond pulses to conduct an acoustic study of the subsurface. For immediate subsurface exploration, the rover will be equipped with a rock grinding tool.

MASSur Seismic Sensor

The MASSur Seismic Sensor, developed by the University of Calgary and GENNIX Technology Corporation, will provide depth profiles of the Martian surface. Specifically, a seismometer will conduct tests to determine the rigidity and elasticity of the Martian topsoil as well as its rock properties. Sediments, permafrost, and water may all have distinct signatures. This seismic system will use a vibrational source and elastic-wave receivers (accelerometers) on both the lander and on the Beaver Rover. The redundancy of lander and rover appartus, ensures that some primary science objectives can be met without rover deployment.

Ground Penetrating Radar

The Ground-Penetrating Radar (GPR) will utilize a 200 MHz radar to provide fine-scale, sub-surface imaging to a depth of 20 m (65 ft) on loose aggregate and up to 100 m (328 ft) on permafrost or ice. It shares several systems with the seismic instruments.

TC Corer

The corer will be capable of drilling up to 10 mm into surface rocks. This tool is used in conjunction with the Aurora spectrometer and microscope to examine the near-surface composition and to look for biosignatures of near-surface life. The core is contributed to the mission from Hong Kong. The flight model instrument has a mass of 350g.

Payload of the Northern Light Lander

Aurora Spectrometer

The spectrometer has a wavelength coverage of 625 nm to 2500 nm and observes the whole sky. The instrument will measure variations in spectral irradiance which can be utilized to determine aerosol and atmospheric composition including the concentration of carbon dioxide, the major constituent of the Martian atmosphere. It will also carry out angular dependency of radiation influx in the atmosphere. The Aurora instrument has a mass of 450g.

Argus 4000 Spectrometer

Similar in design to the Argus 1000 spectrometer, flown on CanX-2, the radiometer will be the primary equipment of the Northern Light lander making measurements of spectral rock reflectance. The spectrometer has a mass of 240g.

Camera systems

The camera systems on the lander will have the capability of narrow and wide field surveys. The narrow field survey will provide a very high resolution, panoramic view of the landing site. Colour filters will perform some spectral mapping and mineral identification of the surrounding soil; the camera will also perform limited atmospheric and astronomical observations. Colour images of Earth will be obtained.

The wide field survey will provide an overall colour view of the lander's surroundings to help rover deployment and route planning.

MASSur Seismic Sensors

Similar specifications as those on the Beaver Rover.

Environmental sensors

Environmental sensors will monitor environmental conditions at the landing site. Various equipment will measure UV rays, oxidising substances, air pressure, air temperature, dust impact, wind velocity, and ground vibration. These sensors will have a combined mass of 130 g. Flight models were previously developed for Britain's Beagle 2 lander.

Launch

If investment targets are met, launch of the Northern Light could be as early as 2012. The main driving factor is the cost of the spacecraft launch; launchers are extremely expensive to build and use. The launcher type has not yet been confirmed.

Tracking

The entry system will be tracked and targeted utilizing a combination of Doppler radar and very long baseline interferometry. This data is processed by a high-resolution orbital model that utilizes high-precision ephemeris to predict spacecraft location and trajectory.

Upon launch, tracking will commence at the Algonquin Radio Observatory. After orbital injection, the spacecraft will be contacted periodically to obtain system status and to determine trajectory. As the package reaches the Matrian thermosphere continuous tracking will commence in order to verify mechanism deployment during descent.

Landing site

Details of the intended landing site have not yet been released. Given the purpose of the equipment aboard the spacecraft, the landing site will more than likely be a dry 'sea', within 5 km of a basin formation. The purported area will serve as both a palaeontogical exploration site, as well as a potential area where ice or liquid water could be found.

Chapter- 5

MAVEN (Spacecraft)

Mars Atmosphere and Volatile EvolutioN (MAVEN)

Artist's Concept of MAVEN. Credit: NASA.

Operator	NASA
Major contractors	Lockheed Martin Space Systems, University of Colorado at Boulder, University of California, Berkeley, Goddard Space Flight Center
Mission type	Orbiter
Satellite of	Mars
Launch date	Launch window between November 18, 2013 and December 7, 2013
Launch vehicle	Atlas V 401

Mission duration	2 years
	Orbital elements
Inclination	75º
Periapsis	150 km
Orbital period	4.5 hours

Mars Atmosphere and Volatile EvolutioN (**MAVEN**) is a space exploration mission to send a space probe to orbit Mars as part of NASA's Mars Scout Program. Scientists conducting the mission will study the atmosphere of Mars. The principal investigator for MAVEN is Bruce Jakosky of the Laboratory for Atmospheric and Space Physics at the University of Colorado at Boulder.

Program overview

On September 15, 2008 NASA announced that it had selected MAVEN to be the Mars Scout 2013 mission, a part of the Mars Scout Program. There was one other finalist and eight other proposals that were competing against MAVEN to be the Mars Scout 2013 mission. MAVEN will be launched in late 2013 and is planned to enter Mars orbit during the fall of 2014. MAVEN will enter into an elliptic orbit 90 to 3,870 miles above the planet's surface. MAVEN will cost US$485 million.

MAVEN will have four primary scientific objectives:

1. Determine the role that loss of volatiles to space from the Mars atmosphere has played through time.
2. Determine the current state of the upper atmosphere, ionosphere, and interactions with the solar wind.
3. Determine the current rates of escape of neutral gases and ions to space and the processes controlling them.
4. Determine the ratios of stable isotopes in the Martian atmosphere.

MAVEN's measurements will provide additional scientific context with which to test models for current methane formation in Mars. NASA will launch MAVEN using an Atlas V 401. The launch window is between November 18, 2013 and December 7, 2013. Assuming a November 18 launch, MAVEN will be inserted into Mars orbit on September 16, 2014.

Hardware overview

MAVEN's design will be based on those of the Mars Reconnaissance Orbiter and Mars Odyssey spacecraft.

Scientific instruments

MAVEN will study Mars' upper atmosphere and how it interacts with the Sun. It will carry instruments to measure characteristics of Mars' atmospheric gases, upper atmosphere, solar wind, and ionosphere. University of Colorado at Boulder, University of California, Berkeley and Goddard Space Flight Center will each build a suite of instruments to fly on the spacecraft.

The instrument suites will include:

Particles and Field (P&F) Package

Built by the University of California.

- Solar Wind Electron Analyzer (SWEA)-Measures solar wind and ionospheric electrons
- Solar Wind Ion Analyzer (SWIA)-Measures solar wind and magnetosheath ion density and velocity
- Suprathermal and Thermal Ion Composition (STATIC)-Measures thermal ions to moderate-energy escaping ions
- Solar Energetic Particle (SEP)-Determines the impact of SEPs on the upper atmosphere
- Langmuir Probe and Waves (LPW)-Determines ionospheric properties and wave heating of escaping ions and solar EUV input to atmosphere
- Magnetometer (MAG)-Measures interplanetary solar wind and ionospheric magnetic fields

Remote Sensing (RS) Package

Built by the University of Colorado.

- Imaging Ultraviolet Spectrometer (IUVS)-Measures global characteristics of the upper atmosphere and ionosphere

Neutral Gas and Ion Mass Spectrometer (NGIMS) Package

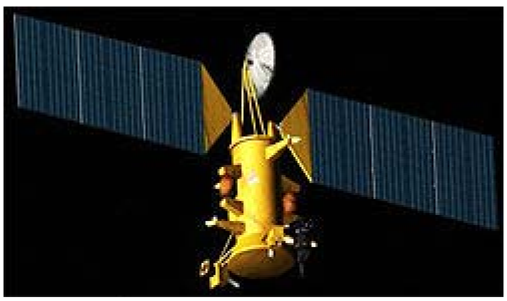
Built by Goddard Space Flight Center

- To measure the composition and isotopes of neutral gases and ions

Chapter- 6

Mars Trace Gas Mission

Mars Trace Gas Mission



Trace Gas Orbiter

Operator	NASA and ESA
Mission type	Orbiter/carrier
Satellite of	Mars
Launch date	January 2016
Launch vehicle	Atlas V 421 rocket
Mass	3130 kg
Power	Photovoltaic array (140 W)
	Orbital elements
Apoapsis	400 km near-circular altitude

The **Mars Trace Gas Mission (TGM)**, previously called **2016 Mars Science Orbiter (MSO)**, is the name for a flexible collaborative proposal within NASA and ESA to send a new orbiter-carrier to Mars in 2016 as part of the European-led ExoMars mission.

This orbiter would deliver the ExoMars static lander and then proceed to map the sources of methane on Mars and other gases, and in doing so, help select the landing site for the ExoMars rover to be launched on 2018.

Joint mission with ExoMars

Previously, the 2016 'Mars Science Orbiter' was envisioned as an all NASA endeavor. However, following the Mars Joint Exploration Initiative, it was agreed that the European-lead orbiter would carry several instruments originally meant for the Mars Science Orbiter, so the Mars Science Orbiter team was asked by NASA to consider scaling down the objectives and focus on atmosphere trace gases detection instruments for their incorporation in ESA's TGM orbiter.

The Mars Trace Gas Mission (TGM) orbiter is proposed to be launched in 2016 and it would carry instruments from both ESA and NASA. If launched, it would be the successor to the Mars Reconnaissance Orbiter, which may still be operational at that time. The TGM orbiter would be launched as part of the ExoMars program in 2016 together with a static lander built by the European Space Agency.

Under the collaboration proposal, the European ExoMars mission would be split into two parts: an orbiter/lander mission in 2016 that would include the TGM orbiter and a static lander build by ESA; this would be followed by the ExoMars rover mission in 2018 — also to be launched with an Atlas V rocket. This joint ESA-NASA mission could help settle whether the methane source in that planet is of biological or geological origin, and would apparently reconcile technological and science goals with available budgets.

Science

The TGM orbiter would separate from the ExoMars stationary surface lander and provide it with telecommunication relay for 8 sols, then the TGM would aerobrake into a more circular orbit for science observations and would provide communications relay for the ExoMars rover and the Mars Astrobiology Explorer-Cacher rover to be launched in 2018, and would continue serving as a relay satellite for future landed missions past 2020.

The mission requirements would require of a broad suite of atmospheric trace gases for detection, characterization of their spatial and temporal variation, and localization of sources.

Detection

Nature of the methane source requires measurements of a suite of trace gases in order to characterize potential biochemical and geochemical processes at work. The orbiter would require very high sensitivity to (at least) the following molecules and their isotopomers: Water (H_2O), hydroperoxyl (HO_2), nitrogen dioxide (NO_2), nitrous oxide (N_2O), methane (CH_4), acetylene (C_2H_2), ethylene (C_2H_4), ethane (C_2H_6), formaldehyde (H_2CO), hydrogen cyanide (HCN), hydrogen sulfide (H_2S), carbonyl sulfide (OCS), sulfur dioxide (SO_2), hydrogen chloride (HCl), carbon monoxide (CO) and ozone (O_3). Detection sensitivities would be of 1-10 parts per trillion.

