DRAFT The Mars Science Orbiter Concept[1] [2]

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Abstract— Launch opportunities to explore Mars repeat every 26 months. In the 2013 opportunity, NASA is considering launching a high performance science orbiter with extended telecom capabilities. This Mars Science Orbiter (MSO) would perform its science investigations and telecom infrastructure tasks over a period of 10 years in two consecutive orbits around Mars: one with science emphasis, the other emphasizing telecommunications services.

While the individual science investigations of MSO would be decided competitively by an Announcement of Opportunity, the NASA science community has identified Atmospheric Science as the primary science thrusts for the mission objectives. A high-resolution camera supporting the Mars infrastructure for landing site selection would complement the atmospheric science goals.

The Atmospheric Science plan for MSO is centered on the two major science goals of atmospheric signatures and atmospheric state. Global maps of atmospheric constituents over time would provide the data necessary to characterize trace gas profiles, their sources and the dynamics of their transport to detect possible signatures of habitable zones and life. In addition, climatological monitoring and observing atmospheric processes would build on current climate/weather data sets, as well as contribute new data for transport and atmospheric dynamics models.

The JPL MSO study team has been focusing on designing a concept for the science mission outlined above. However, other concepts for MSO are under investigation at this time as well. These may include the addition of a hard lander payload and/or adding Earth return capability to support a future Mars Sample Return mission. This paper describes a possible mission concept for the 2013 Mars launch opportunity. The actual NASA Mars Program plans and implementation may differ.

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1 1-4244-1488-1/08/$25.00©2008 IEEE
2 IEEEAC paper #1418, version 1, October 22, 2007

1. MISSION GOALS

The first Science Analysis Group (SAG)[T1] to consider the science goals of MSO returned a recommendation for an aeronomy/atmospheric science mission. But with the choice of two primarily aeronomy missions (MAVEN and TGE) as candidates for the 2011 Mars Scout opportunity, a modification of the science goals was required and a second SAG[T2] was set up to re-evaluate the science priorities for MSO. Out of this study came three possible foci for the MSO science:

Plan A: Atmospheric science – this option focuses on detecting chemical signatures in the atmosphere and on determining the atmospheric state. This was essentially the plan recommended by SAG-1, minus the aeronomy.

Plan P: Polar processes and Modern Climate – to study the sources and sinks of the major volatile systems on Mars and to quantify climate variability.

Plan G: Geology and Geophysics: Near surface science – searching for signatures of past habitable conditions and studying the current water distribution across Mars and how it changes over time.

In July 2007, NASA headquarters made the decision to implement Plan A, with the addition of a high-resolution camera. The overarching themes driving the science of this plan are to seek atmospheric evidence for present habitability and for life, and to provide new insight into the climate processes responsible for seasonal and interannual change. The major objectives of this plan as listed in the SAG2 report are

(1) To identify molecules in the atmosphere that cannot be formed by atmospheric photochemical processes e.g. CO_2, H_2O and N_2 as well as other species that may be indicative of active subsurface processes.

(2) To locate sources and sinks of those atmospheric signatures associated with habitability.

(3) To determine the atmospheric lifetimes of signature species.

(4) To determine how the chemical signatures are produced and to distinguish, if possible, between geologic and biogenic origins.

(5) To determine the processes controlling the present day distributions of water, CO_2, and dust, by determining the short- and long-term trends (daily, seasonal and interannual) in the present climate.

(6) To understand and monitor the behavior of the lower atmosphere on synoptic scales.

(7) To search for micro-climates.

(8) To characterize the stratigraphic record of climate change and understand the processes that control the transport and deposition of volatiles and dust.

In addition to its primary science mission, MSO would also serve as a key strategic relay communications asset in support of future Mars surface exploration. The Mars Exploration Program has established a strategy of carrying a UHF telecommunications relay payload on each Mars science orbiter in order to cost-effectively establish an on-orbit Mars relay infrastructure. [T3] This strategy has yielded great benefits to the Spirit and Opportunity rovers, which have returned over 96% of their data via energy-efficient relay links through the Mars Global Surveyor and Odyssey science orbiters. With the recent loss of MGS, the relay infrastructure has been augmented with the arrival of the 2005 Mars Reconnaissance Orbiter; Odyssey and MRO are now poised to provide relay services to the 2007 Phoenix Lander and the 2009 Mars Science Laboratory. MSO represents a continuation of this strategy, replenishing the relay infrastructure as Odyssey and MRO approach the end of their mission lifetimes, and establishing the core relay capability for Mars exploration during the remainder of the second decade and into the 2020's.

2. EXAMPLE PAYLOAD

MSO would attain its science objectives by carrying a number of instruments. It would carry out experiments to characterize the dust composition and the atmospheric composition, isotopic fractionation, and temperature from the surface to an altitude of at least 100 km. It would profile the dynamics of various atmospheric signatures, including water and provide high-resolution visual and infrared measurements of the atmospheric dust and ices. MSO would provide global surveys of the surface albedo, monitoring its changes with season, and provide measurements of the mineralogy of the surface rocks. In addition to the intrinsic scientific value related to studies of the atmospheric evolution, dynamics, and meteorology, these measurements would provide near-real time monitoring capabilities to aid arriving future spacecraft with their aero-assist or Entry, Descent and Landing (EDL) maneuvers. MSO would also carry a high-resolution imager to continue the science studies begun by the HiRISE camera on Mars Reconnaissance Orbiter (MRO), and to provide support for landing site characterization needs for future missions. Below we describe an example of the kind of payload required to achieve the science goals[3].

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[3] The actual payload will be decided by the NASA Science Missions Directorate, which will competitively select the instruments via the Announcement of Opportunity process

Trace Gas Instrument

One of the science goals of MSO is to characterize the composition of the Martian atmosphere and the dust, with observations of most latitudes being taken at least once per Mars season. The trace gas instrument would measure the vertical distribution of trace gases in the atmosphere between the surface and an altitude of 100km. The required vertical resolution is ~ ½ scale height. The measurements would be obtained by solar occultation, where the Sun is viewed through the atmosphere, just before the spacecraft enters eclipse, or just after it emerges from eclipse. This technique allows simultaneous measurements of multiple chemical species and has been used successfully to characterize important trace gases in the Earth's upper atmosphere (by instruments such as ACE). The inclination of the spacecraft orbit is constrained in part by the requirements of this instrument. To achieve the required frequency of sampling, an orbital inclination of ~ 74° would be optimal. As the inclination increases more poleward of this, the quality of observations at low and mid latitudes diminishes.

