Exhibit I

Mars Exploration Program

Mars Telecom Orbiter

Spacecraft Design Study

Mission and Payload Description, Requirements, and Constraints

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2.0 Introduction and Purpose

The Mars Exploration Program (MEP) at JPL is conducting studies for a Mars Telecom Orbiter (MTO), to be launched in the 2009 opportunity and which will take advantage of the Ka-band spectrum. The studies have matured to the level where it is necessary to solicit support and ROM cost data from industry for continued pre-project planning. It is intended to procure the orbiter from industry using a system contract, with the payload elements described in Appendix A being supplied to the industry contractor. An option being considered is to supply the complete telecommunications system to the industry contractor as government furnished equipment (GFE). Also being considered is the option of JPL taking delivery of the S/C prior to its integration with the potentially GFE-ed telecommunications equipment and the payload, with JPL then being responsible for integration and test of the full flight system and for conducting launch operations. In this option, the selected contractor would integrate and test the orbiter bus and, following delivery, provide support during payload integration, flight system test, and launch operations.

*For the purpose of the industry studies***,** the following sections describe the requirements and constraints imposed by the mission design, end-to-end information system design, and ground system architecture. Similarly, payload elements, comprising the Electra UHF/X-band relay transceiver, optical communications flight hardware, narrow angle imaging camera, and science experiments and/or technology demonstrations, are described in Appendix A.

Note: the information provided in this Exhibit is meant to be representative of requirements and constraints that will eventually apply to the mission. However, it will not necessarily be current at the time the studies begin, nor will there be any attempt to keep it current during the studies.

3.0 Mission Description

3.1 Summary

The NASA Mars Telecom Orbiter (MTO) is to be used as a data relay satellite that enables two-way communications between other vehicles at Mars and operation centers on earth via links operating at UHF through Ka-band frequencies.

Its orbital phase is planned to last 10 years with its primary enduring function being that of providing relay services and coverage of critical events for other Mars assets. However, it also carries a payload for an optical communications demonstration whose activities will be interleaved with its relay duties for minimal impact on the latter. A successful demonstration of this link, which would provide a capability to return data at rates up 100 Mbps, may lead to its use on a regular basis to return more relay data than can be accommodated by RF alone. In addition, MTO will carry cameras to fulfill a backup role in detecting an orbiting sample canister for the Mars Sample Return mission to be launched in 2013. In support of this, MTO will carry a dummy canister, which will be released in Mars orbit and used as a demonstration target. At this point in time, there is no science mission defined for MTO. It is likely, though, that science (and possibly technology demonstration) requirements will eventually be established, and science instruments will be included in the payload.

MTO will provide a step function significant increase to the capability of the Mars network, a collection of Mars orbiters with relay radios. (The Mars network currently consists of NASA's Mars Global Surveyor and Mars Odyssey orbiters. These will be joined by ESA's Mars Express Orbiter and by NASA's Mars Reconnaissance Orbiter.) NASA Mars orbiters (other than MTO) are generally placed into low, near-polar orbits optimized for remote sensing. As a result, their contacts with relay users at mid-latitudes on Mars (near the equator) are short and infrequent - typically a single 8 minute contact each Martian day. MTO will be put into a high, non-polar orbit enabling hours of contact time each Martian day. The high MTO orbit will make it possible to track relay users during critical events such as rover traverses or the entry, descent, and landing (EDL) of a lander.

Properly designed, MTO can increase the data that a large lander, such as the 2009 Mars Science Laboratory, can send to earth by one order of magnitude, if the lander is using UHF and by two orders of magnitude if it is using X-band.

3.2 Trajectory and Orbit Design

Interplanetary trajectory

MTO will be launched in the 2009 opportunity, arriving in the fall of 2010. The launch and arrival dates for MTO must be coordinated with those of MSL, which is also being launched to Mars in the 2009 opportunity. Launching both missions from KSC in late 2009 invokes logistics constraints in the launch pad and work force utilization. The requirement that MTO cover the EDL of MSL requires that MTO arrive at Mars sufficiently far in advance of MSL to establish its orbit, carry out required commissioning operations, and set itself up for the arrival of MSL.

There is still considerable uncertainty in many aspects of this scenario. MSL has yet to select a landing site and, with it, the launch and arrival dates required for its mission. The logistics at KSC will ultimately result from a negotiation between the projects, KSC, and its launch vehicle providers. The arrival date separation required at Mars between MTO and MSL will be decided by operations issues as well as details of mission and spacecraft implementation of the two projects. The interplanetary trajectory selected for this industry study is chosen to satisfy the following constraints:

1. Must not exclude any landing sites for MSL between 60 South and 60 North.
2. There must be at least a 7 day gap between 2 successive launch periods in 2009.
3. There must be a minimum arrival date separation at Mars of 30 days with MTO arriving before MSL.

Given these constraints the following trajectory is to be used:

Launch Date = Nov. 8, 2009
Arrival Date = Sep. 12, 2010

This represents the closing launch date of a 20-day launch period beginning on Oct. 20, 2009 and comprises the maximum C_3 (= 15.9 km^2/s^2) over the launch period, plus the maximum delta-v for Mars Orbit Insertion (MOI).

Mars Orbit

MTO will be placed in an orbit that optimizes the coverage of present and future assets. A wide range of orbits is being considered for MTO. The criteria for final selection will include the following items:

1. Total delta-v to reach final orbit
2. Data throughput from typical landers anticipated to be the main relay users
3. Ability to cover critical events such as EDL of landers and MOI of orbiters
4. Spacecraft design considerations such as eclipse characteristics
5. Mission and spacecraft operability

Based primarily on the first 3 of these items, but with some cursory understanding of the remaining items, we are carrying a circular, sun-synchronous orbit as our reference orbit. Its characteristics are:

Altitude = 4450 km
Inclination = 130.2 deg.
Ascending Node Right Ascension = -142.9 deg. (Mars Mean
Equator and Equinox of date, 9/12/2010, 0h)

This corresponds to the southern approach to MOI, which appears to be required to assure EDL coverage of MSL should it land at 60 North 30 days or more after MTO's arrival on 9/12/2010.

A reference scenario has been developed for progressing from the initial orbit achieved at MOI to the final orbit.

1. MOI occurs at an altitude of 250 km and the orbit is sized to an period equal to 1 sol. This is called the Initial Orbit.
2. 15 days after MOI a maneuver is performed at apoapse of the Initial Orbit to raise periapse up to the altitude required in the final orbit, viz. 4450 km. This is called the Intermediate Orbit.
3. 30 days after the periapse-raise maneuver a second maneuver is executed at periapse of the Intermediate Orbit to lower apoapse to its final altitude of 4450 km, having a period of 1/4 sol. The orbit achieved is called the Final Orbit.

This 3-burn strategy is optimal for propellant usage.

Navigation and Delta-v Budget

Since there are no tight requirements on the orbit for the Telecom Orbiter mission as there might be for an intensive science mission, the navigation problems are likely to be minimal. MOI will occur at a nominal altitude of 250 km, and no data types other than Doppler, Range, and DDOR are anticipated to be required to achieve sufficient accuracy for MOI. Orbit maintenance in the reference orbit is likely to be sufficiently loose to allow natural evolution of the orbit with few maintenance maneuvers required over the 10 year lifetime of the mission.

The maneuver budget allows for 3 –5 Trajectory Correction Maneuvers (TCMs) for the interplanetary phase. The total budget is as follows:

Maneuver	**Allocation** (m/s)
TCMs	60 (maximum single maneuver = 30 m/s)
MOI	855
Gravity losses at MOI (assumed to be 5%)	43
Periapse Raise Maneuver	180
Apoapse Lower Maneuver	667
Orbit Maintenance	40 (maximum single maneuver = 5 m/s)
Phasing Maneuvers	50 (maximum single maneuver = 25 m/s)
Reserves	150
TOTAL	2045

The MOI allocation is for the reference trajectory defined above while the in-orbit maneuver allocations are for the reference 4450 km circular orbit. The gravity loss allocation is probably conservative, even for a monopropellant system with few engines, but should be re-evaluated during the study based on actual implementation decisions. Phasing maneuvers are for the purpose of establishing timing, in a given orbit, for coverage of critical events of other Mars missions by MTO.

Using the Martian Atmosphere for Orbit Modification

Studies to date have not relied on aerobraking to modify the MTO orbit. Purely chemical propellant has been assumed for all translational maneuvers. Consideration of the usefulness of aerobraking, as well as assessment of the impact of such a design feature on all project elements, is left to the study contractor's discretion.

Aerocapture technology is generally considered to be risky and not ready for operational use in a 2009 Mars mission such as MTO. However, study contractors are permitted to provide their own assessment (including costs, benefits, current readiness levels) of *any* technologies proposed in their submitted concept, including any related to propulsive savings such as aerocapture.

Launch Vehicle Considerations

The required C_3, provided above, together with the flight system mass, which will be determined by the study contractor for their submitted concept, will determine the required launch vehicle. It is anticipated that the launch vehicle will likely be in the Atlas V or Delta IV class. However the launch vehicle selection is seen as part of the project level trades available to the study contractor to address the overall performance metrics specified in these study guidelines.

Trajectory Characteristics

Appendix B provides a selection of plots and tables containing data relevant to characterizing both the Interplanetary Cruise and the Mars Orbit phases of the MTO reference mission.

3.3 Mission Scenarios

The following provides high-level objectives and "day-in-the-life" descriptions for 3 major MTO mission scenarios:

[1] Relay
[2] Optical communications feasibility and operations demos
[3] Orbiting sample backup detection for Mars Sample Return (MSR)

Unless otherwise stated, there is no requirement to operate payload elements simultaneously (including the as yet undefined science/technology payloads). However, the mission may include simultaneous operation when it is non-interfering and within spacecraft resources. Therefore, the design should not physically preclude simultaneous operation when it is within the typical S/C resource constraints of power, processing bandwidth, data storage availability, etc.

[1] Relay Mission:

(a) Payload: Electra (see Payload Descriptions).

(b) Mission objective: Transmit/receive UHF and receive X-band data to/from other Mars spacecraft (orbiters, landers, etc.), on a routine basis. All data acquired by MTO will be prioritized and transmitted to earth according to its priority. Data will be sent to earth in one of two modes:

(i) Near real time: MTO transmits relay data to earth with high reliability and minimum delay ("near real-time"). Near real time relay data generally consists of high priority data needed for timely operational or planning purposes.

(ii) Store and forward: MTO stores the relay data that Electra receives from other Mars spacecraft. MTO transmits those stored data to earth at a later time

(c) Operational scenario ("day-in-the-life" description): See EEIS Description for an explanation of the relay users, and for details of the forward link (Earth-MTO-Mars commanding) and return link (Mars-MTO-Earth downlink). During relay operations, the forward component of the relay link will at times operate simultaneously with the return component. During a typical relay day (1 sol), one or more of the following may occur:

(i) Large lander (MSL-type) relay: See EEIS Description for additional MSL details. Relay data will be received at either UHF or at X-band. As MSL comes into view of MTO, point the required proximity link antenna at the lander. Allow for two virtual data channels: (1) high priority, with limited data volume for operational information with strict latency requirements needed for operating the MSL rover; and (2) lower priority, with larger data volume for bulk science data with less strict latency requirements. For a generic large lander, assume three 1-2 hour relay sessions per sol, and assume that one of these will be during the daily DSN pass. This relay pattern will stay essentially the same from day to day, but this daily pattern may evolve over time.

(ii) Small landers (Netlander-type) relay: The small landers (assume four) will be able to communicate with earth only through UHF relays on Mars orbiters. Each small lander will be limited to no more than 20 minutes transmission time each sol while the sun is at an elevation angle no less than 30°. Uniform global longitudinal placement is anticipated, and the latitude of the small landers will be between ±30°.

Additional operational notes:

- Electra supports a relay link with only one user at a time.
- The minimum time between the end of one relay period and the beginning of the next will depend on how fast the spacecraft or a steerable antenna can be moved. This interval will not be hours or seconds; it will probably be on the order of minutes, and involves a trade that may be useful for the RFP respondent to perform.

(d) Concurrent activities during relay link operation: Relay operations are the prime objective of MTO and will usually have higher priority than other MTO activities. The sole exception to this would be orbiting sample (OS) detection in support of the 2013 MSR mission. Optical Comm demonstration will be scheduled around relay sessions, if relay operations would cause mechanical disturbances (e.g., gimbal noise) or result in excess power consumption. In other words, it is not a requirement to support relay operations concurrently with sample detection or optical comm activities. Operation of as yet undefined science will occur simultaneously with relay operations but shall not interfere with the pointing of the proximity antennas.

(e) Relation of Electra activities to other mission aspects:

(i) Spacecraft and payload commissioning: Commissioning of Electra is assumed to occur in three stages: shortly after launch (health and basic operations checkout), before arrival at Mars (verification of basic operations in deep-space environment close to Mars), and after establishment of the final relay orbit at Mars (complete health checkout and verification of operations capabilities for the extended relay mission). The first two activities can be done concurrently with other payload and systems checkouts, while the last will probably preclude other payload operations. The spacecraft shall be ready for full relay operations by about 30 days after MOI, or following aerobraking if that is determined to be advantageous.

(ii) MSL EDL: During entry, descent, and landing of MSL, about 30 days after MTO has arrived at Mars (independent of whether aerobraking is determined to be advantageous), MTO must be able to receive UHF data from MSL during its entry, descent, and landing phase, while simultaneously transmitting in near real time to earth with concurrent backup onboard data storage. Maximum duration of EDL support should be about 10 minutes, including 4-6 minutes during EDL and a few minutes after touchdown. A data rate on the order of 2 kbps, or a total data volume on the order of 1 Mbit, should be sufficient.

[2] Optical Comm Mission:

(a) Payload: Optical Comm (see Payload Descriptions).

(b) Mission objective: The optical comm objectives will be pursued in two stages: (i) a feasibility demonstration and (ii) an operations demonstration.

(i) Feasibility demo: The goal is to demonstrate that optical communications can achieve data rates of 10 to 100 Mbps while at Mars. It is intended to demonstrate that optical communications can work from Mars, but is not an extensive set of experiments to discover all of the issues associated with operating optical communications from Mars. For this study, it is assumed that a single Ground Terminal (GT) will be used to support this effort. The data received by the GT is not expected to be delivered to JPL in real-time (the data may be saved to tape or analyzed at the GT). Health and performance telemetry of the optical communications payload is downlinked via RF through the DSN. During Optical Comm sessions, MTO will point its HGA at earth, and the Optical Comm payload will point its steerable internal mirror at the required GT location. Data required by the payload to point its steerable mirror will be uplinked to MTO and stored in the Optical Comm payload.

(ii) Operations demo: The goal is to operate for one Mars year and to operate across a range of likely operational scenarios and environments, with the intention of finding problems and correcting them. This demo will reduce the risk for future full scale deployment. For this study, it is assumed that two GTs will be used, sited in locations that permit, between the two of them, a very high likelihood of clear weather. Operations will be the same as described above, except that it is likely that actual relay/science data will be transported over the optical link.

(c) Operational scenario (“day-in-the-life” description):

(i) Feasibility demo: Operations will be selected for times when the spacecraft is “quiet,” to minimize mechanical disturbances, and while the MTO to earth RF link is active, to provide real-time telemetry. Therefore, simultaneous near real time relay operations may be precluded, although playback of previously stored relay data will be possible. Sessions can be scheduled around high priority relay operations and will last as long as 8-10 hours. Sessions will occur several times, perhaps daily, during a two-week feasibility demo campaign. Follow-on campaigns will be scheduled to assess performance at various Sun-probe-Earth angles, performance while spacecraft mechanical disturbances are taking place, etc. The optical comm payload will produce its own data for modulation onto the optical signal.

(ii) Operations demo: After successful demonstration of feasibility, the optical comm link may be used to augment science data return. In this mode, sessions will be scheduled on a regular basis (up to once per day), and relay data will be supplied to the optical comm payload over a very high rate (50-100 Mbps) data interface for modulation onto the optical signal. These data will likely come from onboard mass storage (store and forward relay mode). Near real time relay mode utilization of optical comm capability is not required, but may occur contingent upon minimization of spacecraft disturbance effects and system power availability.

(d) Payload commissioning: Engineering functions of the optical comm payload will be checked out after launch. A more thorough checkout involving use of the GT may occur during cruise, over about a 2-week period.

[3] Orbiting Sample Backup Detection (for MSR Mission):

(a) Payload: Two narrow angle cameras (NAC), and a demonstration canister (see Payload Descriptions).

(b) Mission objective: The purpose is to serve as a backup for detection of (but not rendezvous with) a Mars Sample Return (MSR) orbiting sample canister (OS) following the 2013 launch opportunity. In support of this, MTO also will carry a demonstration canister, which will be released in Mars orbit and used as a target for demonstrating OS detection.

(c) Operational scenario ("day-in-the-life" description): Operational scenarios occur in the following phases:

(i) NAC calibration phase: Photometric and geometric calibration events will be distributed throughout cruise. Optical navigation imaging during approach will provide opportunities to calibrate the NAC using Mars, Phobos, and Deimos.