Characterization

- Spatial and temporal variability: Latitude-longitude coverage multiple times in a Mars year to determine regional sources and seasonal variations (reported to be large, but still controversial with present understanding of Mars gas-phase photochemistry.)
- Correlation of concentration observations with environmental parameters of temperature, dust and ice aerosols (potential sites for heterogeneous chemistry.)

Localization

- Mapping of multiple tracers (e.g., aerosols, water vapor, CO, CH_4) with different photochemical lifetimes and correlations helps constrain model simulations and points to source/sink regions.
- To achieve the spatial resolution required to localize sources might require tracing molecules at the ~1 part per billion concentration.

Instrumentation

The two space agencies issued on January 18, 2010 an Announcement of Opportunity inviting scientists to propose instruments to be carried on the mission. Once the proposals have been evaluated, the winning teams will build the actual hardware. Like Mars Reconnaisance Orbiter, the Trace Gas Mission (TGM) orbiter would be a hybrid science-telecom orbiter. Its maximum science payload mass is projected to be about 115 kg. Some of the instruments expected to be carried on board the orbiter are:

- TG-D: Trace Gas Detector (solar occultation; high spectral resolution across broad spectral interval; high data rate)
- FTIR: Fourier Transform IR Spectrometer
- TG-M: Trace Gas Mapper (moderate spectral resolution across selectable spectral intervals; might combine nadir, limb and/or occultation viewing)
- TIR: Thermal Infrared Imager (views atmospheric thermal emission sensitive to presence of dust)
- Sub-mm: Sub-millimeter/microwave spectrometer or equivalent (views atmospheric thermal emission -passive sounder not affected by presence of dust)
- WAC: Wide Angle Camera (provides frequent/global views of atmospheric phenomena and surface change)
- HiSCI: High Resolution Stereo Color Imager (~2 m/pixel, near simultaneous stereo, 4-colors for discrimination of water ice, dust and basic rock types)

Relay telecommunications

Due to the challenges of entry, descent, and landing, Mars landers are highly constrained in mass, volume, and power. For landed missions, this places severe constraints on antenna size and transmission power, which in turn greatly reduce direct-to-Earth communication capability in comparison to orbital spacecraft. As an example, the capability downlinks on Spirit and Opportunity have only 1/600th the capability of the Mars Reconnaisance Orbiter downlink. Relay communication addresses this problem by allowing Mars surface spacecraft to communicate using higher data rates over short-range links to nearby Mars orbiters, while the orbiter takes on the task of communicating over the long-distance link back to Earth. This relay strategy offers a variety of key benefits to Mars landers: increased data return volume, reduced energy requirements, reduced communications system mass, increased communications opportunities, robust critical event communications and *in situ* navigation aide.

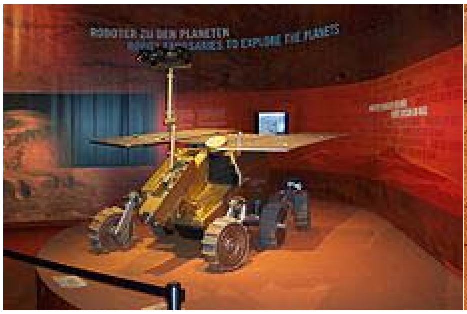
Chapter- 7

ExoMars

ExoMars	
Operator	ESA, NASA
Major contractors	Thales Alenia Space
Mission type	Orbiter, lander and 2 rovers
Orbital insertion date	2017 and 2019
Launch date	2016 and 2018 from Florida, USA
Launch vehicle	Two Atlas V rockets.
Mission duration	Few days for the static lander; 6 months for the ExoMars rover, one year for the MAX-C rover.
Homepage	ExoMars programme
Mass	TGM: 3,130 kg; Lander: 600 kg; ExoMars rover: 270 kg; MAX-C rover: 65 kg.
Power	Solar power

ExoMars (**Exo**biology on **Mars**) is a European-led robotic mission to Mars currently under development by the European Space Agency (ESA) and NASA. Originally conceived as a rover with a static ground station, ExoMars was planned to launch in 2011 aboard a Soyuz Fregat rocket. Within the framework of the new Mars Joint Exploration Initiative signed by NASA and ESA in July 2009, the drastically delayed ExoMars mission was combined with other projects to a multi-spacecraft programme divided over two Atlas V-launches: the Mars Trace Gas Orbiter (TGM) was merged into the project, piggybacking a static meteorological lander being slated for launch in 2016. In 2018 the original robotic ESA rover will be launched together with a smaller NASA rover called Mars Astrobiology Explorer-Cacher (MAX-C).

Background and mission history



An outdated ExoMars rover model at the ILA 2006 in Berlin

Another outdated representation of the rover from the Paris Air Show 2007

Since its beginnings in the early 2000s, ExoMars was subject to massive political and financial strife. Originally, the ExoMars concept consisted of one single, large robotic rover being part of ESA's Aurora programme as a *Flagship mission* and was approved by Europe's space ministers in December 2005. Initially planned to launch in 2011, Italy, a leading nation on the ExoMars mission, decided to limit its financial contribution, causing the first of three delays.

In 2007 Canadian-based technology firm MacDonald, Dettwiler and Associates Ltd. (MDA) was selected for a one-million-euro contract with EADS Astrium of Britain to design and build a prototype Mars rover chassis for the European Space Agency. Astrium was also contracted to design the final rover.

In July 2009 NASA and ESA signed the Mars Joint Exploration Initiative, which significantly altered the technical and financial setting of the ExoMars mission. On June 19, when the rover was still planned to piggyback on the Mars Trace Gas Orbiter, it was reported that a prospective agreement would require that ExoMars lose enough weight to fit aboard the Atlas vehicle with NASA's orbiter.

In August 2009 it was announced that the Russian Space Agency Roscosmos and ESA had signed a collaboration agreement that includes cooperation on two Mars exploration projects: Russia's Phobos-Grunt project and ESA's ExoMars. Specifically, ESA secured a Russian Proton rocket as a backup launcher for the ExoMars rover, which should also include Russian-made parts.

In October 2009 it was reported that under the agreed Mars Joint Exploration Initiative, the project will consist on two separate launches: a lander/orbiter mission in 2016 and a rover mission in 2018, each with a significant NASA role, including the use of two Atlas

V rockets. This initiative would apparently reconcile technological and science goals with available budgets.

On December 17, 2009, the ESA governments gave their final approval to a two-part Mars exploration programme to be conducted with NASA, confirming their commitment to spend €850 million ($1.23 billion) on missions in 2016 and 2018. Another €150 million needed for operating the mission will be solicited during a meeting of ESA government ministers in late 2011 or early 2012. Unlike some ESA programmes, the ExoMars financing will not include a 20 % margin for cost overruns, however.

Mission objectives

The ExoMars mission's scientific objectives, in order of priority, are:

- to search for possible biosignatures of Martian life, past or present.
- to characterise the water and geochemical distribution as a function of depth in the shallow subsurface.
- to study the surface environment and identify hazards to future manned missions to Mars.
- to investigate the planet's subsurface and deep interior to better understand the evolution and habitability of Mars.
- achieve incremental steps ultimately culminating in a sample return flight.

The technological objectives to develop are:

- landing of large payloads on Mars.
- to exploit solar electric power on the surface of Mars.
- to access the subsurface with a drill able to collect samples down to a depth of two metres (just below the degradating reach of UV light, oxidants and ionizing radiation.)
- to develop surface exploration capability using a rover.

Mission architecture

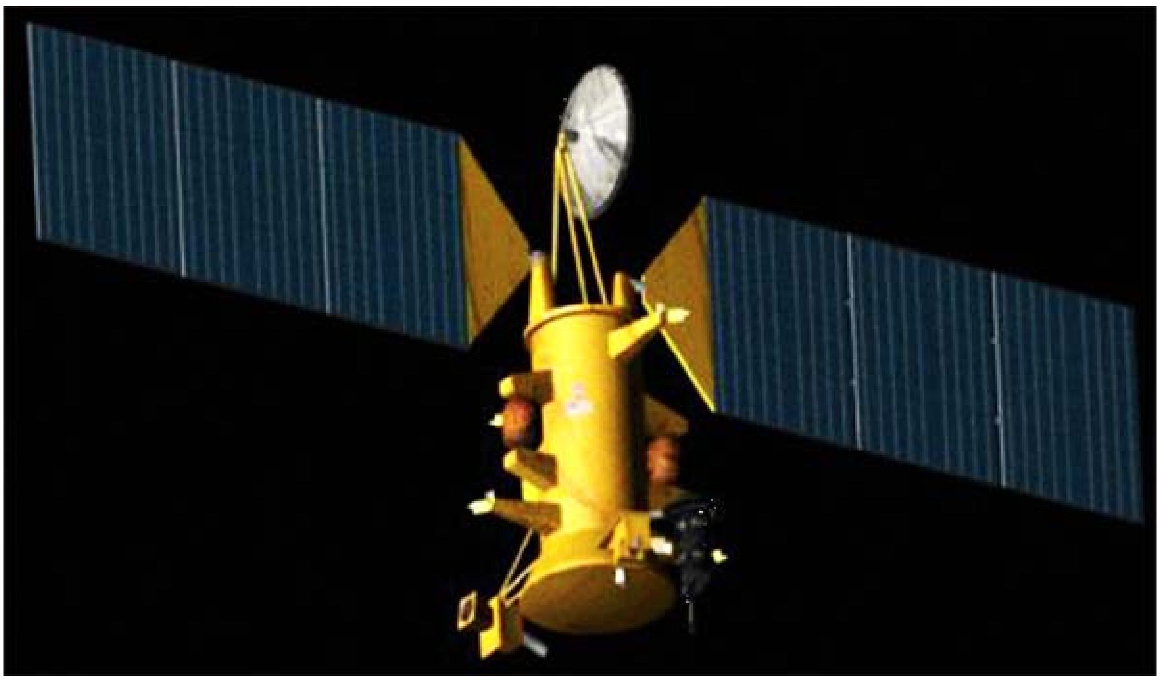
According to current plans, the ExoMars mission will comprise three, possibly four, spacecraft elements sent in two launches, both from Florida:

Contributing agency	First launch in 2016	Second launch in 2018
NASA	Launch vehicle: Atlas V 411	Launch vehicle: Atlas V 551
	One unspecified TGM-payload	Landing system: Sky-crane
		65 kg Mars Astrobiology Explorer-Cacher (Max-C) rover

	Trace Gas Mission (TGM) orbiter	270 kg ExoMars rover
	600 kg static meteorological lander	
	Entry, descent and landing system (EDL)	

2016 launch

Mars Trace Gas Mission orbiter



The Mars Trace Gas Orbiter.

The Mars Trace Gas Mission (TGM) orbiter, to be launched on January 2016, will deliver the ExoMars static lander (a meteorological station) and then proceed to map the sources of methane on Mars and other gases, and in doing so, help select the landing site for the ExoMars rover to be launched on 2018. The presence of methane in Mars' atmosphere is intriguing because its likely origin is either present-day life or geological activity. Upon the arrival of the rover(s) in 2018/2019, the orbiter would be transferred into a suitable lower orbit where it would be able to perform analytical science activities as well as operate as a data-relay satellite. Its operation may be extended to serve future missions well into the 2020s.