Wind Instrument

The wind instrument would be able to measure the concentrations and locations of specific atmospheric signatures including water, as well as the temperature distribution. Importantly, it would allow dispersal characterization for measured trace gases. The global atmosphere would be sampled on a daily basis, through several seasonal cycles – observations over at least 1 Martian year are required to enable the diurnal and seasonal cycles to be distinguished. The observations would cover the region from the surface to an altitude of about 60 km and would be sensitive to the lowest scale height. The instrument would utilize submillimeter wavelengths to ensure that the observations would be unaffected by the presence of dust – hence data could be obtained even in the depths of the densest dust storms. This would allow investigations into the possible effects of heterogeneous chemistry and dust electrification. Observations towards the limb would allow wind velocities to be measured along the line of sight. Knowledge of the wind velocity is important to understand the atmospheric circulation and for use in reverse modeling to identify the source regions of atmospheric tracers.

High Resolution Camera (Hi-Res)

In addition to instruments designed to tackle the atmospheric questions outlined above, MSO would carry a high-resolution imager of similar capabilities to the MRO HiRISE camera. The high-resolution images provided would serve both a scientific and programmatic function. The imager would be able to support landing site surveys for future missions, by providing images of sufficient resolution to identify hazards on a scale of ~1m. To enhance this, the camera would be capable of providing stereo images (by taking two images on different orbits of the same region, but at different viewing angles). For science, the camera would be able to continue the high-resolution mapping of the Martian surface begun by HiRISE (HiRISE will only be able to cover ~0.2 % of the planet's surface at high resolution per Earth year). Other scientific contributions include volcanism, stratigraphy, and landscape evolution. For example, high-resolution images would allow the identification of sand and dust deposits, based on their different morphologies. The long duration of the MSO mission would also provide opportunities for the continued monitoring of landing sites and other areas to establish how they change over time. The high-resolution imaging also places requirements on orbital inclination. High, near polar, inclinations are preferred to satisfy the need for near-global access for imaging.

Visible-Infrared instrument (VIS/IR)

Observations in the visual and infrared can address a variety of science goals. A camera similar to Mars Global Surveyor (MGS)-TES or to MRO-MCO would be able to provide daily global measurements of atmospheric dust and ices, as well as study the mineralogy of the Martian surface. The atmospheric observations would provide information for model simulations by constraining the solar heating that drives the atmospheric circulation and the dust/volatile exchange. The mineralogy studies would enable correlations to be made between the minerals and the different surface layers observed. It may also be possible to identify minerals that trace previous surface water discharges, adding to our knowledge of the history of water on the planet.

Wide-Angle camera (WA)

Daily global monitoring of the distribution of atmospheric dust and ices, together with surveys of the surface albedo, would be provided by a wide-angle camera. This would continue the synoptic monitoring of the surface and atmosphere carried out by MGS and MRO. The wide-angle camera would provide long-term monitoring of dust sources and sinks, and of transport in the atmosphere. On the surface, it would enable observation of the composition of and changes to the permanent and seasonal polar caps.

Relay Payload

MSO's relay payload, based on the Electra software radio onboard MRO, [T4] would provide forward and return link communications in the UHF band (390-450 MHz), delivering commands to and returning science and engineering telemetry from users on the Martian surface. MSO would also provide communications support during critical user mission events such as entry, descent, and landing, acquiring engineering telemetry that would allow fault identification and reconstruction in the event of a mission anomaly. MSO's propulsive delta-V budget will include an allocation for orbit phasing maneuvers to provide flexibility in positioning MSO in view of planned critical events. In addition to these communications services,

MSO's Electra payload would formulate radio metric tracking observables (Doppler and, potentially, range) on the relay link, providing information on the position and velocity of the user spacecraft relative to MSO's trajectory. This radio metric tracking capability can be applied to a range of navigation scenarios, including precision approach navigation, surface position determination, and orbital rendezvous. [T5] Finally, MSO's relay link would be used to provide time synchronization services, allowing user missions to calibrate and synchronize their spacecraft clocks with respect to UTC.

3. Mission Overview

The NASA MSO 2013 mission would be a 10 year on-orbit mission. After a 9-month cruise MSO would be inserted chemically into a 1-sol Mars orbit and then aerobrake for approximately 9 months, including a solar conjunction period, followed by about one month of spacecraft and instrument commissioning. MSO would achieve a first science orbit of approximately 300 km altitude. MSO would spend approximately 1 Mars year in this science emphasis phase and then increase its altitude to approximately 400 km, where it would stay for the next 7 Earth years in relay communication emphasis phase. The atmospheric science and site selection would continue throughout the 10 years extending the science return of the first phase. MSO could provide relay to a 2013 lander (e.g. EXOMARS) and 2016 lander/orbiter (tentative) missions currently envisioned by ESA and NASA. The mission timeline (Figure 1) depicts the key mission events.

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The orbit selection is driven by a combination of science requirements and relay communication requirements. Like MRO, science data is preferentially taken from a lower altitude. A 300 km, near circular orbit would result in approximate 13 revolutions per day. The chosen inclination of 82.5° is primarily the result of a compromise between the trace gas experiment, which prefers an inclination of 74° and the camera and relay which both prefer a more polar orbit. The ensuing orbit, which is non Sun-synchronous with, a regressing node and a frozen periapse, has several advantages for science gathering, but has some impacts on the flight system design.