(ii) Search phase: The optimum searching region is 4000 to 6000 km range; actual ranges vary from 4000 to 9000 km. Observations beyond 9000 km are not possible, due to the Mars limb. Imaging is of a target at approximately 500 km altitude, visible only when near either visible limb of Mars. Repeated and nearly continuous NAC mosaics (except during downlink opportunities) over a period of one to four weeks are sufficient to locate the OS, given the assumed orbital uncertainties. During each of the mosaics, the spacecraft attitude will be controlled to ≤2 mrad pointing accuracy, and the attitude rate commanded to a rate of less than 1 mrad/s ± 20 μrad/s. Individual images within each mosaic will be taken with a maximum frequency of once per 15 seconds. Images will be edited onboard and then transmitted to earth, where the MSR mission operations team will use them to determine the orbital elements of the OS, so that the canister can be recovered by the MSR orbiter. The effective compression rate of the editing algorithm will be at least 100:1, for a maximum net data flow from this effort of approximately 0.5 Gbits/day.

4.0 Ground System Architecture

Although mission operations are not to be costed as a part of this spacecraft design study, the following paragraphs are intended to illustrate the MTO mission operations system approach.

Mission Operations

The MTO Mission Operations System (MOS) team uses a distributed operations structure. Spacecraft team functions, including spacecraft engineering, analysis, and operations, flight system health and maintenance, flight system testbed (STB), fault recovery, flight software maintenance, and engineering commanding and sequencing are conducted at the S/C contractor (CTR) facility, networked with the JPL Multi-Mission Operations (MMO) control center. The payload operations center is at JPL. JPL coordinates the payload effort with GSFC and Lincoln Laboratory (for the Optical Comm Demonstration). JPL's mission operations manager works with Deep Space Mission Systems (DSMS), MMO, and CTR to coordinate mission operations services, including ground services, sequence integration, mission planning, DSN scheduling, navigation, and mission control.

If ATLO is performed at JPL and not at the CTR facility, the flight system operations after launch will continue to be conducted from JPL with support from the CTR. Fault recovery and flight software maintenance remain the responsibility of the CTR in all options.

Ground Data System

The Ground Data System (GDS) is designed around the Interplanetary Network Directorate (IND) (formerly known as TMOD) core and adapted software. MTO uses and builds upon JPL's MMO processes used extensively for JPL interplanetary and planetary missions.

No major core changes are expected to the IND GDS. The mission sequence and analysis core software set includes the planning tool, sequence generation tool, automated sequence processor, telecommunication forecaster, time correlation service, and a DSN allocation scheduler. Flight engineering ground software includes, in addition, the CTR performance and analysis software as well as the flight system testbed (STB). The STB validates flight system activities, new command sets, and sequences. The STB also validates flight software updates and is used for fault analysis and recovery.

DSN Usage

The baseline communications ground station coverage is provided by the DSN 34-m BWG network. Tracking support will be per the table below.

Mission Contact		Antenna	Hours per	No. Tracks	No. Weeks
No	Name (description)	Size (meters)	Track (hours)	per Week (# tracks)	Required (# weeks)
1	Launch & Early Operations	34BWG	8	21.0	4.0
2	Payload checkout	34BWG	4	5.0	4.0
3	Cruise	34BWG	4	1.0	
4	Mars approach	34BWG	8	3.0	4.0
5	Pre-MOI	34BWG	4	14.0	2.0
6	MOI	34BWG	8	21.0	2.0
7	Post MOI and final commissioning	34BWG	8	7.0	4.0
8	Relay	34BWG	8	7.0	516
9	Optical Comm demo	34BWG	overlapping with Relay	--	--
10	TCMs (for each)	34BWG	4	14.0	3.0

Continuous DSN 34-m coverage is scheduled for 4 weeks after launch. Trajectory correction maneuvers get twice-daily coverage of 4 hours for two weeks pre-maneuver and daily coverage of 4 hours for one week after the maneuver. The exception is MOI, which receives full coverage for 2 weeks. During cruise to Mars a single 4 hour track per week provides for navigation data, spacecraft and instrument health/safety telemetry, and uplink sequence commanding to the spacecraft if needed. After MOI a daily 8-hour pass is scheduled to return the science data. In addition, extra time may be provided for Electra (relay), Optical Comm, and NAC checkout sometime during cruise. However, this time may end up being eliminated if all the activities fit in the nominal daily downlinks. Uplink of sequences is expected on a weekly basis following MOI.

Mission Operations Plan/Operations Concept

The ground system development concept is to use existing multimission teams, software and processes that have been used on previous JPL-CTR space missions.

Real-time specific commanding will be minimized and will only be used in emergency situations. The standard procedure for operating the flight system is to use sequences developed ahead of time and uplinked approximately every three weeks during cruise and once a week during normal orbital operations. The MOS team also relies on ground-expanded blocks and other sequences developed and tested pre-launch to sequence all routine activities, such as flight system calibrations, maneuvers, playbacks, reaction wheel dumping, etc. This is done to reduce both risk and operations cost to the mission.

5.0 EEIS Description

The MTO End-to-End Information System (EEIS) includes data flow through all subsystems from the transmission of data on a User Marscraft, through the MTO spacecraft, on to the Deep Space Network, the MTO Ground Data System (GDS), the user Marscraft GDS, and final delivery to User Marscraft scientists. Conversely, it also includes the end-to-end command process from User Marscraft commands sent by the Marscraft GDS to the MTO GDS, then to the DSN for radiation to the MTO spacecraft, then through the MTO spacecraft, and finally relayed to the User Marscraft.
EEIS also includes end-to-end data flow between onboard instruments such as the Optical Communications Demonstration and end users on Earth. This section describes applicable standards and the end-to-end forward and return processes for Mars Telesat. It includes MTO application profiles.

Applicable Standards

MTO must follow all applicable Consultative Committee on Space Data Systems (CCSDS) standards (http://www.ccsds.org/). These include both deep space communications standards and relay link standards.

This section describes the latest two protocols for those who may be unfamiliar with them: the Proximity-1 Space Link Protocol and the CCSDS File Delivery Protocol (CFDP).

Proximity-1 Space Link Protocol

The CCSDS Proximity-1 Space Link Protocol (CCSDS 211.0) was developed specifically for short range, bi-directional, fixed or mobile radio links, generally used to communicate among probes, landers, rovers, orbiting constellations, and orbiting relays. It is not limited to Operations at Mars. Key characteristics of the Proximity-1 protocol include:

- bi-directional, handling both forward and return links
- supports full duplex, half duplex and simplex
- transfers both control information, such as directives or messages, and data like telemetry, commands, radiometric or time data
- transfers packets, directives or User Defined Data Units across the link
- provides coupled non-coherent ranging and timing services
- maximizes data-driven methods
- supports coded or uncoded operations
- asynchronous operation (variable length frames)

There are two basic levels of Proximity-1 service: Sequence Controlled (reliable) Service and Expedited Service.

Sequence Controlled Service uses a Go-Back-N Automatic Repeat reQuest (ARQ) protocol between the relay radios on both ends of the link to ensure reliable delivery of packets in order. This requires full duplex operation.

With Expedited Service, packets are transmitted from the user probe relay radio to the orbiter relay radio without acknowledgement. CFDP can be used at the application layer to ensure reliable delivery even with expedited service as long as a forward link is available, though full duplex operation is not necessary.

CCSDS File Delivery Protocol

The CCSDS File Delivery Protocol (CFDP) is an application-layer protocol that provides flexible end-to-end delivery of data products such as files. Files can be transferred reliably, with automatic retransmission in the event of errors, or unreliably on a “best efforts” basis. CFDP is described in three CCSDS documents: a Blue Book (Recommendation: CCSDS 727.0-B-1) and two Green Books (Introduction and Overview: CCSDS 720.1-G-1; and Implementers Guide: CCSDS 720.2-G-1).

EEIS Requirements

Accounting

Accounting means identifying the named data units and reporting on their attributes (data source, name, size, activity, time needed by, transmission status, completeness)
MTO shall be capable of reporting on the status of forward link data transfers to a User Marscraft.

MTO shall acknowledge receipt in its Direct-To-Earth (DTE) telemetry of User Marscraft forward link data once it has been received by MTO.

MTO shall forward acknowledgement of the reception of the forward link data by the User Marscraft to the User Marscraft GDS.

All MTO elements (MTO Spacecraft, MTO Electra, and the MTO GDS) shall account for both forward and return relay data on a named data unit (NDU) basis. A named data unit is a product, i.e., much bigger than a packet (e.g., file, block, or an aggregate of smaller data units e.g., aggregate of source packets)

MTO shall, at a minimum, account for NDUs based upon:

- Data Source
- Name of Data Unit
- Data Unit Size (Bytes)

Custody Transfer

NDU custody shall be transferred when the NDU is successfully received at each major network node (User Marscraft, MTO, DSN, MTO GDS and User GDS). In other words, once an NDU has been transferred from one major network node to another, and the receiving node has notified the transmitting node that it has been successfully received, the transmitting node is no longer responsible for the NDU and can erase it from memory. Custody transfer will be used on both forward and return links. A high end-to-end completeness of data transfer isintended (on the order of 95%).

Data received by the MTO spacecraft over the relay link at maximum Earth-Mars range should be retained until custody is successfully transferred or for up to six days after it is received, whichever is earlier. For the purpose of this study, participants may assume a 25% retransmission rate to recover data lost from rain outages.

Deep Space Communications

All communications between the MTO spacecraft and Earth will be sent through the Deep Space Network (DSN). The DSN is part of the Deep Space Mission System (DSMS). It consists of three complexes of 70 m, 34 m and other Deep Space Stations (DSSs) located in the Mojave desert of California, near Madrid, Spain, and near Canberra, Australia. Guidelines for using the DSN and DSMS are provided in "NASA's Mission Operations and Communications Services". DSN interface information is provided in "Deep Space Missions System (DSMS) Link Design Handbook, Document 810-5." These documents and other planning documents and tools are available online at JPL's Interplanetary Network Directorate (IND) Future Mission Planning Office web site at http://deepspace.jpl.nasa.gov/advmiss/.

X-band Direct-To-Earth (DTE) communications cannot exceed a 4 MHz bandwidth. The DSN and DSMS will be upgraded in the future, however, and thus current DSN and DSMS bandwidth, symbol rate and data rate capabilities should not be considered as limits for the purposes of this study. 70 m stations are not expected to be able to support K_a-band communications for the foreseeable future.

Direct from Earth (DFE) Communication Modes

There will be two Direct From Earth (DFE) and Earth communication modes: nominal (for commanding MTO and for relaying User Marscraft commands through MTO) and safe mode (for commanding MTO).

The spacecraft must be able to be commanded by a 70 m DSS (Deep Space Station) from the safe mode attitude (when not occulted).

During nominal operations, the command uplink will be provided at a rate of up to 2 kbps from a 34 m DSS. Data sent to MTO on this uplink will be sent as files using the CCSDS File Delivery Protocol (CFDP). Similarly, files to be relayed to User Marscraft will be inserted into the uplink data stream using CFDP.

Direct To Earth (DTE) Communication Modes

MTO must be able to send engineering telemetry to a 70 m DSS while in Safe Mode (when Earth is not occulted).

During nominal relay operations, MTO should be able to send data to Earth at the same time it is communicating with other Marscraft using Electra as long as Earth is not occulted. There will typically be one eight hour 34 m DSS pass each sol. The DSS pass can normally be scheduled to occur at the same time as an MTO relay pass.

Optical Communications Demonstration

The Optical Communications Flight Terminal will send data to an experimental ground station on Earth at a rate of 10 to 100 Mbps. Ground system and link design for this link are beyond the scope of this Study. However, the MTO onboard data system must be capable of sending data from MTO onboard memory to the Optical Communications Flight Terminal at a rate of up to 100 Mbps.

A DTE RF link should be available while the Optical Communications Flight Terminal is operating.

Relay Communications

For the purposes of this study, consider two potential relay users: a Large Lander and four Small Landers. Model these on MSL and the CNES NetLanders, respectively. (Note: CNES has cancelled the NetLander project, but NetLanders serve as a model for typical small landers for the purpose of this study.) The MSL rover,and Small Lander communication systems and relay needs are briefly described below. All of these users might be at Mars at the same time, all requiring relay support from MTO.

Small Landers will be able to communicate with Earth only through UHF relays on Mars orbiters. Each Small Lander will be limited to no more than 20 minutes transmission time each day while the sun is at an elevation angle no less than 30°; if the sun is at an elevation angle below 30°, communication time is limited to 5 minutes. Each Small Lander will have a UHF radio with a 5 W transmitter, an antenna with 0 dBi gain, and a receive system G/T of -27 dB/K. Global longitudinal coverage is desired, though the latitude of the Small Landers will be between ±30°.

The Mars Science Laboratory (MSL) will deploy a single rover on the surface of Mars in late 2010. MSL will probably be sent to a landing site between ±60° latitude. It is expected to last as long as 1000 sols if nuclear powered, and will traverse under 10 km.
The rover will have a 1 m diameter X-band High Gain Antenna (HGA) and a 15 W X-band transmitter. The X-band antenna will be steered, and the rover will not be able to move while it is in use. This, plus their current operational strategy, limit the period in which the HGA can be used to 2 hours/sol, but other large landers would not necessarily be limited. In addition to X-band, the rover will also have a 5 W UHF radio and an omnidirectional UHF antenna (0 dB gain). Assume there is no limit on the amount of time this UHF link can be in use, except for geometrical constraints. Receive system G/T will be -27 dB/K.

Relay Link Establishment

MTO needs to communicate with only a single relay user at a time. A hailing process is used to initiate communications. Either link partner can hail or be hailed. In practice, the link opportunities will be scheduled, at least to the extent required to point the MTO proximity link antenna.

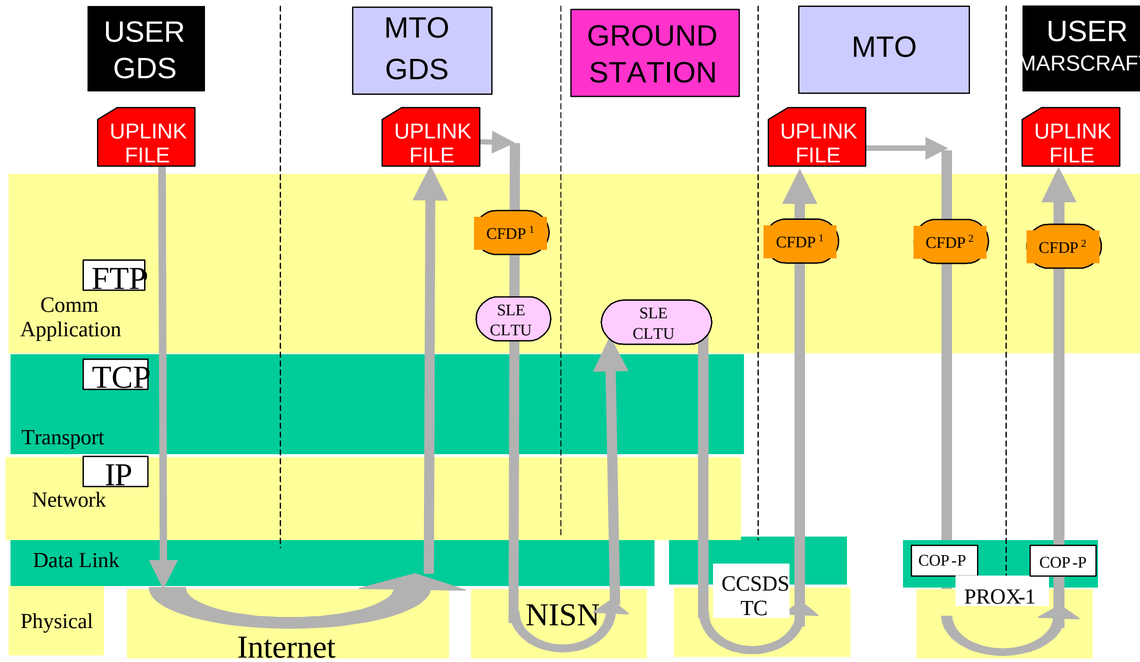
If MTO is transmitting a hail, the relay user determines that a link can be established by detecting a carrier on the hailing channel. Link parameters can be demanded or negotiated.

Upon verification of the hail, the responder sets its communication parameters and responds back on the return frequency. Once the connection is established, the link is moved to a working channel.

There are three ways to terminate the link: through loss of the carrier, an Abort directive, or an End of Data handshake (nominal case).

<u>Forward Link Process</u>

This section describes the MTO forward link process. The figure below illustrates the end-to-end store and forward file delivery process using CFDP mapped into the OSI 7 Layer Model (presentation and session layers not shown).



The end user generates an uplink file and sends it to the MTO GDS over the Internet. The MTO GDS reformulates the uplink file for transport over the deep space link using acknowledged CFDP and utilizes the CCSDS Space Link Extension CLTU Service (SLE – see CCSDS-910.0) to deliver a sequence of CLTUs (composed of CCSDS telecommand (TC) frames) by way of the NASA Integrated Services Network (NISN) (http://www.nisn.nasa.gov/) to a DSN ground station and then over the deep space link to MTO. Once received by MTO, the file is reconstituted into its original form, selective repeat is performed by CFDP if necessary and the file is stored on-board until a relay link is available. Assuming CFDP in running on the User Marscraft, once the link is available, the file is reformatted using (acknowledged) CFDP as the reliable application layer protocol over the data link layer protocol, CCSDS Proximity-1 Space Link Protocol utilizing the expedited service of the Command Operations Procedure-Proximity (COP-P).