Static lander

Originally, this static lander was planned to carry a group of eleven instruments collectively called the "Humboldt payload" that would be dedicated to investigate the geophysics of the deep interior, but a payload confirmation review in the first quarter of 2009 resulted in a severe descope of the lander instruments, and the Humboldt geophysical suite of lander instruments was cancelled entirely. Although the recent partnership with NASA and the decision to launch all mission elements with two rockets has generated new payload reviews, it was decided to first demonstrate ESA's new descent and landing system technology on the lander, so its payload will be very limited.

The Entry, Descent and Landing Demonstrator Module (EDM) will provide Europe with the technology for landing on the surface of Mars with a controlled landing orientation and touchdown velocity. After entering the Martian atmosphere, the module will deploy a parachute and will complete its landing by using a closed-loop Guidance, Navigation and Control system based on a Radar Doppler Altimeter sensor and on-board Inertial Measurement Units. The latter will guide a liquid propulsion system which will produce a semi-soft touchdown on the surface of Mars by the actuation of clusters of thrusters to be operated in pulsed on-off mode.

The EDM lander is expected to survive on the surface of Mars for a short time (about 8 sols) by using the excess energy capacity of its batteries. Its proposed landing site is the Meridiani Planum because it is almost flat and without too many rocks, ideal for its airbag landing system.

2018 launch

Current plans call for the use of NASA's sky crane entry, descent and landing (EDL) system to deliver both rovers together on the surface of Mars.

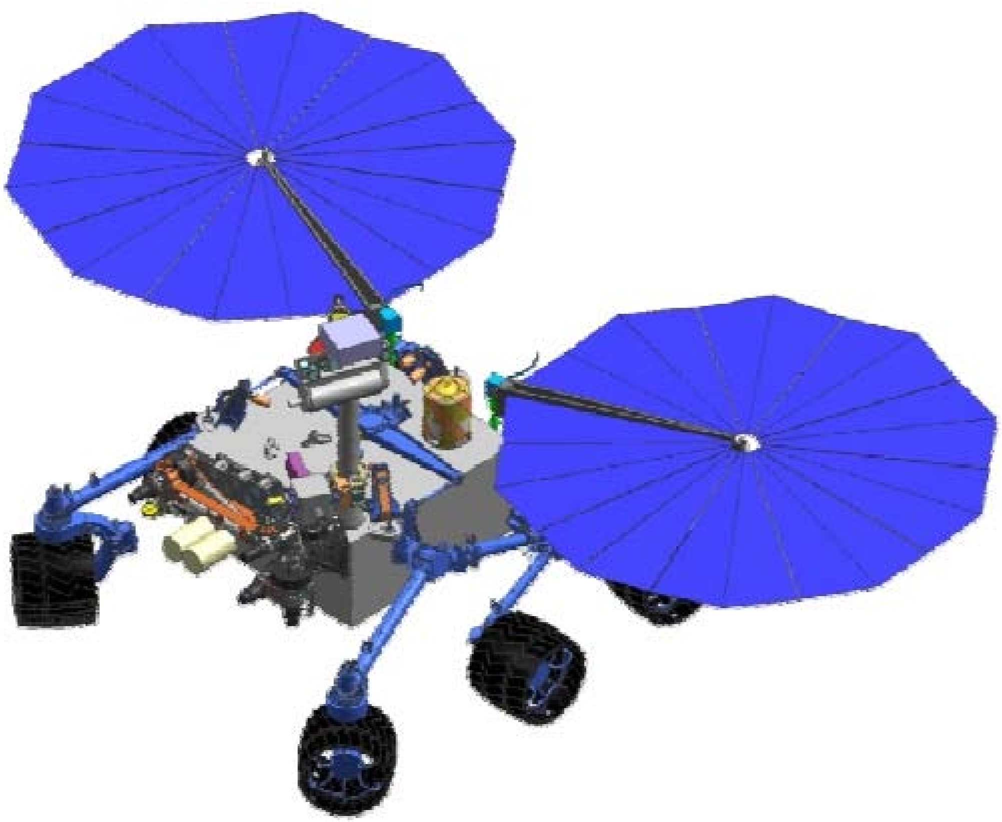
If there will be two rovers delivered to the same location on Mars, Their science objectives and instruments will be complementary in order to minimise duplication. Advantages of operating two rovers in the same area are: rover to rover imaging, cross analysis of similar geological targets, may include a low-frequency ground-penetrating radar on MAX-C and listen with WISDOM on ExoMars to construct rover to rover subsurface transects, and the MAX-C could receive and cache some of the most valuable subsurface samples collected by ExoMars.

ExoMars rover

The ExoMars rover is a highly autonomous six-wheeled terrain vehicle and will weigh 295 kg, ca. 100 kg more than NASA's Mars Exploration Rovers *Spirit* and *Opportunity*. Temporary plans considered a downsized version with a reduced weight of 207 kg. Instrumentation will consist of the 10 kg 'Pasteur Payload' containing, among other instruments, a 2 meter sub-surface drill.

The carrier module will deliver the descent module to Mars from a hyperbolic approach trajectory after which the Sky-crane landing system will ensure a soft landing with high accuracy. Once safely landed on the Martian surface the solar powered rover would begin a 218-sol mission. To counter the difficulty of remote control due to communication lag, ExoMars will have autonomous software for visual terrain navigation using compressed stereo images from mast mounted panoramic and infrared cameras and independent maintenance. For this purpose it creates digital maps from navigation stereo pair cameras and autonomously finds the adequate trajectory. Close-up collision avoidance cameras are used to ensure safety enabling the vehicle to navigate and safely travel approximately 100 meters per day. After the lander has been released and landed on the surface of Mars, the Mars Trace Gas Orbiter will operate as the rover's data-relay satellite.

MAX-C rover



Schematic depiction of the proposed Mars Astrobiology Explorer-Cacher (MAX-C) Rover

The current proposal is that ExoMars will be deployed together with smaller NASA rover, the Mars Astrobiology Explorer-Cacher (MAX-C). The fact that for the first time two rovers will be active at the same location is expected to lead to synergies, such as bistatic radar surveys between the two rovers. The MAX-C rover would collect, analyse, and cache the most valuable samples in a manner suitable for return to Earth by a future mission.

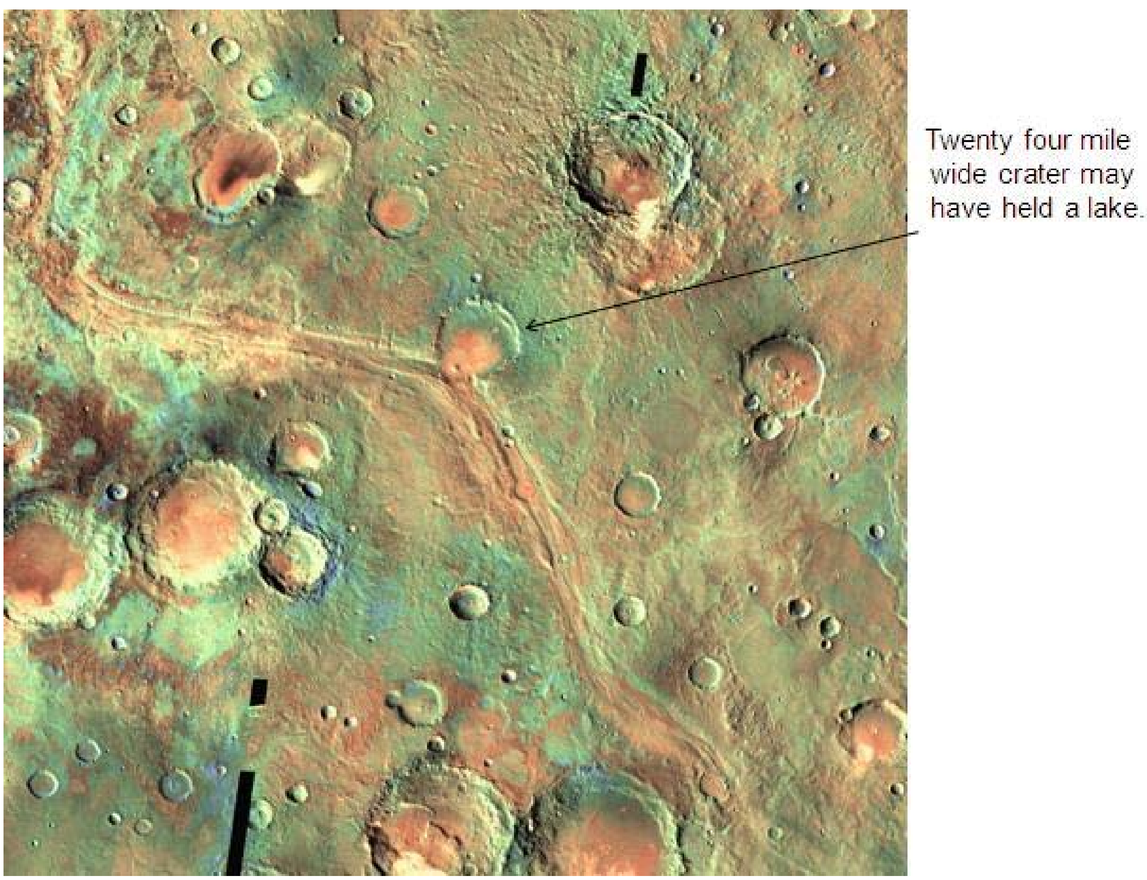
Launch vehicle

Under the agreed collaboration, NASA will provide two Atlas V rockets, as it was decided to divide the weight of the ExoMars system in two launches.

ESA has already worked out a framework agreement with the Russian Space Agency that would allow it to cooperate on ExoMars, including provision of backup launch services and a payload contribution, along with mission support. The backup launcher is the Proton rocket, which is a four-stage rocket that was previously used to launch the Salyut 6, Salyut 7, Mir and some International Space Station components.

Landing system and proposed landing sites

If the collaboration with NASA takes place as proposed, it would be possible to implement NASA's new skycrane entry and descent system to be used on the Mars Science Laboratory rover.



Mawrth Vallis with its potential clues on the history of water on Mars is a landing site-candidate.

As of November 2007, the potential landing sites are:

- Mawrth Vallis
- Nili Fossae
- Meridiani Planum
- Holden Crater
- Gale Crater

However, the 2009 discovery of methane sources on the planet makes them a high value target for exploration. The presence of methane is intriguing because its likely origin is either present-day life or geological activity; confirmation of either would be a major discovery. Methane occurres in extended plumes, and the profiles imply that the methane was released from discrete regions. The profiles suggest that there may be two local source regions, the first centered near 30° N, 260° W and the second near 0°, 310° W. To determine the optimal landing site and secure telecommunications, it was decided to include the Mars Trace Gas Mission orbiter in the 2016 launch in order to map beforehand what appears to be seasonal methane production. The rover could then investigate the methane sources identified by the orbiter.

