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MARS TELECOM ORBITER MISSION OPERATIONS CONCEPTS

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ABSTRACT

The Mars Telecom Orbiter (MTO) relay capability enables next decadal missions at Mars, collecting gigabits of data a day to be relayed back at speeds exceeding 4 Mbps and it facilitates small missions whose limited resources do not permit them to have a direct link to Earth. In addition MTO performs significant technology demonstrations for the Laser Communication Demonstration and the Orbiting Sample Detection. This paper addresses the tall tent pole scenarios and operations concepts that drive the design and operation of MTO. The relay concept explores a "week in the life" of MTO. We address the steps required to execute the technology demonstrations, the commissioning of the flight system, and the critical events. And finally we cover the operations architecture. The concepts and scenarios define the mission in a more realistic setting and support the formulation of the requirements, interfaces, design, plans and cost.

KEY BENEFITS TO THE MARS PROGRAM

MTO is the first interplanetary communications satellite and adds a node to the current Mars Network, which consists already of several science orbiters with relay radios. The Mars Network provides important communication and navigation services to missions at Mars. Two general classes of Mars missions are served by MTO. The MSL-class is large missions like Mars Science Laboratory (MSL) or Mars Sample Return (MSR) with significant capabilities and a huge need for data return. The Scout-class is smaller orbiter, lander, rover, balloon or airplane missions, typically with stringent mass and power limitations.

In addition, MTO serves as a carrier for NASA technology demonstrations including the Laser Communication Demonstration (MLCD) and the Orbital Sample (OS) Canister location finder and tracker.

Increased Science Data Return from Large Landers.

MTO increases the amount of data returned from large landers and rovers by one to two orders of magnitude. This huge data volume is made possible by MTO's high orbit, its X-band relay, its steered relay antennas and its high-performance Ka-band link to Earth.

Improved Coverage

A high orbit optimized for data relay allows Scout-class missions to communicate with MTO when convenient rather than having to design their missions around short, infrequent communication contacts with low altitude polar science orbiters. This significantly improves flexibility at Mars and is mission enabling.

Due to power limitations, Scout-class missions generally only send little data to Earth directly. MTO enables these missions to relay large volumes of data with minimal energy expenditure and without the burden of a large steered antenna. Future missions can choose to communicate only through MTO and save significant mass, power and complexity.

Critical Event Tracking

The Mars Exploration Program requires tracking and telemetry coverage of all critical events such as Mars Orbit Insertion (MOI) and Entry, Descent and Landing (EDL) in the case of landers. Again MTO's orbit is much better placed for critical event coverage than low altitude polar science orbiters. This greatly reduces design constraints on missions requiring critical event coverage. In some cases, critical event coverage can only be provided through MTO. MTO extends coverage (hours rather than minutes) of long-term critical events like aerobot flights or rover traverses.

Precision Navigation

MTO greatly improves our ability to accurately determine the position of rovers, aerobots and landers. Only MTO can track movement over long periods of time. MTO will also be able to track spacecraft approaching Mars.

Laser Communications
MTO will be the first mission to demonstrate laser communications across planetary distances. This could lead to a quantum leap in the amount of data that can be sent from Mars and other planets in the future.

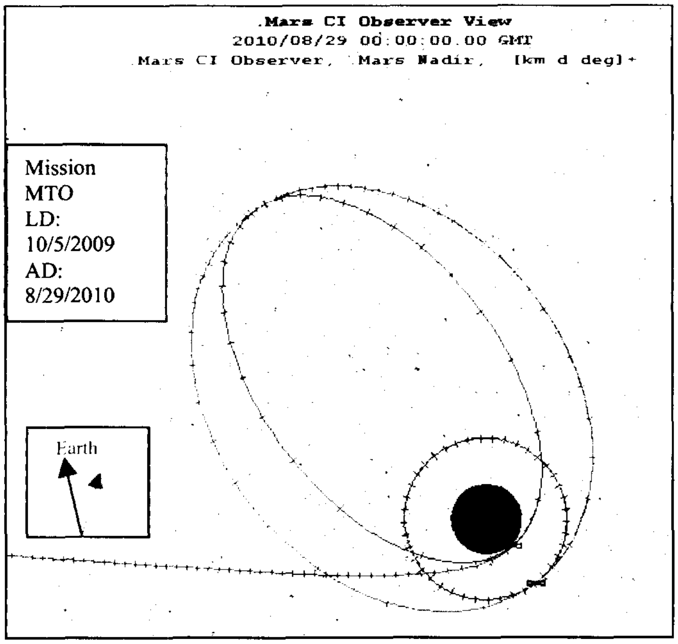

Figure 1. Orbit Transition from arrival to 4450 circular sun-synch for MTO

Type II trajectory Earth-Mars
MOI into 250 km periapse alt. x P=1 sol orbit
Raise periapse to 4450 km
Lower apoapse to 4450 km

Final Orbit:
450 x 4450 sun-syn

Public Engagement
MTO responds to a public expectation of high quality data and images from scientific missions to Mars. MTO's unique extended coverage capability enables a "virtual presence" at Mars. Students could guide a rover on the surface of Mars and see the results of their guidance in less than an hour.