CFDP is used as the application layer protocol both between the MTO GDS and MTO ($CFDP^1$), and between MTO and the User Marscraft ($CFDP^2$).

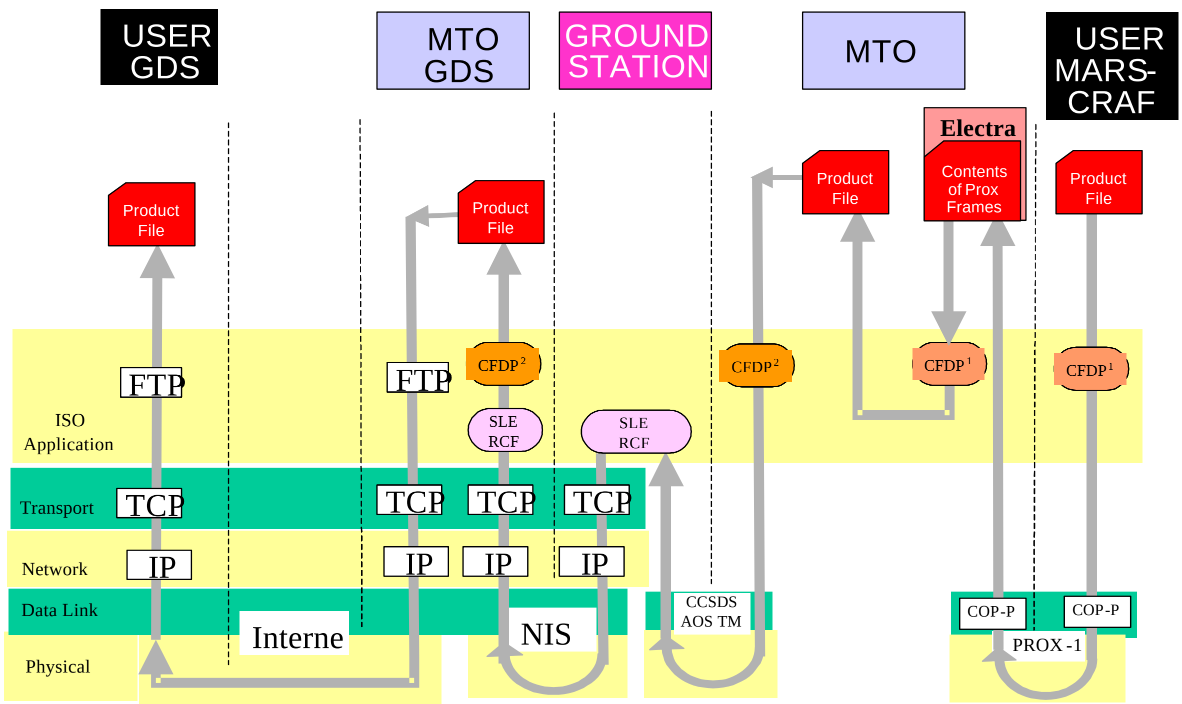
Full accounting is available at each layer and stage of the uplink process. The uplink process supports custody transfer at each node – i.e. after a reliable delivery is completed at each node, custody of the uplink file data is transferred to the node and the previous node may optionally erase the uplink file data.

<u>Return Link Process</u>

Scenario 1: Small Lander. If the User Marscraft has insufficient on-board resources (e.g., memory, CPU time) to run CFDP, then the Marscraft may not support CFDP at the application layer. In this case, a product file (consisting of either CCSDS packets or user-defined data) is transferred over the proximity link as a bit stream using the reliable bit stream mode (sequence controlled COP-P) of the Proximity-1 protocol. The Electra transceiver on MTO receives the bit stream and reconstructs it using reliable Proximity-1. Electra runs unacknowledged CFDP to produce a pass file that contains the user's product encapsulated into CFDP PDUs. The pass file

is transferred to MTO's Command and Data Handling (C&DH) subsystem for storage on-board MTO. When a deep space link is available, the relay sends the pass file over the deep space link to a DSN Deep Space Station (DSS) using acknowledged (reliable) CFDP at the application layer and CCSDS Advanced Orbiting Systems (see CCSDS 700.0-G-3 [link to http://ccsds.org/all_books.html]) telemetry (AOS) at the data link layer. The data stream received by the DSS is forwarded to the MTO GDS, which reconstitutes the Electra pass product file using CFDP and then reconstructs the original product file, if the product structure is known. The MTO GDS then passes either the pass file or the product file over the Internet to the User Marscraft GDS using FTP.

Scenario 2: Large Lander. Links to large landers will be handled using CFDP as illustrated below. The processing is nearly identical to scenario 1, except that the MTO will run CFDP to regenerate the original product file. Note that CFDP is run twice: first over the relay link (CFDP[1]), and then over the deep space link (CFDP[2]).



<u>Delivery Services</u>

Two basic return link delivery services will be provided: near real time ("bent-pipe") and store-and-forward (non real-time). A single Relay User can use both services simultaneously over one or more links.

The near real time delivery service will transfer MTO and User Marscraft data to Earth with high reliability and minimal delay (one way light time plus a few minutes). This service will be used for MTO and User Marscraft health and safety telemetry and data needed for User Marscraft operational planning purposes.

The store and forward delivery service will transfer large quantities of User Marscraft data to Earth with high reliability but potentially long latency (perhaps days). This service will be used to relay bulk science data.

The table below summarizes relay link characteristics and requirements.

Forward Link	Data Volume	• Generally 10 Mb/sol or less
Forward Link	Latency	• End-to-end latency no greater than 10 minutes plus one way Earth-Mars light time
Return Link	Data Volume	***Large Lander*** Store and forward service: 8 Gb/sol at maximum Earth-Mars range, increasing to 64 Gb/sol as DTE link performance permits Near real time service: 25 kbps ***Small Lander*** Store and forward service: 50 Mb/sol Near real time service: 1 kbps

The table below describes DFE/DTE link characteristics and requirements.

DFE	Latency	• Latency no greater than 10 minutes plus one way Earth-Mars light time
DFE	Data Rates	• 7.8125 to 2,000 bps in power of 2 steps
DFE	Safe Mode	• 7.8125 bps minimum
DFE	Coding	• Uncoded
DTE	MTO Spacecraft Services	• Near real time data rate 2 kbps
DTE	Safe Mode	• 10 bps minimum
DTE	Coding	• Specified in module 208 of JPL Document 810-5

6.0 Payload Configuration

The payload consists of the unique equipment necessary to accomplish the objectives of the MTO mission: data relay, optical communications demonstration, and detection of the Mars Sample Return mission's orbiting canister (including early demonstration of capability). The Electra Payload enables UHF links between the Orbiter and other Mars vehicles for telemetry acquisition and command forwarding. The first flight of the Electra is on the Mars Reconnaissance Orbiter in 2005. Electra will be modified for MTO to include X-band receive capability. Note: UHF and X-band antennas are not included with the Electra payload; they will be provided by the S/C contractor or as a part of the GFE-ed telecommunication system. The Optical Communications equipment will be flying for the first time on an interplanetary mission. It contains an internal fine pointing system and requires a fixed mechanical interface with the MTO, as a gimbaled interface will degrade its performance. The MSR orbiting sample detection will be accomplished by the Narrow Angle Camera, which was originally designed for optical navigation when approaching Mars. Its first flight will also be on MRO. A complete description of the payload elements is given in Appendix A.

Mars Telecom Orbiter

APPENDIX A   PAYLOAD DESCRIPTIONS

The descriptions of the payload elements are described herein. This includes the information needed to scope the electrical, thermal, and mechanical interfaces and the integration to the MTO spacecraft. In addition, operational use is described briefly. There is no intent to describe the design of any payload element.

The following is included:

A1. Electra Payload

A2. Optical Communications Payload

A3. Narrow Angle Camera

A4. Orbiting Sample Demonstration Canister

A5. Science Experiments/Technology Demonstrations

APPENDIX A1: THE ELECTRA PAYLOAD

Payload Overview:
The Electra Payload is to be used for two-way communications between the MTO and the deployed Mars Program assets. A block diagram of one Electra unit is shown in Figure 1.

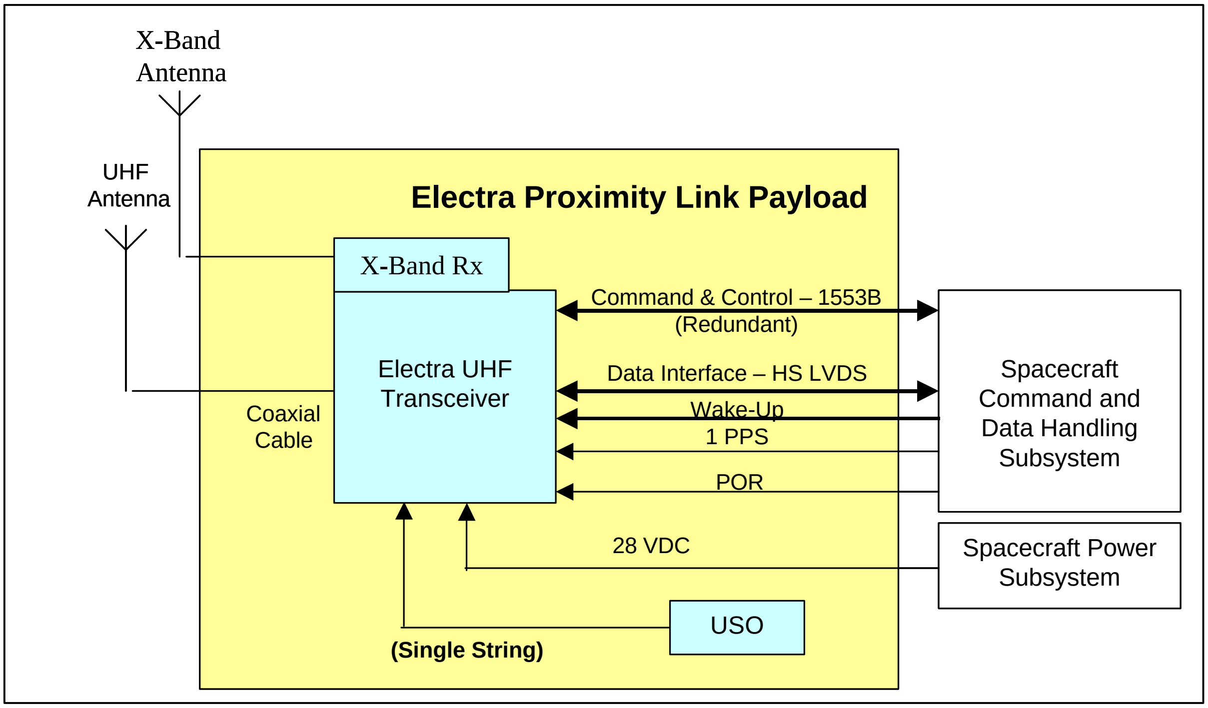


Figure 1: Electra (single unit) Block Diagram

The full Electra Payload will consist of dual string Electra UHF transceivers, dual string Ultra Stable Oscillators (USOs) for precision navigation and surface positioning, and dual X-band receiver/downconverters for improved data rate and improved navigation accuracy.

A block diagram of the full dual-string Electra Payload configuration is shown in Figure 2.

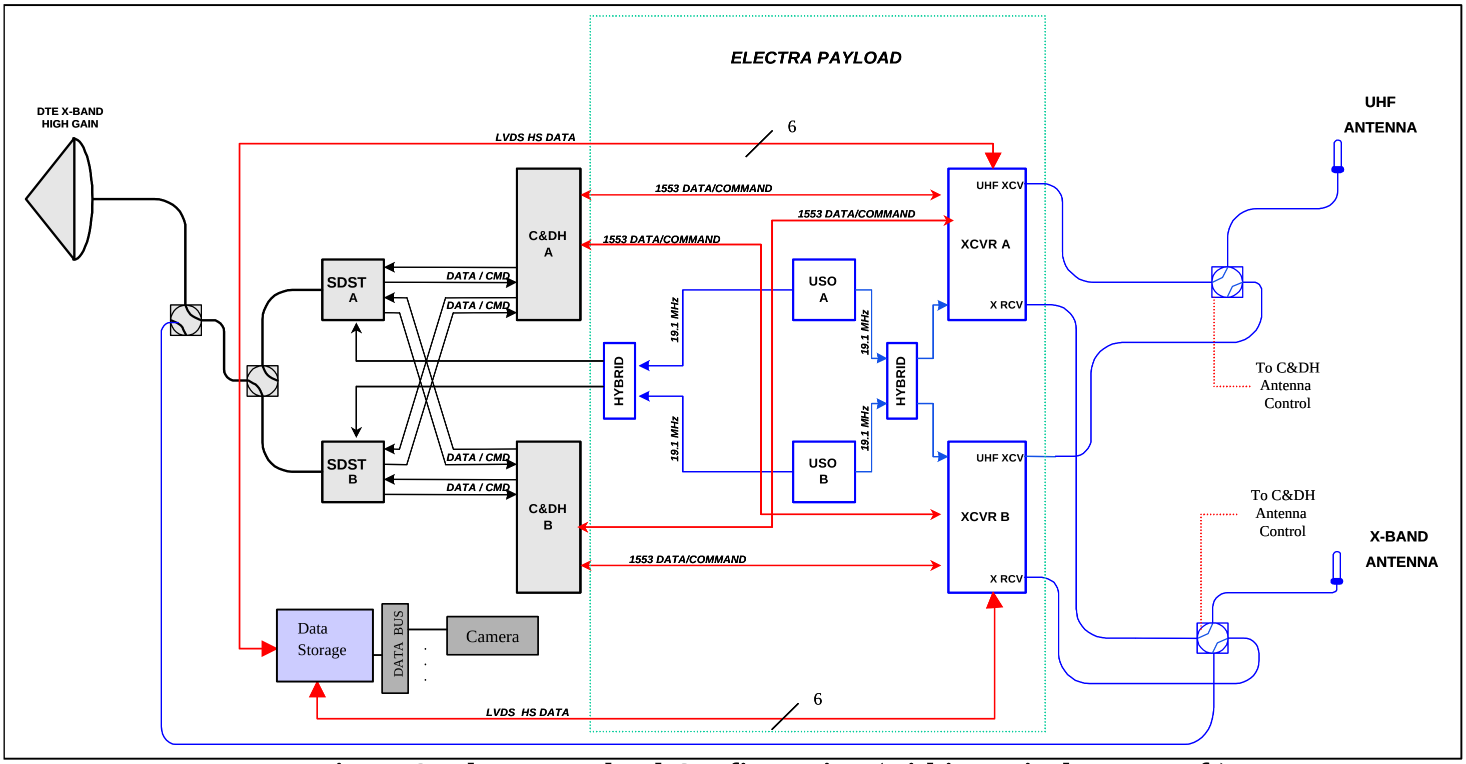


Figure 2. Electra Payload Configuration (within typical spacecraft)

UHF Transceiver Overview:

The Electra UHF transceiver consists of three modules: the RF Module (RFM), the Baseband Processor Module (BPM), and a Power Supply Module (PSM). The RFM will consist of the required high isolation diplexer, filtering and switching, and a single channel UHF transmitter and receiver (receiver channel A). The UHF receiver will be capable of accepting an external downconverted (e.g., X-band) signal in lieu of a received UHF signal on a switchable Secondary Receive Channel (SRC). The BPM will perform all signal processing, provide overall EUT control and service external spacecraft interfaces. The PSM will provide power to the BPM and will provide power under BPM control to the elements of the RFM, the external block converter (i.e. X-band receiver/downconverter for MTO) module (EBM) that will interface with the SRC.

Modes of operation for this system will include full duplex and half duplex overlay operations. The EUT, integrated into the overall Electra Payload, will be utilized for both one-way and two-way data links with user assets at Mars. It will also perform radiometric services for these assets.

A block diagram of the EUT is shown in Figure 3.