Instrumentation of the ExoMars rover

The present environment on Mars is exceedingly hostile for the widespread proliferation of surface life: it is too cold and dry and receives large doses of solar UV radiation as well as cosmic radiation. Notwithstanding these hazards, basic microorganisms may still flourish in protected places underground or within rock cracks and inclusions. The science package in the ExoMars rover will hold a variety of instruments to study the environment for past or present habitability and possible biosignatures on Mars. The first instrument proposal (2004) is as follows:

Imaging system

The **Panoramic Camera System (PanCam)** has been designed to perform digital terrain mapping for the rover and to search for morphological signatures of past biological activity preserved on the texture of surface rocks. The PanCam assembly includes two wide angle cameras for multi-spectral stereoscopic panoramic imaging, and a high resolution camera for high-resolution colour imaging. The PanCam will also support the scientific measurements of other instruments by taking high-resolution images of locations that are difficult to access, such as craters or rock walls, and by supporting the selection of the best sites to carry out exobiology studies.

Drill

The ExoMars core drill is devised to acquire soil samples down to a maximum depth of 2 metres, in a variety of soil types. The drill will acquire a core sample (1 cm in diameter x 3 cm in length), extract it and deliver it to the inlet port of the Rover Payload Module, where the sample will be distributed, processed and analyzed. The ExoMars Drill embeds the Mars Multispectral Imager for Subsurface Studies (Ma-Miss) which is a miniaturised IR spectrometer devoted to the borehole exploration. The system will complete experiment cycles and at least 2 vertical surveys down to 2 metres (with four sample acquisitions each). This means that a minimum number of 17 samples shall be acquired and delivered by the drill for subsequent analysis.

Analytical laboratory instruments

These instruments are placed internally and used to study collected samples:

- **Mars Organic Molecule Analyzer** (**MOMA**) consists of a laser desorption ion source and a GC-MS spectrometry. The laser desorption ion source is capable to evaporate organic molecules even if they are not volatile, while the GC separates the highly volatile small molecules within the gas chromatograph. The final analysis of both instruments is done with an ion trap mass spectrometer.

- **Infrared imaging spectrometer** (**MicrOmega-IR**) is an infrared imaging spectrometer that can analyse the powder material derived from crushing samples collected by the drill. Its objective is to study mineral grain assemblages in detail to try to unravel their geological origin, structure, and composition. These data will be vital for interpreting past and present geological processes and environments on Mars. Because MicrOmega-IR is an imaging instrument, it can also be used to identify grains that are particularly interesting, and assigned them as targets for Raman and MOMA-LDMS observations.

- **Mars X-Ray Diffractometer (Mars-XRD)** - Powder diffraction of X-Rays will give exact composition of the crystalline minerals. This instrument includes also an X-ray fluorescence capability that can provide useful atomic composition information.

- **Raman spectrometer (Raman)** will provide geological and mineralogical context information complementary to that obtained by MicrOmega-IR. It is a very useful technique employed to identify mineral phases produced by water-related processes.

- **Ground-penetrating radar**, called **WISDOM** (for Water Ice and Subsurface Deposit Information On Mars) will explore the subsurface of Mars to identify layering and help select interesting buried formations from which to collect samples for analysis. It can transmit and receive signals using two, small Vivaldi-antennas mounted on the aft section of the rover. Electromagnetic waves penetrating into the ground are reflected at places where there is a sudden transition in the electrical parameters of the soil. By studying these reflections it is possible to construct a stratigraphic map of the subsurface and identify underground targets down to 2 to 3 m depth, comparable to the 2-m reach of the rover's drill. These data, combined with those produced by the PanCam and by the analyses carried out on previously collected samples, will be used to support drilling activities.

- **Mars Multispectral Imager for Subsurface Studies** (**Ma-MISS**) is an infrared spectrometer located inside the drill. Ma-MISS will observe the lateral wall of the borehole created by the drill to study the subsurface startigraphy, to understand the distribution and state of water-related minerals, and to characterize the geophysical environment. The analyses of unexposed material by Ma-MISS, together with data obtained with the spectrometers located inside the rover, will be crucial for the unambiguous interpretation of the original conditions of Martian rock formation.

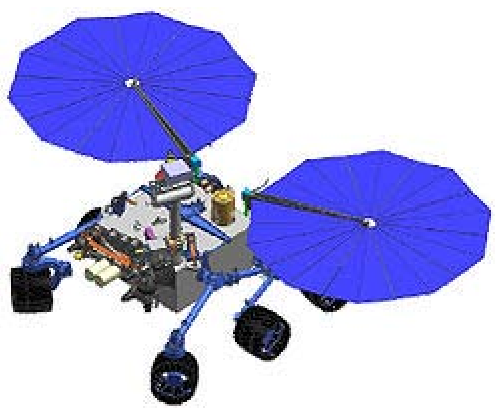
Autonomous navigation

The ExoMars Rover is designed to navigate autonomously across the surface. A pair of stereo cameras allow the Rover to build up a 3D map of the terrain, which the Navigation software then uses to assess terrain around it so that it avoids obstacles and find the most efficient route.

Chapter- 8

Mars Astrobiology Explorer-Cacher

Mars Astrobiology Explorer-Cacher



Operator	NASA
Mission type	Rover
Launch date	2018 from Florida, USA
Launch vehicle	Atlas V rocket
Mission duration	One Earth year.
Mass	65 kg
Power	Solar power

The **Mars Astrobiology Explorer-Cacher (MAX-C)** is a NASA concept for a Mars rover mission proposed to be launched in 2018 together with the European ExoMars rover.

If approved, the rover will be solar powered, with a maximum mass of 65 kg and based largely on Mars Science Laboratory (MSL) components, but would entail a new system design tailored to the specific payload. The MAX-C rover would perform an *in situ* astrobiological exploration, it would evaluate the habitability potential of various Martian environments, and it would collect, document, and cache samples for potential return to Earth by a future mission.

History

The essential energy, water, and nutrient requirements to support and sustain life on Mars are currently present, and the Martian geologic record offers tantalizing clue of many ancient habitable environments. If life emerged and evolved on early Mars then it is possible, and indeed likely, that physical or chemical biosignatures are preserved in the exposed rock record. These discoveries and inferences make a compelling case for a rover mission designed to explore for evidence of past Martian life.

Over most of the last decade, the Mars Exploration Program has pursued a strategy of "follow the water". While this strategy has been highly successful in the Mars missions of 1996-2007, it is increasingly appreciated that assessing the full astrobiological potential of Martian environments requires going beyond the identification of locations where liquid water was present. Thus, in order to seek signs of past or present life on Mars, it is necessary to characterize more comprehensively the macroscopic and microscopic fabric of sedimentary materials. This type of information would be critical to select and cache of relevant samples for addressing the life question in samples intended for study in sophisticated laboratories on Earth.

The possible strategy of using rovers to collect and cache geological samples for possible subsequent return to Earth has been discussed as far back as at least the mid-1990s. In 2007 it was recommended sample caching on all surface missions that follow the Mars Science Laboratory (MSL), in a way that would prepare for a relatively early return of samples to Earth. In mid-2007, NASA directed that a very simple cache be added to the MSL rover and, although they endorsed the potential value of sample caching, experts raised serious concerns regarding sample quality for this specific implementation. In November 2008, the cache was descoped to make room for tools to clean the rover's sample acquisition equipment, which were added due to sample handling problems encountered by the Phoenix lander.

A mid-range rover concept was originally included in the planning work of the Mars Architecture Tiger Team (MATT). By the time of the MATT-3 report in 2009, the potential mission was referred to with several different working names, including both 'Mid-Range Rover' and 'Mars Prospector Rover', and the mission concept was generically envisioned as including a single MER or MSL-class rover with precision landing and sampling/caching capability. To provide a name that fit the mission concept better, it was changed in August 2009 from the generic Mid-Range Rover (MRR) to Mars Astrobiology Explorer-Cacher (MAX-C).

Objectives

The main objective is at a site with high preservation potential for physical and chemical biosignatures, evaluate paleo-environmental conditions, characterize the potential for preservation of biosignatures, and access multiple sequences of geological units in a search for evidence of past life and/or prebiotic chemistry. Samples necessary to achieve the scientific objectives of the proposed future sample return mission would be collected, documented, and packaged in a manner suitable for potential return to Earth.

The primary science objective is to land at a site interpreted to represent high habitability potential, and with high preservation potential for physical and chemical biosignatures:

- Early Noachian astrobiology — Prebiotic environmental context in which life potentially arose.
- Noachian-Hesperian stratigraphy — Whether surface conditions before and after the decline in erosion, aqueous weathering, fluvial activity, and magnetic field were habitable.
- Astrobiology — Test life-related hypotheses in the context of another specific kind of geologic terrain. Sample collection that could have preserved evidence of prebiotic chemistry or life on Mars; characterize the potential for the preservation of biosignatures.
- Methane emission from subsurface.
- Radiometric dating
- Deep core drill — Core samples from a depth of ~ 2m
- Polar layered deposits — investigate potential record of recent global climate changes.
- Mid-latitude shallow ice — investigate the habitability of mid-latitude ice, and how does perchlorate affect the present day habitability of Mars. Could mid-latitude ice provide a resource for In Situ Resource Utilization (ISRU)?

A secondary science objective would be to address the need for long-term atmospheric pressure data from the Martian surface. There are studies evaluating the possibilities for cooperative science between the MAX-C rover and the ExoMars rover if landed together at the same location.

Landing

The proposed MAX-C mission would arrive at Mars in January of 2019 in the northern hemisphere during winter given the favorable atmospheric pressure at this season and performance of the 'sky crane' delivery system likely to be used. Due to the eccentricity of the Martian orbit, latitude access for a solar powered rover, northern latitudes are less severe on the power/thermal design than southern latitudes, allowing effective operation at sites as far north as 25°N and as far south as 15°S.

Given that scientifically interesting features often represent terrain that is too dangerous to land on, the landing ellipse is often driven to be placed right up against but not on top of features of interest. The result is that access is often a product of both ellipse size and rover traverse capability sufficient to get outside of that ellipse in a reasonable amount of time relative to the mission lifetime. The entry, descent and landing system would be of high precision, and landing would occur with a targeting accuracy of 7 km (4.3 mi). The solar-powered rover would need to have a range of no less than 10 km (6.2 mi) and a lifetime of at least one Earth year.

Rover

The MAX-C rover would rely on significant inheritance of MSL spacecraft design, flight design, test design, test and handling hardware to minimize cost and risk. This solar-powered rover would need to have a range of no less than20 km (12 mi) and a lifetime of at least 500 Martian days (sols). Since many of the geologically interesting terrains on Mars expose stratified layers on slopes in craters, channels, and hillsides, it would be extremely useful for the proposed MAX-C mission to be capable to navigate on slopes of up to 30 degrees, as both of the Spirit and Opportunity MERs have done.

The mass would be about 65 kg, that would make it smaller than the MERs, Mars Science Laboratory or the ExoMars rover.

