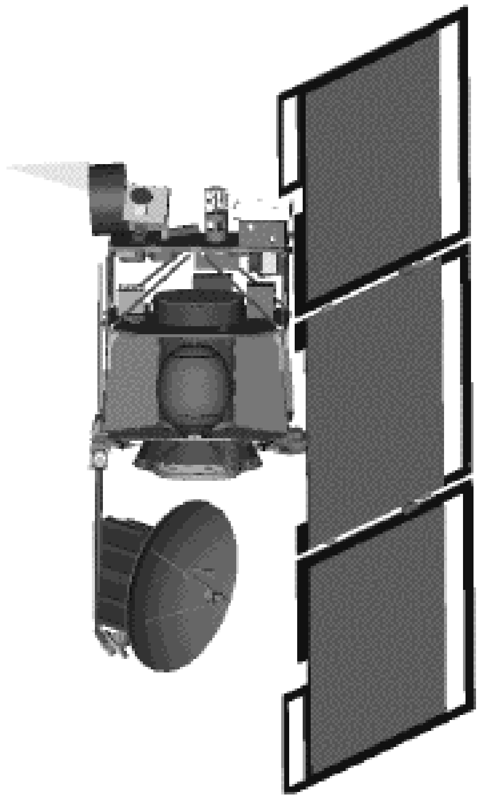
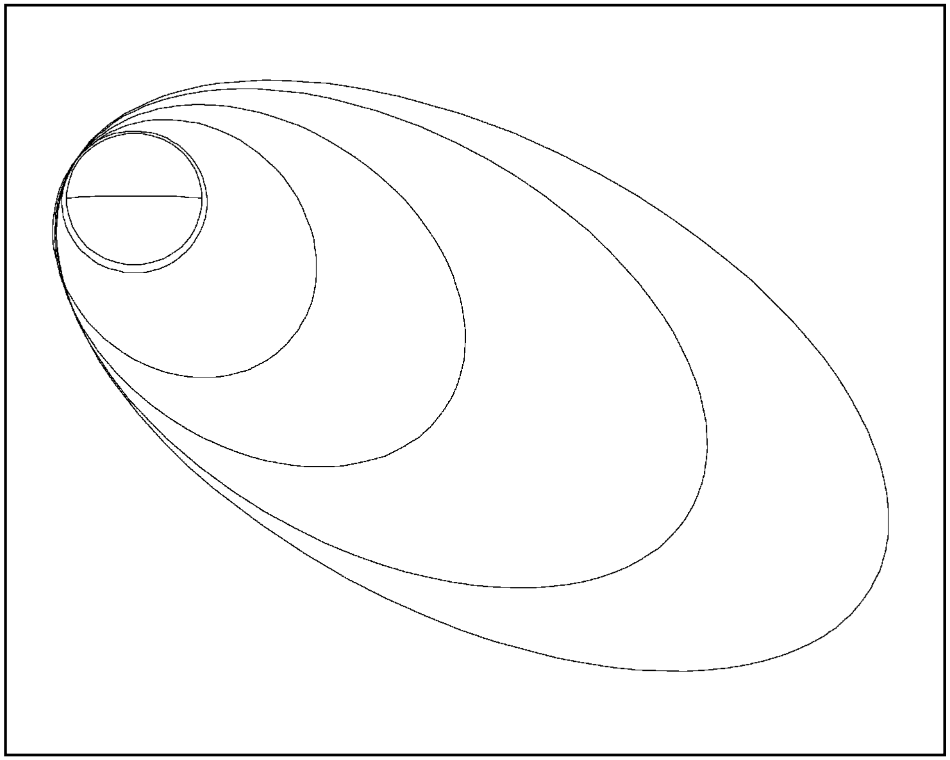
MARS SURVEYOR '98 PROJECT

ORBITER MISSION PLAN and DATABOOK





August 8, 1997

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4.0 MARS SURVEYOR 1998 ORBITER MISSION PLAN

4.1 FLIGHT SYSTEM DESCRIPTION

4.1.1 Orbiter Bus

The Orbiter is 3-axis stabilized in all mission phases following separation from the launch vehicle. The primary attitude determination is via star camera and an inertial measurement unit, and is backed up by analog sun sensors. Reaction wheels provide primary attitude control during most mission phases, and are desaturated via RCS thrusters. Because of IMU lifetime concerns, the IMUs will be turned off during significant portions of Cruise and Mapping, and the vehicle operated in all-stellar mode. except during maneuvers. The RCS thrusters also provide attitude control during TCM's, MOI, aerobraking drag pass, OTM's, and safe mode [until rates are damped, at which point RW control is used]. In all, four 5-lbf thrusters are used for TCM's and pitch/yaw control. Four 0.2-lbf thrusters are used for roll control. The Orbiter C&DH uses the RAD6000 processor. The X-band link with Earth employs Cassini Deep Space Transponders, 15 W RF solid state power amplifiers (SSPA's), one 1.3 m transmit/receive high gain antenna (HGA), one transmit-only medium gain antenna (MGA), and one receive-only low gain antenna. A 10 Watt RF UHF system supports the 2-way link with the Lander. The 3-panel, single wing solar array (SA) uses GaAs/Ge solar cells and also functions as the primary drag brake during aerobraking. The batteries are NiH2 CPV batteries, while the electrical power electronics are based on the SSTI spacecraft electronics. The thermal control subsystem is passive, with louvers to control the temperature of the batteries and SSPA's and combinations of MLI, Kapton, paints, and dedicated radiators for certain other components. Both thermostatically controlled and computer controlled heater circuits are used. The Orbiter equipment module (EM) is a composite truss structure with titanium end fittings and two Aluminum honeycomb panels with composite face sheets. The solar array and HGA track the Sun and Earth, respectively, with 2-axis gimbals. The propulsion subsystem is dual mode, employing a bipropellant main engine for Mars Orbit Insertion (MOI) and TCM (hydrazine) thrusters for all other propulsive events. Most subsystem components are redundant, with critical items cross strapped.

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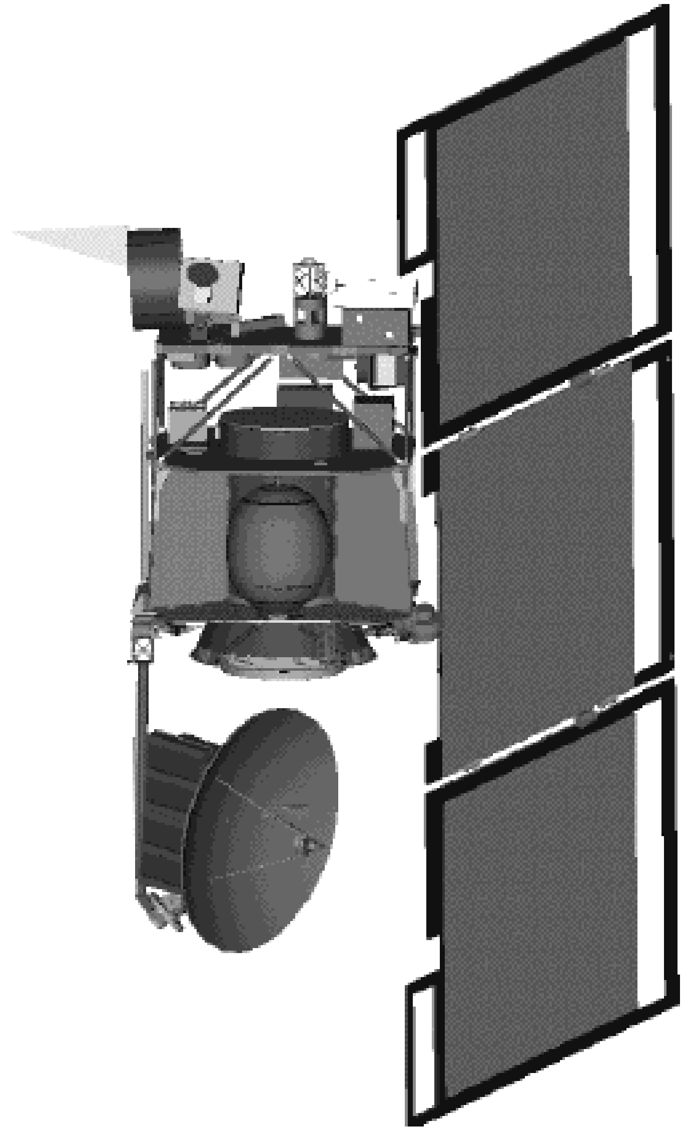
FLIGHT SYSTEM DESCRIPTION: ORBITER BUS

- **AACS:**
  - 3 axis stabilized
  - Reaction wheels desaturated via RCS thrusters
  - IMUs turned off during significant portions of Cruise, Mapping [all-stellar mode] except during maneuvers
    » IMU lifetime concerns.
  - Star camera + IMU, backed up by analog sun sensors
  - 4 5-lbf TCM thrusters also used for Pitch & Yaw
  - 4 0.2-lbf thrusters for Roll control
- **C&DH: RAD6000 processor**
- **Telecom:**
  - Cassini Deep Space Transponders
  - 15W RF SSPA's
  - One 1.3m Tx/Rx HGA, 1 Tx-only MGA, 1 Rx-only LGA
  - UHF 10 Watt RF system for 2-way communication with Lander
- **Power:**
  - Single, 3 panel GaAs/Ge solar array, 2 axis gimballed
  - NiH2 CPV batteries
- **Thermal Control:**
  - Passive: louvers, MLI, Kapton, paints, dedicated radiators
  - Thermostatically controlled and computer controlled heater circuits
- **Propulsion:**
  - Biprop system for MOI only
  - Hydrazine TCM thrusters [4 5-lbf thrusters] for all other maneuvers
- **Structure: Composite facesheets on Aluminum honeycomb.**



4.1.2 Orbiter Payload

Pressure Modulator Infrared Radiometer (PMIRR)

PMIRR is a nine-channel limb and nadir scanning atmospheric sounder designed to vertically profile atmospheric temperature, dust, water vapor and condensate clouds and to quantify surface radiative balance. PMIRR observes in a broadband visible channel, calibrated by observations of a solar target mounted on the instrument, and in eight spectral intervals between 6 and 50 μm in the thermal infrared. High spectral discrimination in the 6.7 μm water vapor band and in two parts of the 15 μm carbon dioxide bands is achieved by employing pressure (density) modulation cells in front of selected spectral detectors. Adequate signal-to-noise in these channels is ensured through the placement of their detectors on a cold focal plane assembly cooled to 80 K by a passive radiative cooler. The PMIRR Principal Investigator is Dr. Daniel McCleese (JPL/Caltech); Vasily Moroz (IKI/Russia) is Joint Principal Investigator.

PMIRR science observations will commence only after the PMIRR radiator door is fully opened. Once PMIRR is deployed in the mapping orbit, vertical profiles of atmospheric properties are constructed from observations in three fields-of-view (FOV) stepped across the limb and onto the planet using a two-axis scan mirror in front of the primary telescope. Nominally, PMIRR views the aft limb, referenced to the spacecraft, except for the polar regions where it routinely views in and out of the plane of the spacecraft track to quantify the polar surface albedo by observing much of the bi-direction reflectance distribution function. PMIRR can also view to the side limb, acquiring observations characterized by different local times. PMIRR’s vertical resolution is 5 km.

Mars Color Imager (MARCI)

MARCI combines Wide Angle (WA) and Medium Angle (MA) cameras with individual optics but identical focal plane assemblies, data acquisition system electronics, and power supplies. Each camera is small in size (≈ 6 x 6 x 12 cm, including baffle) and mass (combined mass ≤ 2 kg). Both cameras operate in a "pushframe" mode, with their CCD detectors overlaid with spectral ("color") filter strips. The cameras are electronically shuttered at intervals timed so that the spacecraft motion spatially overlaps each filter strip view, thereby providing a "color" composite. The MARCI Principal Investigator is Dr. Michael Malin (Malin Space Science Systems, San Diego).

Near the end of the Orbiter's cruise phase, MARCI acquires approach images of Mars. Once in the mapping orbit, MARCI provides daily global images of the Mars atmosphere (and surface) with the WA camera and monitors surface changes with the MA camera during mission periods with high data rates.

The WA camera has seven spectral bands [5 visible, 2 UV] and has spatial resolutions on the planet better than 7.2 km/pixel, for nominal orbital altitude and downlink data rates. Kilometer-scale resolutions are possible, when data rates permit. Limb observations detail the atmospheric structure of clouds and hazes at ≈ 4 km resolution. The MA camera has a 6˚ FOV covering 40 km at 40 m/pixel (nadir) and accessing all positions of the planet (except the rotational poles due to the slight inclination of the spacecraft orbit). Ten spectral channels from 425 to 1000 nm provide the ability to discriminate both atmospheric and surface features on the basis of composition.

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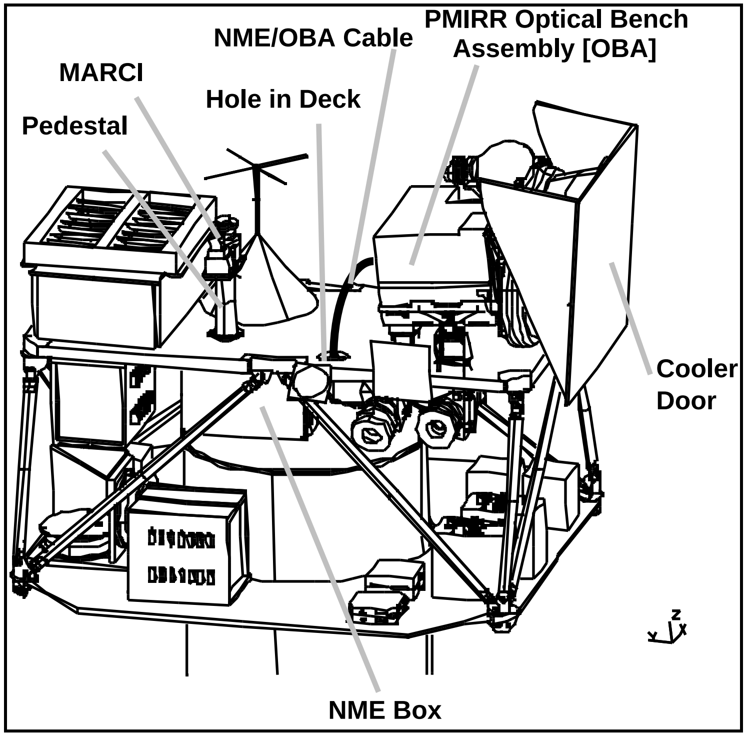
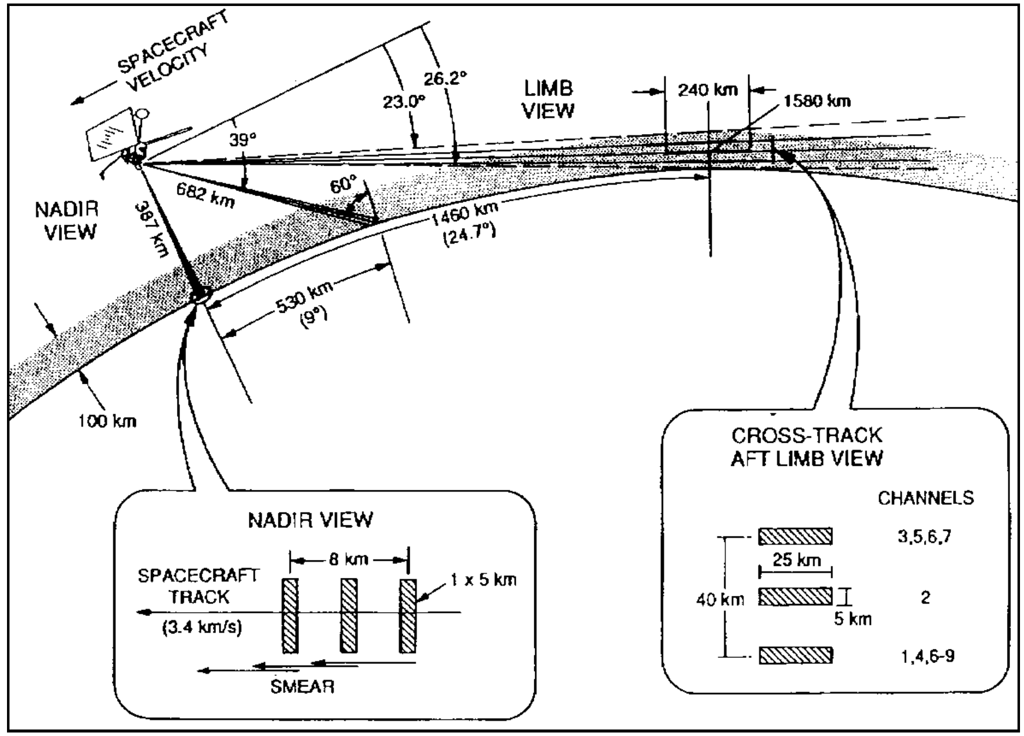
ORBITER PAYLOAD

Orbiter Science and Equipment Decks



PMIRR Fields of View



- **Pressure Modulator Infrared Radiometer [PMIRR]**
  - Multispectral limb and nadir scanning atmospheric sounder
    - » Provides vertical profiles of atmos. temp, dust, water vapor & clouds, quantifies surface radiative balance
  - Radiator door deployed upon achieving mapping orbit
  - Nominal FOV includes aft limb. Can also view out of s/c orbit plane.
  - Vertical resolution = 5 km
- **Mars Color Imager (MARCI)**
  - Combined nadir pointed pushframe Wide Angle [WA] and Medium Angle [MA] cameras, totaling 2 kg
  - WA camera: FOV = 140°, 7 spectral bands [5 visible, 2 UV]; MA camera: FOV = 6°, 10 spectral channels
  - Imaging: Approach imaging, daily global Mars images with WA, monitoring of surface changes with MA during intervals with high data rates.