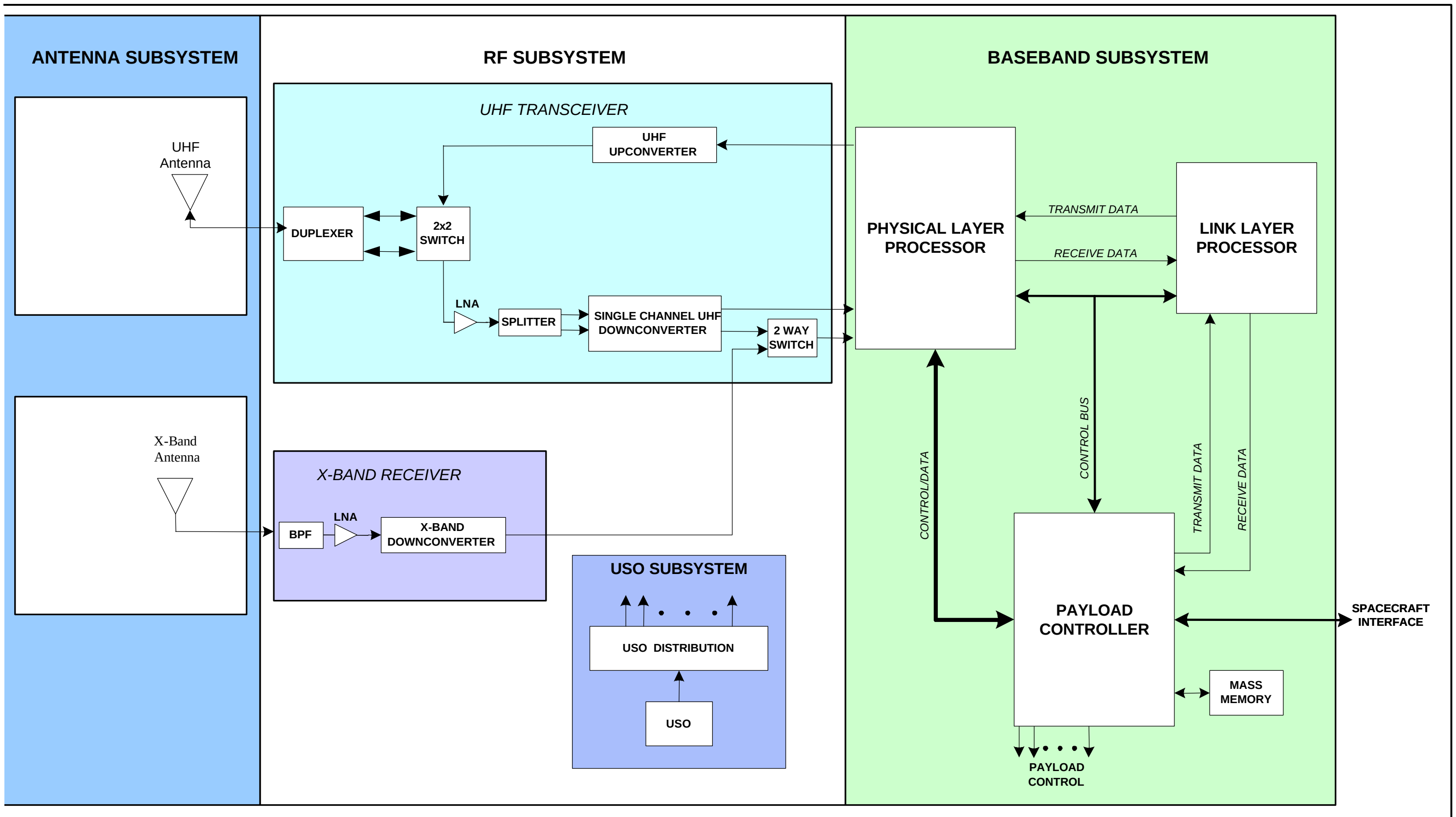


Figure 3: Electra UHF Transceiver (EUT) Assembly

Table 1: Electra Modes of Operation:

Operational Mode
UHF Receive Only
UHF Transmit Only
UHF Transmit and Receive
X-band Receive Only
X-band Receive, UHF Transmit

Table 2: Electra Characteristics- UHF Transceiver Specs

Specification	Requirement
S/C Interfaces	
Command and Control	1553B Cross-Strapped
High Speed Data I/F	LVDS
Power	Standby Mode 16W UHF Receive Only 18W UHF Transmit Only 61W UHF Tx & Rx 63W X-band Receive (delta) ~2-7 W (est)
Voltage	22V-36V
Proximity Communications	
Protocol	CCSDS Proximity 1 Space Link Protocol
Operating Frequencies	• 390-405MHz for receive and 435-450MHz for transmit in full duplex mode • 390-450MHz for transmit and receive in half duplex overlay mode • 8.399GHz - 8.451GHz for receive by X-band receiver
EUT RF Output Power	7W
Symbol Rates	1 through 8192 ksps, in powers of 2
Coding	Receive: uncoded, or (7, ½) convolutional Transmit: uncoded, Reed-Solomon (255, 239), or Reed-Solomon (204, 188) + (7, ½) convolutional
Volume & Mass	
Mass (total, with redundancy)	15 kg (includes USOs and X-band receivers)
Volume (single-string unit)	22.7cm x 24.7cm x 12.6cm (includes USO and X-band receiver)
RF Interface (UHF)	
Frequency Range	389-451 MHz
Receive Signal Level	-58 dBm to -132 dBm
Input Impedance	50 ohm nominal, with VSWR of 1.5:1 over frequency range
Antenna Assembly Interfaces	
Antenna Impedance	50 ohms, with 2:1 or less VSWR at any phase angle
Input Impedance	50 ohms nominal with 1.5:1 VSWR over frequency range
Noise Figure (UHF)	
Half Duplex Overlay Mode	3.9 dB Max
Full Duplex	4.9 dB Max
Noise Figure (X-band)	
Receive Only	3.9 dB Max
Other	
Radiation Requirement	21 Krad TID, with 100 mil aluminum
Receiver Dynamic Range	-70 to –140 dBm (UHF)

APPENDIX A2: The Optical Communications Payload

Overview

The MTO spacecraft will carry a payload designed to demonstrate the capability to transmit high rate data to earth at "optical" wavelengths. The goal is to develop a system capable of transmitting 10 Mbps at the maximum Earth-Mars range with a SPE angle of 2°. At minimum range, data rates in excess of 100 Mbps should be possible. The payload will be developed by Lincoln Labs/MIT, under the direction of Goddard Space Flight Center (GSFC). Key to obtaining these high data rates is the high "gain" provided by the optical system. However, this places extraordinary requirements on the system absolute pointing (~1-2 µrad) and ability to reject spacecraft micro-phonic jitter. As these requirements are expected to be beyond the capability of the spacecraft bus, the payload will contain its own active system designed to provide absolute pointing and jitter rejection. The pointing of the transmitted laser signal is implemented via a Fast Steering Mirror (FSM), inserted into the optical path.

Payload Description

A CAD image of the payload is shown in Figure 1. The payload comprises two elements: 1) an optical assembly consisting a 30 cm diameter telescope and 2) an electronics assembly with 3 enclosures mounted on a thermal radiator. The optical assembly includes the solar window (filter) containing two narrow passbands tuned to the incoming beacon and outgoing communications laser frequencies, which allow the instrument to operate at very low SEP angles. The communication laser operates at a frequency of 1.06 µm with an average power output of 5 watts. Also attached to the optical assembly is the Miniature Inertial Reference Unit (MIRU), which generates an inertially stabilized laser beam that is used as part of the jitter rejection system. The cover is not re-closeable and will be opened after launch. (The contractor should assume that other cover deployment options than the one shown are possible.)

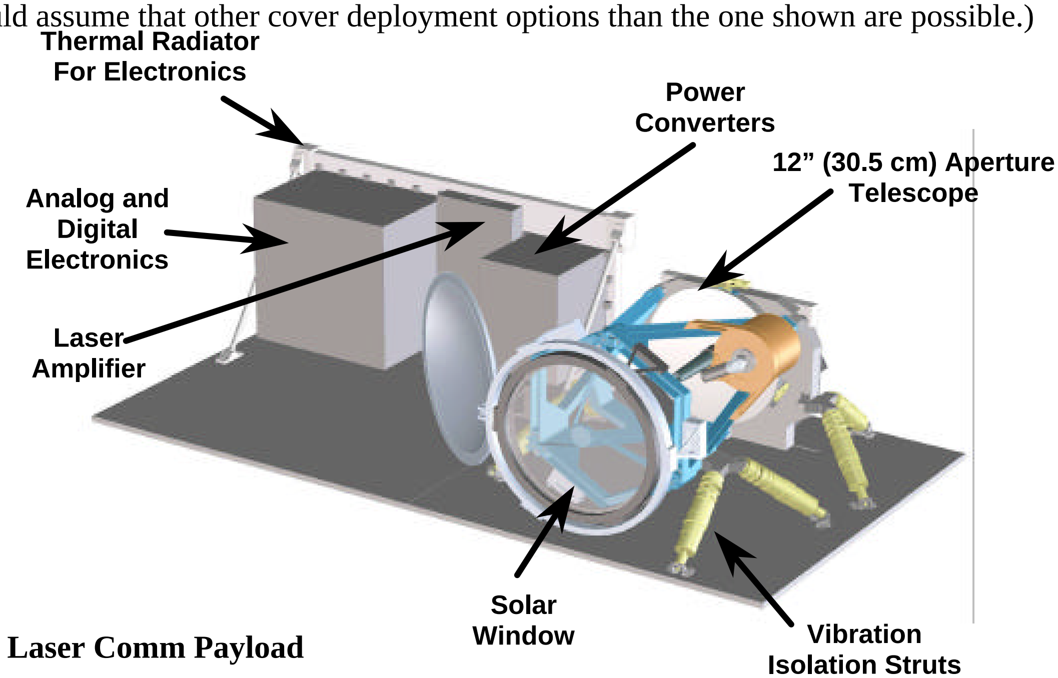


Figure 1. Laser Comm Payload

As delivered, the optical assembly will be mounted on a plate via the 6 isopod vibration-damping struts. These struts are the passive element of the jitter rejection system providing increasing damping as a function of frequency beginning around 20 Hz. The mechanical characteristics of the vibration-damping struts alleviate the requirement to cage the payload during the launch phase. The electronics and radiator assembly need not be co-located with the optical assembly and should be mounted for more optimal radiator FOV. Cable runs between the two assemblies can be as large as 2 meters. The dimensions of the payload are detailed in Table 1.

Interface Requirements

The high-level interface requirements are given in Table 1 and a simplified block diagram is given in Figure 3. The payload has been designed to be completely self-contained; all required electrical and mechanical components are contained within the two instrument enclosures. The spacecraft must provide unregulated DC power via the standard 28-volt power bus. The difference between the average and peak power requirements reflect uncertainty in the heater power required to maintain temperature gradients in the optical system within acceptable limits. Survival power is that required to maintain the temperature of electronics on the rear-facing radiator to within acceptable limits. There is currently no estimate of a "standby" power mode. Commands and telemetry are exchanged over the standard 1553B bus. While the very high data rate transmission tests will utilize a built-in PN sequence generator to develop the bit stream, there is a requirement to transmit valid science data at rates equal to or greater than 50 Mbps, so a dedicated high speed data bus from the spacecraft data system is required.

Table 1. High-Level Interface Requirements

	Requirement	**Comments**
Mass	70 kg	
Power, average	130 watts	Assuming average heater power
Power, peak	170 watts	Assuming peak heater power
Power, survival	47 watts	Survival heaters only
S/C Pointing Control	0.1°	3σ
Spacecraft Stability (Jitter)	See Figure 2.	
Cmd and Tel Bus	1553B	
High Speed Data Bus	≥50 Mbps	LVDS, FireWire, etc.
Mechanical Dimensions		
Optical Assembly	410 mm dia. 700 mm long	
Electronics Box	850 mm wide 430 mm high 260 mm deep (to rad.)	Includes power converter, laser amplifier, and radiator. (Refer to figure 1.)
Telescope Mounting	Aligned with Ka-band HGA electrical boresight to < 0.08°	Estimate (Op Comm FOV/10): Must maintain over time and temperature.

While the payload will accomplish its own fine pointing, the spacecraft must provide acceptable coarse pointing accurate to 0.1°, 3σ. The Lincoln Labs design team assumed a level of jitter at the payload interface as shown in Figure 2.

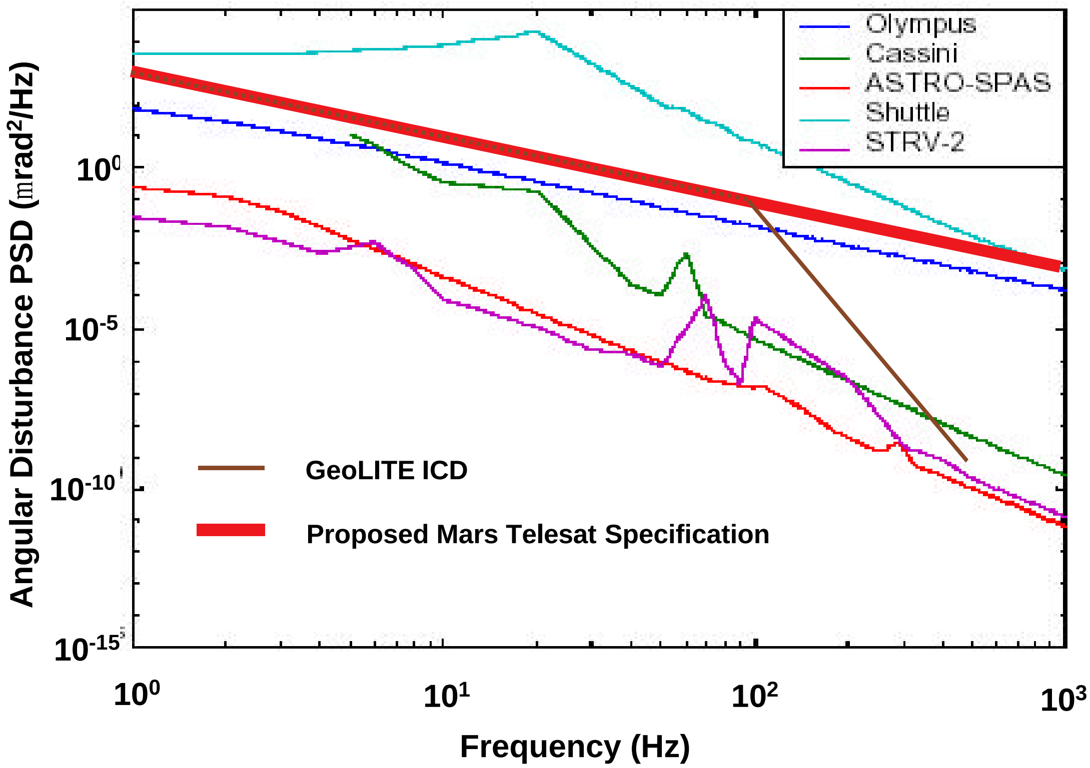


Figure 2. Laser Comm Payload Jitter Requirement

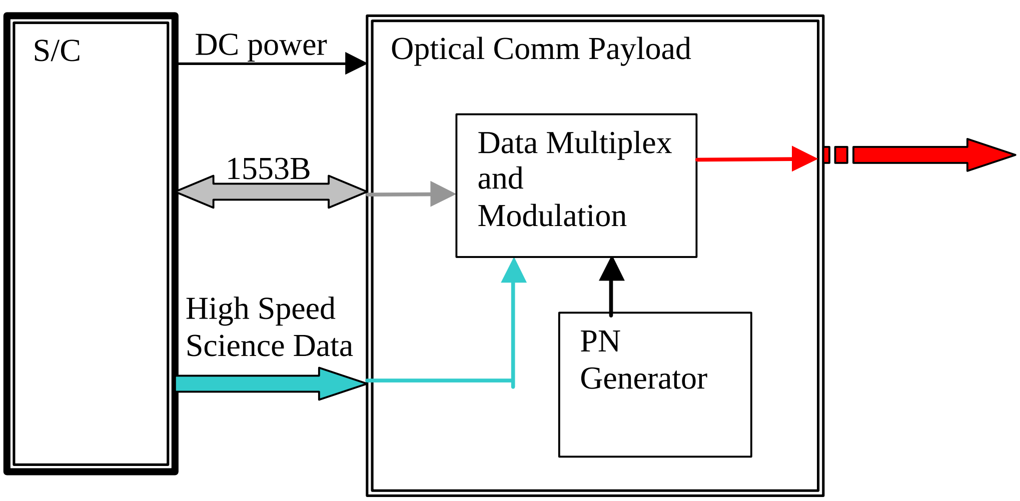


Figure 3. Simplified Spacecraft-Optical Comm Payload Interface Block diagram.

APPENDIX A3: NARROW ANGLE CAMERAS

The Narrow Angle Camera (NAC) was designed for use in optical navigation during Mars approach when the entry parameters are very critical, such as aerocapture operations. It is being used by MTO primarily to fulfill a backup role for locating and tracking the Mars Sample Return OS canister. MTO will carry two of these cameras, reflecting the criticality of this function. Figure A3-1 shows the MRO configuration of the NAC. The Telecom Orbiter NAC is a build to print of the MRO camera. The NAC interface and performance parameters are shown in Table A3-1. The dimensions and footprint size are shown in Figure A3-2.