Proposed science instrumentation

The rover must carry instrumentation sufficient to scientifically select samples for caching. It is assumed that this translates to the following measurements and possible payload suite:

- Must be able to remotely (i.e. with mast-mounted instruments) characterize outcrops and identify features of interest (panoramic camera, Near-IR Spectrometer)
- Must be able to collect microscaleimagery of outcrops; contact instrument (microscopic imager)
- Must be able to expose unweathered rock surfaces using a surface abrasion tool (abrading bits)
- Must be able to measure mineralogy at micro-scales on the abraded rock surfaces; contact instrument (Raman spectroscopy)
- Must be able to measure bulk elemental chemistry on the abraded rock surfaces; contact instrument (Alpha particle X-ray spectrometer)
- Must be able to measure organic compounds on the abraded rock surfaces; contact instrument (Raman spectroscopy)
- Must be able to correlate composition to micro-scale structures and textures in the rocks (microscopic imager)

Sample cache

Returning samples from Mars is essential to meeting the Mars Exploration Program's highest priority scientific objectives. However, a Mars sample return mission entails high cost and risk, and it entails scientific sample selection, acquisition, and documentation for potential return to Earth, so it must also deliver unprecedented value. Even though any sample returned from Mars would be useful for some line of scientific inquiry, it is also true that not all samples would be equally useful for detailed scientific investigation. To address the highest priority scientific questions, selection of "outstanding samples" will be required. Samples necessary to achieve the scientific objectives of the proposed future sample return mission would be collected, documented, and packaged in a manner suitable for potential return to Earth. A future surface rendezvous would recover the cache and load it into the 'Mars Ascent Vehicle' for its delivery to Earth.

If, at the Mars Science Laboratory rover landing site (2012), scientists do not recognize an outstanding sample, they will want to send a rover to an alternate site selected from orbital data and for which an argument could be made that there is better science or access potential; if MSL does discover outstanding samples, scientists would presumably want to send a rover back to collect them for return, therefore, having the MAX-C developed for a 2018 launch could save time and resources. The proposed sampling requirement would be to collect 20 samples at four sites outside the landing ellipse within one Earth year. The rover would then drive to a safe location to deposit the 20-sample cache for a fetch rover to potentially retrieve sometime after 2020. For such a scenario, the MAX-C rover would be expected to traverse 10 km in 150 driving sols, i.e., ~67 m/sol on average, so an improved rover autonomy would be needed for the candidate MAX-C mission.

The MAX-C rover would be able to acquire samples through coring and abrasion. Coring would be accomplished through the use of a core drill that could produce cores of approximately 10 mm diameter up to 50 mm long, which would be encapsulated in individual sleeves with pressed-in caps. Abrading of surface material would be accomplished through the use of a specialized abrading bit placed in the coring tool. This tool would be intended to remove small amounts of surface material in order to allow instruments access past any dust and/or weathering layer. It would abrade a circular area of similar diameter to the core (8–10 mm). Translation of the arm would be used to scan the individual abrasion spots. The rover should be able to cache at least 38 core samples.

Technology development

A cost of $70M is estimated to fund the technology development activities; the mission concept would require technology development in four key areas:

- Coring, encapsulation, and caching: Lightweight tools/mechanisms for obtaining and handling cored samples.

- Instruments: Additional technology focus to mature instruments that could address the measurement needs posed herein, particularly the micro-scale mineralogy, organics, and elemental composition mapping.
- Planetary protection/contamination control: Bio-cleaning, cataloguing of bio-contaminants, and transport modeling to ensure cached samples would be returnable.
- Rover navigation: On-board image processing and navigation to increase traverse rate.
- Precision landing: A major scientific priority is to improve access to complex terrain, which requires significantly narrowing the landing ellipse.

Based on a draft project schedule and a full JPL team experimental study, total project cost in dollars, not including launch vehicle, is estimated to be between $1.5-2.0 Billion.

Investment in curation facilities (and sample quarantine) as well as development of analytical instrumentation will be essential for getting the most from sample return.

Chapter- 9

Mars Sample Return Mission

Mars sample return mission

Mars sample return mission

Operator	NASA, ESA
Mission type	orbiter, lander, rover and sample return
Launch date	2018
Launch vehicle	Ares V, EELV or Ariane 5
Homepage	Mars Sample Return Lander Mission Profile

A **Mars sample return mission** (MSR) would be a spaceflight mission to collect rock and dust samples from Mars and to return them to Earth for analysis. One particular proposal, a joint project between NASA and ESA, would launch in 2018 with the sample return itself expected in the 2020-2022 time frame.

According to Louis Friedman, Executive Director of The Planetary Society, Mars sample return is often described by the planetary science community as the "holy grail" of robotic space missions, due to its high expected scientific return-on-investment.

History

A mission was originally planned to return samples by 2008, but was canceled following a review of the program.

In mid-2006, the international Mars Architecture for the Return of Samples (iMARS) Working Group was chartered by the International Mars Exploration Working Group (IMEWG) to outline the scientific and engineering requirements of an internationally sponsored and executed Mars sample return mission in the 2018–2023 time frame.

In October 2009, NASA and ESA established the Mars Joint Exploration Initiative, whose ultimate aim is "the return of samples from Mars in the 2020's".

Proposed mission profile

The scenario of the joint NASA/ESA mission will depend on the date of launch and performance of the launcher. Before 2018, only launchers such as Ariane 5 and the US EELV are available. Future heavy-lift launch vehicles are currently planned that would provide greater capabilities.

One-element architecture

The mission would consist of an orbiter and a lander. The lander would include a Mars Ascent Vehicle (MAV), and possibly a rover. The orbiter would be designed to deliver the lander/MAV/rover probe to Mars and return sample rocks back to Earth for analysis. The MAV needs to be a miniature launch vehicle the size of a person, in order to deliver the samples to the orbiter (in case of launch with Ares V, the orbiter element may be discarded in favor of a direct ascent scenario).

The rover's main objective would be to collect a variety of rock samples using many instruments provided by scientists from NASA and ESA. If the rover is canceled, the lone lander would possibly have a robotic arm and/or hand to collect rock samples in replacement. But the lander could also have a proposed drilling machine to take samples from the Martian subsurface.

Two-element architecture

In this scenario, the sample return mission would span two launches at an interval of about four years. The first launch would be for the orbiter, the second for the lander. The rest of the mission would follow in the same way as the one-element mission design.

Three-element architecture

According to JPL's Mars Exploration Program manager Fuk Li, a consensus is now forming for a sample return mission split into a total of three launches. In this scenario, the sample-collection rover (e.g. MAX-C) would be launched separately first - preferably in 2018 - land on Mars, and carry out analyses and sample collection over a lifetime of at least 500 Sols (Martian days).

Four years later, the orbiter would be launched, followed by the lander (including the MAV). Instead of a full-blown sample-collection rover, the lander would bring a smaller, simpler "fetch rover", whose sole function would be to retrieve the sample container from the sample-collection rover, and return it to the lander where it would be loaded onto the MAV. The rest of the mission would follow in the same way as the two-element mission design.

This design eases the schedule of the whole program greatly, giving controllers time to carry out all operations in a sound and scientifically well-designed manner. Furthermore, by spreading the landed mass across two payloads (the sample-collection rover and the lander), the program can rely on the landing system that already has been developed for Mars Science Laboratory, avoiding the costs and risks associated with developing a yet another landing system from scratch.

Scientific value

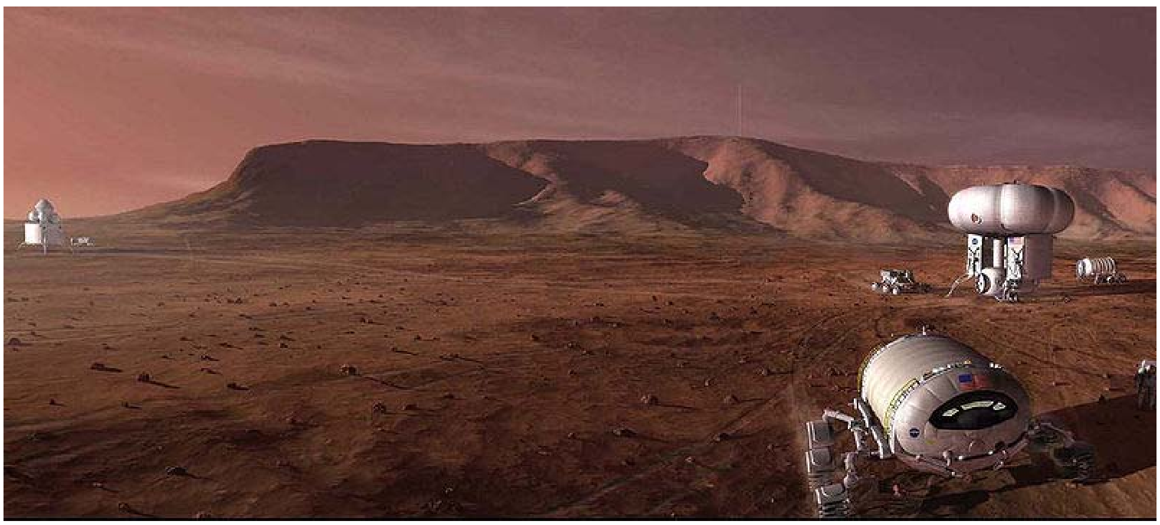
The return of Mars samples would be beneficial to science by allowing more extensive analysis to be undertaken of the samples than could be done by instruments painstakingly transferred to Mars. Also, the presence of the samples on Earth would allow scientific equipment to be used on stored samples, even years and decades after the sample return mission.

In 2006, MEPAG identified 55 important future science investigations related to the exploration of Mars. In 2008, they concluded that about half of the investigations "could be addressed to one degree or another by MSR", making MSR "the single mission that would make the most progress towards the entire list" of investigations. Moreover, it was found that a significant fraction of the investigations cannot be meaningfully advanced without returned samples.

The sample would also undergo laboratory examination for living or dead life forms. However, the difficulty of providing and maintaining life support over the months of transit from Mars to Earth remains to be solved. Providing for still unknown environmental and nutritional requirements is daunting. Should dead life forms be found in a sample, it would be difficult to conclude that those organisms were alive when obtained.

Chapter- 10

Manned Mission to Mars



Concept for NASA Design Reference Mission Architecture 5.0 (2009)

A **manned mission to Mars** has been the subject of science fiction, engineering, and scientific proposals throughout the 20th century and into the 21st century. The plans comprise proposals not only to land on, but eventually also settle the planet Mars, its moons, Phobos & Deimos and terraform the planet.

Preliminary work for missions has been undertaken since the 1950s, with planned missions typically taking place 10 to 30 years in the future. The list of manned Mars mission plans in the 20th century shows the various mission proposals that have been put forth by multiple organizations and space agencies in this field of space exploration.

In 2004 the U.S. administration announced a new Vision for Space Exploration naming a manned Mars mission as one of its milestones. No concrete plan has been decided upon, and the proposal is currently being discussed between politicians, scientists, space advocates and in the public. In 2010, a new bill was signed allowing for a manned Mars mission by the 2030s.