4.2 ORBITER MISSION OVERVIEW

4.2.1 Overall Mission Description

The MSP 98 Orbiter launches aboard a Delta 7425 in December 1998, and arrives at Mars in September 1999. Burnout of the 3rd stage is followed by yo-yo despin of the entire stack, followed by spacecraft separation. At this point both the spacecraft and upper stage have been injected onto a Type 2 trajectory whose aimpoint is biased away from the nominal MOI aimpoint, to assure that the upper stage has less than a 1E-4 probabilty of impacting Mars, as required by Planetary Protection regulations. After separation, the solar panels are deployed and pointed to the sun, and initial acquisition achieved by the DSN. During inner cruise, the solar panel is sun pointed, and contact maintained via the Low Gain and Medium Gain Antennae. Approximately 15 days after launch, the largest Trajectory Correction Maneuver [TCM-1] is executed. This maneuver removes launch vehicle injection errors and the spacecraft's injection aimpoint bias. Provisions have been made to execute up to 3 additional small TCM's during the remainder of cruise, as needed, to shape the orbit and direct the spacecraft to the proper aimpoint for Mars Orbit Insertion. All TCM's are performed with the monoprop Hydrazine thrusters. As the heliocentric distance increases during cruise, communications moves to the High Gain Antenna.

At Mars arrival, the Orbiter biprop engine is used to propulsively insert the spacecraft into an elliptical capture orbit. The biprop engine burns for approximately 16 minutes, until all the loaded oxidizer is exhausted. The oxidizer tank is isolated via pyro firings prior to the end of the biprop burn. One minute later, an additional maneuver is executed by the Hydrazine thrusters, if needed, to reduce the orbit period further. Depending on launch date during the Primary and Secondary launch periods and propellant mass consumed during cruise, the resultant orbit period lies between approximately 26 and 36 hrs, with a nominal periapse altitude of 160 km. A maneuver to lower periapse in preparation for aerobraking occurs at the first apoapse of the final capture orbit. Over the next two months, the energy of the orbit is reduced via successive passes through the atmosphere of Mars, controlled by small Orbit Trim Maneuvers near apoapse. At aerobrake termination, two maneuvers transfer the Orbiter to its final, near-circular, frozen, near sun-synchronous mapping orbit, at a descending node of approximately 4 PM. This occurs some time prior to the MSP98 Lander arrival in December, 1999. During the Lander's surface lifetime, the Orbiter provides command and data relay support, and also engages in a limited amount of orbital science. In its mapping phase, the Orbiter performs systematic daily global sounding and imaging of the Mars atmosphere for approximately one Mars year [687 days]. The nadir-mounted science payload consists of a Pressure Modulator Infrared Radiometer (PMIRR), and the Mars Color Imager (MARCI).

Once its mapping mission is complete, the Orbiter will be available as a communication relay for future Mars landers for up to 3 additional years. Upon completion of its relay mission, the Orbiter may perform a maneuver or be placed in a low-drag attitude to satisfy Planetary Protection regulations.

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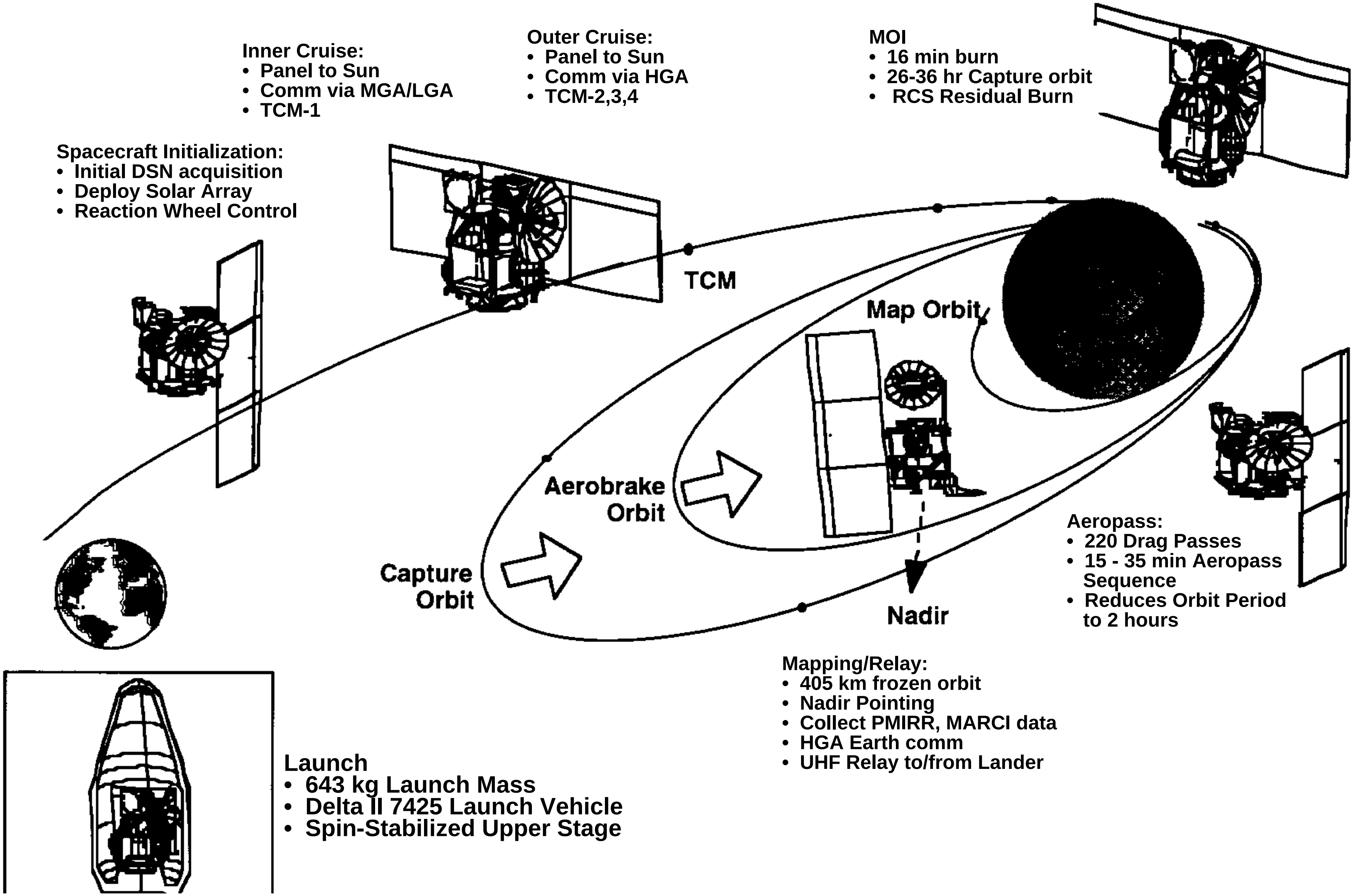
OVERALL MISSION DESCRIPTION



4.2.2 Mission Phases

Launch and Boost & S/C Initialization Phases: The launch phase extends from Liftoff - 20 hours through liftoff. The Boost and s/c Initialization Phase covers Liftoff until initial DSN contact.

Cruise Phase: The cruise phase extends from initial DSN acquisition to preparation for the Mars Orbit Insertion (MOI) maneuver. It includes initial checkout of the spacecraft, instrument calibrations, and trajectory correction maneuvers (TCMs).

Orbit Insertion Phase: The orbit insertion phase extends from MOI preparation through completion of MOI-2.

Aerobraking Phase: The Aerobraking phase starts at completion of MOI and extends through aerobraking termination and transfer to the map orbit.

MSP98 Lander Support Phase: The MSP98 Lander support phase starts at insertion into the mapping orbit, and continues through the end of the Lander's nominal lifetime [2/29/00]. Events during this Phase include Lander relay and commanding support, a reduced level of Orbiter science, and an interval for overlapping observations between the Lander, Orbiter, and MGS.

Mapping Phase: The Mapping Phase starts at the end of the Lander Support Phase and continues for 687 Earth days [one Martian year]. This is the primary science mission phase for the Orbiter instruments.

Relay Phase: The Relay Phase starts at termination of mapping operations, and concludes 5 Earth years after transfer to the Mapping orbit. [Total phase duration is approximately 2.9 Earth years.] This interval shall include needed relay operations from landed surface stations, and, if required, an end-of-mission maneuver and/or reconfiguration to accommodate Planetary Protection.

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MISSION PHASES

- **Launch and Boost and S/C Initialization Phases:**
  - **Launch:** Liftoff - 20 hours to liftoff.
  - **Boost and s/c Initialization:** Liftoff until initial DSN contact.

- **Cruise Phase:**
  - From initial DSN acquisition through preparation for MOI
  - Includes initial checkout of the spacecraft, TCMs and instrument calibrations

- **Orbit Insertion Phase:**
  - From MOI preparation through MOI-2

- **Aerobraking Phase:**
  - From completion of MOI through Aerobraking termination and transfer to the map orbit.

- **MSP98 Lander Support Phase:**
  - From insertion into mapping orbit through end of Lander’s nominal lifetime [2/29/00]
  - Include Lander relay & commanding support, reduced level of Orbiter science
    - » Includes period of overlapping observations between Lander, Orbiter, and MGS

- **Mapping Phase:**
  - Starts at end of the Lander Support Phase and continues for 687 Earth days [one Martian year].
  - Primary science mission phase for the Orbiter instruments

- **Relay Phase:**
  - Starts at termination of mapping operations, concludes 5 Earth years after transfer to the Mapping orbit [Duration = 2.9 Earth years]
  - Support future landers
  - End of mission maneuver and/or turn to low drag attitude, if needed, for Planetary Protection

4.2.3 Orbiter Launch/Arrival Period

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Integrated trajectories with minimum total deterministic ΔV [comprising injection, deep space deterministic maneuvers, and MOI ΔV] have been developed for launches from December 1, 1998 through January 3, 1999. These trajectories included the effects of solar radiation pressure and perturbations from other solar system bodies and were generated using the CATO [Computer Algorithm for Trajectory Optimization] program. In all cases, the minimum ΔV trajectories during this interval were of Type 2 [transfer angle at least 180˚] and did not require the use of a deterministic deep space maneuver.

The results of various trade studies examining the optimal placement of the Orbiter launch period to maximize delivered dry mass, while keeping at least 9 days between the end of the Orbiter launch period and the start of the Lander launch period, led to the selection of the Orbiter launch period: December 10, 1998 - December 23, 1998.

The following figure illustrates the Orbiter interplanetary trajectory projected on the plane of the ecliptic, for the open of the Orbiter launch period. Also shown is a table indicating launch and arrival dates, flight times, launch energy [C3, the square of the hyperbolic excess velocity on the outgoing asymptote], arrival V-infinity [excess hyperbolic velocity on the Mars approach asymptote], and local mean solar time of the descending node. [This table includes the results of a detailed trajectory analysis performed for the first day in the Orbiter launch period, which incorporates the effects of the the biased TCM-1 aimpoint on arrival conditions. See Appendix A.8.] The maximum C3 of 11.19 km^2/s^2 occurs at the start of the launch period, and the maximum V-infinity of 3.41 km/s occurs at the close of the launch period.

Additional state information for the Orbiter Launch/Arrival period can be found in Appendix A.1, the Orbiter Mission Database.

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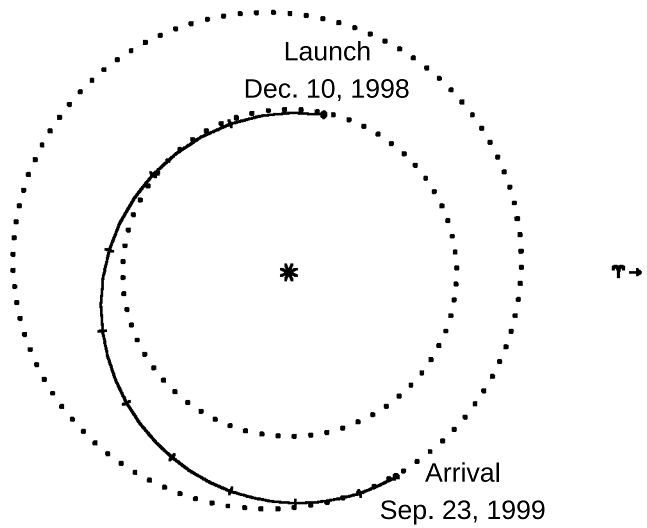
ORBITER LAUNCH/ARRIVAL PERIOD

	Day in Launch Period	Injection Date	Arrival Date	Flight Time [days]	Depart C3 [km^2/s^2]	Arrival Vinf [km/s]	Local Mean Solar Time Desc. Node
P	**1**	**12/10/98**	**9/23/99***	**286**	**11.189**	**3.344**	**6:15 PM**
r	**2**	**12/11/98**	**9/25/99**	**288**	**11.101**	**3.341**	**6:08 PM**
i	**3**	**12/12/98**	**9/25/99**	**288**	**10.941**	**3.343**	**6:07 PM**
m	**4**	**12/13/98**	**9/26/99**	**287**	**10.781**	**3.345**	**6:06 PM**
a	**5**	**12/14/98**	**9/27/99**	**287**	**10.636**	**3.348**	**6:05 PM**
r	**6**	**12/15/98**	**9/27/99**	**287**	**10.508**	**3.352**	**6:04 PM**
y	**7**	**12/16/98**	**9/28/99**	**287**	**10.393**	**3.356**	**6:03 PM**
	8	**12/17/98**	**9/29/99**	**285**	**10.287**	**3.365**	**6:05 PM**
S	9	12/18/98	9/30/99	286	10.193	3.367	6:01 PM
e	10	12/19/98	10/1/99	286	10.109	3.374	5:59 PM
c	11	12/20/98	10/2/99	286	10.036	3.382	5:57 PM
o	12	12/21/98	10/2/99	286	9.974	3.391	5:56 PM
n	13	12/22/98	10/3/99	286	9.924	3.400	5:54 PM
d	14	12/23/98	10/4/99	286	9.885	3.411	5:52 PM

* Includes effects of TCM-1 aimpoint biasing

Open of Primary Launch Period

30 Day Tics on s/c Trajectory



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4.2.4 Orbiter Launch Period Strategy

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The MSP98 Orbiter launch period is divided into an 8 day Primary launch period [12/10/98 - 12/17/98] followed by a 6 day Secondary launch period [12/18/98 - 12/23/98]. These two intervals are characterized by different mission requirements associated with the ability of the Orbiter to finish aerobraking prior to Lander arrival.

Primary Launch Period: For launch during the Primary launch period, the mission and spacecraft design shall support a 95% or greater probability that the Orbiter will complete aerobraking by the time the Lander arrives. Specifically, the Orbiter propellant load must support establishment of a capture orbit with a period low enough to allow aerobraking to circularize the orbit prior to Lander arrival. The maximum C3 of 11.19 km^2/s^2 occurs on the first day of this Primary launch period, and dictates the maximum launch mass the launch vehicle can support over the launch period. The Delta II 7425 capability at this C3 is 643 kg [total wet mass of Orbiter]. The history of the Delta launch vehicle indicates that a high probability [approximately 98% or higher] exists that launch will occur during the Primary interval.

Secondary Launch Period: If launch is delayed past the end of the Primary interval, a lower probability that the Orbiter will complete aerobraking by Lander arrival is allowed. The maximum V-infinity [hyperbolic excess velocity at Mars arrival] of 3.41 km/s occurs for launch on the last day of this secondary interval. Due to the higher values of V-infinity encountered during this time, the Orbiter will be placed into capture orbits higher than those encountered during the Primary interval. If aerobraking is not expected to be completed before Lander arrival, Mars Global Surveyor or the Lander's direct to Earth [DTE] link will support Lander data relay until the MSP98 Orbiter is available. During such an interval, the DTE link would be the only command path for the Lander.

If launch is delayed beyond the end of the secondary period, launch of the Orbiter remains possible, since the C3 continues to decrease for some interval past 12/23/98. However, because the approach velocity increases during this interval, the period of the capture orbit would also increase.