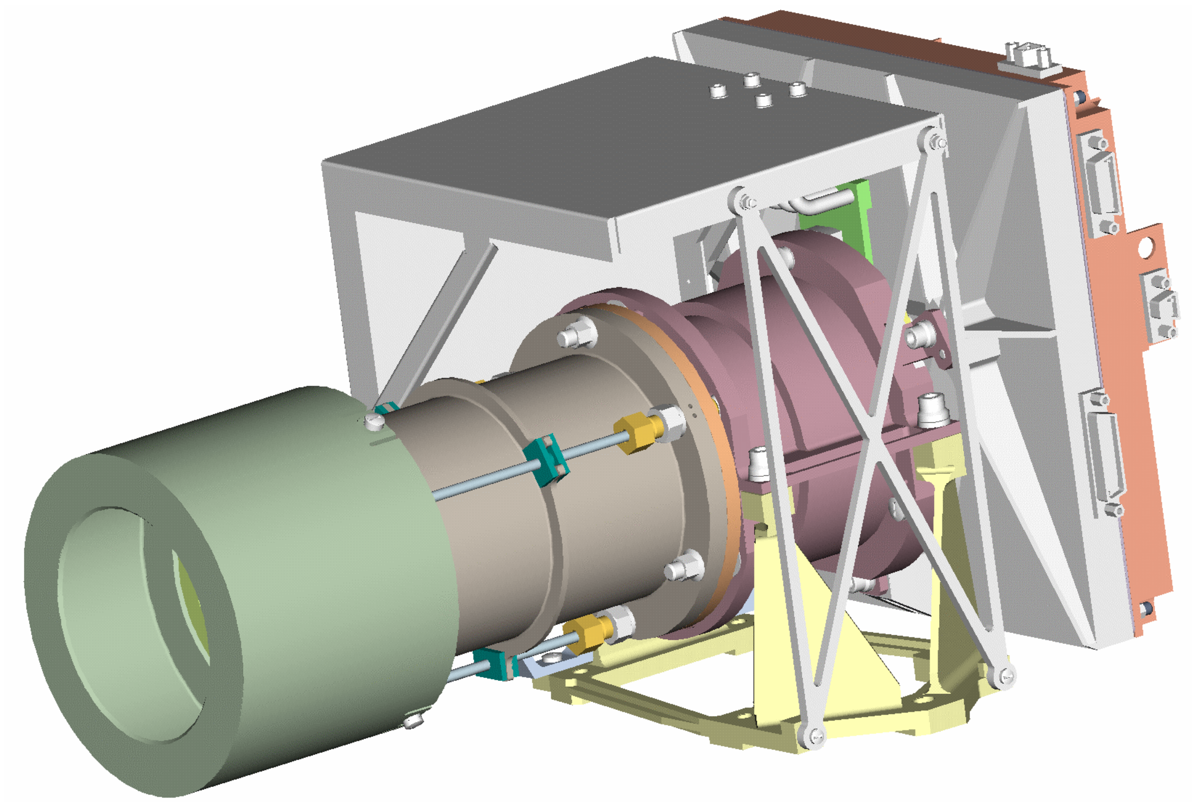


Figure A3-1 MRO Narrow Angle Camera

•	Power	2.5 W (excludes lens cover) + 1.5 W Optics heater
•	Survival Power	2.5 W
•	Mass	2.5 kg (excludes lens cover) (includes ~150 g for the radiator and ~ 200 g for the mount)
•	Operating temp	-40 C to +55 C
•	Survival temp	-55 C to +55 C
•	FOV	1.4º
•	Format	1024 x 1024 active pixels
•	Quantization	16 bits/pixel
•	Interface	LVDS (Command & Data, each having 3 lines)
•	Commands	Integration time, Integrate, Download buffer content, Update time
•	Data transfer rate	1 MHz baseline, 3 full-frame buffer
•	Resolution	1 pixel = 20 cm at 8,500 m

Table A3-1 NAC Interface and Performance Parameters

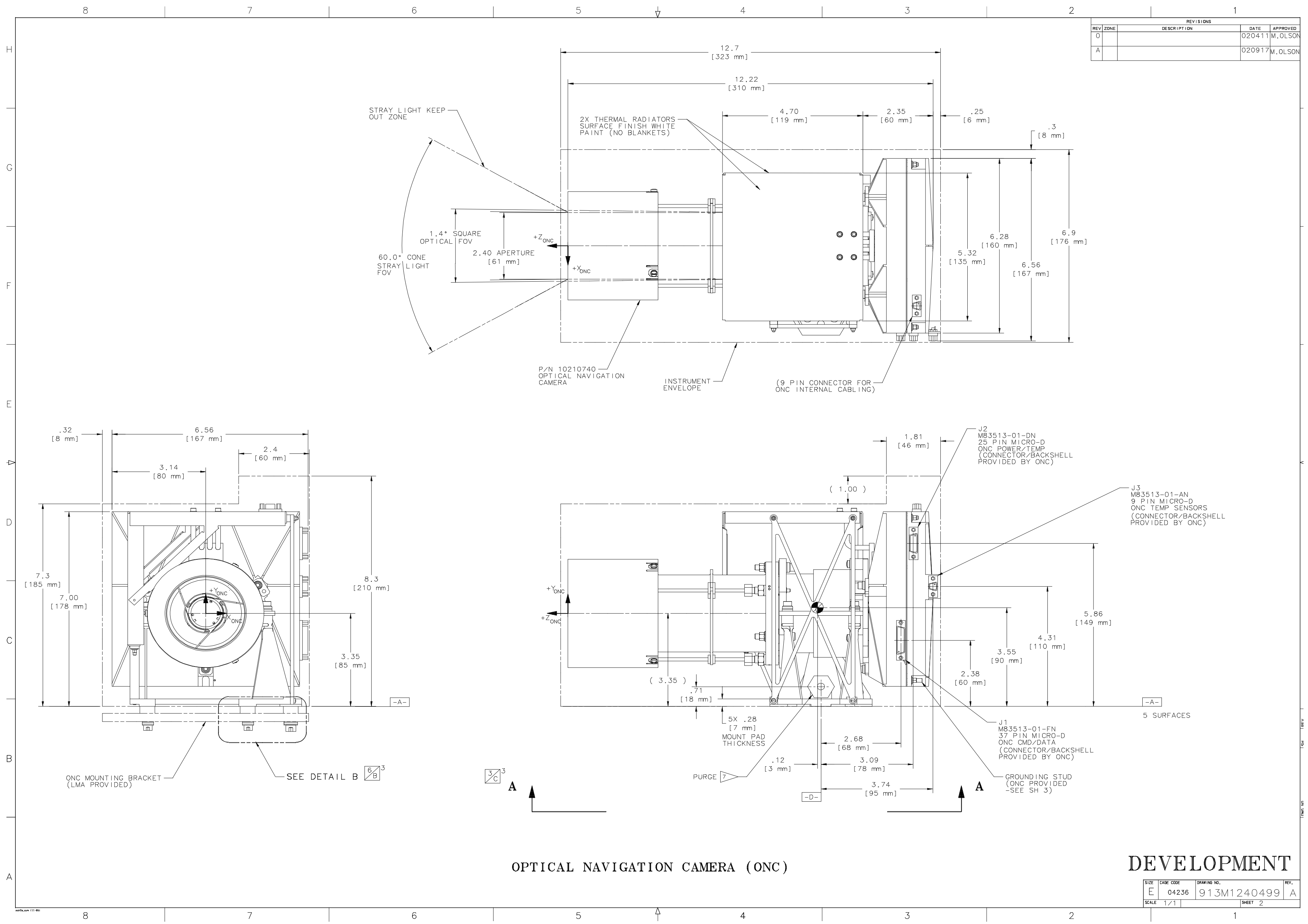


Figure A3-2 NAC Dimensions

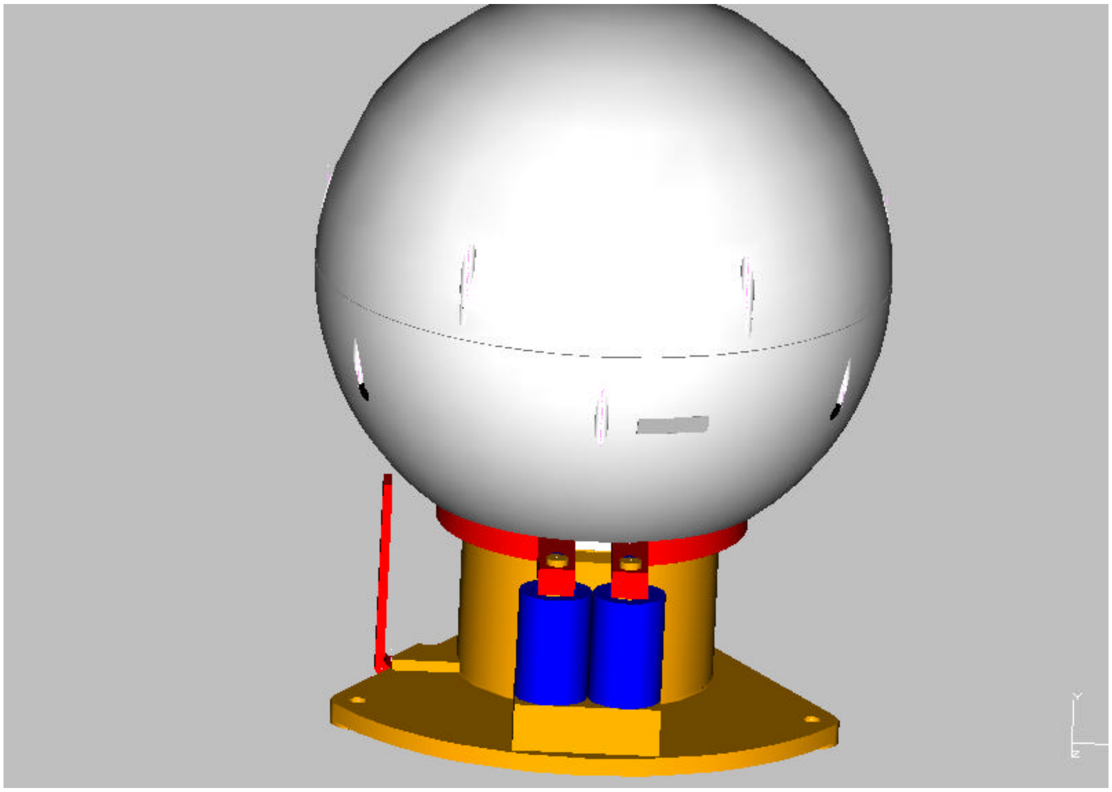
APPENDIX A4: Orbiting Sample Demonstration Canister

The Orbiting Sample (OS) demonstration canister will be carried by MTO in order to provide a target for verifying the techniques that will be used to detect the real OS placed into low orbit by the Mars Sample Return mission. The plan is to release the demonstration canister when MTO is in its final 4450 km orbit, allow it to drift away a sufficient distance, then attempt to detect it using one of the narrow angle cameras.

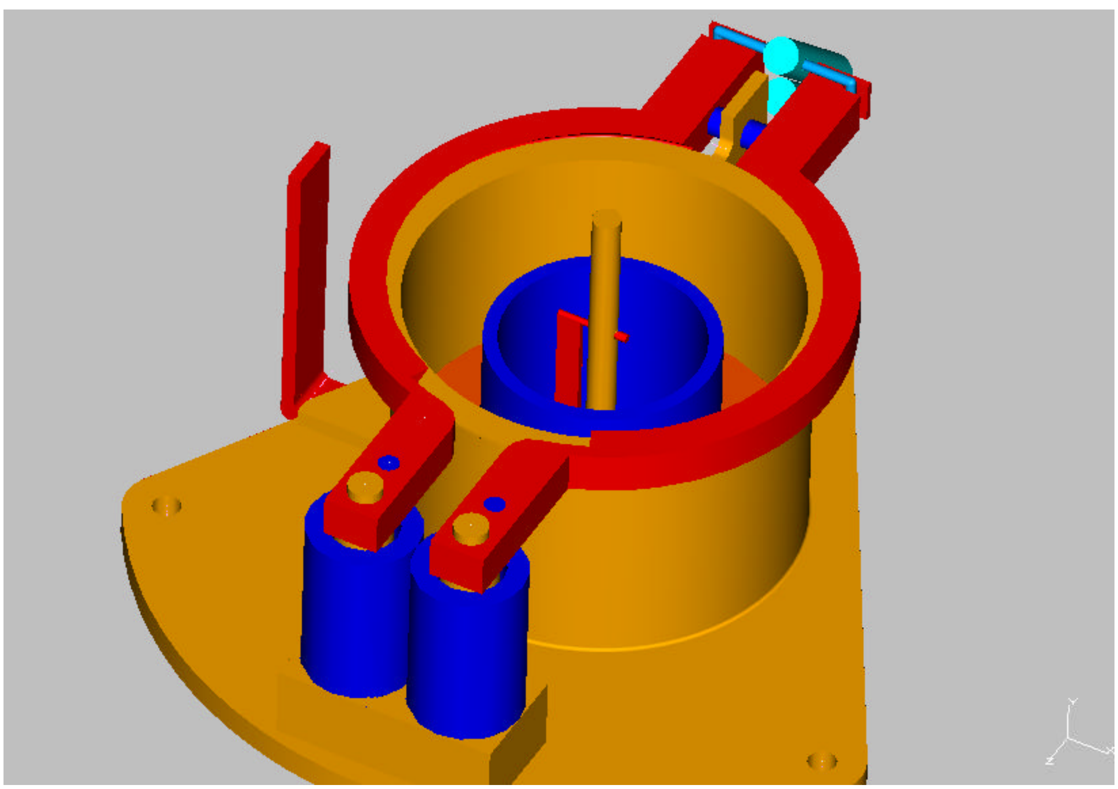
The canister is inert, but its release mechanism requires spacecraft pyro current for ejection. The only thermal control requirements are for the pyro devices/initiators, and might be satisfied by electrical heaters.

Total Mass	4.0kg (Allocation)
Electrical Interfaces	2 ejection NSI pyros • Each pyro with 2 initiators • ~23W for 10ms, each initiator Electrical heaters • < 5 watts (Allocation)
Bounding Volume	20cm diameter x 28cm height

OS Demonstration Canister with Ejector:



Ejector, with OS Demonstration Canister removed:



APPENDIX A5: Science Experiments/Technology Demonstrations

It is anticipated that science experiment(s) and/or technology demonstration(s) will be added to take advantage of the opportunity provided by the MTO mission. For this study, 10 kg and 20 w in all relay and optical communication modes should be set aside to support these as yet unknown payloads.

Volume, mounting footprints, and field of view characteristics of these payloads cannot be estimated at this time. For this study, assume that the selection guidelines for these payloads will include non-interference with the primary objectives of the mission, i.e. their inclusion will not change the basic architecture of the spacecraft from that required to support relay and optical communications demonstration.

APPENDIX B: Trajectory Characteristics/Data

THRUST VECTOR DIRECTIONS FOR 3 MAIN MANEUVERS TO ATTAIN FINAL ORBIT

Coord Frame : MEQIAU

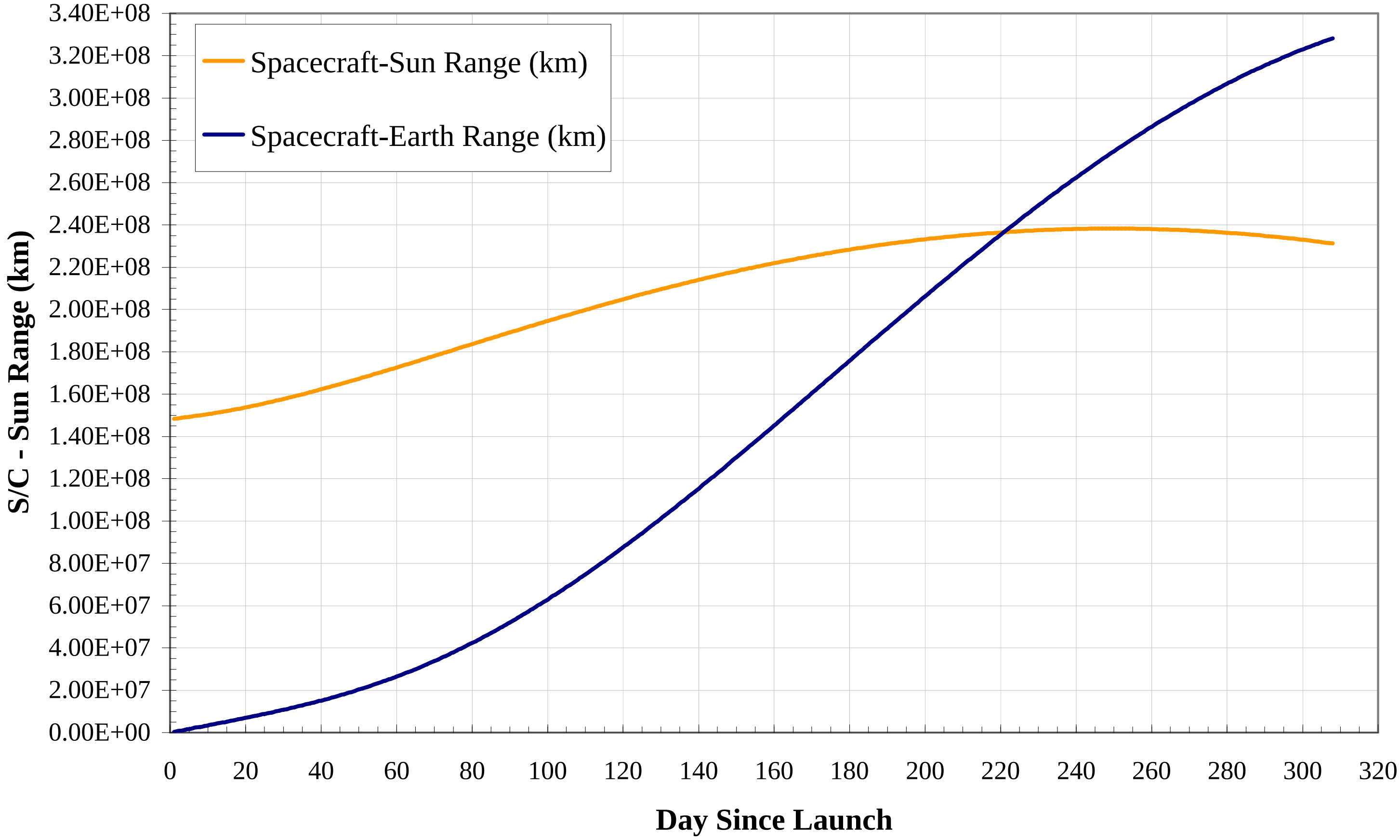
Maneuver State dv's

Mvr	Thrust Vector DX (km/s)	DY (km/s)	DZ (km/s)	Mvr Epoch (ET)	
MOI	7.636215E-04	8.820551E-01	4.711457E-01	9/12/2010 12:00:00.00	
periapse raise	-1.272799E-03	-9.181585E-01	-3.962113E-01	9/27/2010 21:39:21.29	(MOI + 15d)
apoapse lower	1.754975E-04	-8.429391E-01	-5.380089E-01	11/3/2010 3:23:22.30	(MOI + 45d)