(1) To obtain optimized high-resolution camera coverage, the orbit can be slightly adjusted to achieve the required overlaps of swaths for mapping extended regions. (Figure 2)

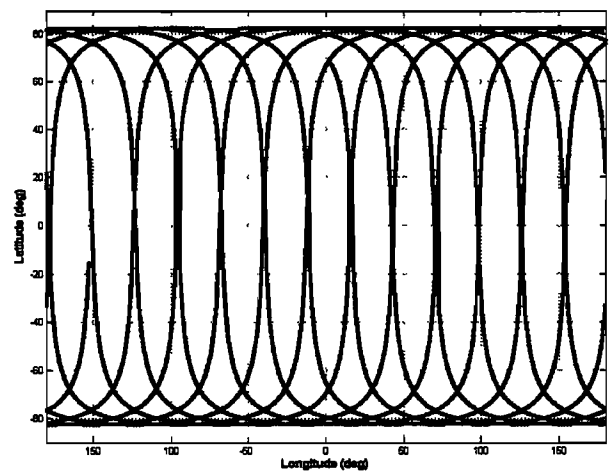


Figure 2 – MSO at ~ 300 km near-circular orbit, inclination 82.5°, initial Node = 3AM/PM, (not Sun-Sync) 1 Earth Day. Each day accommodates approximately 13 revolutions.

(2) The orbit enables the trace gas instrument to collect a high frequency of observations over a large range of latitudes from one season to the next. (Figure 3)

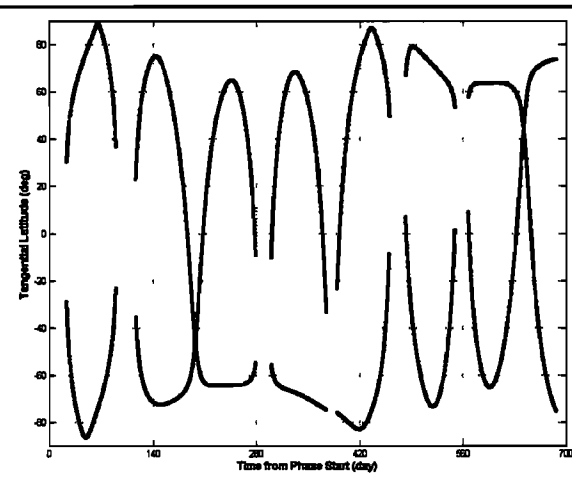


Figure 3 – Depicts the Trace Gas instrument latitude access from a 273x327 km orbit, 82.5° inclination over one Martian year.

(3) However, the solar beta angle of the resulting orbit (figure 4) becomes a significant driver for the mounting of the instruments, the trace gas instrument radiator design and placement, and the execution of observation in flight, as will be discussed in subsequent sections.

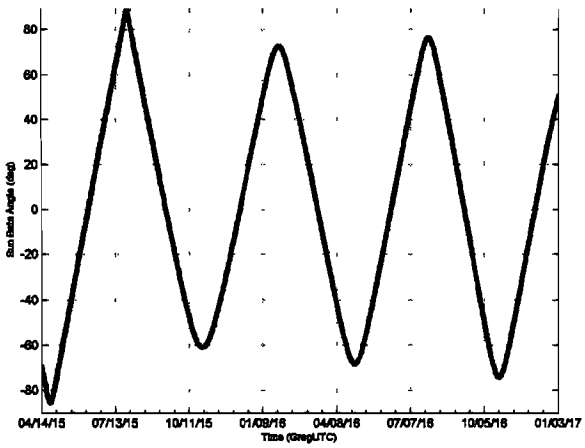


Figure 4- The Solar beta angle vs mission time for an MSO at 273x327 km orbit and 82.5° inclination

After one Mars year the orbit would be boosted to a near 400 km altitude for the telecommunication emphasis phase. In this orbit the camera looses some of its resolution and the trace gas instrument gets a somewhat reduced coverage. This observing phase will add an additional seven years of observing opportunity, extending the mission to almost a full solar cycle, so the cumulative science return is expected to be significant. The telecommunication orbit also meets the safe orbit requirement for planetary protection considerations.

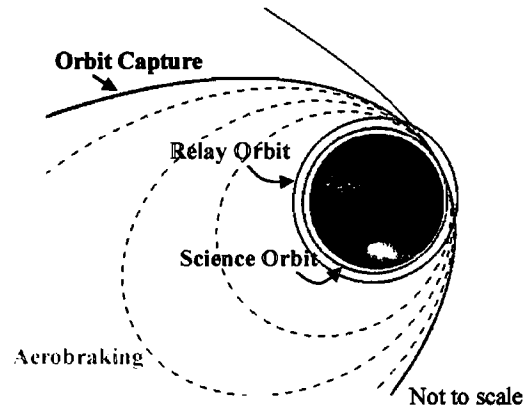
4. Trajectory and Orbit Trades

Interplanetary Trajectory

MSO would be launched from Cape Canaveral Air Force Station (CCAFS) during the 2013 Mars opportunity using a Type II Earth to Mars ballistic trajectory. The launch dates and arrival dates were optimized for maximum delivered mass post-MOI. The current reference launch period for MSO is 20 days and extends from November 21, 2013 to December 10, 2013. This launch period has a maximum launch C_3 of 11.3 km^2/sec^2 and a maximum Mars Orbit Insertion (MOI) Delta-V of 1191 m/sec. The launch of the MSO spacecraft would be conducted onboard an Evolved Expendable Launch Vehicle (EELV), such as Atlas-V or Delta-IV.

Five Trajectory Correction Maneuvers (TCMs) are currently planned to correct launch vehicle dispersions, remove planetary protection biasing and control the cruise and approach to Mars. Following the interplanetary cruise, MSO would capture on a 300 x 34000 km orbit (~25-hr) using a chemical propulsive burn. The selection of a Northern or Southern approach is still pending. Mars orbit capture would be followed by an aerobraking phase to reduce the apoapsis altitude of ~300 km. The duration of aerobraking is approximately 9 months.

Figure 5 – Orbit Commissioning



Mars Orbit

The MSO mission consists of two primary orbits. The first Mars year after aerobraking and orbit commissioning would have a science emphasis at an altitude of 273 x 327 km. This science phase would be focused on trace gas investigations and landing site selection. The science phase would be followed by seven earth years in a relay orbit at an altitude of 400 km. The landing site selection activities would be continued during this phase. The transition between both orbits would be achieved by executing a periapse raise and an apoapsis raise maneuver at the end of the science emphasis phase. The orbit commissioning is illustrated in Figure 5.