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ORBITER LAUNCH PERIOD STRATEGY

- **14 Day Launch Period: 12/10/98 - 12/23/98**

  - **Primary Launch Period: 8 days: 12/10/98 - 12/17/98**
    - During this period, assure high probability [≥ 95%] that Orbiter will complete aerobraking by Lander arrival.
    - 98% Launch Probability
    - Max C3 = 11.19 km^2/s^2 occurs on first day

  - **Secondary Launch Period: 6 days: 12/18/98 - 12/23/98**
    - Accept lower probability that Orbiter will complete aerobraking in time.
      - Use MGS or direct link to support lander until MSP98 Orbiter is available.
    - Max V_∞ = 3.41 km/s occurs on last day

- **Launch and Mars capture into higher orbits remain possible beyond the 14 day launch period**

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4.2.5 Summary of Mission Events and DSN Tracking Requirements

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Shown on the following 3 pages is a summary of the timing of major mission events and associated DSN support requests. Data are provided for the open and close of the Primary Launch Period, and the end of the Secondary Launch Period.

34m Coverage: Baseline coverage is via the 34m subnet for the majority of the mission, and use of the 34m HEF antennae has been maximized during this time. TBD: 34m BWG support will be necessary for limited intervals, however, to accommodate DSN usage conflicts and maximize tracking of the Orbiter during the last 30 days of Lander approach [interval of near-simultaneous tracking]. In addition, some modification of the nominal tracking profile is occasionally required in order to accommodate conflicts with other missions using the same DSN assets. Expected BWG use and modifications to nominal tracking schedules is detailed in Appendix A.12.

70m Coverage: 70m coverage for MOI and conjunction is currently baselined. In addition, 70m coverage during the Lander Support Phase and the two MARCI Science Campaigns will be requested. The 70m subnet is not scheduled to have X-band uplink capability until late 2001. As a result, with the exception of the second MARCI science campaign, 34m support will be required in addition to 70m coverage, to support uplink.

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Orbiter Open Primary Launch Period

Phase	Sub-Phase	Event		Start Date	Start DOM	End Date	End DOM	# Days	Hrs/ Pass	Passes/ Day	Passes/ Week	Total Hrs	Note
									DSN REQUIREMENTS				
		Launch		**12/10/98**	0								
Cruise		Launch to Launch + 7	Launch + 7 d	12/10/98	0	12/17/98	7	7	8	3	21	168	A
Cruise		Cruise		12/17/98	7	12/22/98	12	5	4	1	7	20	
Cruise		TCM1, entry		12/22/98	12	12/25/98	15	3	4	1	7	12	
Cruise		TCM1, maneuver	TCM1 @ Launch + 15 d	12/25/98	15	12/26/98	16	1	4	1	7	4	
Cruise		TCM1, exit		12/26/98	16	12/29/98	19	3	4	1	7	12	
Cruise		Cruise		12/29/98	19	1/21/99	42	23	4	1	7	92	
Cruise		TCM2, entry		1/21/99	42	1/24/99	45	3	4	1	7	12	
Cruise		TCM2, maneuver	TCM2 @ Launch + 45 d	1/24/99	45	1/25/99	46	1	4	1	7	4	
Cruise		TCM2, exit		1/25/99	46	1/28/99	49	3	4	1	7	12	
Cruise		Cruise		1/28/99	49	7/22/99	224	175	4	1	7	701	
Cruise		TCM3, entry		7/22/99	224	7/25/99	227	3	4	1	7	12	
Cruise		TCM3, maneuver	TCM3 @ Arrival - 60 d	7/25/99	227	7/26/99	228	1	4	1	7	4	
Cruise		TCM3, exit		7/26/99	228	7/29/99	231	3	4	1	7	12	
Cruise		Cruise to Arrival - 45 d	Ends at Arrival - 45 d	7/29/99	231	8/9/99	242	11	4	1	7	44	
Cruise	Approach	Arrival - 45d to TCM4		8/9/99	242	9/10/99	274	32	4	3	21	384	A
Cruise	Approach	TCM4, entry		9/10/99	274	9/13/99	277	3	4	3	21	36	A
Cruise	Approach	TCM4, maneuver	TCM4 @ Arrival - 10 d	9/13/99	277	9/14/99	278	1	4	3	21	12	A
Cruise	Approach	TCM4, exit		9/14/99	278	9/17/99	281	3	4	3	21	36	A
Cruise	Approach	Cruise		9/17/99	281	9/18/99	282	1	4	3	21	12	A
Cruise	Approach	Cruise [34m + 70m coverage]	Starts at MOI - 5 d	9/18/99	282	9/21/99	285	3	4	3	21	36	A,B
Cruise	Approach	Start continuous coverage [34m + 70m]	Starts at MOI - 2 d	9/21/99	285	9/23/99	287	2	8	3	21	48	A,B
Orbit Insertion	Mars Capture	MOI [34m + 70m]		**9/23/99**	287	9/23/99	288	1	8	3	21	12	A,B
Orbit Insertion	Aerobraking	Walk-in [34m + 70m]	Starts at MOI + 0.5 d	9/23/99	288	9/25/99	290	2	8	3	21	48	A,B
Orbit Insertion	Aerobraking	Walk-in [End 70m & cont. coverage]	MOI + 2 d	9/25/99	290	9/25/99	290	0	8	3	21	0	A,B
Orbit Insertion	Aerobraking	Walk-in		9/25/99	290	9/27/99	291	2	4	3	21	19	A
Orbit Insertion	Aerobraking	Main	Starts at MOI + 4.1 d	9/27/99	291	11/3/99	328	37	4	3	21	439	A
Orbit Insertion	Aerobraking	Main, start near-simul tracking		11/3/99	328	11/22/99	347	19	4	3	21	233	A,D
Orbit Insertion	Aerobraking	Walk-out	Starts at MOI + 60 d	11/22/99	347	12/1/99	356	9	4	3	21	103	A,D
Orbit Insertion	TMO	Transfer to Map Orbit	Duration = 1 d	12/1/99	356	12/2/99	357	1	4	3	21	12	A,D
Orbit Insertion	Transition	Support of Approaching Lander		12/2/99	357	12/3/99	359	2	4	3	21	22	A,D
Lander Support	Lander Support	Lander Support Phase [34m + 70m]		12/3/99	359	3/1/00	447	88	10	1	7	881	B,C
Mapping	Mapping	Mapping ops	Total Duration = 687 d	3/1/00	447	3/26/00	472	25	10	1	7	250	
Mapping	MARCI SC #1	MARCI Sci. Campaign #1 [34m + 70m]	10 d	3/26/00	472	4/4/00	482	10	10	1	7	100	B
Mapping	Mapping	Mapping ops		4/4/00	482	6/21/00	559	77	10	1	7	770	
Mapping	Mapping	Conjunction support [34m + 70m]	20 d	6/21/00	559	7/11/00	579	20	10	1	7	200	B
Mapping	Mapping	Mapping ops		7/11/00	579	12/18/01	1104	525	10	1	7	5250	
Mapping	MARCI SC #2	MARCI Sci. Campaign #2 [70m only]	30 d	12/18/01	1104	1/16/02	1134	30	10	1	7	300	E
Relay	Relay	Relay only	ends 5 Earth yrs > TMO	1/16/02	1134	12/1/04	2183	1049	10	1	7	10493	
		EOM				**12/1/04**	2183				Grand Total	20806	

Notes

A: S/C transmitter operation limited to 4 hrs on: 5 hrs off or equivalent ratio

B: 70m D/L support required in addition to 34 m coverage for uplink

C: This 10 hr interval must be correlated with Lander site local "day". Overlap with 1 hr Lander daily contacts TBD. [See Lander req.]

D: Near-simultaneous tracking. Orbiter tracked on each rev: HEF tracks coordinated w/ Lander, remaining tracks on BWG

E: 70m U/L and D/L support. No 34m support required.

** This page under Change Control **

Orbiter End Primary Launch Period

Phase	Sub-Phase	Event		Start Date	Start DOM	End Date	End DOM	# Days	Hrs/ Pass	Passes/ Day	Passes/ Week	Total Hrs	Note
									DSN REQUIREMENTS				
		Launch		**12/17/98**	0								
Cruise		Launch to Launch + 7	Launch + 7 d	12/17/98	7	12/24/98	14	7	8	3	21	168	A
Cruise		Cruise		12/24/98	14	12/29/98	19	5	4	1	7	20	
Cruise		TCM1, entry		12/29/98	19	1/1/99	22	3	4	1	7	12	
Cruise		TCM1, maneuver	TCM1 @ Launch + 15 d	1/1/99	22	1/2/99	23	1	4	1	7	4	
Cruise		TCM1, exit		1/2/99	23	1/5/99	26	3	4	1	7	12	
Cruise		Cruise		1/5/99	26	1/28/99	49	23	4	1	7	92	
Cruise		TCM2, entry		1/28/99	49	1/31/99	52	3	4	1	7	12	
Cruise		TCM2, maneuver	TCM2 @ Launch + 45 d	1/31/99	52	2/1/99	53	1	4	1	7	4	
Cruise		TCM2, exit		2/1/99	53	2/4/99	56	3	4	1	7	12	
Cruise		Cruise		2/4/99	56	7/28/99	230	174	4	1	7	696	
Cruise		TCM3, entry		7/28/99	230	7/31/99	233	3	4	1	7	12	
Cruise		TCM3, maneuver	TCM3 @ Arrival - 60 d	7/31/99	233	8/1/99	234	1	4	1	7	4	
Cruise		TCM3, exit		8/1/99	234	8/4/99	237	3	4	1	7	12	
Cruise		Cruise to Arrival - 45 d	Ends at Arrival - 45 d	8/4/99	237	8/15/99	248	11	4	1	7	44	
Cruise	Approach	Arrival - 45d to TCM4		8/15/99	248	9/16/99	280	32	4	3	21	384	A
Cruise	Approach	TCM4, entry		9/16/99	280	9/19/99	283	3	4	3	21	36	A
Cruise	Approach	TCM4, maneuver	TCM4 @ Arrival - 10 d	9/19/99	283	9/20/99	284	1	4	3	21	12	A
Cruise	Approach	TCM4, exit		9/20/99	284	9/23/99	287	3	4	3	21	36	A
Cruise	Approach	Cruise		9/23/99	287	9/24/99	288	1	4	3	21	12	A
Cruise	Approach	Cruise [34m + 70m coverage]	Starts at MOI - 5 d	9/24/99	288	9/27/99	291	3	4	3	21	36	A,B
Cruise	Approach	Start continuous coverage [34m + 70m]	Starts at MOI - 2 d	9/27/99	291	9/29/99	293	2	8	3	21	48	A,B,E
Orbit Insertion	Mars Capture	MOI [34m + 70m]		**9/29/99**	293	9/29/99	294	1	8	3	21	12	A,B,E
Orbit Insertion	Aerobraking	Walk-in [34m + 70m]	Starts at MOI + 0.5 d	9/29/99	294	10/1/99	296	2	8	3	21	48	A,B,E
Orbit Insertion	Aerobraking	Walk-in [End 70m & cont. coverage]	MOI + 2 d	10/1/99	296	10/1/99	296	0	8	3	21	0	A,B,E
Orbit Insertion	Aerobraking	Walk-in		10/1/99	296	10/3/99	297	2	4	3	21	19	A
Orbit Insertion	Aerobraking	Main	Starts at MOI + 4.1 d	10/3/99	297	11/3/99	328	31	4	3	21	370	A
Orbit Insertion	Aerobraking	Main, start near-simul tracking		11/3/99	328	11/28/99	353	25	4	3	21	302	A,D
Orbit Insertion	Aerobraking	Walk-out	Starts at MOI + 60 d	11/28/99	353	12/3/99	359	6	4	3	21	68	A,D
Orbit Insertion	TMO	Transfer to Map Orbit	Duration = 1 d	12/3/99	359	12/4/99	360	1	4	3	21	12	A,D
Lander Support	Lander Support	Lander Support Phase [34m + 70m]		12/4/99	360	3/1/00	447	87	10	1	7	872	B,C
Mapping	Mapping	Mapping ops	Total Duration = 687 d	3/1/00	447	3/26/00	472	25	10	1	7	250	
Mappiing	MARCI SC #1	MARCI Sci. Campaign #1 [34m + 70m]	10 d	3/26/00	472	4/4/00	482	10	10	1	7	100	B
Mappiing	Mapping	Mapping ops		4/4/00	482	6/21/00	559	77	10	1	7	770	
Mappiing	Mapping	Conjunction support [34m + 70m]	20 d	6/21/00	559	7/11/00	579	20	10	1	7	200	B
Mappiing	Mapping	Mapping ops		7/11/00	579	12/18/01	1104	525	10	1	7	5250	
Mappiing	MARCI SC #2	MARCI Sci. Campaign #2 [70m only]	30 d	12/18/01	1104	1/16/02	1134	30	10	1	7	300	E
Relay	Relay	Relay only	ends 5 Earth yrs > TMO	1/16/02	1134	12/4/04	2186	1052	10	1	7	10521	
		EOM				**12/4/04**	2186				Grand Total	20762	

Notes

A: S/C transmitter operation limited to 4 hrs on: 5 hrs off or equivalent ratio
B: 70m D/L support required in addition to 34 m coverage for uplink
C: This 10 hr interval must be correlated with Lander site local "day". Overlap with 1 hr Lander daily contacts TBD. [See Lander req.]
D: Near-simultaneous tracking. Orbiter tracked on each rev: HEF tracks coordinated w/ Lander, remaining tracks on BWG
E: 70m U/L and D/L support. No 34m support required.

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Orbiter End Secondary Launch Period

DSN REQUIREMENTS

Phase	Sub-Phase	Event		Start Date	Start DOM	End Date	End DOM	# Days	Hrs/ Pass	Passes/ Day	Passes/ Week	Total Hrs	Notes
		Launch		**12/23/98**	0								
Cruise		Launch to Launch + 7	Launch + 7 d	12/23/98	13	12/30/98	20	7	8	3	21	168	A
Cruise		Cruise		12/30/98	20	1/4/99	25	5	4	1	7	20	
Cruise		TCM1, entry		1/4/99	25	1/7/99	28	3	4	1	7	12	
Cruise		TCM1, maneuver	TCM1 @ Launch + 15 d	1/7/99	28	1/8/99	29	1	4	1	7	4	
Cruise		TCM1, exit		1/8/99	29	1/11/99	32	3	4	1	7	12	
Cruise		Cruise		1/11/99	32	2/3/99	55	23	4	1	3	92	
Cruise		TCM2, entry		2/3/99	55	2/6/99	58	3	4	1	7	12	
Cruise		TCM2, maneuver	TCM2 @ Launch + 45 d	2/6/99	58	2/7/99	59	1	4	1	7	4	
Cruise		TCM2, exit		2/7/99	59	2/10/99	62	3	4	1	7	12	
Cruise		Cruise		2/10/99	62	8/2/99	235	173	4	1	3	692	
Cruise		TCM3, entry		8/2/99	235	8/5/99	238	3	4	1	7	12	
Cruise		TCM3, maneuver	TCM3 @ Arrival - 60 d	8/5/99	238	8/6/99	239	1	4	1	7	4	
Cruise		TCM3, exit		8/6/99	239	8/9/99	242	3	4	1	7	12	
Cruise		Cruise to Arrival - 45 d	Ends at Arrival - 45 d	8/9/99	242	8/20/99	253	11	4	1	3	44	
Cruise	Approach	Arrival - 45d to TCM4		8/20/99	253	9/21/99	285	32	4	3	21	384	A
Cruise	Approach	TCM4, entry		9/21/99	285	9/24/99	288	3	4	3	21	36	A
Cruise	Approach	TCM4, maneuver	TCM4 @ Arrival - 10 d	9/24/99	288	9/25/99	289	1	4	3	21	12	A
Cruise	Approach	TCM4, exit		9/25/99	289	9/28/99	292	3	4	3	21	36	A
Cruise	Approach	Cruise		9/28/99	292	9/29/99	293	1	4	3	21	12	A
Cruise	Approach	Cruise [34m + 70m coverage]	Starts at MOI - 5 d	9/29/99	293	10/2/99	296	3	4	3	21	36	A,B
Cruise	Approach	Start continuous coverage [34m + 70m]	Starts at MOI - 2 d	10/2/99	296	10/4/99	298	2	8	3	21	48	B,E
Orbit Insertion	Mars Capture	MOI [34m + 70m]		**10/4/99**	298	10/4/99	299	1	8	3	21	12	B,E
Orbit Insertion	Aerobraking	Walk-in [34m + 70m]	Starts at MOI + 0.5 d	10/4/99	299	10/6/99	301	2	8	3	21	48	B,E
Orbit Insertion	Aerobraking	Walk-in [End 70m & cont. coverage]	MOI + 2 d	10/6/99	301	10/6/99	301	0	8	3	21	0	B,E
Orbit Insertion	Aerobraking	Walk-in		10/6/99	301	10/8/99	302	2	4	3	21	19	A
Orbit Insertion	Aerobraking	Main	Starts at MOI + 4.1 d	10/8/99	302	11/3/99	328	26	4	3	21	311	A
Orbit Insertion	Aerobraking	Main, start near-simul tracking	Ends at Landing	11/3/99	328	12/3/99	358	30	4	3	21	360	A,D
Orbit Insertion	Aerobraking	Main		12/3/99	358	12/17/99	372	14	4	3	21	169	A
Orbit Insertion	Aerobraking	Walk-out	Starts at MOI + 74 d	12/17/99	372	12/23/99	378	6	4	3	21	72	A
Orbit Insertion	TMO	Transfer to Map Orbit	Duration = 1 d	12/23/99	378	12/24/99	379	1	4	3	21	12	A,D
Lander Support	Lander Support	Lander Support Phase [34m + 70m]		12/24/99	379	3/1/00	447	68	10	1	7	679	B,C
Mapping	Mapping	Mapping ops	Total Duration = 687 d	3/1/00	447	3/26/00	472	25	10	1	7	250	
Mapping	MARCI SC #1	MARCI Sci. Campaign #1 [34m + 70m]	10 d	3/26/00	472	4/4/00	482	10	10	1	7	100	B
Mapping	Mapping	Mapping ops		4/4/00	482	6/21/00	559	77	10	1	7	770	
Mapping	Mapping	Conjunction support [34m + 70m]	20 d	6/21/00	559	7/11/00	579	20	10	1	7	200	B
Mapping	Mapping	Mapping ops		7/11/00	579	12/18/01	1104	525	10	1	7	5250	
Mapping	MARCI SC #2	MARCI Sci. Campaign #2 [70m only]	30 d	12/18/01	1104	1/16/02	1134	30	10	1	7	300	E
Relay	Relay	Relay only	ends 5 Earth yrs > TMO	1/16/02	1134	12/23/04	2205	1071	10	1	7	10714	
		EOM				**12/23/04**	2205				Grand Total	20930	

Notes
A: S/C transmitter operation limited to 4 hrs on: 5 hrs off or equivalent ratio
B: 70m D/L support required in addition to 34 m coverage for uplink
C: This 10 hr interval must be correlated with Lander site local "day". Overlap with 1 hr Lander daily contacts TBD. [See Lander req.]
D: Near-simultaneous tracking. Orbiter tracked on each rev: HEF tracks coordinated w/ Lander, remaining tracks on BWG
E: 70m U/L and D/L support. No 34m support required.