Link	Direction	Power	Data Rate Range
Direct to Earth			
LCD	up/down	4 W	3-100 Mbps
Ka-band	down	35 W	.5- 17 Mbps
Ka-band	down	100 W	1.6 - 51 Mbps
X-band	up/down	100 W	.4-6 Mbps
Proximity Link			
UHF	forward/return		256 kpps
X-band	return	15-20 W	10 Mbps

Table 1. Link capabilities of MTO. *MTO carries a laser communication flight terminal, two RF links X-band and Ka-band for communication back to Earth and a UHF and X-band proximity link to communicate with the Mars missions.*

MISSION BACKGROUND
The MTO spacecraft is launched in September 2009 into a type II Earth - Mars trajectory from an Atlas V launch vehicle, arriving in August 2010 at Mars. Mars Orbit insertion (MOI) is performed at 250 km periapse. (Figure1) The orbit is elliptical at first but is circularized to a 4450 x 4450 km sun synchronous orbit, with an inclination of 130 degrees and a period of 5.8 hours. The orbit being "high" and non-"equatorial" lends itself well for relay coverage of assets at Mars. The orbit accommodates both equatorial and polar landing sites.

MSL launches in the same launch window opportunity than MTO and arrives approximately thirty days after MTO at Mars. MTO is providing link capabilities for MSL approach and EDL.

The spacecraft will be procured on a competitive basis from industry. The reference spacecraft calls for a basic bus serving the relay needs of the mission.

The relay links are defined by the Electra transceiver package containing both UHF forward/return and the X-band return. (Table 1) The UHF and X-band proximity antennas are located on a deployable, sterrable platform. The Earth links are secured by an X-band up/down a Ka-band downlink and a 3 m non-steerable High Gain Antenna (HGA) and Low Gain Antenna. (LGA)

The attitude control is primarily adjusted via reaction wheels. MTO features a body fixed HGA and fixed solar arrays. The camera and relay antenna platforms have a single degree of freedom.

Rolling the spacecraft about the HGA boresite provides the second degree of freedom. The monopropellant propulsion system is used for delta-V's, detumble, and desaturations. No aerobreaking is required at Mars. The payloads are broken into the Laser Communications Demonstration package, the narrow angle camera, the Orbiting Sample Demonstration canister and possibly science. The operational concept that served as the initial baseline for this mission assumed that the simultaneous operation of payloads is not required with the exception of the MLCD and RF operation. may function longer than anticipated, are not excluded from the concept.

After Launch and spacecraft checkout, the flight system, including the relay links are commissioned. The Laser Communication feasibility is conducted in cruise with the goal of being ready for demonstration at Mars. The Camera and the orbit sample detection algorithms are checked out in cruise as well. Within a month after MOI, MSL arrives at Mars. MTO supports MSL EDL and starts the relay service function for MSL and other missions. All activities are done on a non-

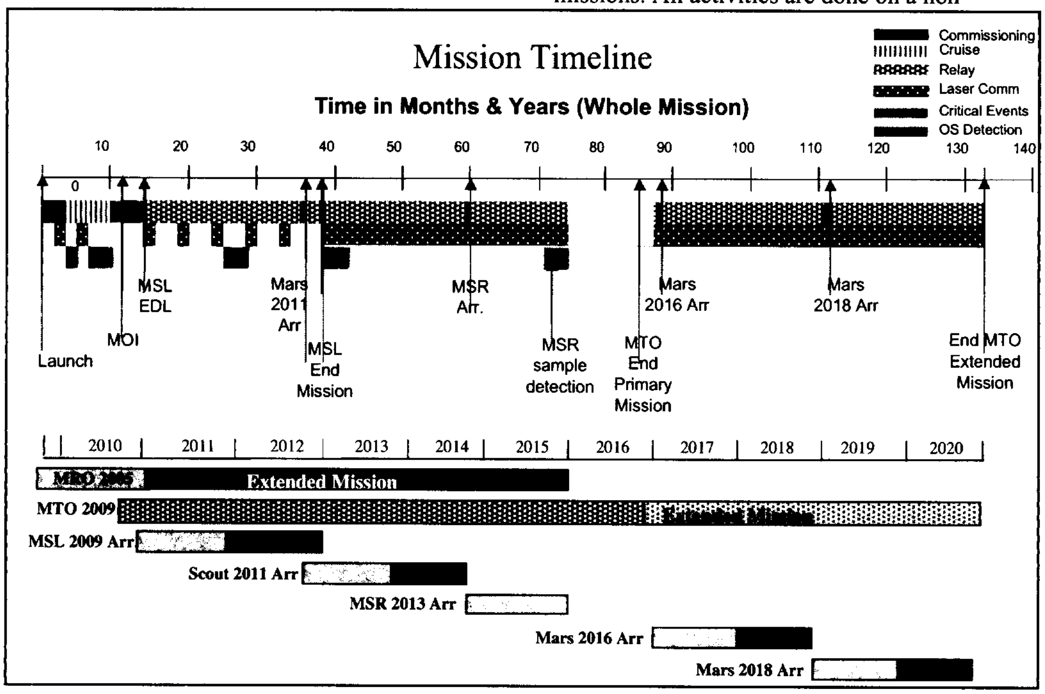

Figure 2. MTO Mission Timeline and Potential Mars Missions through the 2020 Launch Opportunity

On-board data storage needs are significant in order to accommodate the data quantity and return quality

Standard fault protection will put the spacecraft into safe mode, should a fault condition arise. While in safe mode, the solar arrays stay sun pointed at all times and the spacecraft relies on the LGA 10 bps link to communicate to Earth.