The two science objectives prefer significantly different orbit inclinations; hence, multiple orbit trades were performed to ensure the objectives of both could be met. On the one hand, in order to have a robust and capable relay and critical event coverage asset, high inclinations to provide global coverage capabilities are desired. In contrast, the trace gas experiment collects the best results at 74 deg inclination. It was concluded that the optimal orbit inclination to satisfy all mission requirements was 82.5 deg.

Table 1 – Delta-V Budget

Maneuver	ΔV (m/s)
TCMs	36
Mars Orbit Insertion (MOI)	1191
Gravity Losses (5% of MOI)	60
Aerobraking Phase	130
Orbital Maintenance	50
Critical Event Coverage	150
Orbit Raise	45
Reserves	50
Total	**1712**

This inclination trade study was critical since both science and relay emphasis orbits must share the

same inclination in order to avoid large inclination change maneuvers.

The Delta-V budget allows for critical event coverage of up to 5 events given 600-day notice of required alignment and timing. It also includes an allocation for orbital maintenance to support both science and relay orbits. This Delta-V budget is shown in Table 1.

5. Flight System Concept

Figure 6 shows the conceptual MSO flight system configuration with the example science payload and other key elements identified. A central cylindrical structure encloses a single propellant tank while all avionics and science instruments are mounted to a forward deck, thus allowing the parallel integration of two separate modules. Power is provided by a 2-wing solar array with single axis gimbals. High rate Earth communication is provided through either a 2-axis gimbaled X-Band HGA or a fixed Ka-Band HGA.

Figure 6: Configuration- *picture at end of paper, needs to go on this page.*

Key driving flight system requirements are to provide:

(1) Propulsive ΔV of 1700 m/s

(2) Aero-braking in < 9 months from a 24 hour orbit to an ~2 hour orbit

(3) Nadir pointing of several science instruments and keep apertures aligned to the ground track

(4) Sun pointing of the Trace Gas Experiment at solar occultation

(5) Cold space FOV for a Trace Gas Experiment thermal radiator at 80°K

(6) Simultaneous downlink with science data acquisition

(7) Real-time data relay between Earth and assets on the surface of Mars

(8) Downlink ≥ 10 Gbits of data in 8 hrs D/L time at maximum Earth range

(9) On-orbit operating life ≥ 10 years

The preliminary implementation in response to these requirements is now described along with any open issues.

The propulsive ΔV requirement is high relative to recent Mars orbiters and leads to a relatively high launch wet mass. A simple hydrazine propulsion design is conservatively selected. Table 2 shows a summary of the current mass estimates. This mass is consistent with the launch capabilities of Atlas-V 400 series or Delta-IV launch vehicles.

Table 2 - MSO Mass Summary

Element	Mass with Margin (kg)
Orbiter Bus	1,110
Payload Allocation	170
Propellant	1,540
Launch Wet Mass	2,820

The solar arrays currently provide 18 m^2 of drag surface area for aerobraking. This mass and drag area yield a relatively high ballistic coefficient and simulations show that the 9-month aerobraking requirement is not satisfied. Additional panels without solar cells are under consideration. During aerobraking the solar arrays are symmetric relative to the velocity vector and provide aerodynamic stability by pushing the center of pressure well behind the center of mass.

The instrument pointing requirements (# 3-5), combined with a non-Sun-synchronous orbit, led to selection of a "Sun-nadir yaw steering" pointing strategy. For the primary science observational modes, a designated axis is pointed to nadir, while the yaw orientation about nadir is controlled to keep the long axis of the solar arrays normal to the Sun vector. The solar arrays are rotated about their long axis to point at the Sun.

This pointing strategy keeps a spacecraft face always pointed away from both the Sun and Mars and the trace gas instrument thermal radiator is mounted to this face. The radiator does, however, have a partial view of one solar array and this remains an open issue at this time, with alternate configurations under study. The trace gas instrument aperture is oriented 66° off nadir to minimize the spacecraft slew angles required to point the aperture at the Sun during occultation.

Several of the science instruments are mounted to a turntable that counteracts the spacecraft yaw motion to maintain proper alignment with the ground track. The High Resolution Camera is not turntable mounted. Rather, the spacecraft would temporarily slew to the proper imaging attitude.

The gimbaled X-Band HGA satisfies the driving requirement to downlink simultaneous with science data gathering and to relay data between Earth and Mars surface assets in real-time (#6,7). The current, conservative

estimate of X-Band downlink performance gives an 8 Gbits volume in 8 hours at maximum range, which is close to meeting the corresponding data volume requirement of 10 Gbits (#8). Estimated Ka-Band performance gives twice the data volume as the X-Band link, but requires interrupting science gathering to point the fixed antenna at Earth.

The preliminary data collection strategy is to use the X-Band link on a daily basis and the Ka-Band link on a weekly basis to unload the solid-state recorder. A fixed Ka-Band antenna is selected to save mass and avoid complications associated with precision gimbals and the outboard mounting of the Ka-Band TWTAs. For the baseline amplifiers (100W X-Band and 35W Ka-Band) the higher Ka-Band performance relative to X-Band is attributed to the reduced pointing and circuit losses associated with a fixed antenna.

The system architecture provides full onboard redundancy. On-orbit operation for 10 years (#9) would also require careful consideration of parts selection, fault protection and contingency plans for graceful degradation. Extended life testing may be necessary to re-qualify heritage hardware.

The C&DH and Power electronics are implemented using JPL's new Multi-Mission System Architectural Platform (MSAP). A significant portion of the flight software is also provided as part of MSAP.

Brief Description of Key Subsystems

The Propulsion subsystem is a regulated monopropellant hydrazine design with a single propellant tank. MOI and other large ΔV burns are performed with eight off-pulsed 50 lbf main engines. Use of a single large main engine is also under consideration. A set of 5 lbf thrusters provide small ΔV burns and a set of 1 lbf thrusters provide attitude control with balanced couples about all 3 coordinate axes.

The Attitude Control subsystem is a 3-axis stabilized design with star-trackers, coarse sun sensors and inertial measurement units providing attitude sensing and reaction wheels and thrusters providing attitude control and momentum management. During aerobraking passes the spacecraft is passively stabilized with rate control. Computing is integrated with the C&DH computer.

The Command and Data Handling subsystem is provided by JPL's MSAP, which uses a RAD 750 computer. The MSAP program will also deliver the core flight software. A separate solid-state recorder provides 512 Gbits of data storage.