Challenges

Artist's conception of a human mission on the surface of Mars
1989 painting by Les Bossinas of Lewis Research Center for NASA

There are several key challenges that a human mission to Mars must overcome:

1. physical effects of exposure to high-energy cosmic rays and other ionizing radiation
2. physical effects of a prolonged low-gravity environment
3. physical effects of a prolonged low-light environment
4. psychological effects of isolation from Earth
5. psychological effects of lack of community due to lack of real-time connections with Earth
6. social effects of several humans living under crowded conditions for over one Earth year
7. inaccessibility of terrestrial medical facilities

Some of these issues were estimated statistically in the HUMEX study. Ehlmann and others have reviewed political and economic concerns, as well as technological and biological feasibility aspects.

While fuel for roundtrip travel could be a challenge, methane and oxygen can be produced utilizing Martian H_2O (preferably as water ice instead of chemically bound water) and atmospheric CO_2 with mature technology.

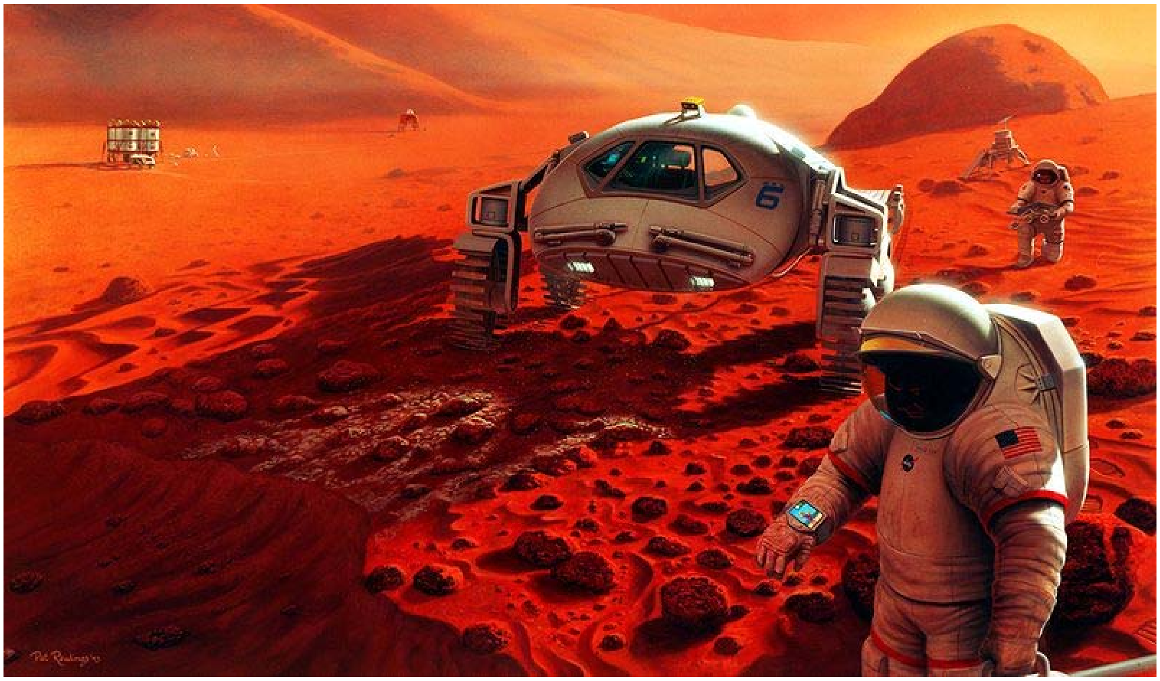
One of the main considerations for traveling to Mars from Earth or vice versa is the energy needed to transfer between their orbits. Every 26 Earth months a lower energy transfer from Earth to Mars opens, so missions are typically planned to coincide with one of these windows. In addition, the low-energy windows varies higher or lower on roughly a 15 year cycle. For example, there was a minimum in the 1969 and 1971 launch windows, rising to a peak in the late 70s, and hitting another low in 1986 and 1988, and then repeating on the same interval.

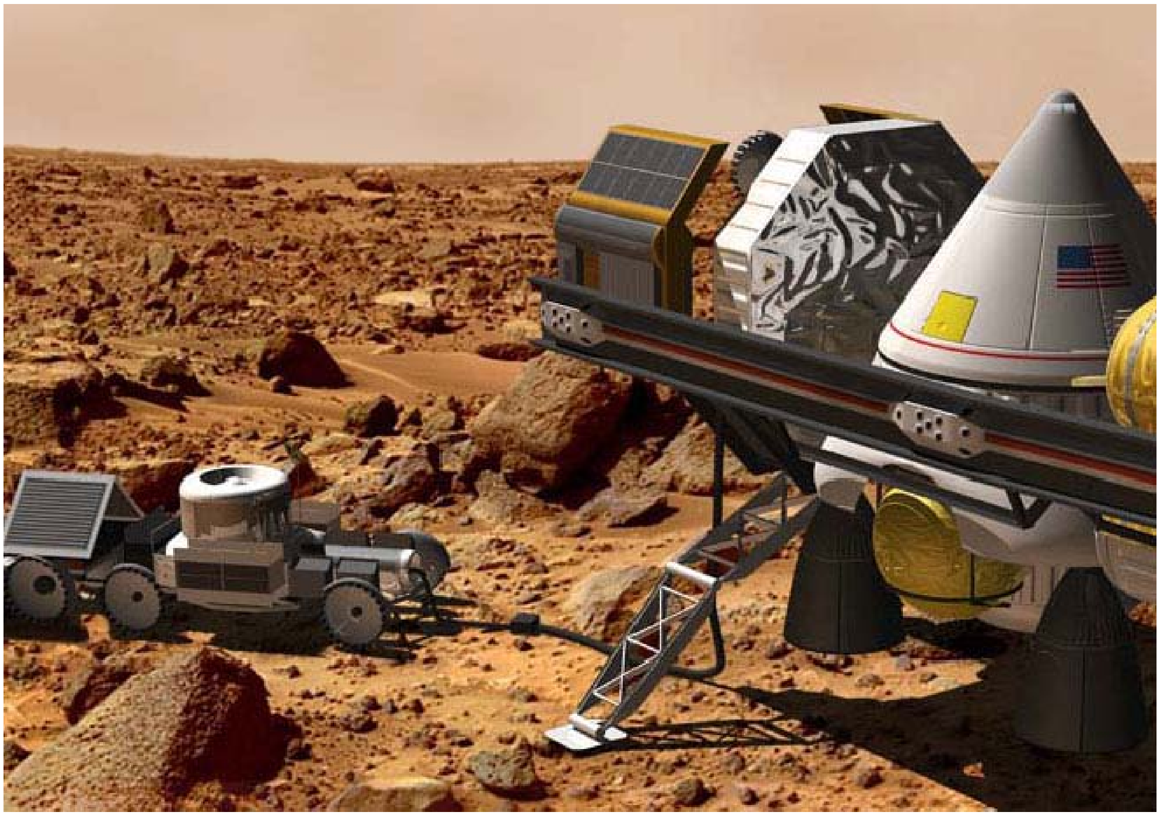
20th century proposals

Over the last century, a number of mission concepts for such an expedition have been proposed. David Portree's history volume *Humans to Mars: Fifty Years of Mission Planning, 1950 - 2000* discusses many of these.

Wernher von Braun proposal (1947 through 1950s)

Wernher von Braun was the first person to make a detailed technical study of a Mars mission. Details were published in his book *Das Marsprojekt* (1952); published in English as *The Mars Project* (1962) and several subsequent works, and featured in *Collier's magazine* in a series of articles beginning March 1952. A variant of the Von Braun mission concept was popularized in English by Willy Ley in the book *The Conquest of Space* (1949), featuring illustrations by Chesley Bonestell. Von Braun's Mars project envisioned nearly a thousand three-stage vehicles launching from Earth to ferry parts for the Mars mission to be constructed at a space station in Earth orbit. The mission itself featured a fleet of ten spacecraft heading to Mars, each one carrying 70 people, bringing three winged surface excursion ships that would land horizontally on the surface of Mars. (Winged landing was considered possible because at the time of his proposal, the Martian atmosphere was believed to be much denser than was later found to be the case.)





In the 1956 revised vision of the Mars Project plan, published in the book *The Exploration of Mars* by Wernher Von Braun and Willy Ley, the size of the mission was trimmed, requiring only 400 launches to put together two ships, still carrying a winged landing vehicle. Later versions of the mission proposal, featured in the Disney "Man In Space" film series, showed nuclear powered ion propulsion vehicles for the interplanetary cruise.

U.S. proposals (1950s and 1960s)

Artist's depiction of Mars Excursion Module landed on Mars, from a 1963 NASA study

In 1962, Aeronutronic Ford, General Dynamics and the Lockheed Missiles and Space Company made studies of Mars mission designs as part of NASA Marshall Spaceflight Center "Project EMPIRE". These studies indicated that a Mars mission (possibly including a Venus fly-by) could be done with a launch of eight Saturn V boosters and assembly in low Earth orbit, or possibly with a single launch of a hypothetical "post Saturn" heavy-lift vehicle. Although the EMPIRE missions were only studies, and never proposed as funded projects, these were the first detailed analyses of what it would take to accomplish a human voyage to Mars using data from the actual NASA spaceflight, and laid much of the basis for future studies, including significant mission studies by TRW, North American, Philco, Lockheed, Douglas, and General Dynamics, along with several in-house NASA studies.

Following the success of the Apollo Program, von Braun advocated a manned mission to Mars as a focus for NASAs manned space program. Von Braun's proposal used Saturn V boosters to launch nuclear-powered (NERVA) upper stages that would power two six-crew spacecraft on a dual mission in the early 1980s. The proposal was considered by (then president) Richard Nixon but passed over in favor of the Space Shuttle.

Soviet mission proposals (1956 through 1970)

The Martian Piloted Complex or "'MPK'" was a proposal by Mikhail Tikhonravov of the Soviet Union for a manned Mars expedition, using the (then proposed) N-1 rocket, in studies from 1956 to 1962.