The mission timeline is depicted in Figure 2. MTO's primary mission in orbit extends from August 2010 through 2016. The extended mission goes through 2020. The mars missions that will be operational at Mars and are potential MTO customers are the extended MRO mission, MSL, a scout opportunity in 2011, MSR 2013 and further undetermined opportunities in 2016 and 2018. ESA missions and older NASA missions to Mars that

interfering basis. After the MLCD flight system is well understood or MLCD is proven to be non-interactive with the relay activities, the laser link is going to be used on a regular basis.

IMPORTANCE OF EARLY CONCEPT & SCENARIO DEVELOPMENT

On MTO, the process of establishing capabilities and requirements is accomplished through the use of scenarios and operations concepts. Scenarios describe in detail the steps to be accomplished for a given event at a given instance during the mission operations phase. By "walking" through each step in the process and "visualizing" the execution of the activities, it becomes quickly evident what capabilities and interfaces are needed to meet the desired goals. The scenarios address foremost the tall tent pole drivers of the mission. In the case of

MTO, those events are related to the service of relaying data from Mars to Earth. The scenario spells out the daily activities required on-board and on the ground in order to maintain the relay in a reliable way. Complexities in operations that arise for example due to limited resources, inherited flight software or inflexible design features, are identified early and dealt with through design trade studies. Thus in order to eliminate complex operations, changes to mission design, flight system, payloads or ground system are done fairly easily, since the design remains fluid at this early phase of the project.

Similarly, operations concepts delve into the operations process, describing for example a possible architecture for the end-to-end data system required to accomplish a given event successfully. Thus the project gets an insight into possible flight and ground system software architecture requirements

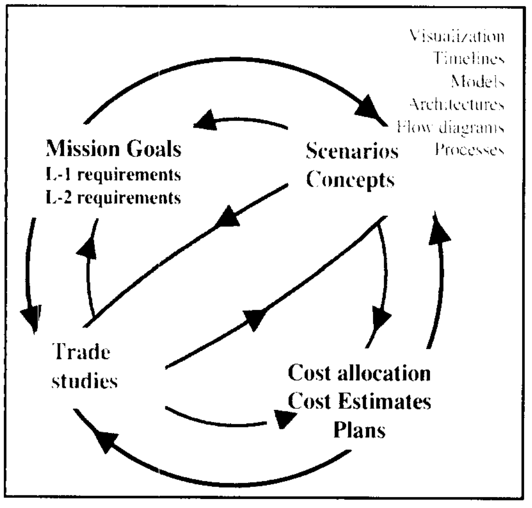

Figure 3. Iterative process, using a concurrent approach to establishing requirements, design, and life cycle cost of a space mission. *Each iteration refines the scenarios and operations concepts to meet more closely the sponsor's needs and cost allocation. When combined with trade studies across all project elements such as mission design, flight system, payloads, technology demonstrations, operations system and mission assurance, the project requirements and design converge toward a less complex, more operable, less costly and overall more reliable mission.*

Mission timelines display an integrated skeleton plan for the execution of the MLCD phases, for example. The timelines combined with the scenarios and operations concepts, including architectures, and data flow diagrams establish at a very early stage in the project development a reference design for the whole mission. The cost of the mission lifecycle can now be estimated more accurately.

Trade studies help define the least risky, and least costly design to pursue. If the mission does not fit within the cost guidelines, the project tweaks the scenarios and concepts, frequently weeding out niceties from basic requirements. It is not unusual for such iterations to spark brainstorming of new and innovative ways of designing the mission. This iterative process between requirements, concept, cost, and trade studies is a concurrent engineering process that ensures that the planned mission is achievable within a set of constraints. (Figure 3)

OPERATIONS PHILOSOPHY

The underlying philosophy for MTO flight operations is that it should be made as simple as possible. MTO will, therefore, use heritage operations systems and processes currently used in Mars Orbiter operations at JPL This provides a low-cost, low-risk approach to mission operations and synergy with the current Mars Orbiter missions at JPL.

MTO Mission Operations System (MOS) and Ground Data System (GDS) will be an evolutionary extension of existing institutional capabilities, based on operations experience with past and current Mars missions. MTO MOS/GDS will use core data system capabilities supplied by the JPL Deep Space Mission System (DSMS) and the multi-mission operations infrastructure provided within the JPL Mission Management Office (MMO). The institutional capabilities made available by DSMS and MMO have been used extensively on the currently operational Mars missions Mars Global Surveyor (MGS) and Mars Odyssey as well as on the Mars Reconnaissance Orbiter (MRO) Project, which is currently in the development phase. These capabilities have also been used extensively on the Discovery missions Stardust and Genesis, which are operated jointly by JPL within the MMO framework. The heritage capabilities will require only limited modifications to support the MTO mission. Much of the MTO unique operations and GDS development will be in the area of UHF operations and MLCD

MTO CRITICAL EVENTS

The period of time between launch and arrival at Mars is known as cruise and is characterized by a number of critical spacecraft events, as well as checkout and calibration of various subsystems and payloads. Key critical events are the four trajectory correction maneuvers (TCMs) performed to adjust the spacecrafts interplanetary path to insure arrival at the proper aim-point, and the Mars Orbit Insertion (MOI) maneuver, which reduces the spacecraft velocity to allow capture into Mars orbit. Approximate relative times for the TCMs are as follows; TCM-1 = L + 10 days; TCM-2 = L + 60 days; TCM-3 = L + 250 days (MOI – 60 days); TCM-4 = MOI – 12 days.