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4.2.6 Orbiter ΔV and Propellant Mass Summary

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Propellant required by the Orbiter during its mission life has been calculated using an end-to-end Monte Carlo simulation. The assumptions and approach used in this analysis are summarized in Appendix A.9. The driving requirement is that the Orbiter, if launched within its primary launch period, achieve a minimum 95% probability of completing aerobraking by Lander arrival. Assuming Orbiter launch at the end of its primary period [launch 12/17/98, arrival 9/29/99] and arrival of the Lander during its primary period [arrival 12/3/99], the maximum allowable capture orbit period is approximately 29 hrs. For the Primary launch period, this yields a 99% probability of completing aerobraking by Lander arrival. This is the most stressful case within the Orbiter's primary launch period because it allows the least time for aerobraking, and also has the highest arrival V-infinity value. For this analysis, a maximum wet mass capability of 643 kg was assumed, consistent with the performance of the Delta II 7425 launched at the start of the Orbiter's primary period, where the required launch energy is highest.

The following table summarizes the ΔV or ACS mass drops expected for each mission event. These events include all 4 interplanetary TCM's, attitude control during cruise, MOI [rotational and translational], aerobraking [including walk-in, rotational and translational corridor control, an emergency exit/re-entry maneuver, and end game], inclination trims during aerobraking [TBD] to correct for MOI and aerobraking dispersions, transfer to the mapping orbit, ACS usage during mapping, and ACS contingency. It does not currently include an allocation for inclination trims which may be required during or after aerobraking termination or during the transfer to map orbit [TBD]. Ranges are shown in those cases where statistical models of the events [e.g. TCM's] were included as part of the Monte Carlo simulation. Fixed parameter values are reported in the "mean" column only. The succeeding table summarizes propellant load required to accommodate 95% of the simulated cases.

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ORBITER ΔV AND PROPELLANT MASS SUMMARY

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- **REQUIREMENT:** ≥ 95% probability of Orbiter completing aerobraking by Lander arrival
  - Loading based on Orbiter launch at end of its primary and Lander arrival during its primary launch period
    - » 29 hr initial capture orbit [yields 99% probability of aerobraking completion by Lander arrival, for Primary]
  - **643** kg wet mass capability

ORBITER ΔV AND MASS DROPS

Event	Type	95% Low	Mean	95% High
TCM-1	Translational ΔV	12.4	34.0	68.1
TCM-2	Translational ΔV	0.07	0.29	0.69
TCM-3	Translational ΔV	0.03	0.19	0.51
TCM 4	Translational ΔV	0.01	0.04	0.08
Cruise RCS	Mass Drop [kg]	-	2.0	-
MOI - biprop	Translational ΔV	1221.1	1248.2	1279.8
MOI - hydrazine	Translational ΔV	0.0	25.8	53.1
MOI - ACS	Mass Drop [kg]	-	0.9	-
Walk-in	Translational ΔV	2.5	3.5	4.5
Corridor Control - Trans	Translational ΔV	-	12.0	-
Corridor Control - ACS	Rotational ΔV	-	15.2	-
Inclination Trim #1	Translational ΔV	0.0	0.4	1.0
Inclination Trim #2	Translational ΔV	0.1	1.6	3.1
Aerobraking exit/re-entry	Translational ΔV	-	17.0	-
Aerobraking End Game	Translational ΔV	-	1.5	-
Transfer to map	Translational ΔV	84.3	87.2	90.1
Map/Relay ACS	Rotational ΔV	-	22.6	-
ACS Contingency*	Rotational ΔV	-	16.0	-

* includes RCS uncertainty, failed reaction wheel, other contingency, project mgr reserve

DRY MASS CAPABILITY AND REQUIRED PROPELLANT

Maximum Dry Mass	**359.0**	kg
Oxidizer Load	**95.0**	kg
Hydrazine Load	**188.1**	kg
Pressurant	**0.9**	kg
Total Wet Mass	**643.0**	kg

4.3 ORBITER LAUNCH AND BOOST & S/C INITIALIZATION PHASES

4.3.1 Orbiter Pre-launch Countdown

The following timeline shows the Orbiter Pre-launch Countdown.

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ORBITER PRE-LAUNCH COUNTDOWN

Time	Operation
Launch - 8 days	• Final Orbiter Functional Test
Launch - 6 days	• F-6 Launch Vehicle Test Ascent Sequence
Launch - 20:00:00	• Orbiter Power up • Orbiter Closeout • Install Battery Enable Plug
Launch - 12:00:00	• Start MST Rollback for Launch
Launch - 06:00:00	• MST Rollback Complete
Launch - 03:00:00 (T - 150 min)	• Terminal Count Initiation and Briefing
Launch - 02:40:00 (T - 130)	• Orbiter Go for LV LOX Fueling
Launch - 00:20:00 (T - 4)	• Provide MSP Go for Launch
Launch - 00:04:00 (T - 4)	• Transfer to Battery Power
LAUNCH	Primary Window: 12/10 - 12/17, 1998 Secondary Window: 12/18 - 12/23, 1998

4.3.2 Launch Events Summary

Shown below is a representative launch events timeline for the Launch Vehicle.

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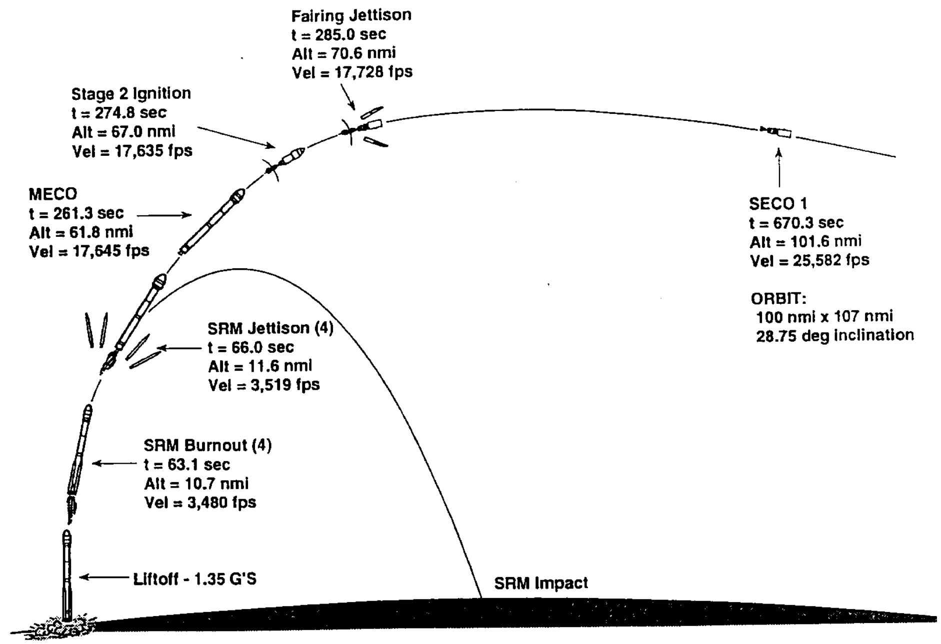
LAUNCH EVENTS SUMMARY

Launch Event	Time (sec)
Stage I Liftoff	0.000
Main Engine Cutoff (MECO)	261.3
Stage I–II Separation	269.3
Stage II Ignition Signal	274.8
Jettison Fairing	285.0
First Cutoff–Stage II (SECO 1)	670.3
Restart Stage II	2219.7
Second Cutoff–Stage II (SECO 2)	2245
Start Stage III Ignition Time Delay Relay	2295
Fire Spin Rockets	2295
Jettison Stage II	2298
Stage III Ignition	2335
Stage III NCS Enable	2335
Stage III Burnout (TECO)	2422.1
NCS Disable/Yo-Yo Despin Initiation	2705
Spacecraft Separation	2710

Note: Assumes a “short-coast” trajectory for launch on 10 December 1998.



4.3.3 Orbiter Ascent and Spacecraft Initialization Timelines

The following timelines illustrate events during boost and spacecraft initialzation after separation [CDR 1/22/97]. Following separation, the primary objective is to acquire the Sun. See Appendix A.2 for initial DSN and Air Force Tracking Station acquisition geometry data.

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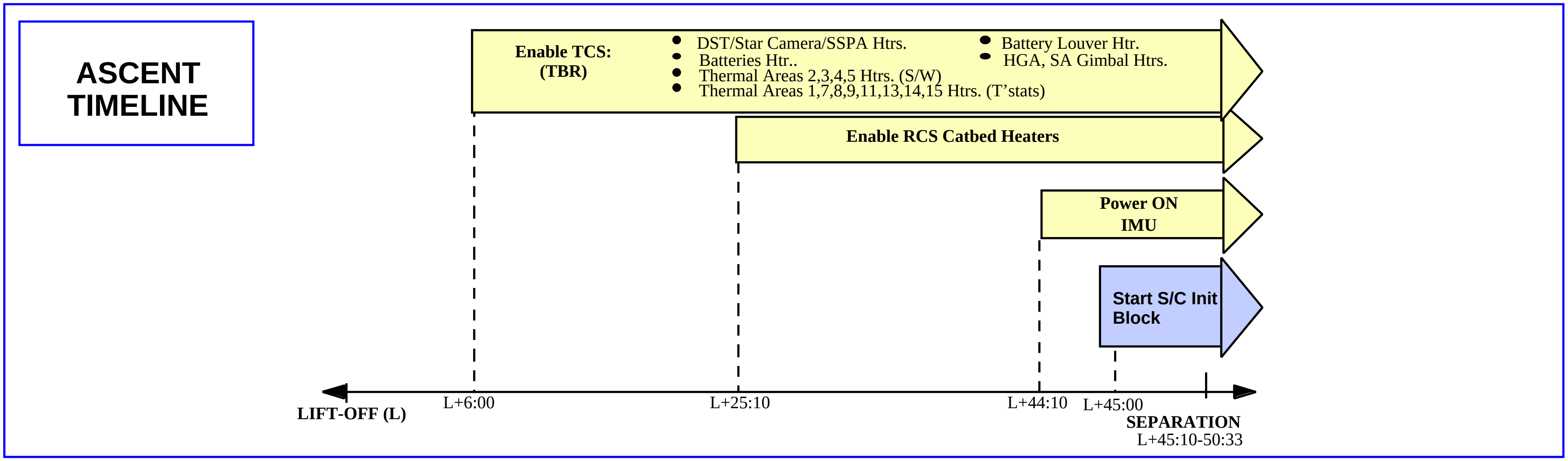
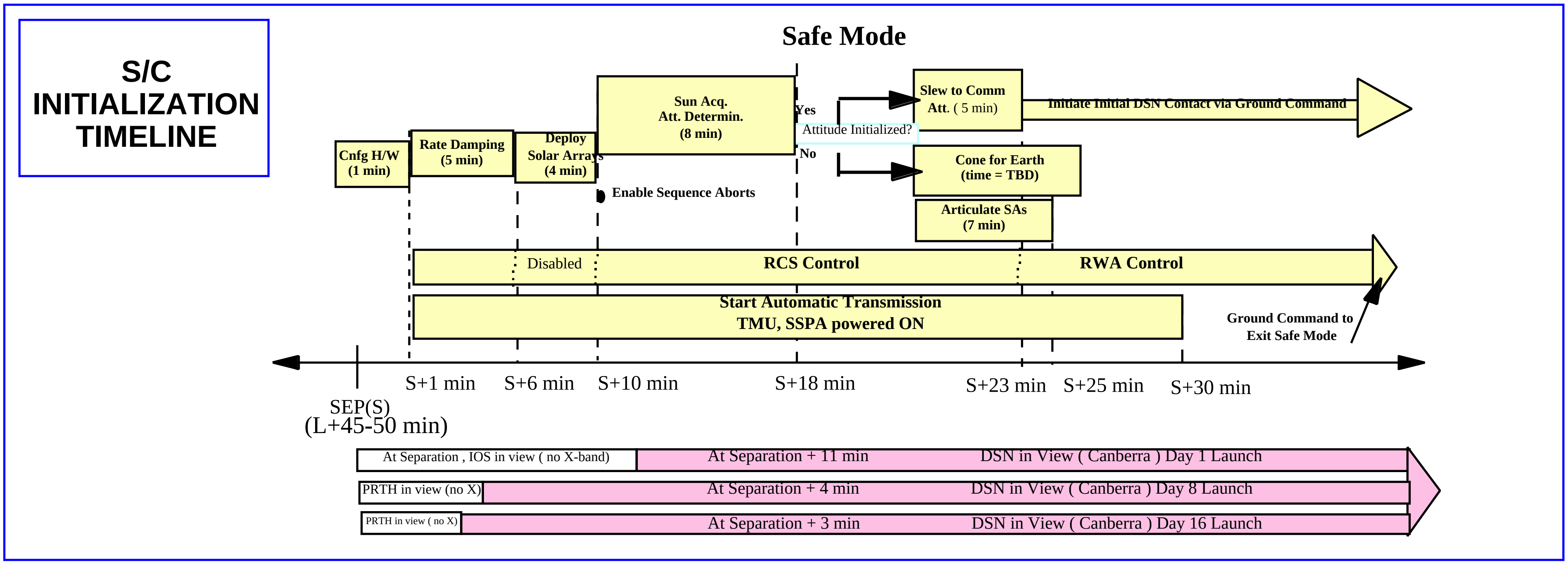
ORBITER ASCENT AND SPACECRAFT INITIALIZATION TIMELINES





4.4 ORBITER CRUISE PHASE

4.4.1 Orbiter Cruise Navigation

** This page under Change Control **

Radiometric tracking requirements during cruise involve the use of two way coherent doppler and ranging according to the schedule described in the following table. As indicated, for the first 30 days after launch a minimum of one 4 hour pass per day is required. During quiescent cruise, only one 4 hour pass per DSN complex per week is required. For TCM's 1 - 3, one 4 hour pass per day would be required during a 7 day interval centered about the TCM. For the track occuring during the 24 hour interval centered at TCM, the entire pass must be visible from a single DSN station. [Note: The analysis described in Appendix A.8 assumed 3 4-hr passes per day during the 24 hours centered on each TCM. Analyses performed for the Lander indicate that a single 4-hr pass is sufficient.] Additional tracking is required for the 45 days prior to MOI; during this time, three 4 hour passes per day are required for the higher precision navigation needed prior to MOI. These numbers reflect minimum navigation requirements. Additional tracking is being requested for the purpose of daily s/c monitoring.

4.4.2 TCM's

** This page under Change Control **

Although the Orbiter trajectory does not require any deterministic deep space maneuvers to reach Mars, Trajectory Correction Maneuvers [TCM's] are required to shape the cruise trajectory. Four TCM's are planned to occur at Launch + 15 days, Launch + 45 days, MOI - 60 days, and MOI - 10 days. Provision has also been made for executing a contingency maneuver as late as MOI - 2 days, if needed. At injection, the trajectory is aimed at a point in the arrival B Plane such that the probability of impact of the upper stage is less than 1E-4*, as required by Planetary Protection regulations. The primary purpose for TCM-1 is to correct injection errors and remove the Planetary Protection injection aimpoint bias. TCM-1 constitutes more than 97% of the total TCM ΔV required during a mission.