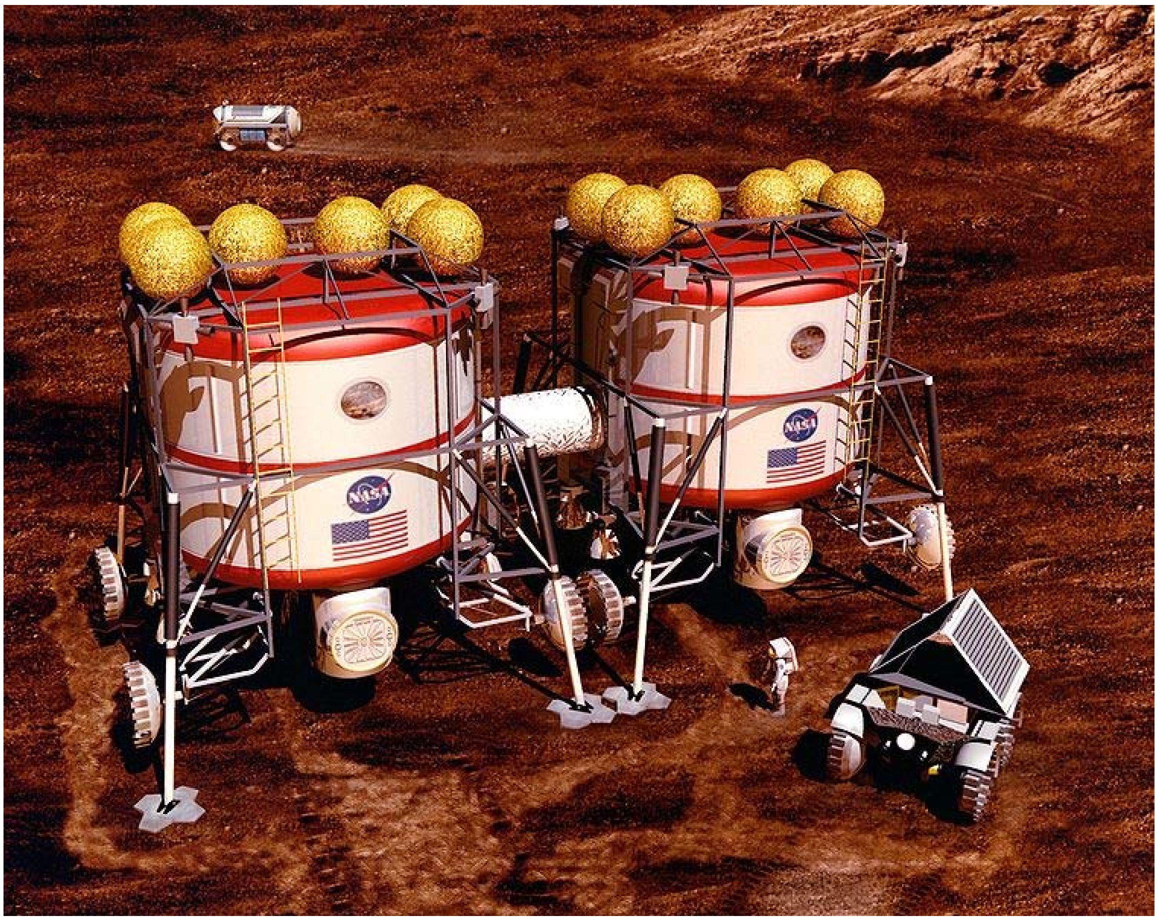
Artist's depiction of TMK-MAVR

Heavy Piloted Interplanetary Spacecraft (known by the Russian acronym **TMK**) was the designation of a Soviet Union space exploration proposal in the 1960s to send a manned flight to Mars and Venus (TMK-MAVR design) without landing. The TMK spacecraft was due to launch in 1971 and make a three-year long flight including a Mars fly-by at which time probes would have been dropped. The TMK project was planned as an answer from the Soviet Union to the United States manned moon landings. The project was never completed because the required N1 rocket never flew successfully.

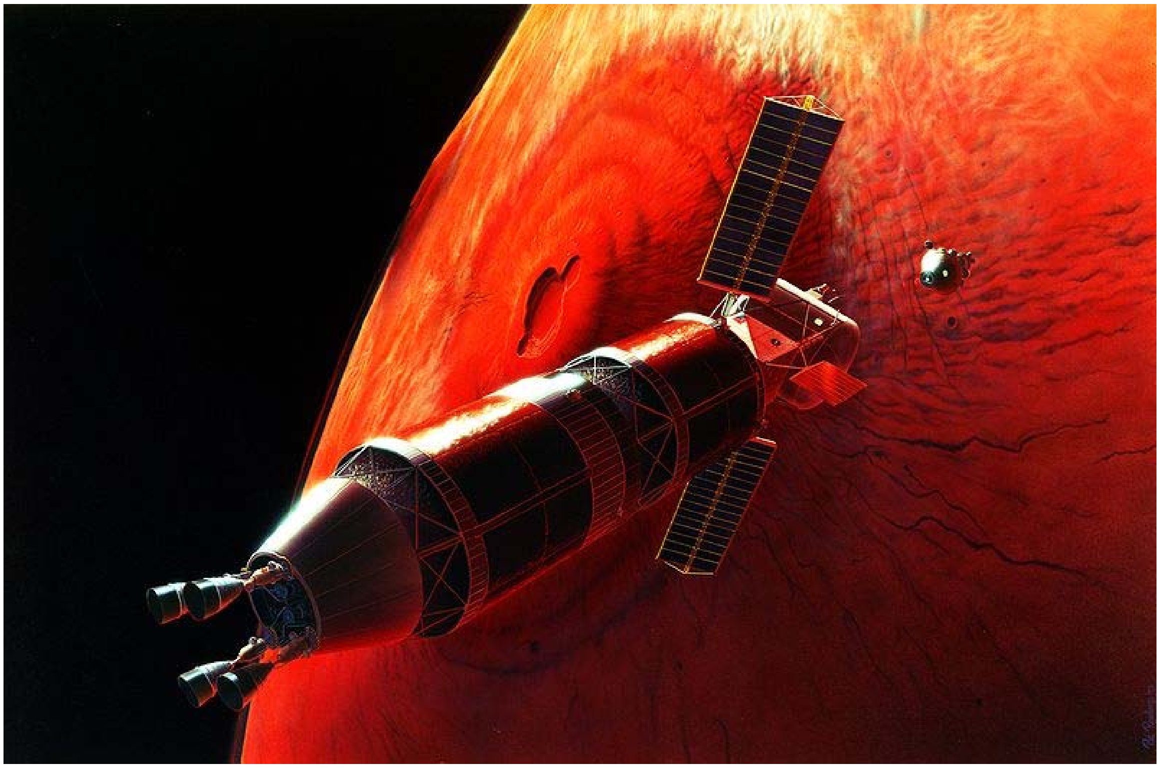
The *Mars Expeditionary Complex*, or "'MEK'" (1969) was another Soviet proposal for a Mars expedition that would take a crew from three to six to Mars and back with a total mission duration of 630 days.

Case for Mars (1981–1996)

Following the Viking missions to Mars, between 1981 and 1996 a series of conferences named The Case for Mars were held at the University of Colorado at Boulder. These conferences advocated human exploration of Mars, presented concepts and technologies, and held a series of workshops to develop a baseline concept for the mission. The baseline concept was notable in that it proposed use of In Situ Resource Utilization to manufacture rocket propellant for the return trip using the resources of Mars. The mission study was published in a series of proceedings volumes published by the American Astronautical Society. Later conferences in the series presented a number of alternative concepts, including the "Mars Direct" concept of Robert Zubrin and David Baker; the "Footsteps to Mars" proposal of Geoffrey A. Landis, which proposed intermediate steps before the landing on Mars, including human missions to Phobos; and the "Great Exploration" proposal from Lawrence Livermore National Laboratory, among others.




United States
NASA



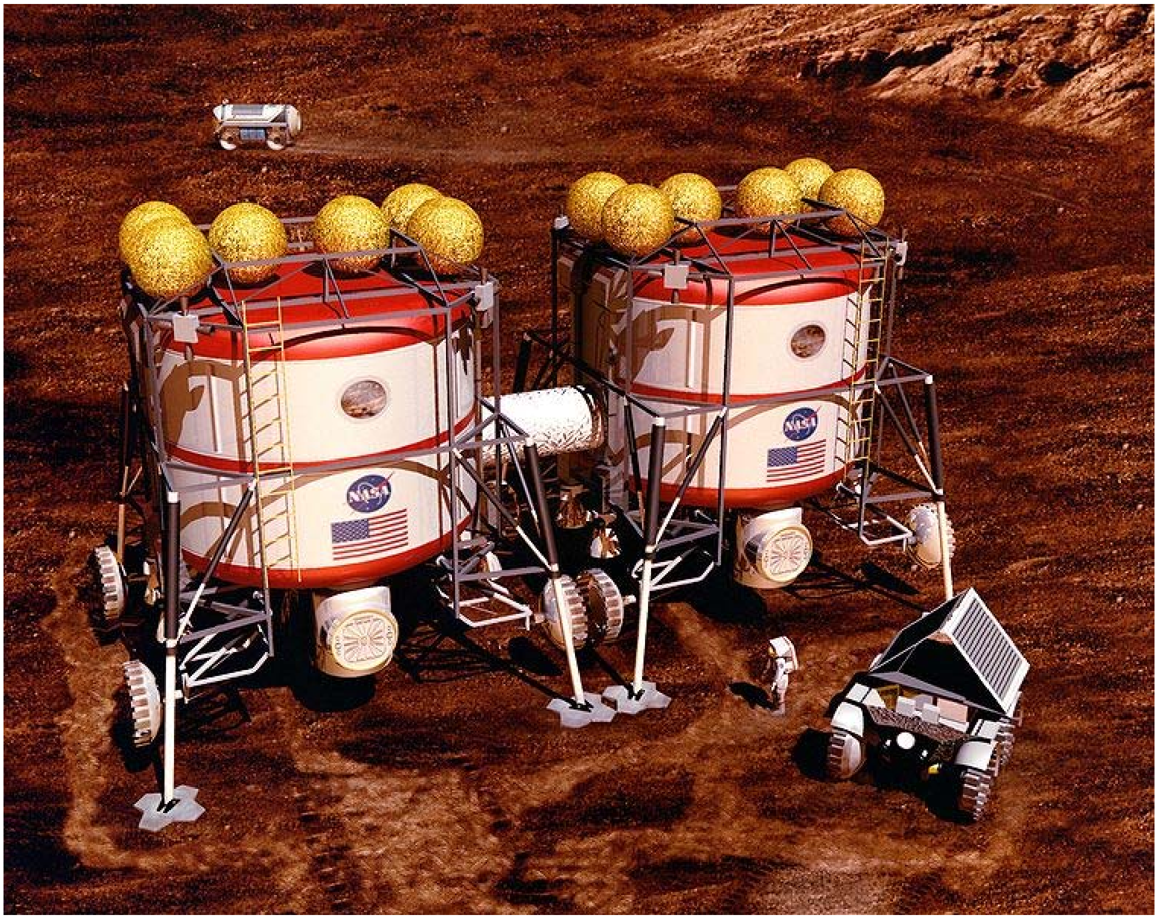
NASA Space Exploration Initiative (1989)

In response to a presidential initiative, NASA made a study of a project for human lunar- and Mars exploration as a proposed follow-on to the International Space Station project. This resulted in a report, called the *90-day study*, in which the agency proposed a long-term plan consisting of completing the Space Station as "a critical next step in all our space endeavors," returning to the moon and establishing a permanent base, and then sending astronauts to Mars. This report was widely criticized as too elaborate and expensive, and all funding for human exploration beyond Earth orbit was canceled by Congress.