The number of calibrations and checkout activities performed during cruise can be extensive so this section will focus on those that are more unique to the MTO mission. Shortly after launch, the boom containing the gimbaled proximity antennas will be unlatched and deployed into its nominal operating position. Because MTO must be prepared to support critical MSL functions upon MSL arrival, which occurs approximately 30 days after MTO arrival, it is desirable to check out as much of the Electra subsystem as early as possible. Opportunities exist to communicate using both the forward and return UHF links with ground receive stations at Stanford University during the early cruise period. Performing these tests at this time will give the flight team ample time to investigate any anomalies that may be discovered.

Additionally, the plan is to conduct some of the preliminary tests of the MLCD payload during the early part of the cruise phase. As the spacecraft will not be supporting any other payload activities, the operation of the MLCD payload can be characterized without risk of interference to other mission critical activities. Also, the short 2-way light time during this early cruise period facilitates the "ground-in-the-loop" approach planned for the initial commanding of the payload. Gaining an early understanding of how the payload interacts with the spacecraft will aid the flight team in preparing for nominal operations upon arrival at Mars. Additionally, if these early tests are successful, it should be possible to achieve some of the MLCD objectives during the remaining cruise period.

Much of the activity in the month prior to Mars arrival is focused on preparations for MOI. If it has not already been done, it is desirable to perform one of the remaining TCMs using the spacecrafts main engines as a MOI maneuver functionality and critical sequence test. For approximately 2 weeks prior to MOI through 2 weeks following, the spacecraft observes a "no activity" period. The period prior is enforced to ensure unperturbed MOI preparations and critical sequence loading, verification and execution. The period post MOI is reserved to ensure adequate time to assess and recover from any anomalies that might have occurred as a result of this mission critical event.

Finally, approximately 30 days after MTO arrival at Mars, MSL arrives and begins its atmospheric entry and descent to the surface (EDL). During this period, MSL will transmit critical engineering data via a pair of antennas characterized by a hemispherical radiation pattern. MSL will transmit out of whichever antenna is pointing in the direction of the MTO spacecraft. MTO will receive these critical event data through its UHF proximity link. The EDL period lasts for approximately 10 minutes, during which data will be received at a rate of 2 kbps.

LASER COMMUNICATIONS DEMONSTRATION CONCEPT

The MTO Laser Communications Demonstration (MLCD) will demonstrate optical communication between Mars and Earth and thereby gain the knowledge and experience base that will enable NASA to design, procure, and operate cost-effective future deep space optical communications systems. The demonstration will last through one Earth year on orbit at Mars. First the MLCD will demonstrate that the spacecraft, optical flight terminal and ground terminals can point to the accuracies required to establish the communications link. Specifically, this demonstration will show a link from Mars to Earth at a minimum of 1 Mbps under nominal conditions over the duration of the Demonstration. There is a goal of at least 30 Mbps at some time during the demonstration. The demonstration will also address operability issues such as predefined sequence operation, link set up and tear down, and weather mitigation techniques. Since MLCD will fly on MTO, their operations are intimately intertwined. Note that navigation functions using the optical communications system are not a part of the MLCD.

The flight terminal, with a mass of roughly 70 kilograms, will contain a 30-centimeter telescope, a 5-Watt average output laser, and an inertial reference subsystem. The total power consumption of the payload is expected to be on the order of 130 Watts. A high performance stabilization and pointing subsystem will be implemented through the use of passive stabilization and active tracking of an uplink beacon. The flight terminal will be capable of providing data rates between 10 kbps and 100 Mbps. The actual rate supported on the link will depend upon the instantaneous distance between Mars and Earth, the equivalent aperture size of the receive terminal and weather/atmospheric conditions. A 30 Mbps data rate will be a ten-fold improvement over current RF systems and will be largely due to the use of efficient signaling, detection architectures, and near-capacity achieving error-correcting codes.

The ground terminal(s) provides both receiving and uplink beacon transmission functions though potentially from physically separate terminals. The team is investigating the use of existing astronomical telescopes as well as the development of new apertures, either single large apertures or arrays of smaller apertures. The equivalent aperture diameter could range from 1 to 10 meters depending upon the data rate to be supported. The current plan is to have at least one ground terminal capable of operating with Sun-Earth-Probe angle as low as 3 degrees to minimize the outage around superior conjunction and with an equivalent aperture diameter of 5-10 m. If affordable, multiple ground terminals will be deployed to demonstrate weather mitigation and other operations strategies Critical technologies for receiving the deep space signal include low-cost large collection apertures and low-noise photon-counting detectors. Transmitting an uplink beacon through the turbulence in the atmosphere will be accomplished by using multiple simultaneous beams.