The following page includes a table of the 95% high, mean, and 95% low values of each TCM and the summary statistical ΔV for the beginning of the Primary launch period. [Note: these values are higher than those listed in Appendix A.8, due to analysis of PCS effects subsequent to the issuing of that memo.] Propellant loading is based on an end-to-end Monte Carlo analysis of Orbiter propellant usage, including the effects of maneuver execution errors and orbit determination errors.

* MGS Planetary Protection Plan

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- **Navigation Cruise Tracking Requirements:**

Mission Event	Estimated Nav Tracking Requirements	Comments
Launch to Launch + 30 days	1 4-hr pass/day	
Quiescent Cruise	3 4-hr passes/week	One pass per complex per week
TCM (1,2,3) entry [TCM-3.5 days to TCM]	1 4-hr pass/day	
TCM (1,2,3) [24 hrs centered on TCM]	1 4-hr pass/day	<- Must be visible from single DSN station
TCM (1,2,3) exit [TCM to TCM + 3.5 days]	1 4-hr pass/day	
Approach [MOI-45 days to MOI]	3 4-hr passes/day	

- **Navigation Data Types:** Two-way Coherent Doppler and Ranging

- **Trajectory Correction Maneuvers:**
  - Nominally 4 maneuvers, with 5th contingency maneuver [if needed] not later than MOI - 2 days
  - Probability(Mars impact) of upper stage < 1E-4 [Planetary Protection] used to bias injection aimpoint
  - TCM placement and magnitudes for Open of Primary Launch Period:

TCM #	Placement	95% Low ΔV	Mean ΔV	95% High ΔV
1	Launch + 15 days	12.36	33.98	68.11
2	Launch + 45 days	0.07	0.29	0.69
3	MOI - 60 days	0.03	0.19	0.51
4	MOI - 10 days	0.01	0.04	0.08
Totals		**12.66**	**34.51**	**68.81**

Modeling includes maneuver execution and OD errors
MACDAC Injection covariance dated 9/5/96, including effects of 95% PCS.

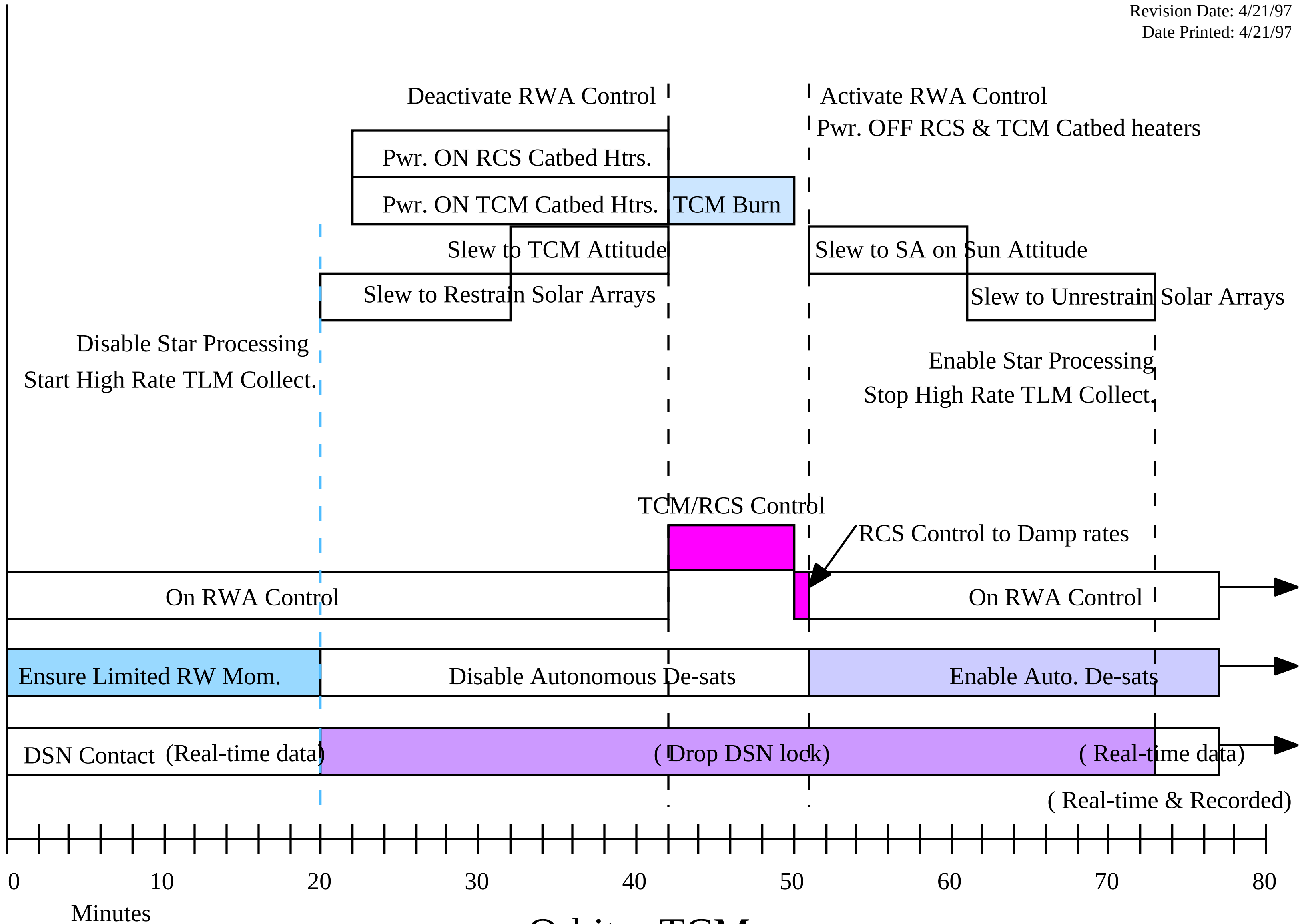
4.4.3 TCM Sequence of Events

The following timeline illustrates the TCM maneuver implementation. In general, DSN lock will be lost upon slewing to the TCM burn attitude.

Go to TOC

TCM SEQUENCE OF EVENTS

Revision Date: 4/21/97
Date Printed: 4/21/97



Orbiter TCM

4.4.5 Orbiter Science Payload Cruise Checkout, Characterization and Calibration

4.4.5.1 Overview

CPU speed: during cruise, in the all-stellar mode, the CPU speed is 10 Mhz.

CONSTRAINTS: Cruise calibrations of PMIRR and MARCI must be de-conflicted with Orbiter and Lander mission-critical events. No science checkouts, calibrations, or playback of data will be performed within 3 days of an Orbiter TCM, 15 days of MOI or 15 days of Orbiter launch. [The esception is the MARCI Earth-Moon calibration, described below.] PMIRR and MARCI operation duirng periods of HGA transmissions is TBD during cruise, due to potential EM interference from the undeployed HGA. PMIRR cruise calibrations should not occur when the PMIRR X-Z plane is within 5° of the sun.

MARCI EARTH-MOON CALIBRATION [Launch + 4 days]: This consists of a slew to a certain point, a scan across Earth-Moon system with a single slew, and a slew back to cruise attitude. During the scanning slew, MARCI takes TBD pictures with the Medium Angle Camera and TBD pictures with the Wide Angle Camera. Data volumes are: 1 Megabyte=8 Mbits (uncompressed) per MAC picture, 0.1 Megabyte=0.8 Mbits (uncompressed) per WAC picture. This activitiy requires an interruption to normal cruise operations.

If the post-launch s/c condition is nominal, this activity is performed at Launch + 4 days, with complete playback of data by Launch + 7 days, to avoid interference with TCM-1 at Launch + 15 days. Thus, the data volume must be sized to be returned in 3 days of D/L at 2100 bps [see section 4.4.5.2 for data volume estimates]. Data taken in excess of this allocation would be returned after TCM-1 on a best-efforts basis. One issue to be resolved is the impact on required ΔV of a 2 week - 30 day delay in TCM-1, should the s/c go into safe mode as a result of the slew.

PMIRR [Launch + 7 days]: The nominal plan is to move the PMIRR radiator door to the vent position at Launch + 7 days. [It is desired that this occur no later than Launch + 2 weeks.]

ORBITER PAYLOAD CRUISE CHECKOUT, CHARACTERIZATION AND CALIBRATION CAMPAIGN [Launch + 80 days]: This week-long activity consists of PMIRR checkout and the MARCI star calibration. The duration of the PMIRR checkout is 4 hours, starting one hour before a DSN contact. The purpose of this sequence is to perform internal checkouts of PMIRR and exercise the PMU's [Pressure Modulator Units]. Backup commands for shutting off the PMC's will be available to be uplinked during the DSN contact. The Sun should be kept off the scan mirror during this activity [TBD]. The MARCI star calibration occurs after the PMIRR checkout [contingency is to perform it later], and consists of a slew to a certain point, a scan across a specific star cluster [e.g. Pleiades] with a single slew, and a slew back to cruise attitude. MARCI star calibration data volume will be sized to be returned in 3 days of D/L at 2100 bps [see section 4.4.5.2 for data volume estimates].

MARCI MARS IMAGES [MOI - 18 days]: This sequence is nominally performed at MOI - 18 days, with complete playback of data by MOI - 15 days. The data volume is therefore sized to be returned in 3 days of D/L at 2100 bps [see section 4.4.5.2 for data volume estimates].

IMPLEMENTATION: Under nominal conditions, the baseline is a single attempt for each activity. Retries on a best-efforts basis are at the discretion of the MSOP Flight Operations Manager. These sequences are initiated by ground command. Selected portions of these sequences [blocks] can be re-run via ground command as well.

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ORBITER PAYLOAD CRUISE CHECKOUT, CHARACTERIZATION AND CALIBRATION - Overview

- **CPU speed =** 10 Mhz during cruise [all-stellar mode]
- **Constraints**:
  - Checkouts, Calibrations of PMIRR and MARCI must be de-conflicted with Orbiter & Lander mission-critical events.
  - No calibrations, checkouts or playback of data within 3 days of an Orbiter TCM, 15 days of MOI, or 15 days of Orbiter Launch.
    - Exception is MARCI Earth-Moon Calibrations
  - PMIRR and MARCI operation during HGA transmissions is TBD during cruise [undeployed HGA]
  - PMIRR calibrations should not occur when the PMIRR X-Z plane is within 5˚ of the sun.
- **MARCI EARTH-MOON CALIBRATION [Launch + 4 days]**
  - Slew to a certain point, scan across Earth-Moon system with a single slew, slew back to cruise attitude.
    - » During the scanning slew, MARCI takes TBD pictures with the Medium Angle Camera and TBD pictures with the Wide Angle Camera. 1 Megabyte=8 Mbits (uncompressed) per MAC pciture, 0.1 Megabyte=0.8 Mbits (uncompressed) per WAC picture.
    - » Requires an interruption to normal cruise operations.
  - If s/c condition is nominal, perform at Launch + 4 days. Complete playback of data by Launch + 7 days
    - » Data volume sized to be returned in 3 days of D/L at 2100 bps [see section 4.4.5.2 for data volumes]
    - » Data beyond this allocation would be returned after TCM-1 on best efforts basis
  - Issue: ΔV impact of a 2 week - 30 day delay in TCM-1, should the s/c go into safe mode as a result of the slew.
- **PMIRR RADIATOR DOOR moved to the vent position [Launch + 7 days]**
- **ORBITER PAYLOAD CRUISE CHECKOUT, CHARACTERIZATION AND CALIBRATION CAMPAIGN [Launch + 80 days]:**
  - Total duration = 7 days
  - **PMIRR Checkout:**
    - » Duration=4 hrs, starting 1 hour before a DSN contact
    - » Purpose: perform internal checkouts and exercise the PMU's [Pressure Modulator Units].
    - » Backup commands for shutting off the PMU's will be available to be uplinked during the DSN contact.
    - » Sun should be kept off the scan mirror during the checkout [TBD]
  - **MARCI Star Calibration:**
    - » Done once, after PMIRR checkout. [Contingency: perform later in cruise].
    - » Slew to a certain point, scan across a specific star cluster [e.g. Pleiades] with a single slew, slew back to cruise attitude.
    - » Data volume sized to be returned in 3 days of D/L at 2100 bps [see section 4.4.5.2 for data volumes]
- **MARCI MARS IMAGES [MOI - 18 days]:**
  - Perform at MOI - 18 days. Complete playback of data by MOI - 15 day
    - » Data volume scoped to be returned in 3 days of D/L at 2100 bps [see section 4.4.5.2 for data volumes]
- **Implementation:** Under nominal conditions, baseline is a single attempt for each activity. Retries on a best-efforts basis are at the discretion of the MSOP Flight Operations Manager. These sequences are initiated by ground command. Selected portions of these sequences [blocks] can be re-run via ground command as well.

4.4.5.2 Orbiter Cruise Data Playback Strategy:

Downlink Priority and Allocations: APID tables are used to control the priority of data return. During nominal cruise, Engineering receives 100% of the available downlink. During Checkout/Calibration Intervals, Science receives 50% of the available downlink.

Cruise Phase Science Data Volume: Science data volume returned during the cruise phase, after Launch + 7 days and prior to Approach, is calculated assuming one 4 hour DSN contact per day, a data rate of 2100 bps, 50% usage percentage, and 15% overhead. Thus, daily data volume = 2100 bits/sec * 3.92 hours /day (interleaved portion of one DSN pass, assuming 5 minutes telemetry lockup time) * 3600 sec/hr * 0.5 * [1-0.15] = 12.58 Mbits per day.

Post-launch and Approach Science Data Volume: During post-launch tracking [Launch to Launch+ 7 days] and Approach [MOI - 45 days to MOI] tracking levels are at 4 hours on/5 hours off. Thus, during these intervals, the daily data volume = 2100 bits/sec. * 3600 sec/hr * 10.4 hours/day * 0.5 * [1-0.15] = 33.56 Mbits/day.

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ORBITER CRUISE DATA PLAYBACK STRATEGY

- APID tables control the priority of data return.
- **Downlink Allocations:**
  - **Nominal cruise: Engineering receives 100% of available downlink**
  - **Checkout/Calibration Intervals: Science receives 50% of available downlink**
    - » **Cruise Phase Science Data Volume:**
      - One 4 hour DSN contact per day
      - Data rate of 2100 bps, 50% usage percentage, and 15% overhead.
      - Daily data volume = 2100 bits/sec * 3.92 hours /day (interleaved portion of one DSN pass, assuming 5 minutes for telemetry lockup) * 3600 sec/hr * 0.5 * [1-0.15] = **12.58 Mbits per day.**
    - » **Post-launch [L to L+7 days] and Approach [MOI-45 days to MOI] Science Data Volume:**
      - Tracking at 4 hrs on / 5 hrs off
      - Daily data volume = 2100 bits/sec. * 3600 sec/hr * 10.44 hours/day * 0.5 * [1-0.15] = **33.56 Mbits/day**.

4.5 ORBIT INSERTION PHASE

4.5.1 Mars Orbit Insertion

4.5.1.1 MOI Strategy

Approach: Approximately 9.4 months after launch, the Orbiter arrives in the vicinity of Mars. The Orbiter is targeted for closest approach over the Northern hemisphere, with an initial inclination biased approximately 0.1° higher than the mapping orbit inclination, to account for the expected mean variation in this parameter during aerobraking. Also, in order to prevent unacceptable heating, the periapse altitude must be kept above approximately 150 km. This is accomplished by choosing the final aimpoint to keep the altitude above 150 km at a TBD confidence level, given the dispersion of the approach trajectory.

MOI biprop and Hydrazine Burns: For launch at the end of the Primary launch period, it is required that the capture orbit have a period of 29 hrs or less after MOI [Mars Orbit Insertion], so that aerobraking can be completed prior to lander arrival. MOI starts with MOI-1, the biprop burn, which lasts approximately 16 - 17 minutes. Main engine cutoff occurs at an accelerometer reading of 65% - 75% thrust [TBD], backed up by a timer cutoff. This maneuver exhausts the supply of oxidizer. The biprop system is isolated prior to cutoff. The ΔV imparted to the spacecraft from this maneuver depends on the approach mass of the Orbiter, which in turn depends on TCM and other propellant usage during cruise. After a one minute coast, the hydrazine system must, in most cases, provide a supplemental maneuver [designated MOI-2] to trim the orbit period to the needed value of 29 hrs. The supplemental burn, which may last as long as 7 minutes, occurs as soon after the biprop burn as possible, to minimize gravity loss. By placing the hydrazine burn soon after the biprop burn, the hydrazine maneuver is less efficient than if it were placed at periapse, but time is saved because walk-in can occur at the apoapse of the capture orbit, approximately 14 hours after MOI. Cutoff for MOI-2 is determined by an accelerometer detection of the total ΔV required, backed up by a timer cutoff.