The MSAP program will also deliver the Power subsystem electronics. Power is generated by triple junction solar cells mounted to a 2 wing solar array with 3 panels per wing. Energy is provided by Nickel Hydrogen batteries sized for science operation during worse case eclipse periods of 42 minutes.

The Telecommunications subsystem included in the reference spacecraft concept provides Ka-Band and X-Band deep space communications with Earth and UHF in-situ communications with other assets at Mars.

The *deep space* link would include first Mars operational Ka-Band usage, after the MRO Ka-Band demonstration. The Ka-Band system uses 35 W TWTAs and a fixed 2.5m HGA. The project is considering a possible addition of a 200 W Ka-Band TWTA to be included as a technology demonstration. The X-Band system uses 100 W TWTAs, a separate 2.5m gimbaled HGA and 2 LGAs. A pair of Small Deep Space Transponders support both X and Ka-Band. The MSO Ka-band deep space link is capable of supporting data rates between 0.5 and 10 Mbps in Mars orbit, depending on Mars-Earth distance, which translates into more than 10 Gbits of data returned per nominal DSN pass.

The *UHF relay link* for in situ communications would use on-board Electra radios with a fixed omni antenna. The UHF link supports data rates up to 2 Mbps depending on the elevation angle and the slant range from the lander to the orbiter. The higher data rates than those achieved by previous Mars missions, and improvements in the UHF antenna gain result in data volume per an in-situ pass of the order of 500 Mbits, depending on link geometry.

6. Operations Scenarios

MSO operations are planned considering the science objectives, instrument operations constraints, spacecraft capabilities and ground operations resources.

Operations scenarios are high-level description of spacecraft, and instrument operations in the performance of specific mission objectives. Operations scenarios are identified early in the conceptual phase to aid in the identification of capabilities required to satisfy the mission objectives. These capabilities include spacecraft resources for instrument operations and ground capabilities for planning and data processing. This paper addresses operations scenarios during the science and relay emphasis phases of the mission.

The basic premise of MSO operations is that of continuous science during all orbits with daily communications to Earth via X-band for tracking, commanding and return of key science and engineering data. The exception to continuous science is one Ka-band communications session every seven days to return the bulk of data collected during the previous six days. During this weekly Ka-band communications, the spacecraft is maneuvered such that no science observations are possible.

Continuous science, during appropriate science viewing opportunities, consists of global measurements of atmospheric dust and ices (Visual and Infrared instrument),

global surveys of albedo changes (WA), measurements of specific atmospheric signatures including water as well as temperature distribution and wind speed (Wind instrument), measurements of the vertical distribution of trace gases during Sun occultations (Trace Gas instrument) plus high resolution imaging to support scientific and landing site surveys for future missions (Hi-Res).

MSO is also capable of providing relay support to other Mars missions without interruption to science observations. Real time relay (bent-pipe mode) operations are possible when the spacecraft is not occulted from Earth and DSN is tracking the spacecraft.

Operations constraints and assumptions

(1) Trace gases observations require a quiet spacecraft, no articulations or mechanical action that may introduce vibration are permitted.

(2) The trace gas experiment requires cooling, and the passive thermal radiator assumed in the MSO configuration, prohibits the Sun, Mars or any spacecraft surface viewing by this radiator

(3) High-resolution imaging also requires a quiet spacecraft and alignment of the camera with ground-track to allow push-broom images.

(4) Instrument Operations is time multiplexed due to resource sharing and incompatibility of operating modes.

Scenarios

Operations Scenarios are groups of compatible science and engineering activities.

A turntable carries instruments that perform observations while nadir pointed. The turntable counter-rotates to null out the effects of continuous spacecraft yaw steering. These instruments operate continuously every orbit, except when the spacecraft turns to perform other functions.

Other instruments operate when observation opportunities are present, e.g. Sun occultations or surface targets.

For efficiency of operations, compatible scenarios are combined for execution during one revolution of Mars, and this is called an orbit "type".

Sample orbit types may include:

Type A - Continuous science by turntable mounted instruments (WA, Visual/infrared and Wind), one or two Sun occultation observations by the trace gas instrument. This orbit may also provide X-band communications and support "bent-pipe" relay with no interruption of science observations. (Figure 7)

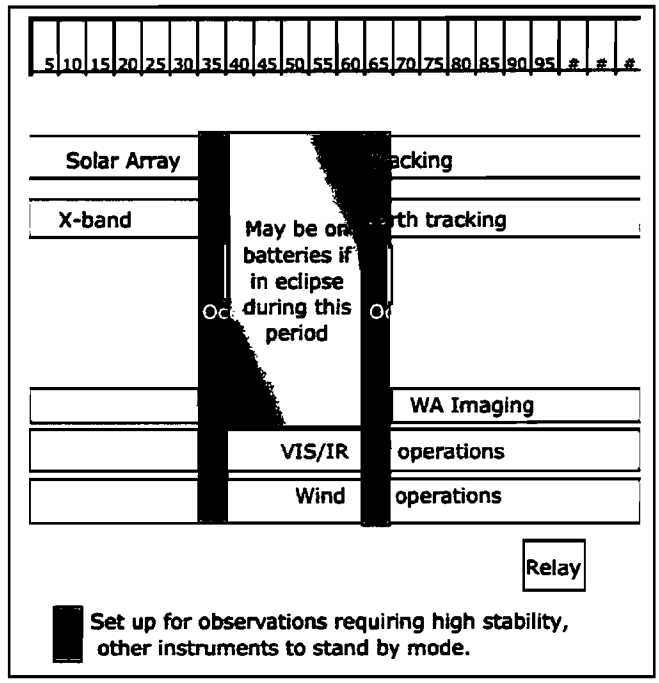


Figure 7 - Type A Orbit

Type B - Continuous science by Wind and Visual/infrared instruments, one or two Sun occultation observations plus a Hi-Res image. This orbit may also support relay communications with a surface spacecraft for data relay to Earth at the next available Earth tracking opportunity. (Figure 8)

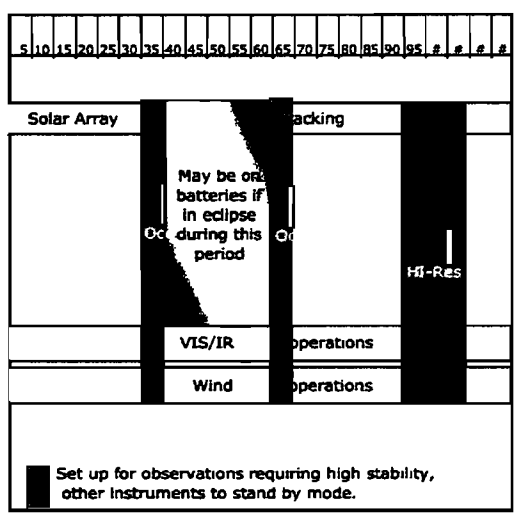


Figure 8 - Type B Orbit

Type C - Ka band communications orbits when spacecraft fixed antenna is pointed at Earth and no science observations are possible.