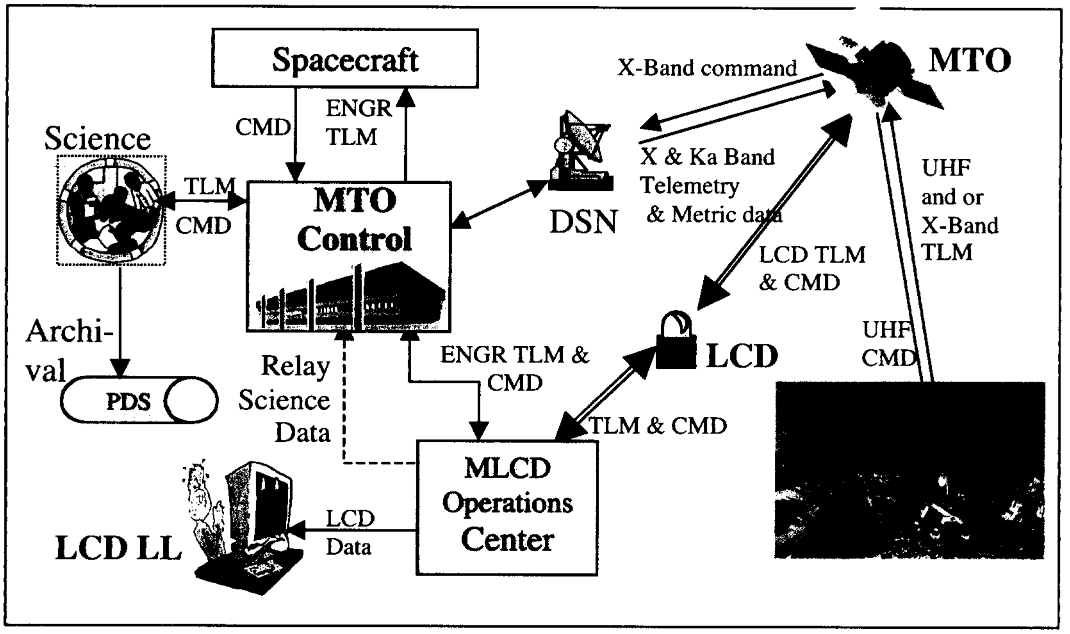

Figure 4. MTO Mission Operations System Architecture.

As depicted in Figure 4, the mission operations for MTO and the MLCD are intimately intertwined. The unique nature of the demo is that there is a path to and from the Spacecraft (S/C) that is outside the usual DSN. Commands for the MLCD flight terminal can be sent via either the optical uplink or via the RF uplink. There are two paths for getting engineering data, again via optical or RF. There is the telemetry path via the optical that can be used to transmit "science" data from the S/C. The MLCD Operations Center (DOC) coordinates all activities on the optical links and provides an interface to MTO operations.

The primary commanding mode for the flight terminal is via the DSN. For each MLCD pass, the desired operations (time to turn FT on/off, select data source(s), data rate, etc.) will be predefined, sent from the DOC into the MTO MSA which will package them appropriately to send to the spacecraft via the DSN. Some "real-time" commanding via this link is desired to deal with weather and atmospheric conditions, which may require changing, for example, the data rate. The second method for commanding the FT is through the optical uplink from Earth. Though this is primarily used as a beacon for pointing, acquisition and tracking, there will also be a low rate communications channel, which can pass "real-time" non-interactive commands to the FT. These commands, generated at the DOC, can change the internal configuration (data rate, etc.) of the FT but will be firewalled so that commands may be forwarded from the FT to the S/C and inadvertent interactions between the FT and the spacecraft are avoided.

On the telemetry side there are again two paths. Data (science or engineering telemetry) from the S/C can be sent from the S/C to Earth via the optical link. The selection of data, formatting, etc is done by the command and data handling system (C&DH) and the FT accesses the appropriate space in storage to extract the data, add its own internal formatting and error-correction coding, and then transmit it to Earth where it will be received by one or more terminals. The data may be the same data that is being transmitted over the RF links, albeit potentially at different rates. It is possible that the FT may add/ multiplex additional engineering data into the data stream. The flight system monitors FT parameters like power and includes them in engineering telemetry that is passed over the RF link. In addition to these, there are many 'test points" within the FT that are available and that data can be requested by the S/C and then sent via RF as part of the engineering telemetry. It is worth noting that, at least during the initial stages of the demonstration, a DSN pass must be scheduled to coincide with each optical pass to allow downlinking of the FT engineering data. Note that data received at the MLCD ground terminals will be archived locally, either at the DOC or at individual terminals, and not transmitted to the MSA. Due to the vagaries of weather and atmospheric conditions operations strategies for mitigation of these effects will be explored. One possibility would be to have multiple terminals within the same beam simultaneously receive the same data to guarantee a reasonably high percentage of the time getting through to at least one terminal. On the other hand, buffering and retransmission strategies can be used to downlink the data to single geographically (and hopefully meteorologically) diverse stations in a form of temporal diversity.

OPTICALLY FINDING AN ORBITING SAMPLE CONTAINER AT MARS

In the next decade, missions to Mars may attempt to return samples from the surface or near surface. After the sample has been gathered and launched into a low (500 km) near circular orbit, an orbiter will rendezvous with the sample container, capture it, depart from Mars, and return the sample to earth.

The first necessary step in the rendezvous will be location of the sample container (hereafter called the OS for Orbiting Sample) as soon as possible after it has been launched. One method to do that initial detection after launch from the surface is by using a visible light camera to detect the sunlight reflected from the surface of the spherical OS. Radio systems either in the OS itself or on a stage of the launch rocket may also be used but the passive optical approach described here can detect the OS even if all radio contact is lost

The OS may be about 20 cm with a reflectivity of about 0.5. Calculations have shown that sufficient signal exists to detect the OS from the sample return orbiter. In addition, simulations have also shown that a camera on the MTO orbiter could also capture enough photons to allow detection and tracking of the OS. Current plans are for the MTO orbiter to carry at least one and possibly two 6 cm aperture cameras to be used to detect the OS as a backup to the cameras on the prime sample return orbiter. The MTO cameras can also be used to perform precursor proof-of-concept sample detection experiments before the sample return mission itself is launched. Important factors to test would be the effects of scattered light from Mars or from the possible dust in the upper atmosphere (higher than 100km altitude).