Capture Orbit Periods: For launch at the end of the primary interval, the biprop burn yields orbit periods between 27 and 44 hrs [95% range]. For launch at this time, there is a probability of approximately 88% that a hydrazine burn will be required to trim the orbit to the required 29 hrs. The final range of capture orbit periods after the hydrazine makeup burn is approximately 27 - 29 hours [95% range], depending on TCM usage during cruise. These results vary slightly across the primary launch period. As one moves further and further into the Secondary interval, the final capture periods get larger and larger. At the end of the Secondary period, the orbit period is 37 hours after the hydrazine burn. In this case, an additional ~2 weeks of aerobraking are required before mapping orbit can established.

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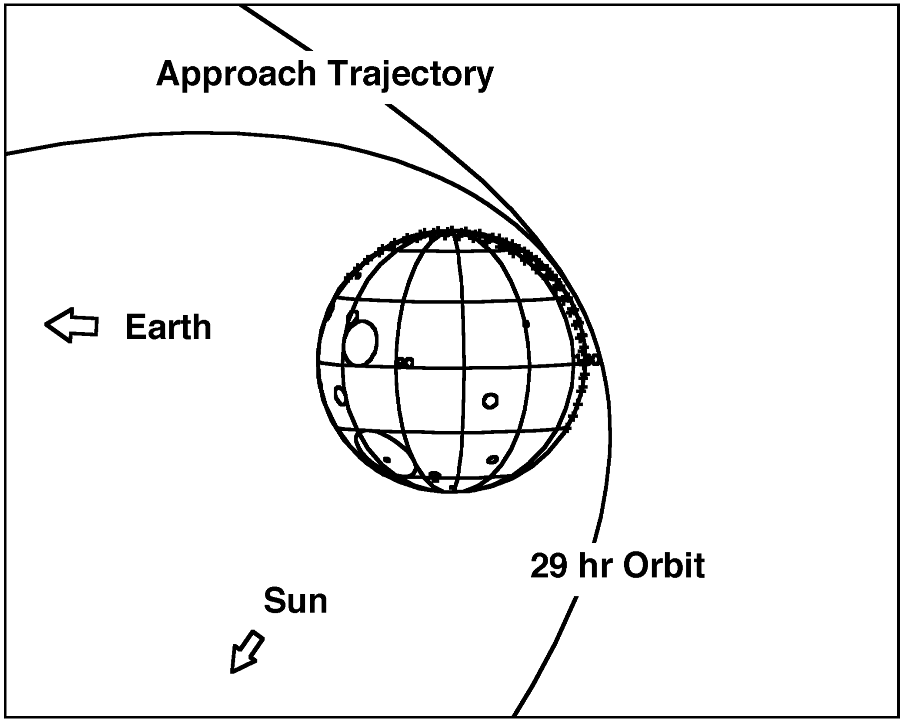
MARS ORBIT INSERTION STRATEGY



- **Northern Approach**
  - Initial inclination targeted 0.1° high to accommodate inclination perturbations during aerobraking.
  - Aimpoint chosen to keep periapse altitude > 150 km during MOI [heating constraint].

- **MOI-1: biprop burn**
  - Burn Oxidizer to depletion [16 minute burn]
  - Main engine cutoff at accelerometer reading of 65% - 75% thrust [TBD], with timer backup.
    - » Biprop system is isolated prior to cutoff
  - Imparted ΔV depends on approach mass, and performance of biprop system

- **MOI-2: Hydrazine makeup burn:**
  - Supplemental Hydrazine burn follows 60 sec. later, as needed, to yield desired orbit period.
  - For launch at end of primary, makeup burn is required 88% of the time.
  - Allows earlier walk-in maneuver than a next-rev burn
  - Cutoff determined by accelerometer detection of total ΔV required, with timer backup.

- **Target is 29 hr maximum orbit period for launch at end of Primary**
  - 99% probability of aerobraking completion by Lander arrival
  - Orbit period ~ 26 hrs at start of Primary, ~ 36 hrs at end of Secondary

4.5.1.2 Mars Orbit Insertion SOE

The following chart illustrates the Mars Orbit Insertion sequence of events, which begins with a 4 hour DSN contact starting approximately 18h45m before the MOI biprop burn. Safe Mode is disabled some time during this DSN contact [time TBD]. Additional DSN contacts are planned: a 4 hour contact starting 9h45m before the burn, and a 23 minute contact starting 45 minutes before the burn. As part of a stored sequence, less than 1 hour before MOI, the Autonomous Momentum Management [AMM] deadbands are decreased, compelling the system to dump momentum prior to MOI if needed; the AMM software is then disabled until after MOI, to prevent further autonomous momentum wheel desaturation during MOI. Starting approximately 22.5 minutes before MOI, the Catbed and Main Engine Valve/Flange Heaters are enabled. The solar arrays are then restrained, and the main engine lines are evacuated. The slew to the MOI attitude is performed ont he reaction wheels. Configuration of the biprop system continues with hard fill of the engines beginning about 5 minute before MOI, and filling of the Helium pressurant tanks.

The MOI biprop burn itself lasts approximately 16 minutes, and is terminated when oxidizer depletion is sensed by the accelerometers. A minimum timer enables the accelerometer cutoff, and a maximum timer prevents excessive Hydrazine usage. Another timer is used to fire the pyros which isolate the biprop system. This occurs before the end of the biprop burn. The remainder of the burn is performed in blowdown mode. Attitude control, including the constant pitch rate turn during the biprop burn, is maintained via the TCM and RCS thrusters. After the biprop burn, the RCS thrusters fire for approximately 1 minute to damp out the spacecraft rates. The supplemental hydrazine burn, if needed, is then executed using the 5 lbf TCM thrusters. Typically, this burn lasts less than 7 minutes, and is terminated when the accelerometers detect that the needed additional ΔV has been supplied, backed up by min and max timers. Upon completion of the supplemental burn, safe mode is re-enabled, the spacecraft is slewed via reaction wheels to an attitude permitting post-MOI DSN contact, and the Catbed and main engine heaters are disabled. The solar arrays are unstowed and sun-pointed. DSN contact is re-established at the earliest opportunity after exit from occultation.

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MARS ORBIT INSERTION SOE

Time	Contact	Activities	
MOI_BP_BURN - 18:45:00 to MOI_BP_BURN - 14:45:00	DSN Contact 1	• Disable System Safe Mode Response • Disable Sequence Abort Response	• Set Comm Loss Times to Exceed MOI • Mission Phase Bits to MOI • Set up MOI Global Variables
MOI_BP_BURN - 09:45:00 to MOI_BP_BURN - 05:45:00	DSN Contact 2	• Downlink Health and Status	
MOI_BP_BURN - 00:45:00 to MOI_BP_BURN - 00:22:20.9	DSN Contact 3	• Enable RCS Catbed Heaters • Enable TCM Catbed Heaters • Config AMM • Processor to 20 MHz	• Enable ME valve, Flange, line heaters • Restrain solar arrrays
MOI_BP_BURN - 00:11:05 to MOI_BP_BURN - 00:00:00.1		• Open/Close ME valves OV1, FV1 • Slew to MOI Burn Attitude	• Fill Oxidizer and fuel lines • Pressurize Oxidizer and Fuel tanks
MOI Burns		• Bi-Prop Burn	• Mono-Prop Burn
MOI_END + 00:00:00.1		• Enable AMM • Disable TCM, RCS catbed heaters • Disable ME heaters • Enable Safe Mode	• Enable Sequence Aborts • Set Comm Loss Times for A/B • Unrestrain SA/Gimbal to Sun • Slew to DSN Attitude/Initiate Contact • Processor to 5 MHz

4.6 AEROBRAKING PHASE

4.6.1 Post-MOI Activity

Nominal Operation: The following graphic illustrates the flow of activities after termination of MOI-2. Approximately 22 minutes after the completion of the MOI burns, the spacecraft will have been turned to its communications attitude. DSN contacts then occur on a schedule of 4 hours on / 5 hours off, allowing opportunities for downlinking telemetry data, obtaining tracking data, and sending commands. Once the stored MOI data are downlinked to Earth, the result of the MOI burns must be quickly evaluated, along with the state of the spacecraft itself. If telemetry shows that MOI-1 and MOI-2 have executed nominally, preparations are made for walk-in at the first apoapse of the capture orbit. A default walk-in maneuver will have been uplinked prior to execution of the MOI sequence. TBD: This maneuver will be updated, if required, using the post-MOI DSN contacts. Execution of the walk-in burn is enabled by ground command.

Contingency Operation: If post-MOI telemetry or tracking indicate an anomalous condition of the spacecraft or capture orbit, the aerobraking walk-in maneuver would be delayed until the anomalies are identified and resolved. For example, anomalous performance of the biprop engine may result in MOI-1 being terminated via the MOI-1 backup timer, in which case oxidizer may remain in the tank. Regardless of whether MOI-1 is terminated normally or via a timer cutoff, the biprop system is always isolated via pyro firings. Similarly, MOI-2 may be terminated via its backup timer, signalling an anomalous burn. If sufficient oxidzer remains, a second biprop burn in blowdown mode may be commanded. This would occur at periapse of a subsequent orbit. In this case the solar array would be restrained, the spacecraft slewed to the burn attitude, and thruster control enabled. The burn cuts off upon achieving the requisite ΔV, backed up by a timer. The spacecraft then re-establishes contact with Earth and downlinks data from the burn.

Oxidizer Heater Operation: The nominal plan is to keep the oxidizer heaters operating until it is determined that it is safe to turn them off. This may occur well after the aerobraking walk-in maneuver.

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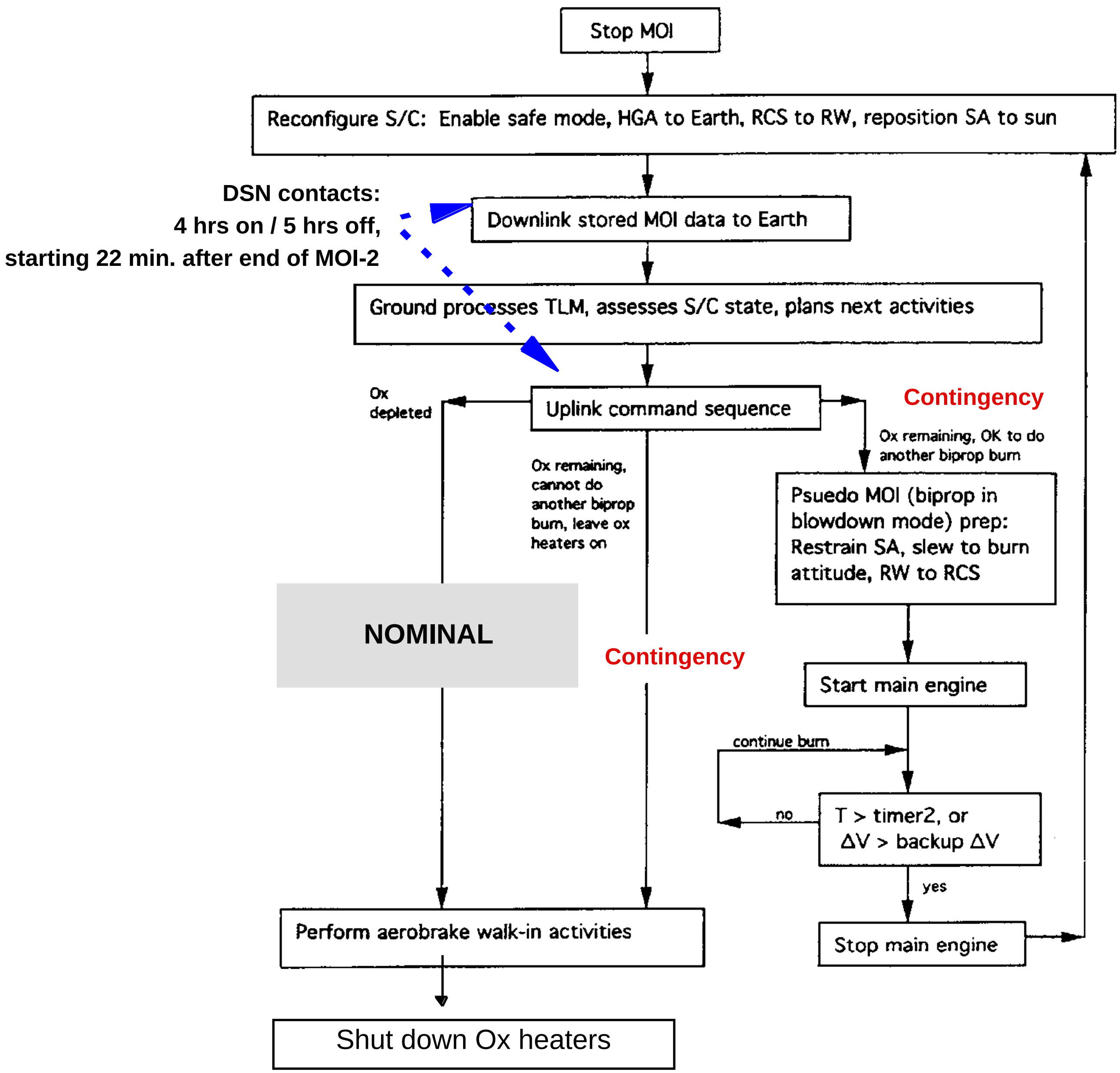
POST MOI ACTIVITY



4.6.2 Aerobraking

4.6.2.1 Aerobraking Strategy

After MOI, an aerobraking schedule is planned which allows the Orbiter to complete aerobraking and place it in an orbit from which it can support Lander data relay and commanding, prior to Lander arrival. The current mission design can support this only if the Orbiter is launched within its Primary launch period [12/10 - 12/17/99] during which the resultant capture orbit periods are sufficiently short. If launch occurs during the Secondary launch period, the capture orbit periods will likely be too long to allow completion of aerobraking before Lander arrival.

For the Primary launch period, the most stressful aerobraking case occurs at the end, since this affords the least time for aerobraking prior to Lander arrival. The first walk-in maneuver occurs at apoapse of the final capture orbit [approx 0.6 days after MOI]. The Walk-in phase, during which the periapse altitude is cautiously lowered, occurs over approximately 3 orbits [3.6 days]. The Main phase of aerobraking lasts 52.6 days, and the End Game or Walk-out interval lasts 8.6 days. Aerobraking is terminated with a periapse raise maneuver as part of the transfer to map orbit. See section 4.2.5 for phase durations and mission events for other launch dates.

The following plots illustrate the evolution of the orbit during aerobraking. As the orbit period decreases, the argument of periapse, initially at 28°N, moves Northward. At the end of aerobraking, periapse is located approximately at the North pole of Mars. The sun-relative node is also changing during this interval, due primarily to the motion of Mars about the Sun. During the majority of Aerobraking, the orbit is so elliptical that the node orientation changes very little inertially, while Mars continues to move at an average rate of 0.524° per day with respect to the Sun. As a result, the node moves to earlier and earlier local mean solar times.

Appendix A.5, the Aerobraking Database, contains states as a function of time during the aerobraking phase, for open and close of the primary launch period.

Inclination Trims: The dispersion of the incoming trajectories, coupled with pointing errors during MOI and the effects of aerobraking, result in a perturbation of as much as ±0.3° away from the desired inclination. In order to maintain the desired degree of sun synchrony for the final mapping orbit, the majority of this dispersion is corrected during the aerobraking phase, when the orbit is still highly elliptical. Two inclination trims are planned: one when the orbit period is approximately 20 hrs [assuming a nominal capture period of 29 hrs] and the other at 10 hrs. The optimal placement for these maneuvers is at a true anomaly of approximately 190°, and results in a combined change in the inclination and the node. An inclination change of 0.2° is bookkept in the propellant calculations. A final inclination trim after aerobraking may also be required, and may be combined with the first Transfer to Map Orbit burn.