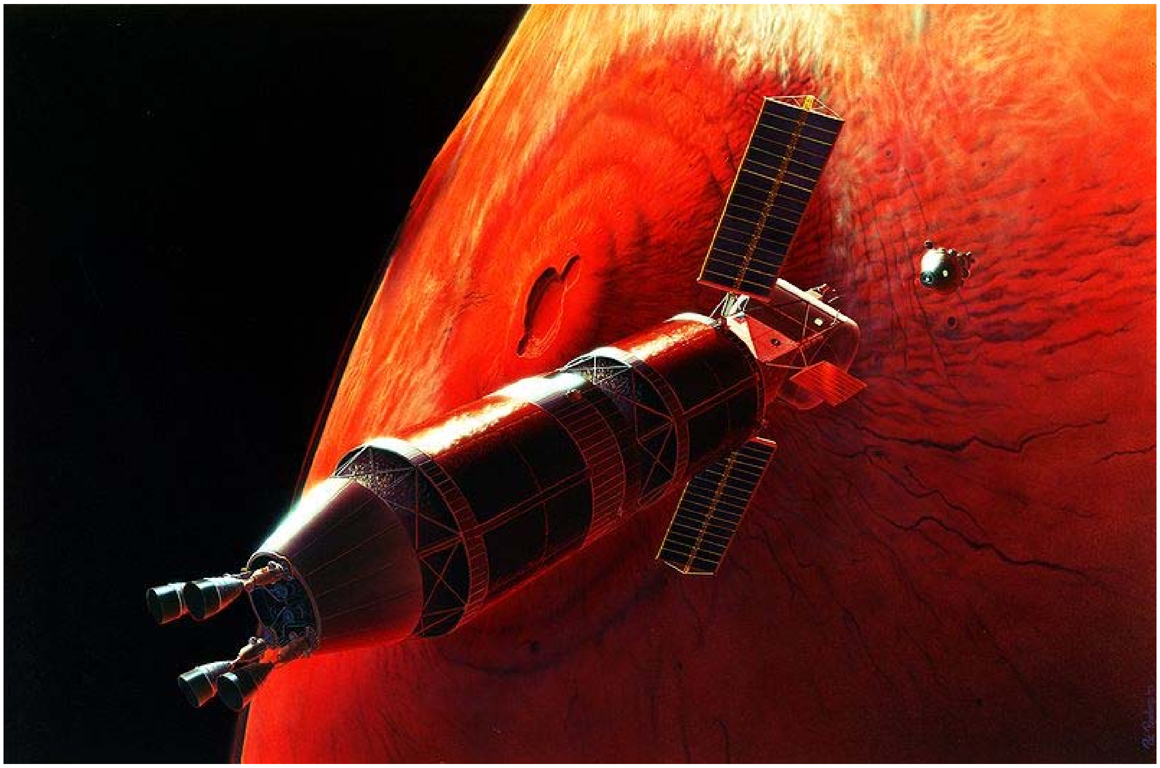
Mars Direct (early 1990s)

Because of the distance between Mars and Earth, the Mars mission would be much more risky and more expensive than past manned flights to the Moon. Supplies and fuel would have to be prepared for a 2-3 year round trip and the spacecraft would have to be designed with at least partial shielding from intense solar radiation. A 1990 paper by Robert Zubrin and David A. Baker, then of Martin Marietta, proposed reducing the mission mass (and hence the cost) with a mission design using In Situ Resource Utilization to manufacture propellant from the Martian Atmosphere. This proposal drew on a number of concepts developed by the former "Case for Mars" conference series. Over the next decade, this proposal was developed by Zubrin into a mission concept, Mars Direct, which he developed in a book, *The Case for Mars* (1996). The mission is advocated by the Mars Society, which Zubrin founded in 1998, as a practical and affordable plan for a manned Mars mission.

NASA Design reference mission (late 1990s)



Mars design reference mission 3.0



Artist's concept of Mars Orbit Rendezvous between spaceship and Martian ascent stage. Painting by Pat Rawlings (SAIC) for NASA.

In the mid to late 1990s NASA developed several conceptual level human Mars exploration architectures. One of the most notable and often quoted was the NASA Design reference mission 3.0 (DRM 3.0). The study was performed by the NASA Mars Exploration Team at the NASA's Johnson Space Center (JSC) in the 1990s. Personnel representing several NASA field centers formulated a “Reference Mission” addressing human exploration of Mars. The plan describes the first human missions to Mars with concept of operations and technologies to be used as a first cut at an architecture. The architecture for the Mars Reference Mission builds on previous work, principally on the work of the Synthesis Group (1991) and Zubrin’s (1991) concepts for the use of propellants derived from the Martian atmosphere. The primary purpose of the Reference Mission was to stimulate further thought and development of alternative approaches, which can improve effectiveness, reduce risks, and reduce cost. Improvements can be made at several levels; for example, in the architectural, mission, and system levels.

21st century proposals

Vision for Space Exploration (2004)

United States President George W. Bush announced an initiative of manned space exploration on January 14, 2004, known as the Vision for Space Exploration. It included developing preliminary plans for a lunar outpost by 2012 and establishing an outpost by 2020. Precursor missions that would help develop the needed technology during the

2010-2020 decade were tentatively outlined by Adringa and others. On September 24, 2007, Michael Griffin, then NASA Administrator, hinted that NASA may be able to launch a human mission to Mars by 2037. The needed funds are to be generated by diverting $11 billion from space science missions to the vision for human exploration.

NASA has also discussed plans to launch Mars missions from the Moon to reduce traveling costs.

Aurora programme (early 2000s)

The European Space Agency has the long-term vision of sending a human mission to Mars by 2030. Laid out in 2001, the project's proposed timeline would begin with robotic exploration, a proof of concept simulation of sustaining humans on Mars, and eventually a manned mission; however, objections from the participating nations of ESA and other delays have put the timeline into question.

Russian mission proposals (current)

A number of Mars mission concepts and proposals have been put forth by Russian scientists. Stated dates were for a launch sometime between 2016 and 2020. The Mars probe would carry a crew of four to five cosmonauts, who would spend close to two years in space.

In 2011, Russian and European space agencies will have successfully completed the ground-based MARS-500. The biomedical experiment simulating manned flight to Mars was completed in Russia in July 2009.

Mars Society Germany - European Mars Mission (EMM) (2005)

The Mars Society Germany proposed a manned mars mission using several launches of an improved heavy-lift version of the Ariane 5. Roughly 5 launches would be required to send a crew of 5 on a 1200 days mission, with a payload of 120,000 kg (260,000 lb)

The one-person, one-way option (2006)

In 2006, former NASA engineer James C. McLane III proposed a scheme to initially colonize Mars via a one way trip by only one human. Papers discussing this concept appeared in The Space Review, Harper's and SEARCH magazine.

NASA Design Reference Mission 5.0 (2007)

NASA released initial details of the latest version conceptual level human Mars exploration architecture in this presentation. The study further developed concepts developed in previous NASA DRM and updated it to more current launchers and technology.

MarsDrive mission design (2008)

The MarsDrive Organization has been working at a series of new human mission designs starting with Mars for Less. Their current design program under Director of Engineering Ron Cordes has discarded many of the Mars for Less elements and is a work in progress as of June 2008. Some of their design philosophy is focused on using current or near term existing launch vehicle systems, permanent human settlement, conceptual EDL systems and enhanced surface ISRU. Their proposed methods of funding the mission are also an alternative to the current plans with a private consortium approach being investigated.

ESA plans

Another proposal for a joint ESA mission with Russia is based on two spacecraft being sent to Mars, one carrying a six-person crew and the other the expedition's supplies. The mission would take about 440 days to complete with three astronauts visiting the surface of the planet for a period of two months. The entire project would cost $20 billion and Russia would contribute 30% of these funds.

Chinese Mars exploration program

Little is known of the **Chinese Mars exploration program**. While the Moon is the first priority, there are plans for Martian exploration that follow upon the work done in the Chinese Lunar Exploration Program. China has been studying the necessity and feasibility of Mars exploration since early 1990s as part of the national "863 Planetary Exploration" project, according to Liu Zhenxing, a researcher from the CAS Center for Space Science and Applied Research (CSSAR).

Mars to Stay

Mars to Stay is the proposal that astronauts sent to Mars for the first time should stay there indefinitely, both to reduce mission cost and to ensure permanent settlement of Mars. Among many notable Mars to Stay advocates, former Apollo astronaut Buzz Aldrin has been a particularly outspoken promoter, suggesting in numerous forums "Forget the Moon, Let’s Head to Mars!" . On October 2010 NASA Ames Research Center Director Pete Worden introduced the Hundred Year Starship initiative, a project to embark on a one-way mission from Earth to Mars by 2030. The astronauts would be sent supplies from Earth on a regular basis.

NASA Design Reference Mission Architecture 5.0 (2009)

DRMA 5.0 Mars ascent stage (2009)

NASA released an updated version of NASA DRM 5.0 in early 2009, featuring use of the Ares V launcher, Orion CEV, and updated mission planning. In this document.

Mars by the mid-2030s

In a major space policy speech at Kennedy Space Center on April 15, 2010, U.S. President Barack Obama predicted a manned Mars mission to orbit the planet by the mid-2030s, followed by a landing:

> “By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow. And I expect to be around to see it.”

The United States Congress has approved manned missions to the Moon, followed by Asteroid exploration in 2025 and Mars in the 2030s.

Preparedness

A number of nations and organizations have long-term intentions to send humans to Mars. The state of their readiness is summarized below.

- The United States has a number of missions currently exploring Mars, with a sample-return planned in the near future. The US does not have a launcher capable of sending humans to Mars, although the Orion spacecraft, currently under development by NASA, could ferry astronauts from the surface of Earth to join a Mars-bound expedition in Earth orbit and then back to Earth's surface once the expedition has returned from Mars. NASA has used the Haughton impact crater on Devon Island as a proving ground due to the crater's similarity with Martian geology. According to *New Scientist*, an argon plasma-based VASIMR rocket could reduce the transit time to less than 40 days.
- The European Space Agency has sent robotic probes, and has long-term plans to send humans but has not yet built a human-capable launcher. There is a proposal to convert ESA's existing Automated Transfer Vehicle (ATV) for crewed launches.
- Russia (and previously the Soviet Union) has sent a large number of probes. It can send humans into Earth-Orbit and has extensive experience with long-term manned orbital space flight due to its space station programs. Russia does not have a launcher capable of sending humans to Mars, although the Kliper program was proposed as the Russian-European counterpart to the United States' Orion Spacecraft. A simulation of a manned Mars mission, called Mars-500, was completed in Russia in July 2009.
- Japan's robotic missions to Mars have so far failed.
- China plans to cooperate with Russia in sending robotic sample return mission to Phobos. China was the third country after Russia and the USA to launch humans into Earth orbit.

Criticism

Some scientists have argued that attempting manned flight to Mars would actually be counterproductive for science. In 2004, the Special committee on the funding of Astrophysics, a committee of the American Physical Society, stated that "shifting NASA priorities toward risky, expensive missions to the Moon and Mars will mean neglecting the most promising space science efforts".