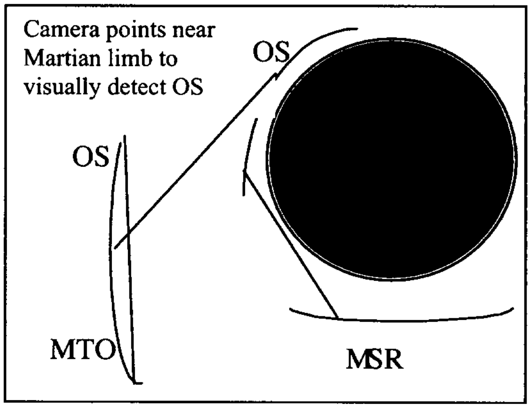

Figure 5. Basic Concept for OS-finding Demonstration

Te optical detection of an OS has been studied under the assumptions that the altitude is bounded (between about 450 km and 550 km) and that the orbital inclination and node are known to within about one degree. However the position of the OS along the orbit track is assumed to be unknown.

For any position of the sample return orbiter, small mosaics using the camera field-of-view are scheduled if the signal-to-noise ratio of the OS signal would be expected to exceed some modest number such as 3-5. Recall that the OS's longitude is assumed unknown, so the sequence design process on the ground will have to use the known orbiter's position to examine all possible observable positions of the OS and compute the SNR at that time. There are only a few useful positions to point at and those typically occur when the OS is near the terminator because the scattered light from Mars is minimized at that location. (Figure 5) The searching may occur for only about one hour in each MTO orbit.

The picture sequences would typically be planned on earth and uplinked to the orbiter. As many as 3 or 4 pictures may be taken per minute when the favorable SNR conditions are thought to exist. Full frames will in general not be returned, but the frames will be searched in the spacecraft computer for candidate images above an SNR and the local patches around those candidates will be downlinked. The data volume will be about 5 gigabits per day. The search time from the MTO orbit may need to be as long as several weeks to provide a high probability of capture.

RADIO NAVIGATION SERVICES

MTO greatly improves our ability to accurately determine the position of rovers, aerobots and landers. Only MTO can track movement over long periods of time. MTO will also be able to track spacecraft approaching Mars and provide search, detection, and orbit determination of low power radio beacons proposed for Mars sample return during orbital rendezvous.

A fundamental component of the MTO's navigation services include collection of radiometric tracking data on links between MTO and a user, which might include a surface asset, another orbiter, or an approaching/landing spacecraft. Initially, this data will be post-processed at Earth to determine positions or trajectories of user vehicles. Later, these services could be expanded to include in-situ processing since MTO carriers the Electra reconfigurable transceiver that has its own processing unit.

Electra is currently in development and is being designed for dual use as a communication and radiometric tracking device. It will also reside on other Mars network elements and its users[3]. The first network element to carry Electra is the Mars Reconnaissance Orbiter (MRO) that will launch in 2005. The Electra design currently includes the ability to formulate and collect 1-Way and 2-Way coherent integrated carrier phase data (which can be converted into equivalent Doppler data). Another capability, useful for critical events or scenarios with very low signal-to-noise ratios (SNRs), is open loop recording of a selected frequency band. The recorded data is sent back to Earth for signal processing to extract phase and/or Doppler data. The reconstructed data is, by definition, 1-Way, and can be processed like other 1-Way radiometric data. Since Electra's radiometric tracking capabilities are implemented in software, it will be possible to add other radiometric tracking data types (such as ranging using a pseudo-noise sequence) in the future and update even existing Electra transceivers already at Mars.

The navigation services that are supported by MTO fall into several categories and include the following:

1. Position determination of a Mars lander or rover;
2. Trajectory determination of a Mars approaching spacecraft
3. Orbit determination of a Mars orbiting spacecraft;
4. Trajectory determination of a Mars landing spacecraft during its entry, descent, and landing.

"WEEK IN THE LIFE"

A "Week in the Life" is a high-level plan that mimics the events that occur during a week's of operations both on-board the flight system as well as on the ground and in a coordinated manner. The week in the life selected needs to be representative of a typical week of operation during the prime mission, a week during the early relay part of MTO. This type of scenario is essential to understand the interaction of on-board events that must take place in order to meet the relay requirements and other planned activities such as flight system calibrations, the laser communication demonstration events, and the orbiting sample detection activities.

Drivers

The on-board events are primarily driven by MSL requests for relay coverage, measured in the data return quantity, quality and latency. MSL in turn is driven by the daily surface activities at Mars. Every sol MSL needs new instructions to perform its daily science experiments and engineering traverse activities. The high volume of data generated requires multiple X-band relays with MTO. The MSL data is divided into high priority data, necessary for scientists and spacecraft analyst to determine the next sol's sequences on Mars and lesser priority data relayed as DSN coverage permits.