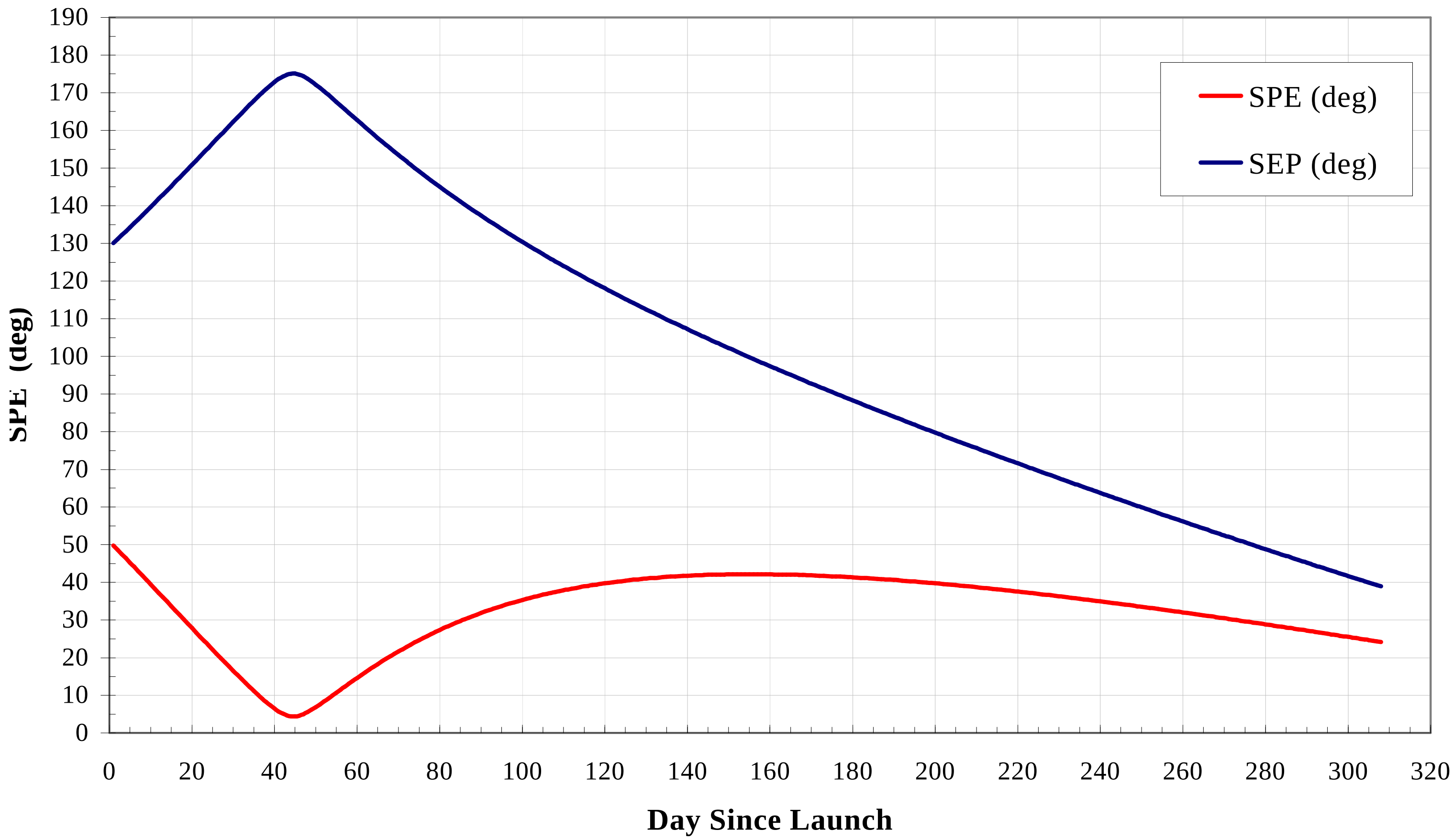
S/C Position (unit vector) wrt Mars, Earth, Sun at time of each Maneuver

	Mvr	Position X (km)	Y (km)	Z (km)	Mvr Epoch (ET)	
wrt Mars (inertial)	MOI	8.315507E-01	5.543671E-01	3.464795E-02	9/12/2010 12:00:00.00	
	periapse raise	2.378644E-02	-9.050153E-01	-4.247134E-01	9/27/2010 21:39:21.29	(MOI + 15d)
	apoapse lower	-2.595651E-01	-8.432032E-03	9.656888E-01	11/3/2010 3:23:22.30	(MOI + 45d)
s/c wrt Earth (inertial)	MOI	-8.838150E-01	-4.678354E-01	-1.001117E-03	9/12/2010 12:00:00.00	
	periapse raise	-7.814667E-01	-6.239340E-01	-4.026215E-03	9/27/2010 21:39:21.29	(MOI + 15d)
	apoapse lower	-4.373006E-01	-8.992568E-01	-1.027023E-02	11/3/2010 3:23:22.30	(MOI + 45d)
s/c wrt Sun (inertial)	MOI	-6.151748E-01	-7.883894E-01	-1.418912E-03	9/12/2010 12:00:00.00	
	periapse raise	-4.967856E-01	-8.678530E-01	-5.939704E-03	9/27/2010 21:39:21.29	(MOI + 15d)
	apoapse lower	-1.793188E-01	-9.836573E-01	-1.621889E-02	11/3/2010 3:23:22.30	(MOI + 45d)

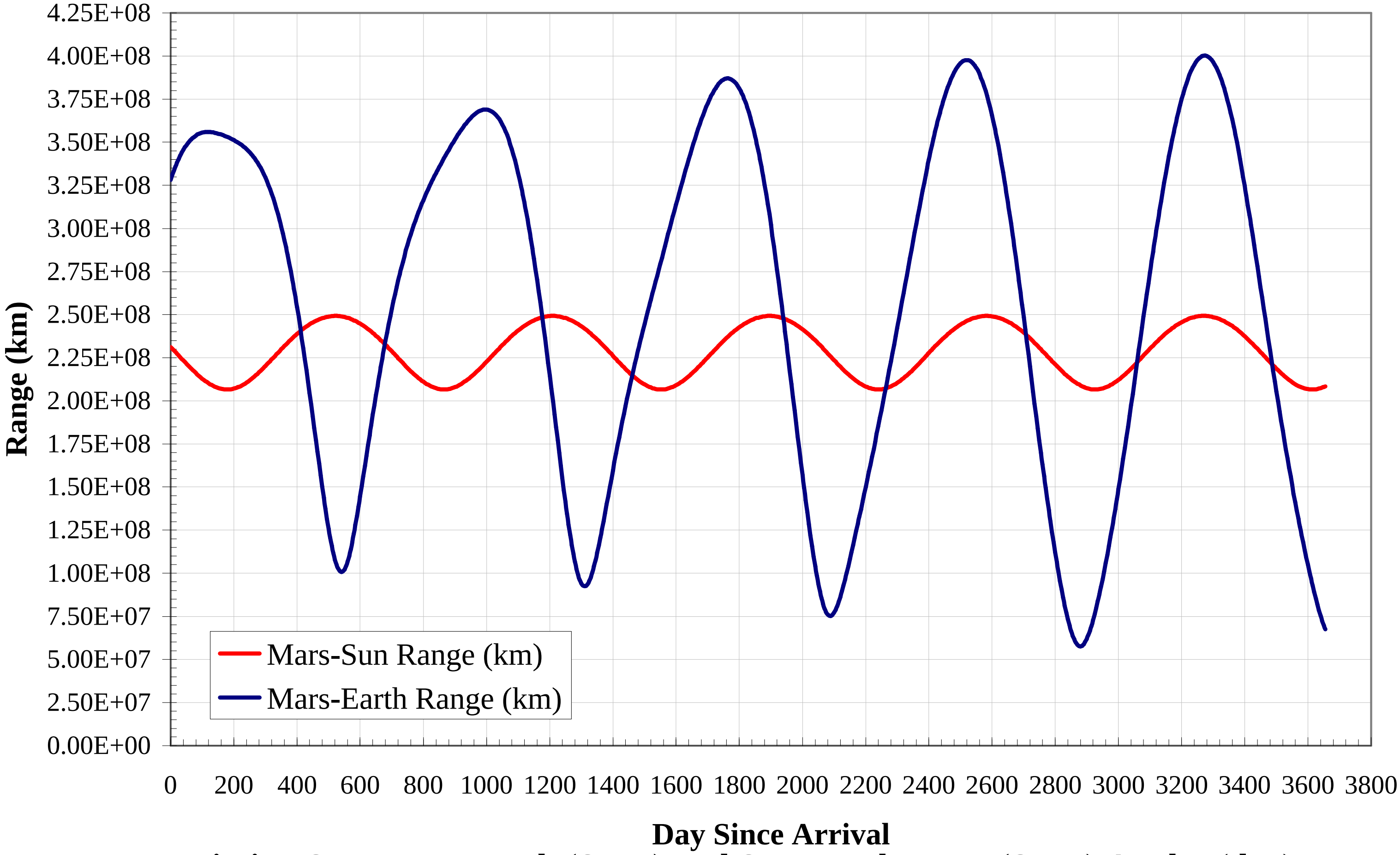
Cruise Spacecraft Range from Earth and Sun (km)



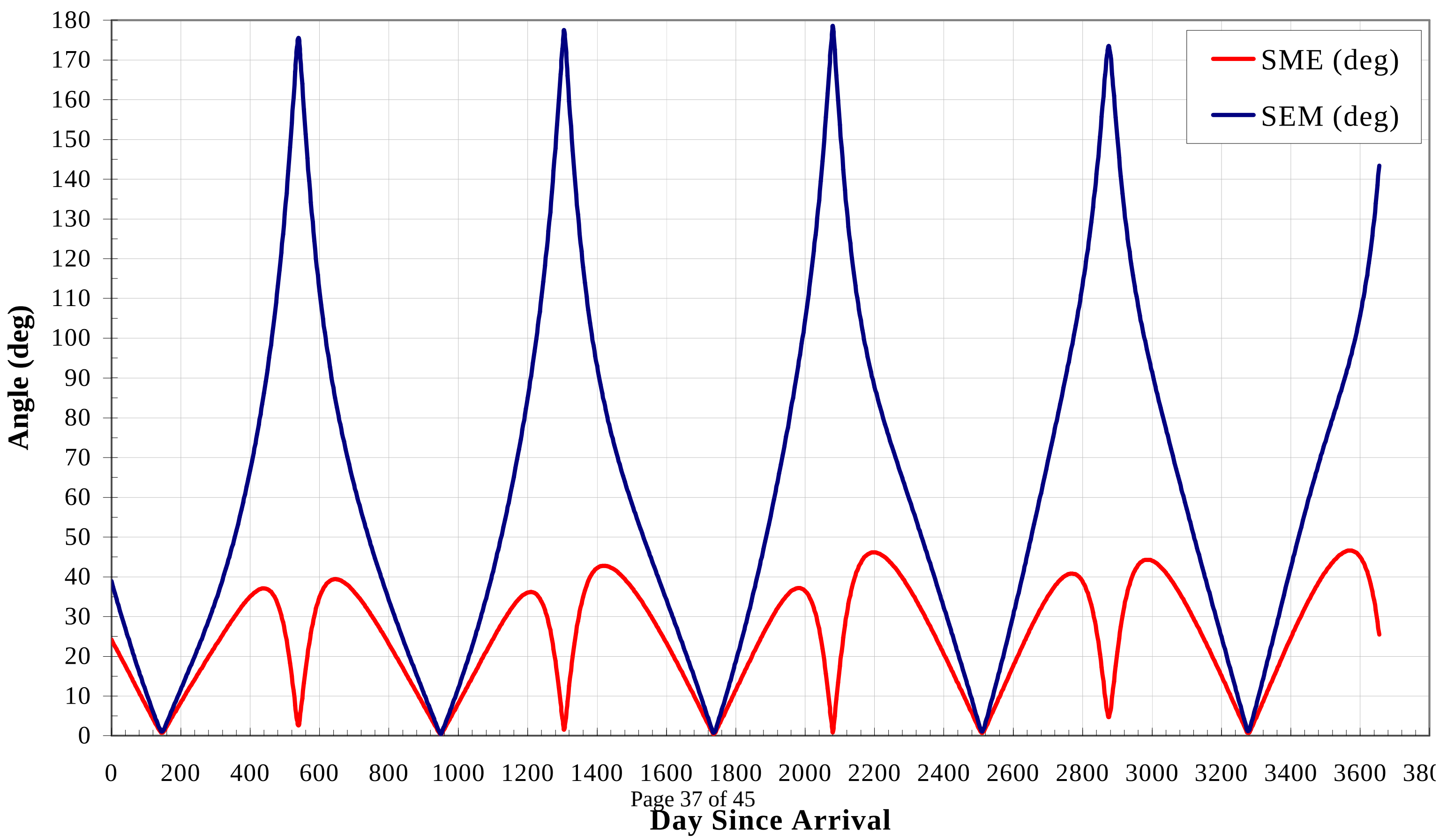
Cruise Sun-Probe-Earth (SPE) and Sun-Earth-Probe (SEP) Angles (deg)