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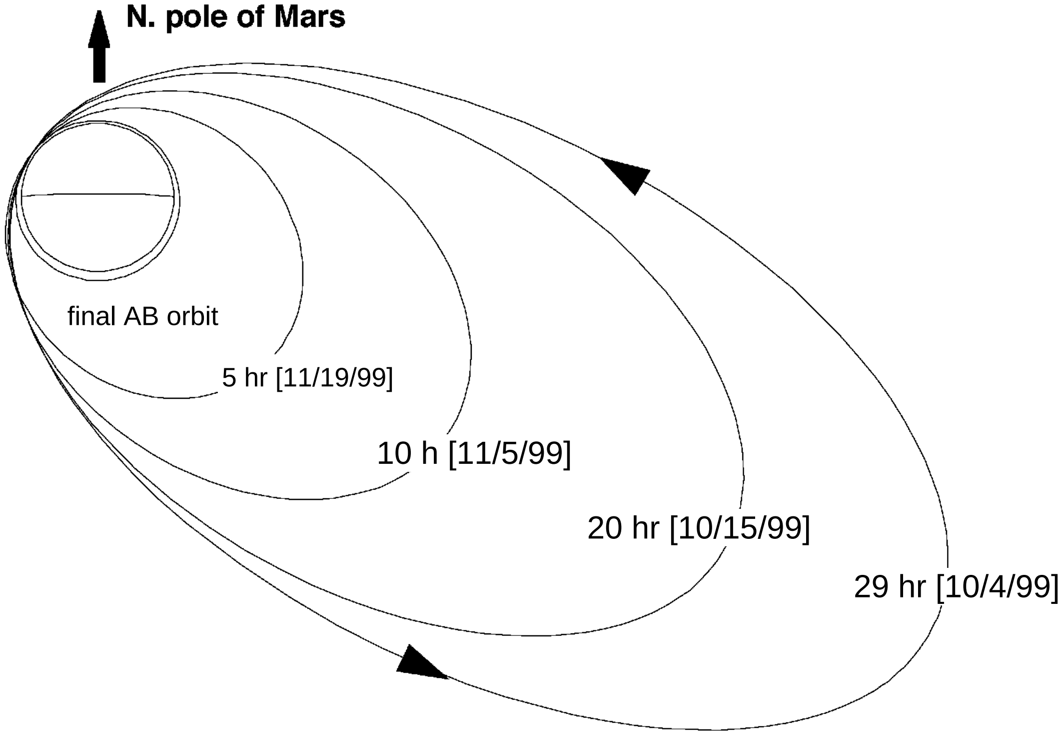
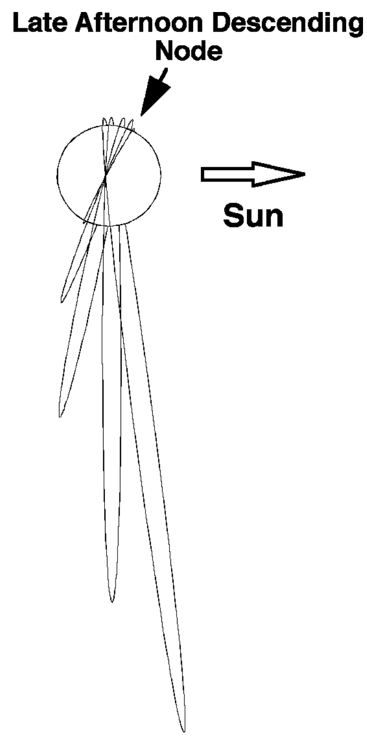
AEROBRAKING STRATEGY

- **The chosen aerobraking strategy, along with sufficiently low initial orbit periods, allows the Orbiter, if launched within its Primary Launch Period, to complete aerobraking by the earliest Lander arrival date.**

- **Timeline for End of Primary:**
  - Start walk-in 0.5 revs [approx 0.6 days] after MOI. Walk-in lasts 3 revs [3.6 days].
  - Main phase lasts 52.6 days
  - End game [Walk-out] lasts 8.6 days
  - Aerobraking is terminated with TMO-1, the first Transfer to Map Orbit maneuver

- **Inclination trim ΔV's** planned at orbit periods of 20 hrs and 10 hrs during aerobraking.
  - Corrects ±0.2° of the expected ±0.3° of dispersions in inclination.





4.6.2.2 Aerobraking Navigation

The driving navigation requirement for aerobraking is accurate prediction of both the timing and radius of periapse passage. The requirement currently assumed for the Orbiter is derived from the MGS requirement that the time of periapse passage be predicted to an accuracy of 225 sec [2σ], and the periapse radius predicted to 1.5 km [3σ]. The periapse passage timing requirement can be violated on occasion, but must be satisfied in general to prevent high propellant usage in stabilizing s/c attitude after each aeropass. The MGS requirement was derived based on 70% orbit-to-orbit density variation, plus 20% nav uncertainty. Unlike MGS, whose transmitter can support near continuous tracking, the MSP98 Orbiter has thermal and power constraints severely limiting its transmitter cycle. The transmitter cycle being assumed is: 4 hrs on/5 hrs off during outer cruise and early aerobraking, an on/off ratio of 0.8 in lower orbits, and a minimum of 30 minutes per orbit for the final TBD days of aerobraking. The nominal tracking schedule starts with a tracking pass as soon after the aeropass as possible. Appendix A.5 includes strawman tracking schedules for Open and Close of Primary.

Preliminary analyses using worst-case conditions during aerobraking [orbit periods ~2 hrs] indicate that periapse prediction to the desired accuracy may only be possible 2 or 3 orbits ahead, for the last part of aerobraking. As a result, during a limited interval, one or more of the following measures may be required [feasibility TBD]: more frequent nav predicts than were required for MGS, reduction of nav turnaround time on the ground compared with MGS, collection and analysis of accelerometer data taken during the aeropasses, and accepting longer intervals during which the prediction requirement is not met. It is assumed that improved gravity field modeling provided by MGS will reduce the nav uncertainty MSP98 must account for, to 10%.

4.6.2.3 Support of Lander Approach Navigation - Near Simultaneous Tracking

In order to support precision approach navigation for the MSP98 Lander, a program of near-simultaneous tracking of the Lander and the MSP98 Orbiter is required, starting 30 days from Lander arrival. [At this point, the Orbiter period is 9-11 hours.] This requires that a track of the Lander be immediately followed or preceded by an Orbiter pass, and that both passes be supported from the same HEF antenna. Analyses of these data can be used to reduce the effects of error sources common to both spacecraft, such as station-dependant biases, Earth orientation errors, and errors in media and solar plasma modelling. Close coordination of Orbiter tracking passes and Lander passes are required during this interval. In general, because the MSP98 Orbiter is engaged in aerobraking at this time, there is little flexibility in timing the Orbiter passes, which will be scheduled in accordance with aeropass times and transmitter on/off cycles. The Lander passes must be timed to fit in with the Orbiter tracking schedule, as well as DSN pre- and post-calibration times.

If the MSP98 Orbiter is not available for support of near-simultaneous tracking with the Lander, the MGS spacecraft will be used as a backup.

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AEROBRAKING NAVIGATION

- **Driving Requirement**
  - Periapse Prediction accuracy: 225 sec [2σ], 1.5 km [3σ]
    - » MGS requirement to prevent high propellant usage for stabilizing attitude after aeropass.
    - » Based on 70% orbit-to-orbit density variation, 20% nav uncertainty.
    - » Must be satisfied in general. Occasional violations are acceptable.

- **S/C Constraints and Tracking Assumptions**
  - Continuous tracking [assumed for MGS] not feasible due to thermal and power constraints to transmitter on times. Current design capability:
    - » 4 hrs on / 5 hrs off during outer cruise and early aerobraking
    - » 80% on:off duty cycle in lower period orbits
    - » minimum of 30 minutes per orbit during final TBD days.
  - Perform first tracking pass as soon after aeropass as possible

- **Preliminary Results - Nav Capability**
  - Periapse prediction to desired level may be possible only 2-3 orbits ahead when orbit period ~ 2 hrs.
    - » May require one or all of the following during a limited interval [feasibility TBD]:
      - More frequent nav predicts than needed for MGS
      - Reduction of nav turnaround time on ground
      - Collection and analysis of accelerometer data during aeropasses
      - Longer intervals during which prediction requirement is violated.
  - Assumption is made that MGS will reduce nav uncertainty to 10% due to improved gravity field model

- **Orbiter/Lander Near Simultaneous Tracking**
  - Lander precision approach nav requires Lander tracks to be immediately preceded or followed by an Orbiter pass from the same HEF antenna, to reduce effects of error sources common to the Lander & Orbiter [station-dependant biases, Earth orientation errors, media & solar plasma modelling errors].
  - Starts at Entry - 30 days - The M98 Orbiter is in aerobraking [period = 9-11 hrs]
    - » Orbiter passes are fixed, determined by timing of aeropasses and transmitter on/off cycles.
    - » Lander must schedule its tracks to fit in with Orbiter tracks, and DSN pre- and post-cal
  - If M98 Orbiter not available, MGS is backup

4.6.2.4 Aerobraking Maneuvers

Transition to Aerobraking: Walk-in Maneuver

Nominally, Aerobraking is initiated at the first apoapse of the final capture orbit, with the walk-in maneuver. Prior to MOI, a default walk-in maneuver will be present on-board. TBD: Post-MOI DSN tracking data will be used to perform orbit determination and update the default maneuver, as needed. For the first walk-in maneuver, the Autonomous Momentum Management deadbands are tightened, followed by temporarily disabling the AMM software architecture. RCS and TCM Catbed heaters are enabled. Star camera processing is disabled, the spacecraft is slewed on wheels to the burn attitude, and the solar array passively restrained. RCS thrusters are used to control attitude during the burn, which lasts approximately 20 seconds. Immediately following the burn, AACS control is restored to the reaction wheels, which effect a slew to the DSN contact attitude. Star camera processing and AMM is re-enabled, and the solar arrays are unrestrained and gimballed to sun-point. Subsequent walk-in maneuvers are smaller, and do not require restraining the solar array.

Orbital Trim Maneuvers

Approximately 14 OTM's [Orbit Trim Maneuvers] are expected to be required during this phase. Two types of OTM's can be implemented: small maneuvers ≤ 6 seconds which do not require the solar arrays to be stowed, and maneuvers > 6 seconds which require the solar array to be passively restrained.

Unrestrained Maneuvers. Unrestrained maneuver durations are based on required ΔV, with a simple back-up timer set to the maximum time allowed for unrestrained burns [i.e. 6 seconds]. These OTM maneuvers are "canned", pretested maneuvers. At any given time, a minimum of 6 maneuvers will be available on-board [3 raise periapse, and 3 lower periapse], defined by 3 burn durations and two inertial burn directions [quaternions]. The set of maneuvers is updated periodically during aerobraking.

Restrained Maneuvers. Restrained maneuvers are also cut off based on ΔV delivered, i.e. AACS commands the TCM thrusters until the specified ΔV is delivered. The back-up timer in this case is based on the 3-sigma long burn time. Prior to the burn, the solar array is restrained, using the same protocol as elsewhere in the mission.

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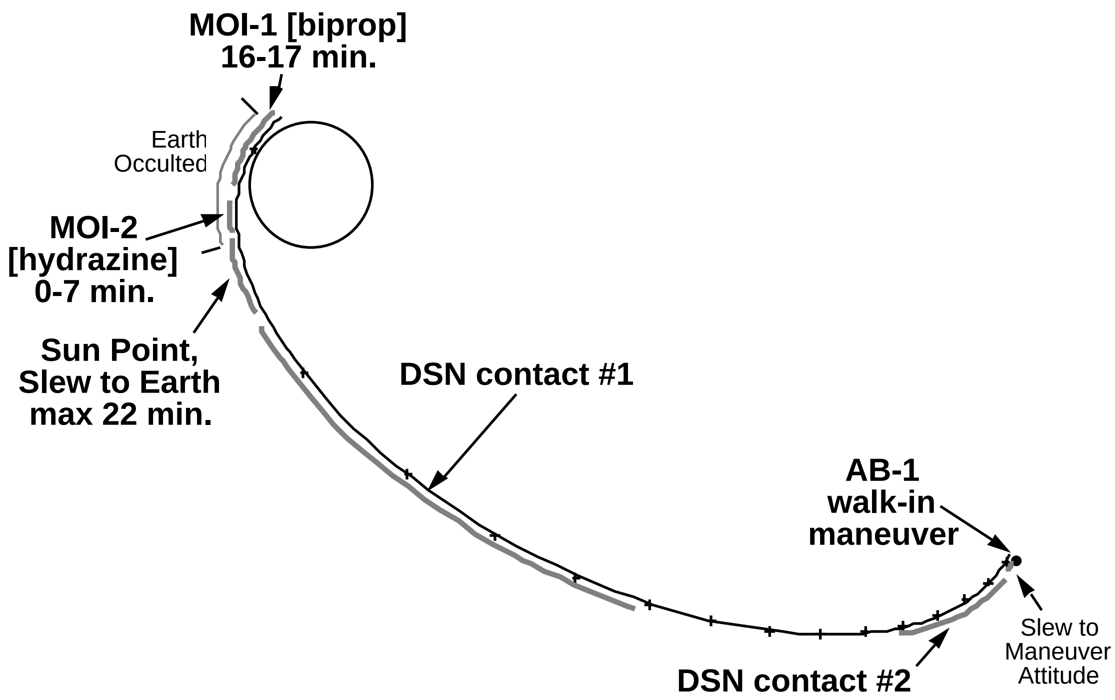
AEROBRAKING MANEUVERS



- **Transition to Aerobraking: Walk-in Maneuvers**
  - Walk-in starts at first apoapse of final capture orbit
    - » Default maneuver on-board prior to MOI. TBD: Updated using post-MOI DSN passes
    - » First walk-in maneuver requires solar array to be restrained.
  - Subsequent walk-in maneuvers done without restraining solar array.

- **Orbital Trim Maneuvers:**
  - Approx 14 expected during aerobraking phase
  - **Unrestrained OTM's:**
    - » Maneuvers ≤ 6 sec which do not require solar array to be restrained
    - » These maneuvers may be "canned"
      - Minimum of 6 maneuvers available on-board [3 periapse raise, 3 periapse lower], defined by 3 burn durations and two inertial burn directions
      - Maneuver set updated periodically throughout aerobraking phase.
    - » Cutoff based on attainment of desired ΔV. Backup timer set to max time allowed for unrestrained burns [i.e. 6 seconds]
  - **Restrained OTM's:**
    - » Maneuvers > 6 sec requiring solar array to be restrained
    - » Cutoff based on attainment of desired ΔV. Backup timer based on 3σ-long burn time.

4.6.2.5 Aeropass Sequence of Events

During active aerobraking, an aeropass is defined as the passage of the Orbiter through periapse, during which atmospheric drag reduces the orbit period. Approximately 220 aeropasses are expected during the Aerobraking phase. Preparation for this activity starts with tightening the AMM deadbands, at a pre-determined point prior to the aeropass, followed by temporarily disabling the AMM software. RCS Catbed heaters are enabled, Star Camera processing is disabled, and the slew to the aeropass attitude starts. During Main Phase, the slew to and from aeropass attitude is on the reaction wheels. During the last 10 orbits of the End Game, thrusters are used for these slews, to minimize the time off-sun. Solar arrays are restrained shortly before the pass. During the aeropass itself, attitude is controlled via the RCS system. After the aeropass is over, RCS Catbed heaters are disabled, and the spacecraft is slewed to the Aerobraking DSN contact attitude. Star camera proccessing and AMM are re-enabled, and the arrays are unrestrained.

Aeropass durations tend to increase during the Aerobraking phase, as the orbit period shrinks. Drag pass durations [including 5 minute uncertainty bands at the start and end of the aeropasses] are summarized for the end of the Primary period, in Appendix A.5 - the Aerobraking Database. Also included in this appendix is the total amount of time the spacecraft is in sun, i.e. the orbit period less the drag pass duration and time the panels are off-sun. As indicated, the solar eclipse times also increase during aerobraking, as the node moves to earlier and earlier sun times and the apoapse altitudes decrease.