Constraints

The on-board events are constrained by the flight system design, the available on board resources, flight software capabilities, and ground resources such as DSN, workforce, and the turn-around-time. Ground turn-around-time is a function of the ground capabilities: tools, science and engineering analysis capabilities, science decision making process, risk philosophy of the project, and planning capabilities.

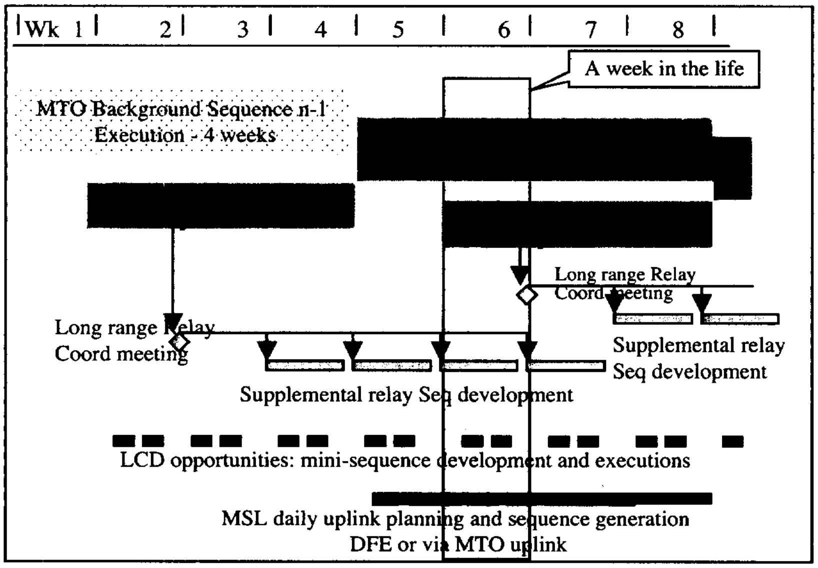

Figure 6. Operations Activity Planning Scenario on the Ground

The flight system HGA and solar arrays are fixed and point at Earth throughout the mission. The Electra platform points the UHF transceiver and X-band receiver toward the Martian asset on the surface. In order to maintain lock during the relay, the Electra platform single axis gimbal provides one degree of movement, while the spacecraft roll provides the second degree of freedom. The data flow from the Martian surface to MTO is done using the latest CCSDS recommendations for data protocols and provides the flexibility and reliability required for this type of service[2]. The data received by the flight system is stored and forwarded at the earliest scheduled DSN pass. Studies suggest 3-6 days of storage, up to 400 Gb will be required for transmission. The characteristics of the Electra limit our ability to communicate simultaneously with multiple assets at the same time, but they can be accommodated serially. Data relay to Earth is provided on a priority basis: near real time (low latency) and non-real time (relaxed latency) bulk data relay to earth. Near real time is available during scheduled DSN tracking of MTO and it is a service for high priority data; non-real time is a mode used for relaxed data delivery timeliness and it is performed following transmission of high priority data, if any, as the DSN tracking support allows.

The MLCD and OS Detection technology demonstrations are more flexible from a scheduling point of view. The MLCD flight terminal is susceptible to gimbal generated jitter, which may interfere with its accurate tracking of the ground terminal. The Camera used for the OS detection has a single gimbal too. During its operation, the whole flight system may need to roll in order to be able to track the target. Despite these constraints, there remains plenty of opportunity in the schedule to place events such that they do not interfere with each other and the MSL relay.

Capabilities

The communications link from MTO is robust enough to keep up on a sol by sol with data transmitted from a large mission like MSL and other smaller missions. It is anticipated that only one large volume mission is operational at any time during the MTO lifecycle (Figure 2). The combination of the baseline Ka-band and of the Laser communications link, when declared operational, is expected to give MTO the capability to establish a virtual presence on the surface with near real time video to support future human exploration missions to mars.

MTO also supports command file delivery to a mars asset (forward Link). The same protocols used for data handling are used for command delivery. Customer projects deliver their command files to the MTO Operations team for preparation of the properly identified files annotated with priority and relay window duration. These files are handled as non-interactive by the MTO flight system, stored onboard and relayed to the asset within the specified window. MTO is accountable for command product deliveries and it is the single point of contact to customer's data needs.

product required by the orbiters to support the scheduled assets. (Figure 6)

Operations

A day in operations begins at the start of a DSN track. A Mission Controller is the only person required during routine operations for commanding the orbiter and monitoring the ground configuration and orbiter performance.