Other types may be defined when Sun occultation observation opportunities are not available.

During a typical day of operations, approximately thirteen revolutions around Mars, a variety of orbit types are executed based on the observation opportunities and operations assumptions.

A week in the Life of the Mission best depicts the general concept of MSO operations. (Figure 9)

Science is continuous for six out of seven days. Daily non-interfering X-band communications occur during four orbits, relay support is also available during this period. This communications session includes key science and engineering data for monitoring the health and safety of the spacecraft and science payload plus science data for quick look assessment.

The seventh day includes an interruption of science observations in order to turn the spacecraft to point the fixed Ka antenna to Earth (Type C orbits). This communication transmits all the data stored during the previous six days in the spacecraft solid-state recorder.

Figure 9 figure should go across both columns on this page

7. CONCLUSIONS

This wraps up the current concept design. The MSO requirements remain fluid, and the current MSO proof of concept may undergo substantial changes. The science goals are being expanded and possibly revised by the Science Design Team and the Mars Program is developing its plans for the decade and beyond. MSO has developed a number of alternate concepts in response to "what-if" queries in the past. Some of the earlier questions that MSO responded to pertained to hard-lander payloads, Mars Sample Return support capabilities, and technology demonstrations. The actual NASA Mars plans may substantially change the current concept.

ACKNOWLEDGEMENTS

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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BIOGRAPHY

Marie Deutsch *leads the MSO project system engineering task at NASA Jet Propulsion Laboratory. As a mission architect Marie has developed proposals and advanced concepts for the Mars Program since 2001. She has managed Operations Systems and delivered ground software and processes for VGR, GLL and Cassini. Marie has also extensive experience in systems engineering on a variety of space missions and at the project level on the SPITZER mission. Marie has a M.S. in Physics from Grenoble, France, and in Geophysics and Space Science from University of California, Los Angeles, as well as an EMBA from Claremont Graduate University where she is a PhD candidate in Strategic Management.*

Fernando Abilleira *is an aerospace engineer at the NASA Jet Propulsion Laboratory. He holds a B.S and a M.S. in Aerospace Engineering from Parks College of Saint Louis University. Abilleira is part of the Inner Planet Mission Analysis Group and has provided trajectory analysis, and mission design to the Mars Telecommunications Orbiter Project, Mars Sample Return and several other Mars missions. He is currently supporting the Mars Science Orbiter and Mars Science Laboratory Projects.*

David Bell

Jan Chodas *is currently the Mars Science Orbiter Project Manager at JPL. Previously, Jan was the Manager of the Systems and Software Division. Jan's contributions on the Mars Exploration Rover Project include managing the*

rover flight software deliveries during the development phase and managing the post-landed software developments after the rovers landed successfully on Mars. Prior JPL assignments include managing the Mission Software Systems Section, Flight System Manager for the Space Interferometry Mission, and managing the successful deliveries of the attitude control subsystems for both Cassini and Galileo. Jan received her BASc and MASc degrees in Aerospace Engineering from the University of Toronto. She is the recipient of the NASA Exceptional Service Medal, the Exceptional Achievement Medal and the Outstanding Leadership Medal for her work on Galileo, Cassini and MER respectively.

Chad Edwards

***Corey Harmon** is a member of the Mars Concepts Group in the Mission Systems Concepts Section at the Jet Propulsion Laboratory. She has been a member of JPL's Advanced Project Design Team and has supported the systems engineering teams on several NASA space mission proposals. She has been a member of the MSO systems engineering team since October 2006. Corey received her B.S. in Aerospace Engineering from the University of California, Los Angeles, and is currently pursuing her M.S. in Astronautical Engineering at the University of Southern California.*

***Stuart Kerridge** originally hails from Norfolk, England and has been with JPL since November 1977. Most of his engineering career has been in the advanced studies area with occasional forays into line management and program office positions. He is currently leading a study for a potential New Frontiers proposal as well as the mission design efforts of the 2013 Mars Orbiter mission.*

***Robert Kinsey** is a Senior Project Engineer with the Aerospace Corporation, where he has worked since 1983. He holds a Ph.D. in Aerospace Engineering awarded by UCLA in 1991. His expertise is in spacecraft dynamics and control. He has provided technical support for a variety of DOD space programs and NASA flight projects in all phases of development and operations. Dr. Kinsey has led and participated in hundreds of concept design studies of the NASA/JPL Advanced Projects Design Team (Team X). He is currently providing system engineering support for Mars Science Orbiter flight system trades and design option studies.*

***Tom Komarek** leads the concept development for the Mars Science Orbiter at NASA/Jet Propulsion Laboratory (JPL) in Pasadena, CA. His previous work at JPL included project formulation for Mars Telecommunications Orbiter, laser communications, and autonomous navigation. During his tenure at JPL, he also managed the spacecraft radio and antenna section which developed telecom systems for Mars Pathfinder and Cassini missions, among others. His interests and work also include ground and spaceborne radar and radio science investigation. Tom has a BSEE and MSEE degrees from the Czech Technical University in Prague, and an advanced engineering degree from the Technical University of Delft, The Netherlands. He is member of IEEE, AIAA.*

***Doug Lisman** is a system engineer in the Mission Systems Concept section at JPL. He received a B.S. degree from Washington University in St. Louis. He currently serves as the Flight Systems Lead for the Mars Science Orbiter project. Previous projects at JPL include Galileo, NASA Scatterometer, QuikSCAT, Solar Probe and Terrestial Planet Finder.*