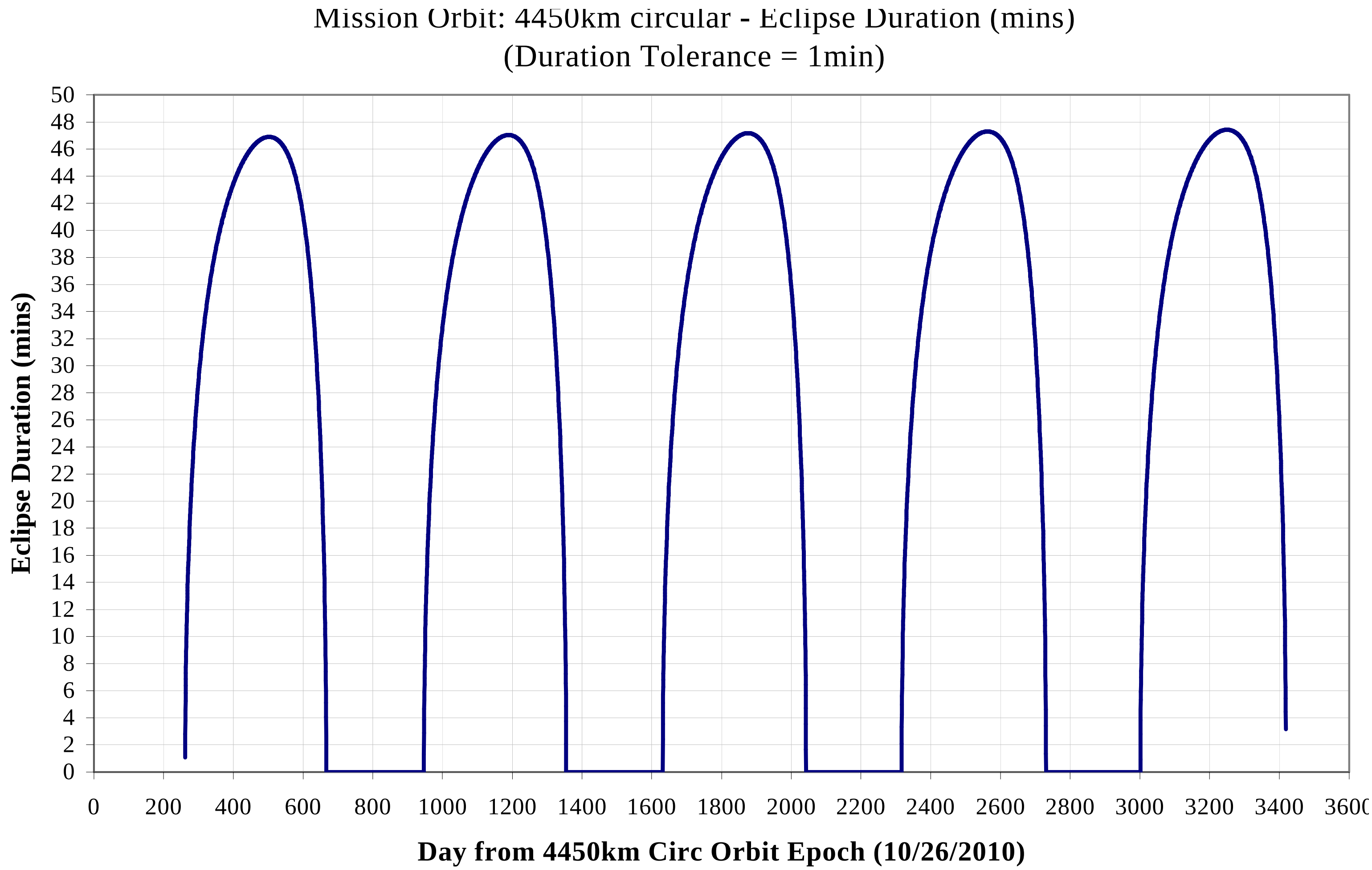


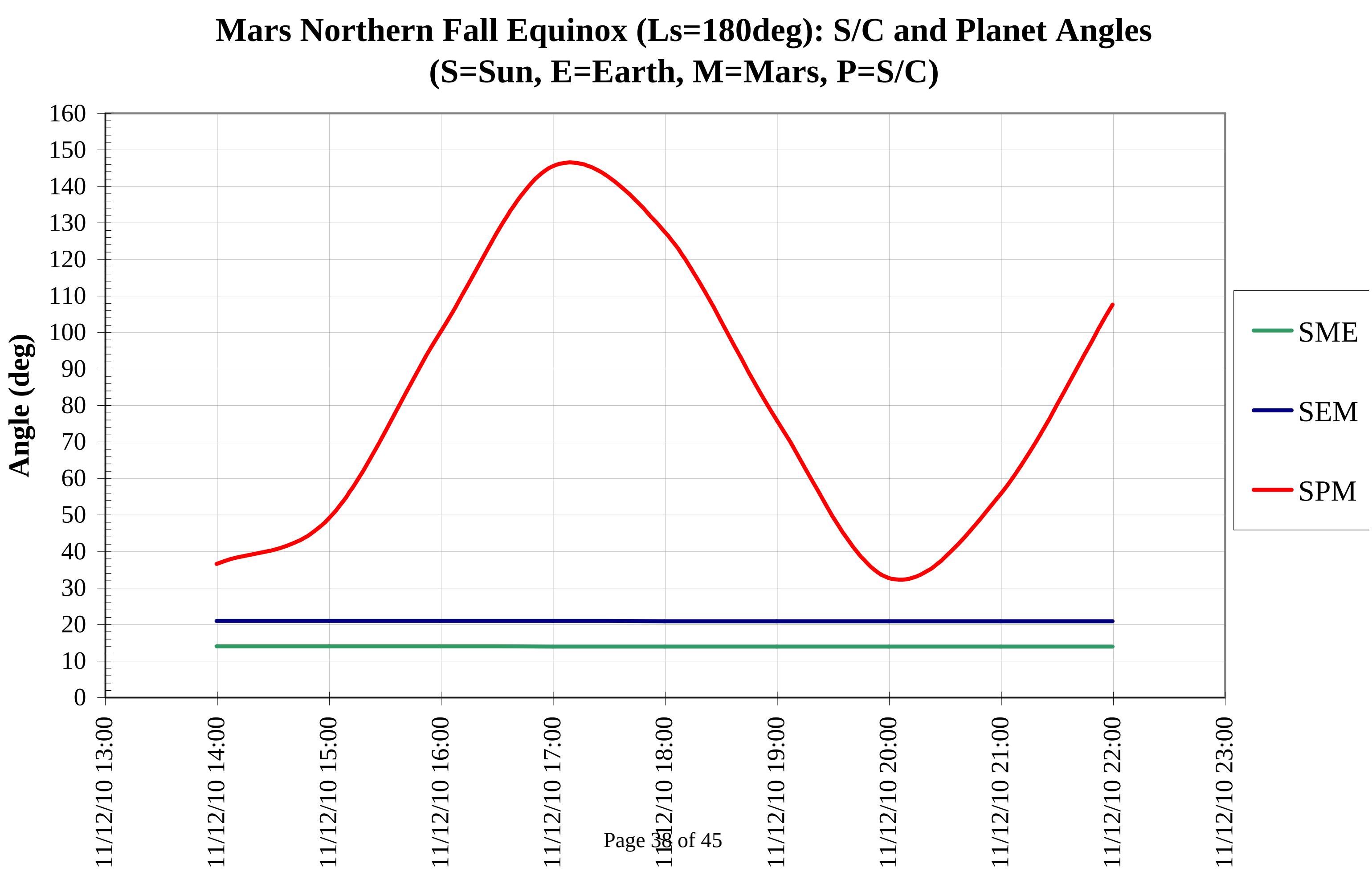
Mission Mars-Sun and Mars-Earth Range (km)



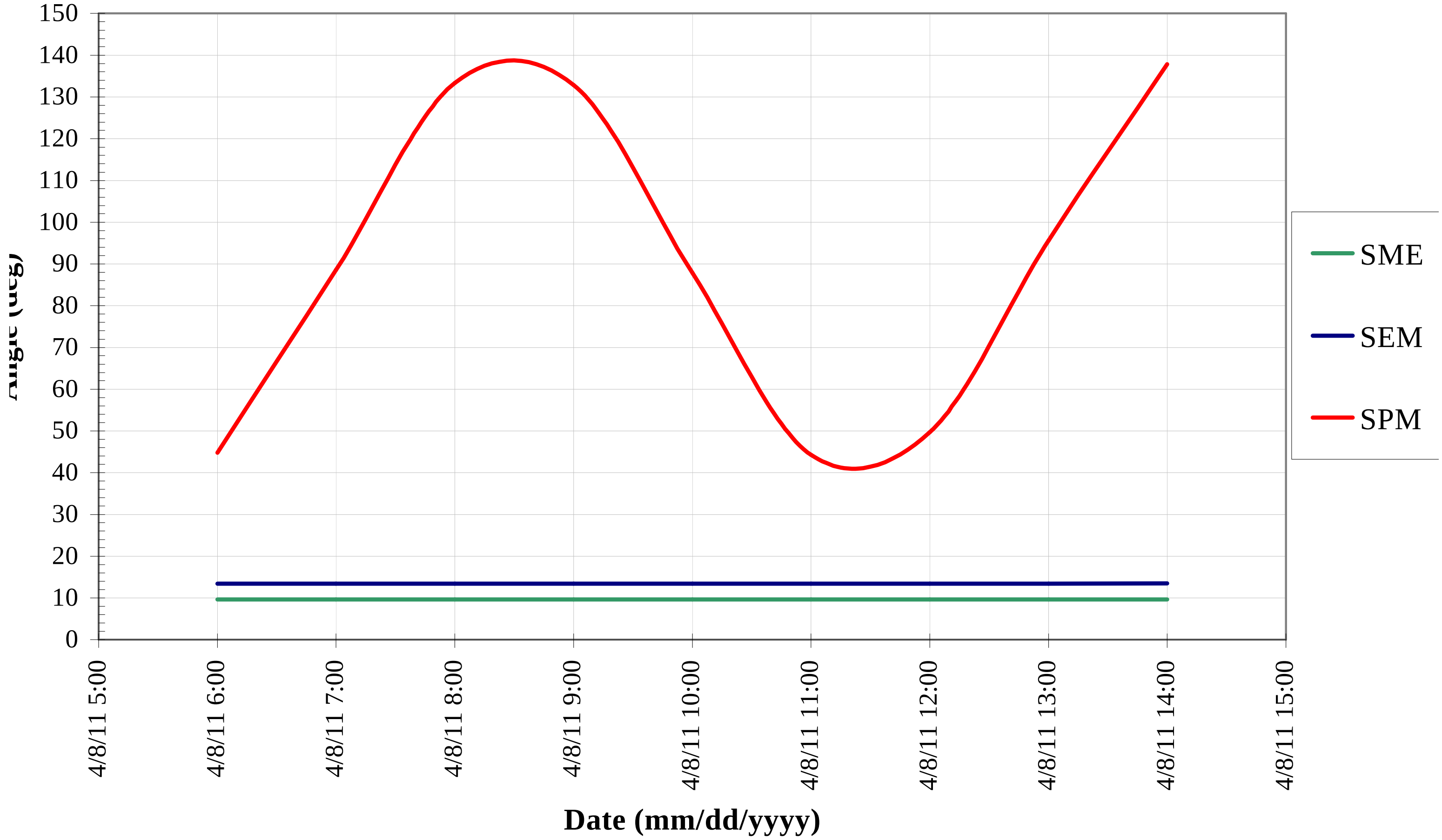
Mission Sun-Mars-Earth (SME) and Sun-Earth-Mars (SEM) Angles (deg)



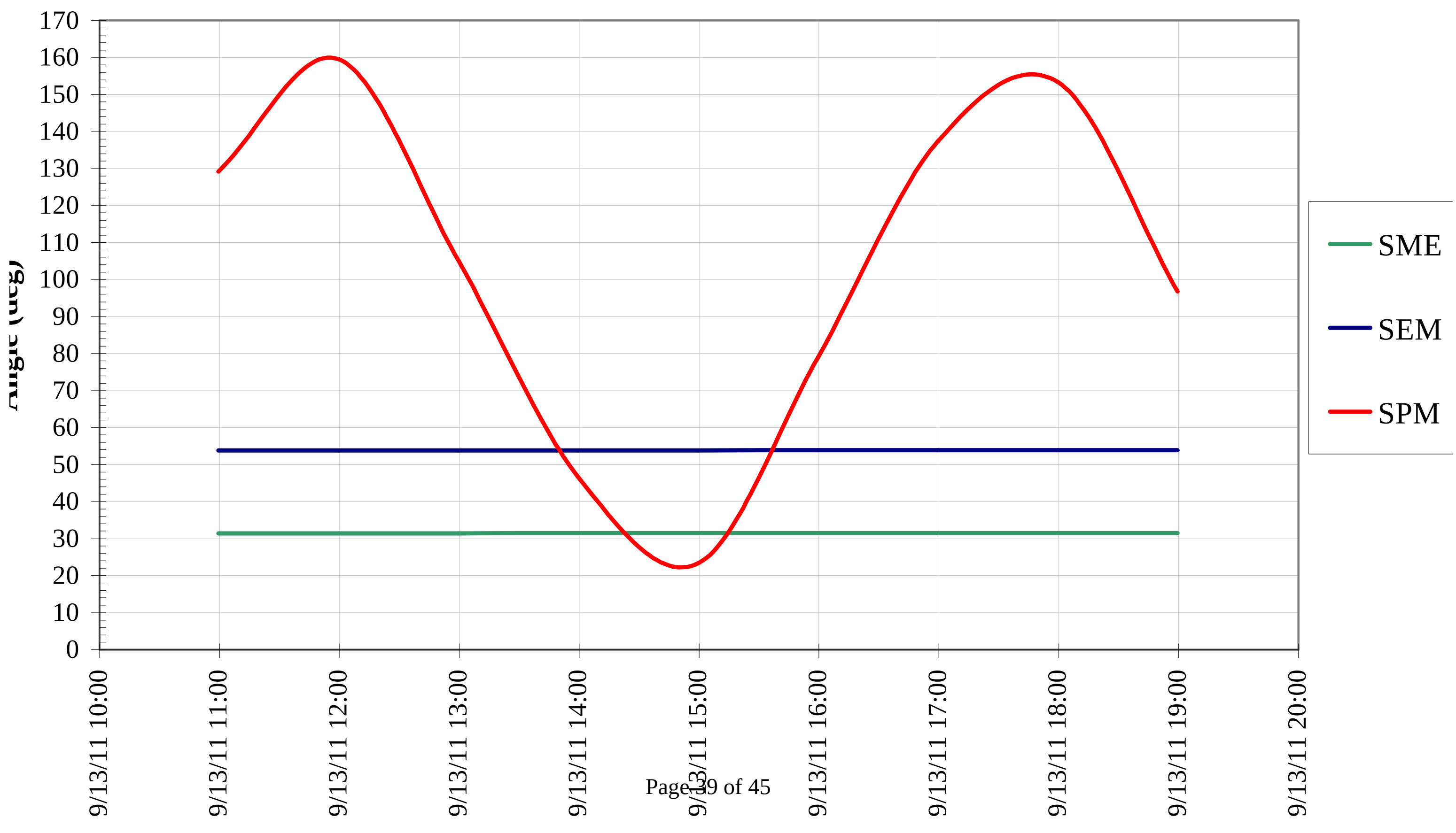

Mission Orbit: 4450km circular - Eclipse Duration (mins)
(Duration Tolerance = 1min)
Eclipse Duration (mins)
Day from 4450km Circ Orbit Epoch (10/26/2010)


Mars Northern Fall Equinox (Ls=180deg): S/C and Planet Angles
(S=Sun, E=Earth, M=Mars, P=S/C)
Angle (deg)
SME
SEM
SPM
Date (mm/dd/yyyy)

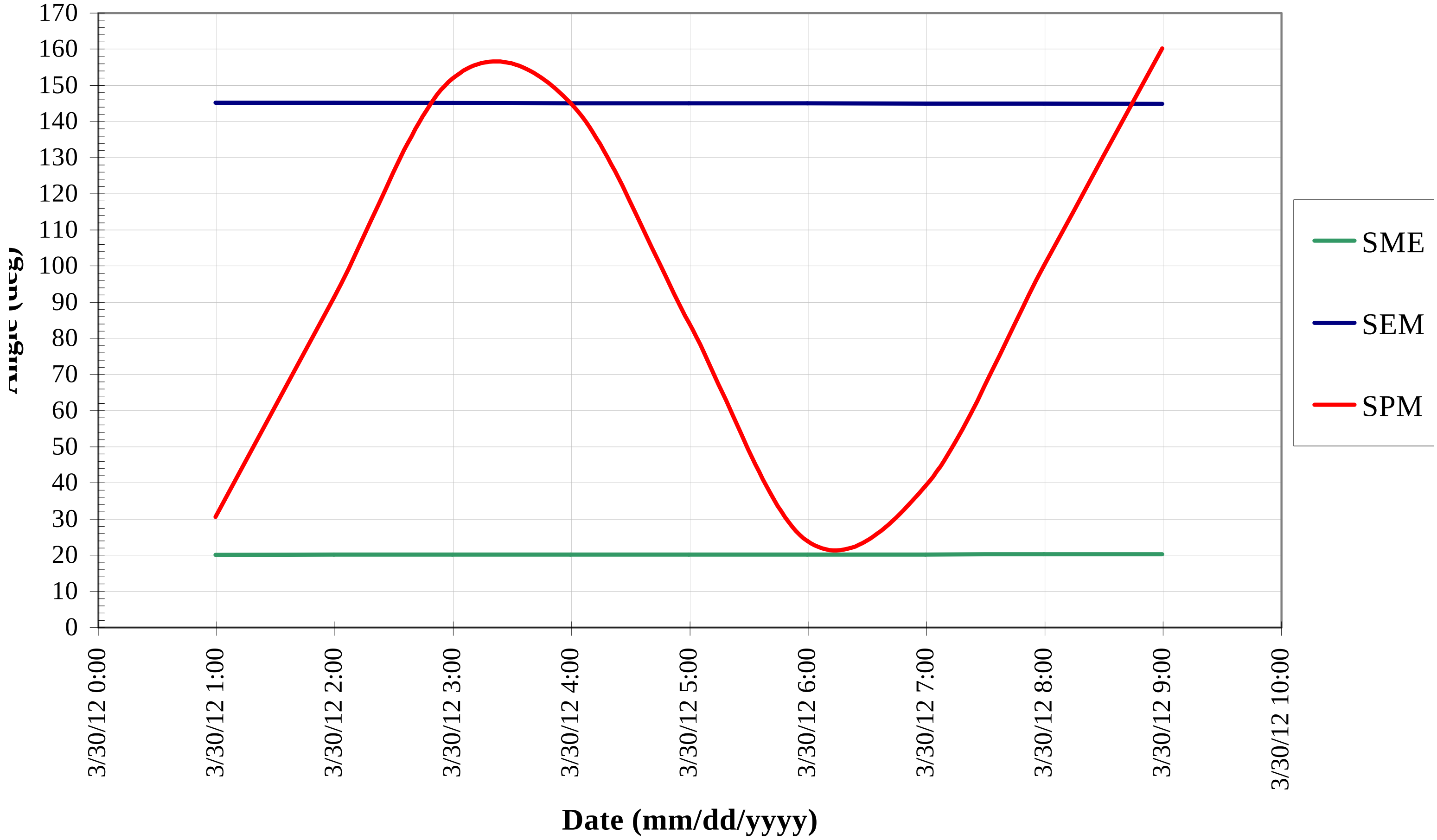
Mars Northern Winter Solstice (Ls=270deg): S/C and Planet Angles (S=Sun, E=Earth, M=Mars, P=S/C)