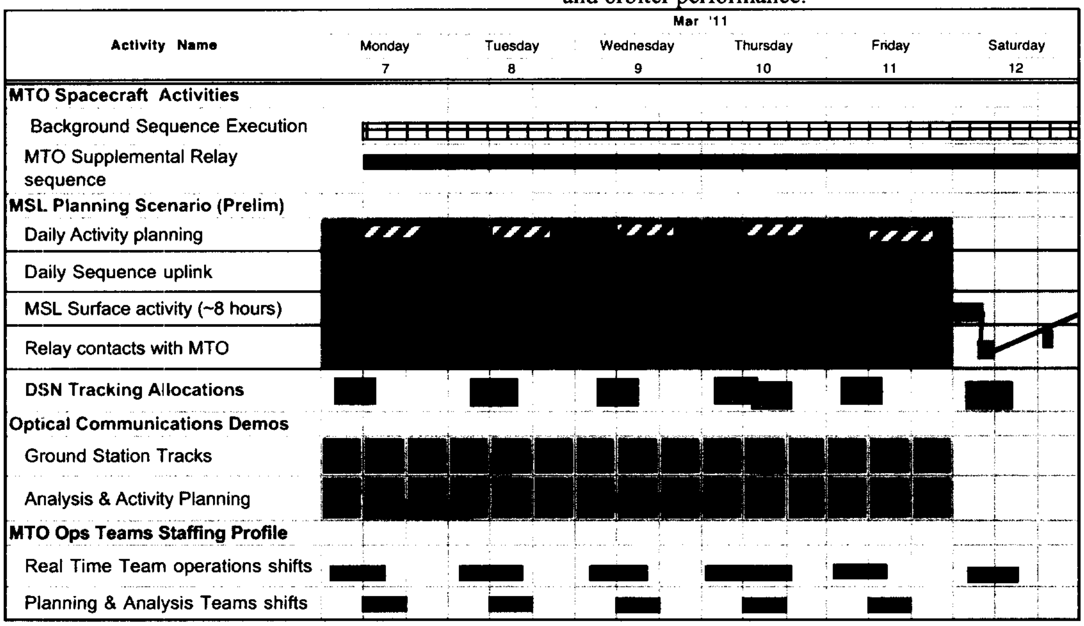

Figure 7. Integrated plan depicting both the onboard sequences for MTO and MSL and portraying MTO ground team activities as part of the "Week in the Life

Activity Planning (Figure 6 &7)

MTO executes the basic engineering functions to maintain the health and safety of the orbiter from a four-week background sequence. The development of the background sequence starts three weeks before execution to allow for latest DSN tracking adjustments.

Some events in this sequence may create exclusion zones for relay support; the relay events are executed from other programs (mini-sequences) that fit in windows of opportunity identified in the background sequence. Relay Operations Planning is a multi-mission planning activity involving the other orbiters in the relay network (possibly Odyssey, MRO and MGS in addition to MTO) and the user projects.

Planning is performed in two phases, strategic and tactical. Strategic planning is done at the end of the first week of the background sequence planning to coordinate the orbiters engineering activities over the next four-week period. The tactical planning is done weekly to generate the weekly sequence

Subsystem engineers work off line; but they may be notified immediately when a Mission Controller observes an anomalous behavior that requires expert attention.

A typical relay day during the MSL prime mission may consist of two to four contacts of approximately seventy minutes durations. A command file transfer from MTO to MSL may start the activities during the contact. At least one of the contacts occurs while MTO is also in contact with a DSN tracking station to enable high priority data relay with minimum delay. Immediately following the transaction, MTO relays all the MSL data collected during the remaining of the pass and into the next one, if necessary. Additional DSN tracking passes may be used when the excepted data volumes exceed a single pass capacity.

Other missions can be supported during the same MTO orbit. This support is sequential due to the Electra limitations and requires coordination by the MTO planners. It is anticipated that after a reasonably successful operations period, this coordination function will be performed onboard using a priority scheme for each mission and for each mission data priority, hence reducing the operators in the loop.

Utilization of more than one contact between MTO and MSL is determined by the volume of MSL data and by its activity density since MSL must interrupt data collection while transmitting to MTO. MTO is ready to support all transactions with a customer during all over pass opportunities except when previously identified as an exclusion zone.

Laser communications demonstrations are conducted two or three days per week following a MSL contact during the direct to earth (DTE) relay of MSL data. These demonstrations require a Laser ground terminal to collect and process the data received over the Laser link in addition to a DSN station to collect the engineering data from the Laser flight terminal. Some data may be the same science data already transmitted on the RF link. The requirement to track with a DSN station and the Ground Terminal is applicable during the Laser link feasibility demonstration phase and it may not be needed when the link is declared operational.

A secondary objective of MTO is to successfully demonstrate the use of the Laser link in deep space and make it operational to augment the total data volume capability. The MTO ground system architecture is flexible and will evolve to include the MCDL operations as required.

The Orbiting Sample Search demonstration is performed after the MSL relay support for the prime mission is completed to avoid interruption to the relay service.

OPERATIONS ARCHITECTURE CONCEPT.

The Mission Operations Architecture depicted in Figure 4 consists of a main control center at JPL for Project management and day-to-day operations; the spacecraft operations center for engineering analysis and planning, is remotely located at the contractor facility and the MCDL center, is currently at an undetermined location.

The MLCD uses an optical ground terminal for telemetry and commanding and it interfaces directly with the control center where link and data analysis is performed. A link to the Lincoln Laboratory is available for principal investigator analysis of the LCD performance.

A ground network infrastructure links the centers with high speed and volume capability for engineering and ancillary data transfer from the MTO center to the remote locations. This same network provides the link for planning inputs and command files from the remote centers to the MTO center for coordination, sequence generation and command generation for uplink to the MTO Spacecraft. The infrastructure also links the science users for data retrieval and observation planning. The science investigator are responsible for delivery of the reduce science data products to Planetary Data System (PDS).

SUMMARY

The first tall tent pole set of scenarios and operations concepts have been developed at a preliminary level and are helping the project get a better insight into the capabilities required to perform the mission at a given cost. Further scenarios and concepts in the coming months will lay the foundation for the MTO mission.

MTO is unique and will represent an important node in the Mars infrastructure laying significant groundwork for future robotic and human mars exploration missions.

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