***Saturnino Lopez** is a senior member in the Systems Engineering Section at JPL. He received a B.S. degree in Electrical Engineering from the University of Southern California in Los Angeles. Previous assignments include support in development of mission proposals, end-to-end information systems engineering and support of Project operations for VGR, GLL, Magellan and Genesis.*

***Karen Willacy** is a research scientist in the Astrophysics and Space Plasmas Group at JPL. Her research focuses on the chemistry of star and planet formation, and astrobiology. She received M.Sc. and Ph.D. degrees from the University of Manchester, England. On the Mars Science Orbiter project she is supporting the work of the study scientist.*

Daniel Winterhalter

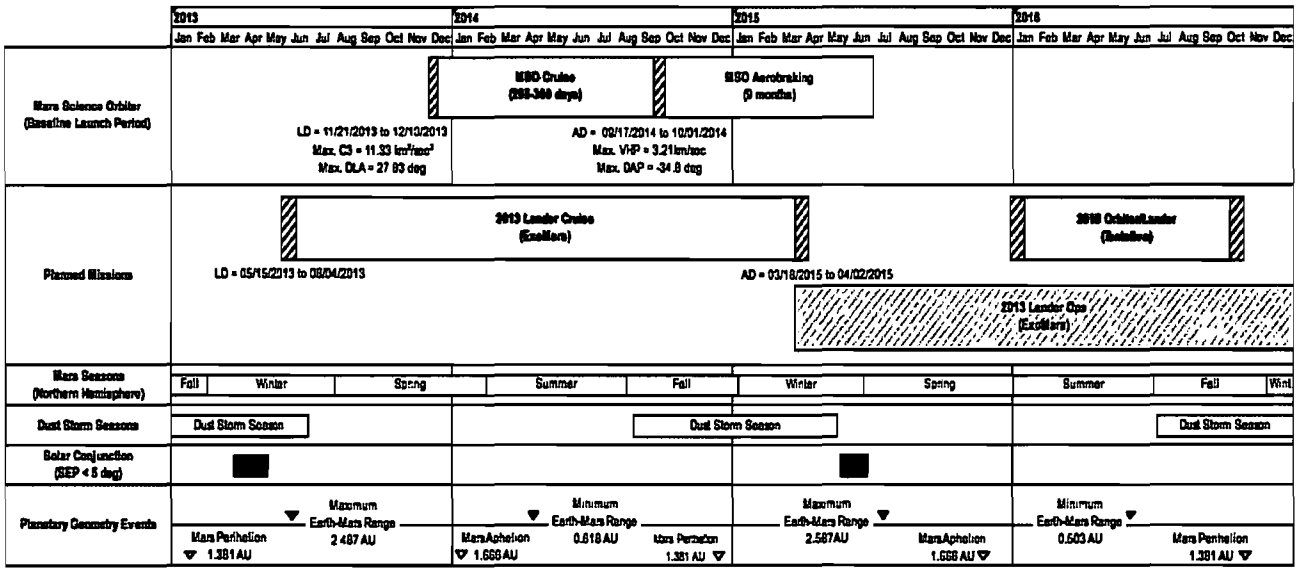


Figure 1 – MSO Mission Timeline depicts the key geometric events and other missions expected to be present at Mars during MSO's operations time frame