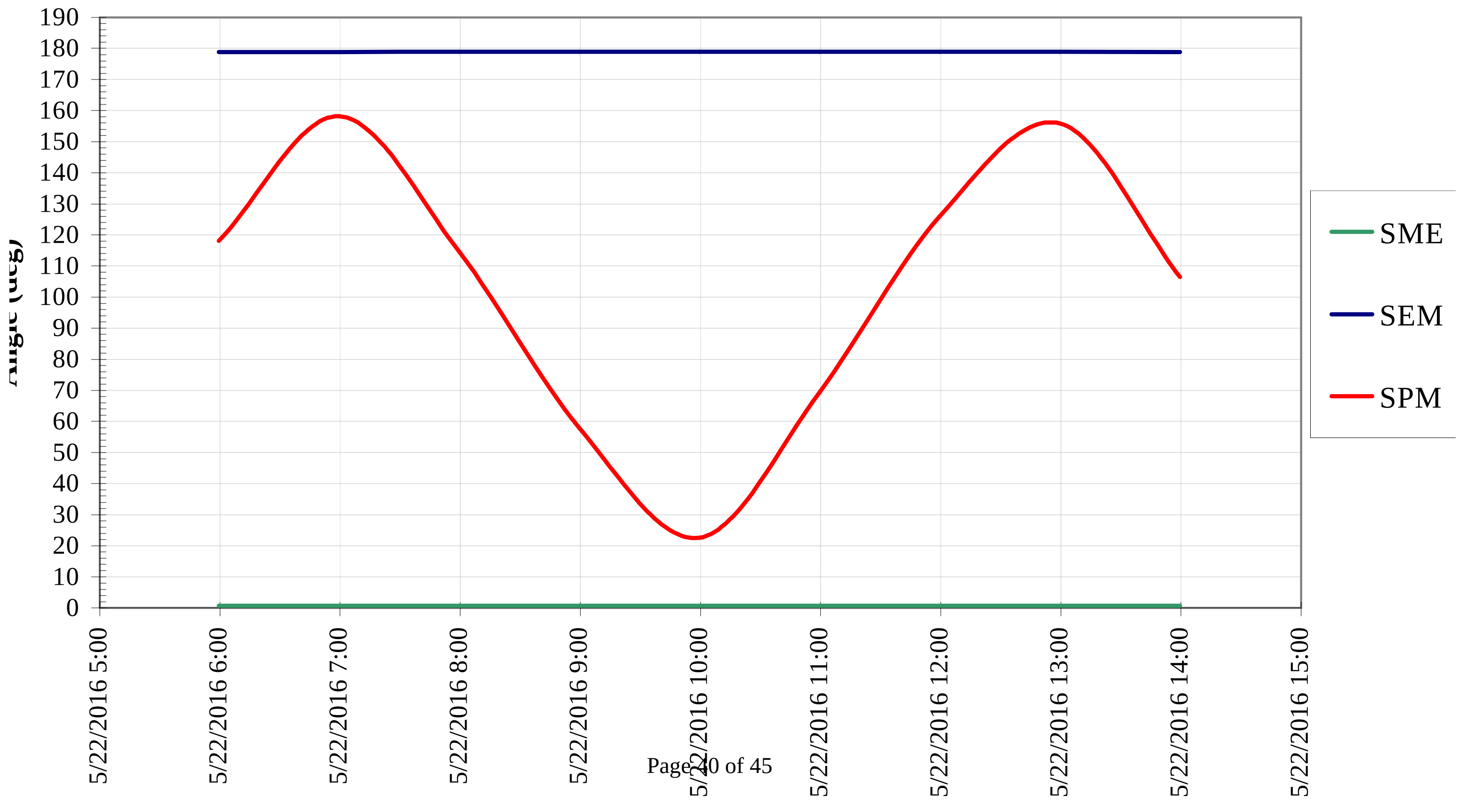
Mars Northern Spring Equinox (Ls=0deg): S/C and Planet Angles (S=Sun, E=Earth, M=Mars, P=S/C)

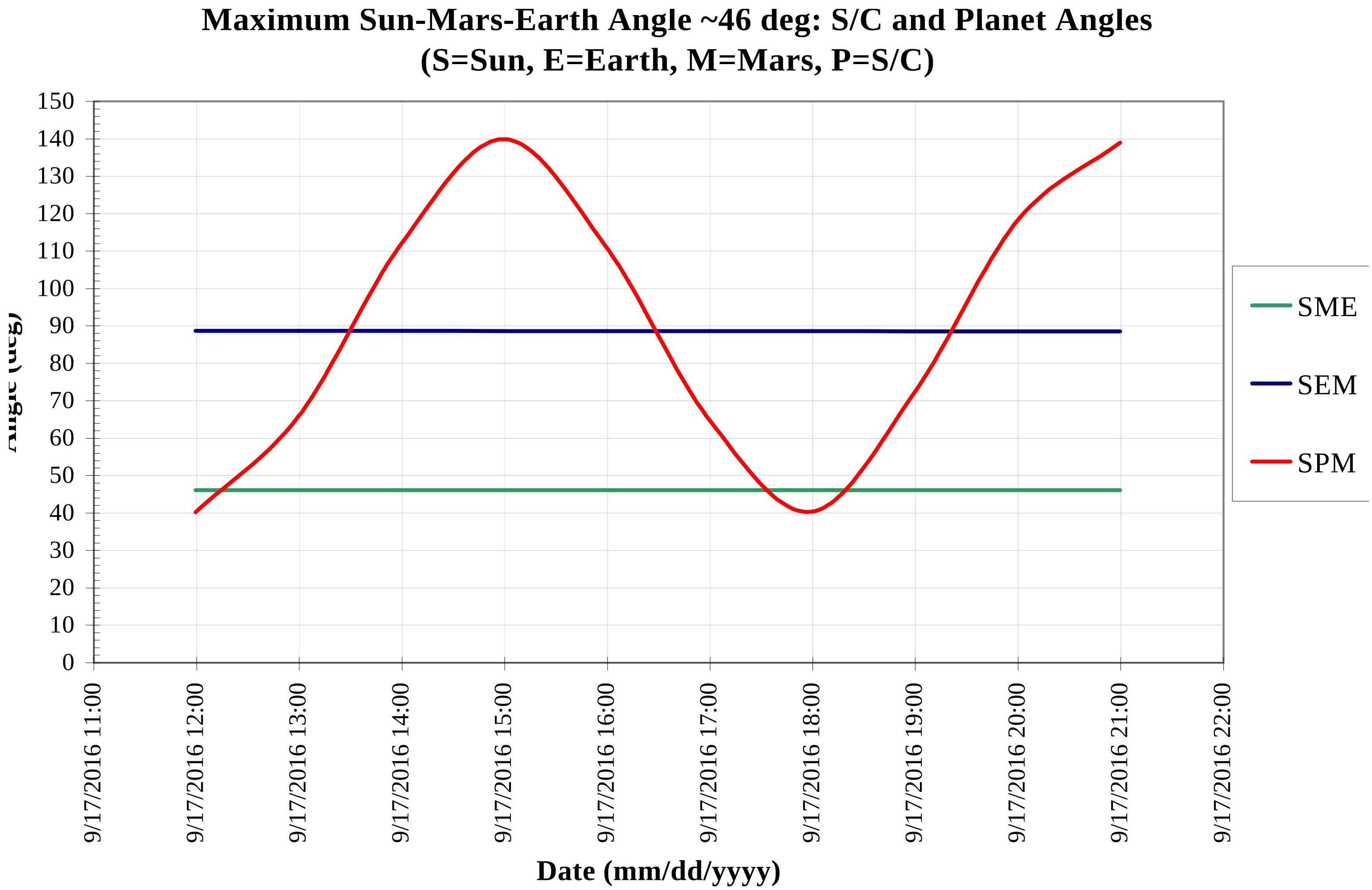


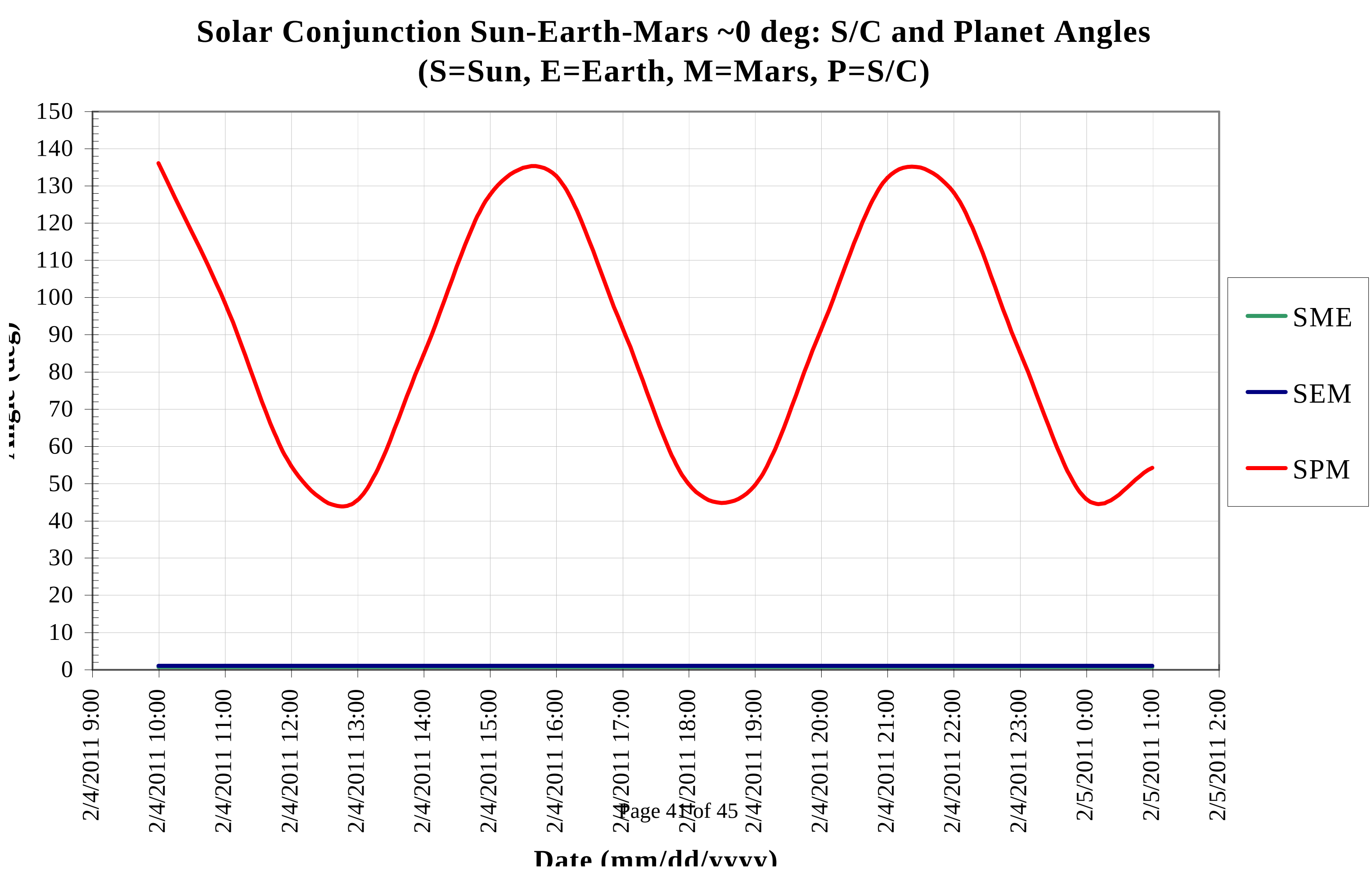
Mars Northern Summer Solstice (Ls=90deg): S/C and Planet Angles (S=Sun, E=Earth, M=Mars, P=S/C)



Minimum Sun-Mars-Earth Angle ~0 deg: S/C and Planet Angles (S=Sun, E=Earth, M=Mars, P=S/C)




Maximum Sun-Mars-Earth Angle ~46 deg: S/C and Planet Angles
(S=Sun, E=Earth, M=Mars, P=S/C)
Angle (deg)
Date (mm/dd/yyyy)
SME
SEM
SPM


Solar Conjunction Sun-Earth-Mars ~0 deg: S/C and Planet Angles
(S=Sun, E=Earth, M=Mars, P=S/C)
Angle (deg)
Date (mm/dd/yyyy)
SME
SEM
SPM

APPENDIX CAcronyms

Acct	Accounting
ACK	Acknowledgement
A/D	Analog to Digital converter
AGC	Automatic Gain Control
AMMOS	Advanced Multi-Mission Operations System
AOS	Advanced Orbiting System; acquisition of signal
ARQ	Automatic Repeat Request
ASI	Italian Space Agency
ASM	Attached Synchronization Marker
ATME	ATLO Test Engineer
ATLO	Assembly, Test, and Launch Operations
ATP	Acceptance Test Plan
BPM	Baseband Processing Module
BCH	Bose-Chaudhuri-Hocquenghem coding
BPSK	Binary Phase Shift Keying
CCSDS	Consultative Committee for Space Data Systems
CE	Cincinnati Electronics
CFDP	CCSDS File Delivery Protocol
C&DH	Command and Data Handling (subsystem)
CLTU	Command Link Transmission Unit
COP-P	Command Operations Procedure - Proximity
CRC	Cyclic Redundancy Check
CW	Continuous Wave
dB	Decibel
dBiC	Decibels relative to a circularly polarized isotropic antenna
Demod	Demodulator
DFE	Direct From Earth
DSN	Deep Space Network
DTE	Direct To Earth
DVB	Digital Video Broadcasting
Eb/No	Energy per Bit/Noise Power Spectral Density
EDL	Entry Descent and Landing
EDU	Engineering Design Unit
EEIS	End-to-End Information System
Electra	Relay radio under development by JPL & Cincinnati Electronics for use on MRO and later Mars relay orbiters
EMI	Electromagnetic Interference
EOP	End Of Product
ESA	European Space Agency

EUT	Electra UHF Transceiver
FEC	Forward Error Connecting
FPGA	Field Programmable Gate Array
Forward Link	From ground operations outbound to spacecraft or relay user
FSK	Frequency Shift Keying
FSW	Flight Software
FTP	File Transfer Protocol
f_{USO}	USO Frequency
GDS	Ground Data System
GHz	GigaHertz (Frequency of 10^9 Hertz)
GOES	Geostationary Operational Environmental Satellites
GSE	Ground Support Equipment
GSW	Ground Software
GTD	Geometric Theory of Diffraction
H/W	Hardware
ICD	Interface Control Document
IF	Intermediate Frequency
IMU	Inertial Measurement Unit
IND	Interplanetary Network Directorate
IPN	Interplanetary Network
IP	Internet Protocol
IS	Information System
ISO	International Standards Organization
ITAR	International Traffic in Arms Regulation
ITU-T	International Telecommunications Union - Telecommunications
K_a-Band	27-40 GHz
LHCP	Left Hand Circularly Polarized
LLC	Logical Link Control
LNA	Low Noise Amplifier
LO	Local Oscillator
LVDS	Low Voltage Differential Signal
Marscraft	A lander, rover, aerobot or spacecraft at or in the vicinity of Mars
MBR	Mars Balloon Relay
MEP	Mars Exploration Program
MEX	Mars Express
MIB	Management Information Base
MGS	Mars Global Surveyor
Mod	Modulator
MOM	Methods of Moments
MOS	Mission Operations System
MRO	Mars Reconnaissance Orbiter

MSL	Mars Science Laboratory (aka Mars Smart Lander or Mobile Science Laboratory)
MTO	Mars Telecommunications Orbiter
NAK	No Acknowledgement
NDU	Named Data Unit
NCO	Numerically Controlled Oscillator
NISN	NASA Integrated Services Network
NOAA	National Oceanic and Atmospheric Administration
NRE	Non-Recurring Expense
NRZ-L	Non-Return to Zero - Level
ODY	Odyssey
OMG	Object Management Group
Ops	Operations
OTO	Orbiter Test Set Operator
PC	Personal Computer
PDU	Packet Data Unit
PLOP	Physical Layer Operations Procedures
POCC	Payload Operations Control Center
Prox-1	CCSDS Proximity-1 relay protocol
PSK	Phase Shift Key
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
QQCL	Quality, Quantity, Continuity, and Latency
RCF	Return Channel Frame Service
Rcv	Receive
Return Link	From relay user or spacecraft inbound to ground operations
RF	Radio Frequency
RFM	Radio Frequency Module
RHCP	Right Hand Circularly Polarized
RLT	Radio Link Testing
RO	Receiver Ocsillator
RS	Reed-Soloman
S/C	Spacecraft
S/W	Software
SCID	Spacecraft Identification
SCMF	Spacecraft Message File
SCPS	Space Communications Protocol Software
SCPS-FP	SCPS File Protocol
SCPS-NP	SCPS Network Protocol
SCPS-SP	SCPS Security Protocol

SCPS-TP	SCPS Transfer Protocol
SDST	Small Deep Space Transponder
SLE	Space Link Extension
SNR	Signal-to-Noise Ratio
SOE	Sequence Of Events
SSR	Solid State Recorder
STE	Support Test Equipment
Tbit	Terabit (10^12 bits)
TBR	To Be Reviewed
TC	Telecommand; Test conductor
TCM	Trajectory Correction Maneuver
TCP	Transfer Control Protocol
TCXO	Temperature Controlled Crystal Oscillator
TDA	Test Data Analyst
TE	Test Engineer
TLM	Telemetry
TO	Transmitter Oscillator
TTACS	Test Telemetry and Command System
UDP	User Datagram Protocol
UHF	Ultra High Frequency, 300-1000 MHz
USHE	UHF System/Hardware Engineer
USO	Ultra Stable Oscillator
UTC	Coordinated Universal Time
X-Band	8-12 GHz
Xmit	Transmit