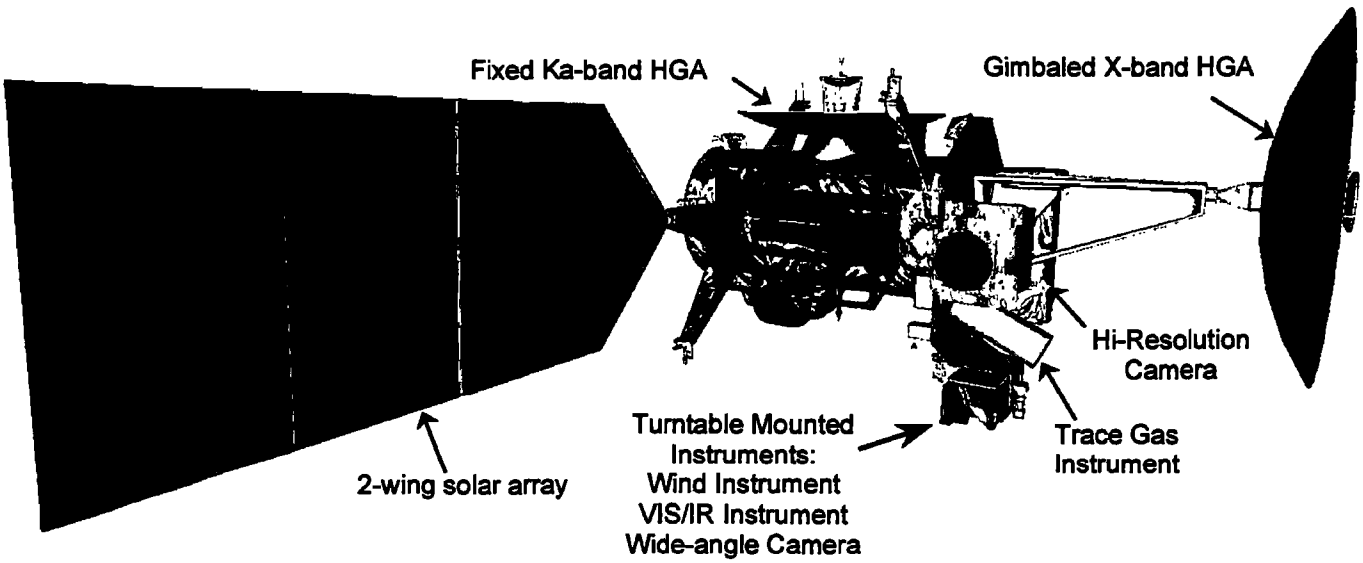


Figure 6 – MSO Configuration

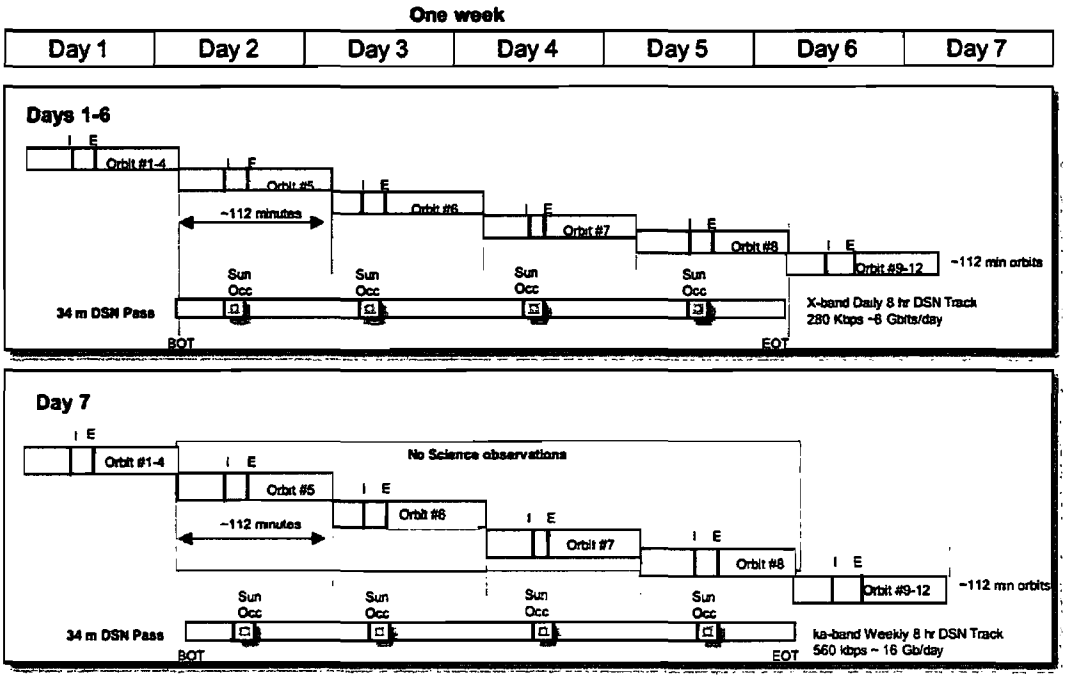
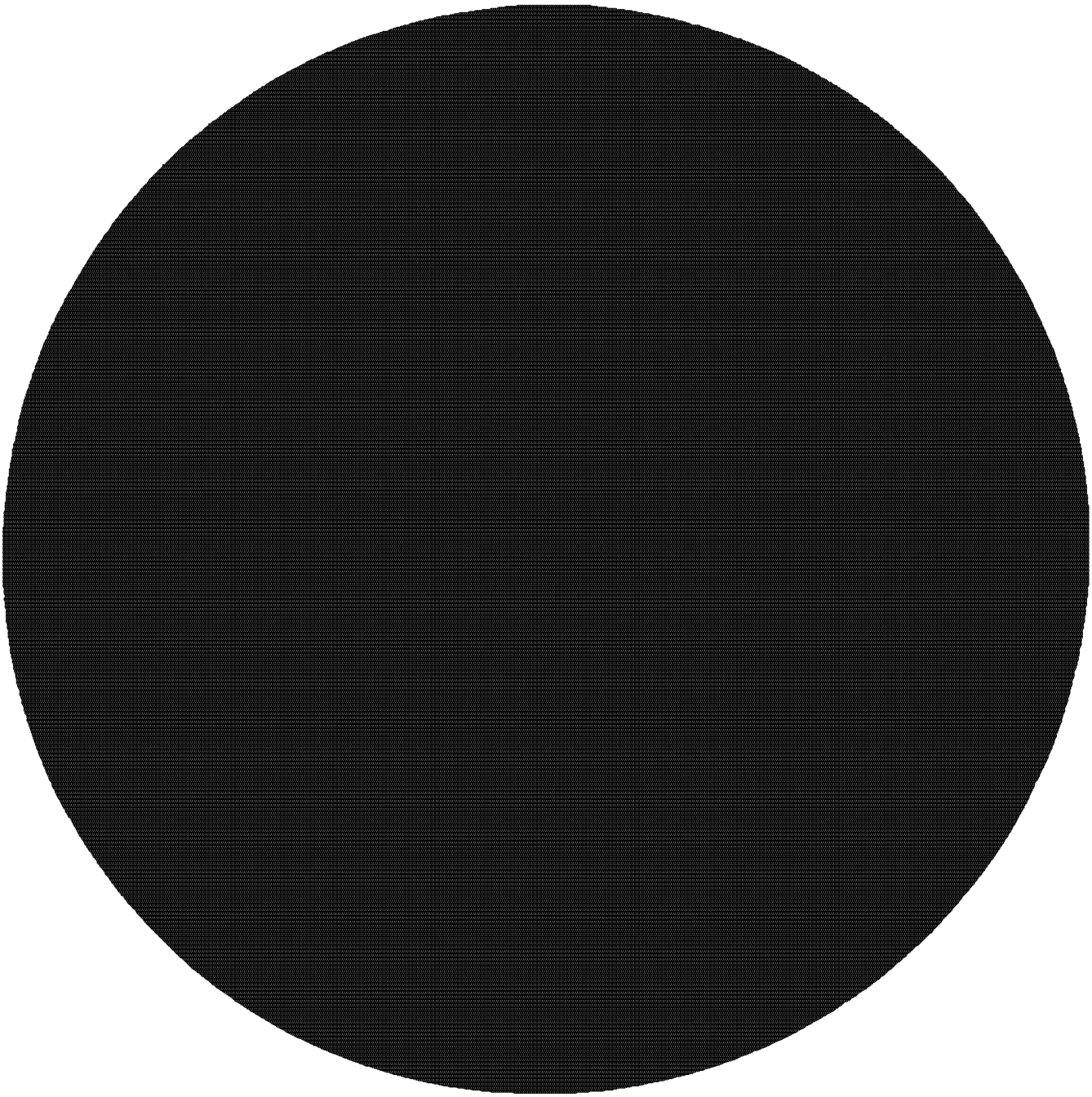


Figure 9 – Week in The Life of MSO Mission

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