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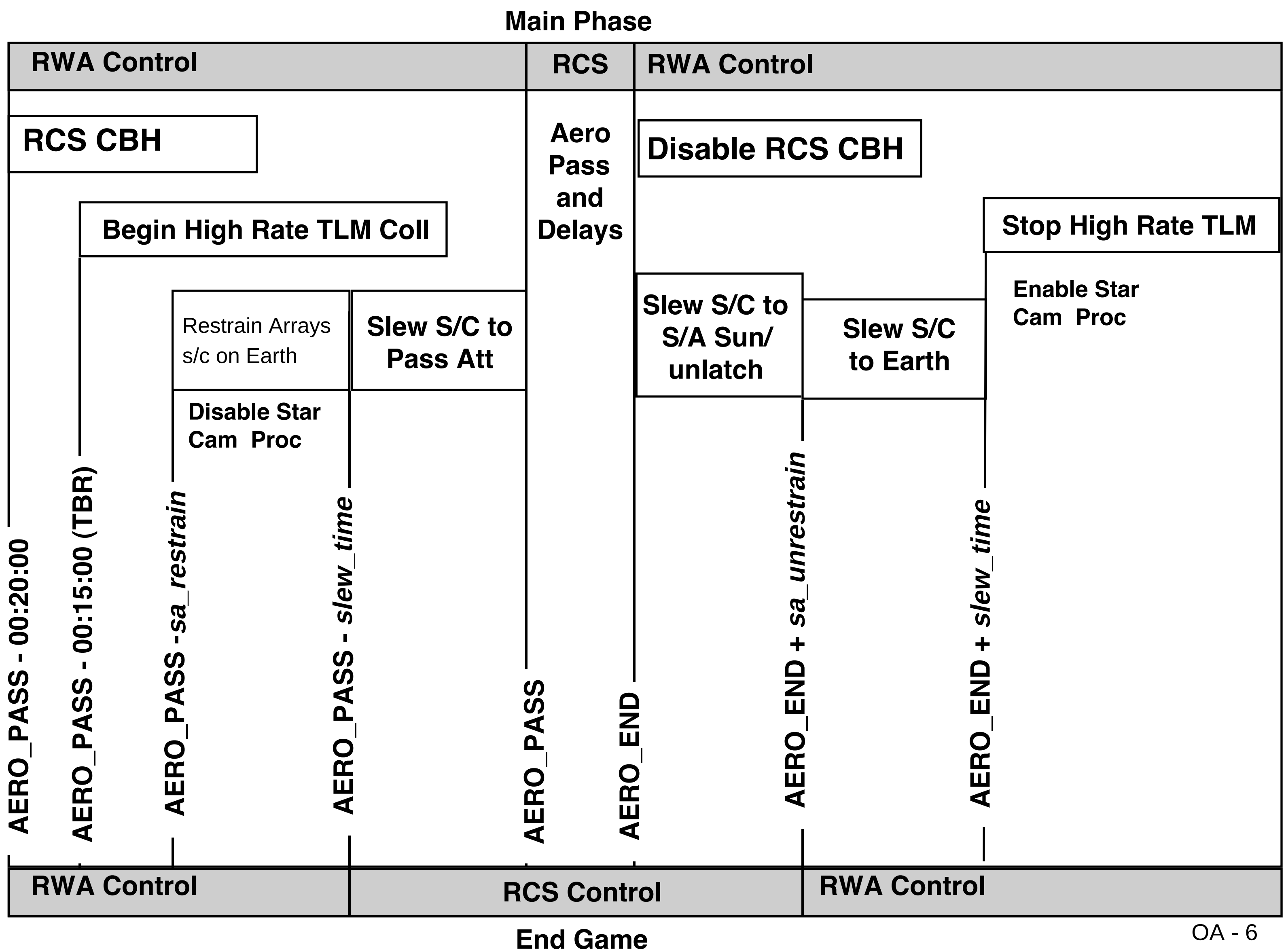
AEROPASS SOE



4.6.2.6 Aerobraking Communications Strategy

DSN contacts during aerobraking change as the orbit period and orbit plane geometry varies. In early aerobraking, the 4 hours on / 5 hours off transmitter duty cycle is maintained, with the first contact occurring as soon after aeropass exit as possible. As the orbit period decreases, a 4:5 on:off ratio is maintained in accordance with the power and thermal limitations of the transmitter. The receiver is on all the time. During walk-out, as eclipse and occultation durations increase, transmit intervals are severely limited to accommodate needed battery recharge time. DSN contacts may be as short as 30 minutes per orbit during walk-out or during OTM orbits towards the end of aerobraking. The downlink data rate at this point is 2.1-9.9 kbps.

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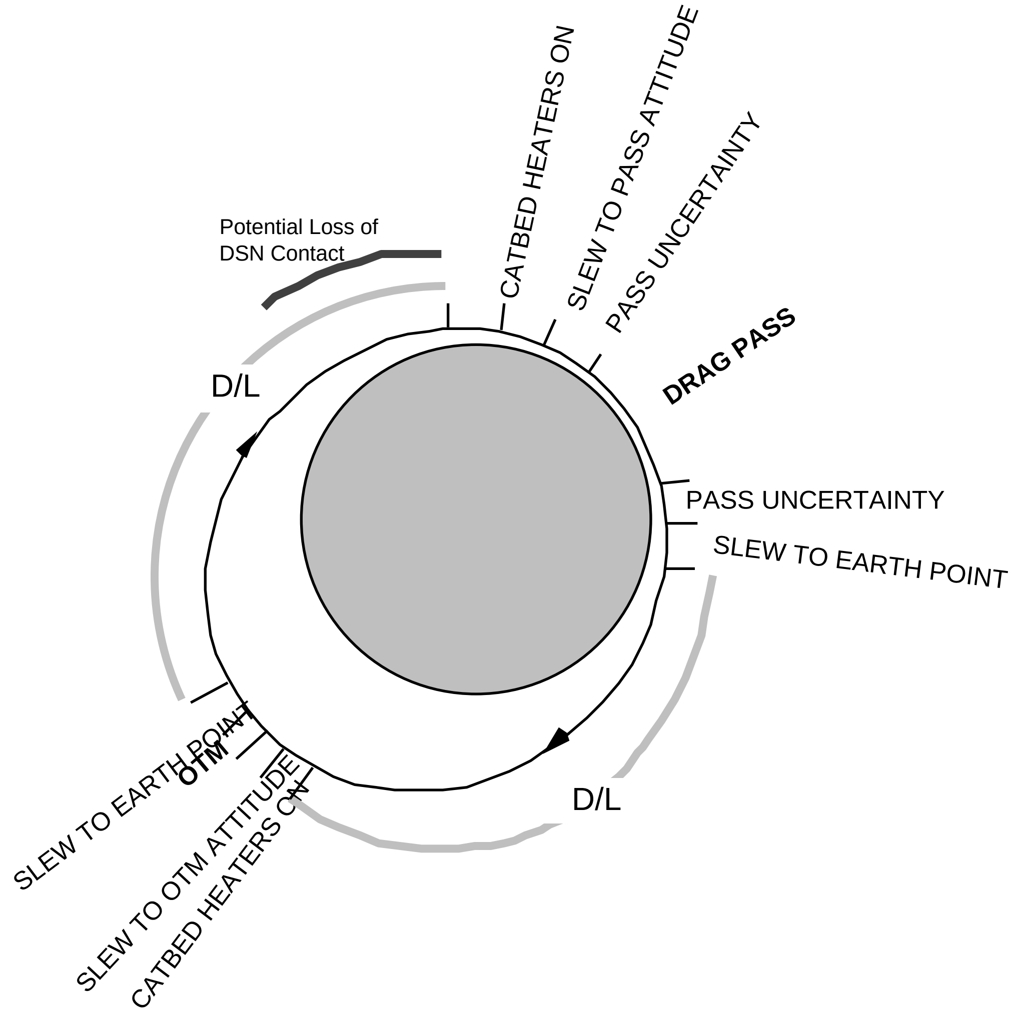
AEROBRAKING COMMUNICATIONS STRATEGY

- **Transmitter:**
  - Downlink Transmit at 2.1-9.9 kbps
  - On/off cycle changes as period and orbit plane geometry evolves:
    - » Early Aerobraking: 4 hrs on/5 hrs off
    - » Intermediate Orbit Periods:
      4:5 on:off ratio maintained
    - » End Game: 30 minutes per orbit
      - Constrained by energy balance as eclipse and occultation durations increase
- **Receiver** always on



4.6.3 Transfer to Map Orbit

4.6.3.1 TMO Maneuvers

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Overview: At the end of aerobraking walk-out, periapse is very close to the North pole. A maneuver at or near apoapse of this orbit [near the South pole of Mars] raises periapse out of the atmosphere to terminate Aerobraking. This manuever, called TMO-1 [Transfer to Map Orbit #1] also places apoapse near the North pole. The magnitude of TMO-1 is 80-82 m/s. The transition orbit the spacecraft occupies at this point has an apoapse of approximately 437 km [frozen orbit apoapse] and a periapse equal to the apoapse of the final aerobraking orbit [405±15 km]. TMO–2 is a smaller maneuver [4-10 m/s] occurring at the transition orbit's apoapse, which trims the periapse altitude to 373 km and places the spacecraft in its final frozen mapping orbit. By thus propulsively rotating the line of apsides, it is possible to enter the frozen orbit without a drift interval.

The total time for transfer to the mapping orbit is TBD but must be sufficient for tracking data to be taken, the TMO-2 maneuver to be designed, uplinked and executed, and any additional trim maneuvers to be implemented. A maximum of 24 hours is currently allocated between the final aeropass and start of mapping operations.

Post-Aerobraking Final Inclination Trim [TBD]: The current ΔV budget includes propellant sufficient to perform two inclination trims during aerobraking, at orbit periods of 20 hours and 10 hours. This leaves approximately ±0.05˚ of remaining inclination uncertainty at aerobraking termination, which, along with the ±20 minutes uncertainty in final node location, must either be tolerated [impacting science and energy balance] or trimmed up [impacting the ΔV budget]. By placing the TMO-1 maneuver a few degrees away from the South pole, and introducing an out-of-plane component, this maneuver may be used to perform a final inclination trim to ameliorate the effects of uncertainties in aerobraking end state [both node and inclination], and thus prevent either very late solar times [bad for science] or very early solar times [bad for energy balance]. Appendix A.6 [Post-Arrival Trajectory Characteristics] illustrates the effect on solar time and eclipse durations of no inclination trim, a maximum trim magnitude of 0.05˚ , and a maximum trim magnitude of 0.1˚, for the full range of possible aerobraking end nodes. Performing a post-Aerobraking inclination trim of 0.05˚ requires 5-7 m/s if included as part of TMO-1, or about 3 m/s if done as a separate maneuver at the node. Changing inclination by 0.1˚ as a part of TMO-1 would require a prohibitive 23 m/s; in this case the maneuver would have to be done at the node, for a cost of 6 m/s. If schedule pressures dictate, a final inclination trim at the node could be delayed until after Lander arrival. This would probably require a burn after the HGA has been deployed. The feasibility and/or maximum size of a maneuver after HGA deployment is TBD.

ΔV Magnitudes: Manuever ΔV magnitudes have been estimated for the open and close of the Primary Launch Period, using as starting points the end state peripases listed in Appendix A.5 - Aerobraking Database, and an assumed final apoapse of 405 km ± 15 km. The following table summarizes the range of ΔV required, without inclination trim.

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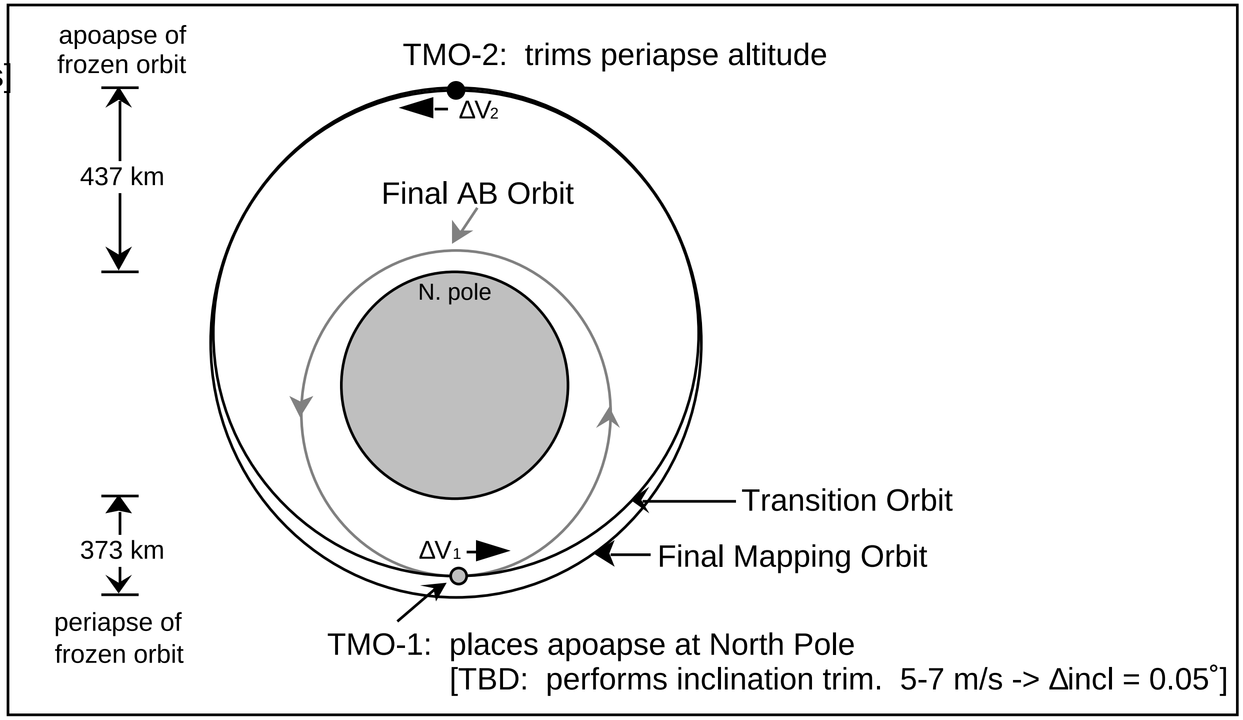
TRANSFER TO MAP ORBIT - TMO Maneuvers ** This page under Change Control **

- **Transfer to Mapping Orbit:**
  - Direct propulsive insertion into the frozen Mapping orbit [2 maneuvers]
  - Time between TMO-1 and TMO-2 is TBD. 24 hrs allocated between final aeropass & start of mapping.
    - » Includes trim maneuvers, if required.



- **Final Inclination Trim [TBD]:**
  - Previous inclination trims during aerobraking [at orbit periods of 20 hrs, 10 hrs] leave 0.05° uncertainty in inclination.
  - See Appendix A.6 for effects on solar time & eclipse durations of no inclination trim, 0.05° trim, and 0.1° trim, for full range of Aerobraking end nodes [± 20 minutes]
  - **Inclination trim of 0.05°:** costs 5-7 m/s if included as part of TMO-1, or 3 m/s if a separate maneuver at the node
  - **Inclination trim of 0.1°:** too costly to include as part of TMO-1, requires 6 m/s separate maneuver at the node
  - Final inclination trim could be delayed until after Lander arrival [feasibility &/or max size of maneuver after HGA deploy TBD]

- **ΔV Magnitudes [without inclination trims]:**

	Aerobrake End State [periapse alt x apoapse alt (km)]	ΔV1 [m/s]	ΔV2 [m/s]	**Total ΔV [m/s]**
Open Primary	85 x 390	81.7	3.8	**85.4**
Open Primary	85 x 420	81.5	10.4	**91.9**
Close Primary	91 x 390	80.2	3.8	**84.0**
Close Primary	91 x 420	80.0	10.4	**90.4**

4.6.3.2 Mapping Initialization Activities

After transfer to the map orbit is complete, spacecraft initialization for relay operations is undertaken in anticipation of Sol 0 Lander support.

HGA Deployment and Calibration: Some time after transfer to the map orbit, the High Gain Antenna [HGA], which is restrained during Cruise, MOI, and Aerobraking, is deployed. The boom heater is first turned on to warm up the one-time release mechanism. Once it is deployed the HGA cannot be stowed again. All attitude control is disabled during the deployment. After the HGA is deployed the gimbals must be initialized. The HGA may need to be calibrated after deployment [TBD]. This would occur as soon as feasible during a DSN contact after deployment, by moving the HGA in a pre-defined pattern and analyzing the received signal power. Maneuvers larger than TBD m/s cannot be performed after HGA deployment.

Additional Bus Activities: The Mission Phase Bits, which govern how the spacecraft recovers from anomalies during Safe Mode, are set to MAPPING. New momentum limit deadbands for mapping are set for the autonomous momentum wheel desaturations. During mapping/relay operations the nominal processor speed is 20 MHz.

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MAPPING INITIALIZATION ACTIVITIES

- Orbiter intialization occurs after transfer to map orbit, in preparation for relay operations prior to Lander Sol 0:

  » **HGA Deployment and Calibration:**
  - HGA [restrained during Cruise, MOI, and Aerobraking] is deployed.
  - Boom heater activated to warm up the one-time release mechanism.
  - Attitude control disabled during deployment.
  - Gimbals initialized.
  - TBD: HGA may need calibration after deployment.
    - Occurs as soon as feasible during a first DSN contact after deployment
    - HGA moves in a pre-defined pattern, and received signal power is analyzed.
  - Maneuvers larger than TBD m/s cannot be performed after HGA deployement.

  » **Additional Bus Activities:**
  - Mission Phase Bits [govern how s/c recovers from anomalies during Safe Mode] set to MAPPING.
  - New momentum limit deadbands for mapping are set for the autonomous momentum wheel desaturations.
  - Processor speed 20 MHz.

4.7 LANDER SUPPORT PHASE

4.7.1 Overview

** This page under Change Control **

The Lander Support Phase occurs after transfer to the map orbit and mapping/relay initialization, and prior to the full-up mapping mission. Its duration is equal to the nominal landed science lifetime [12/3/99 - 2/29/00]. The use of 34m DSN antennae is baselined throughout. [Use of 70m support is under review; it can substantially improve orbiter data return and reduce ops complexity by eliminating the need for Lander relay support by MGS during the 3rd month of the Lander's mission.] It is also assumed that MGS is available for relay starting 2/1/00, and that the MSP98 Orbiter transitions to its lowest data rate [5.7 kbps] on or near 2/1/00. MSP98 Orbiter commanding support of the Lander is assumed throughout this phase. Note: eletromagnetic interference with the Orbiter payload due to UHF transmissions is TBD, rendering Orbiter payload operations during this phase TBD as well.

Subphase 1: 12/3/99 - 1/2/00 [Dedicated Lander Relay Support] During this subphase, Lander support is the Orbiter's highest priority; Lander science receives the majority of the 150-160 Mbits of science the MSP98 Orbiter can downlink every day. [At this point the Orbiter is communicating at 9.9 kbps.] MSP98 Orbiter science receives whatever remains in terms of D/L data volume [<10 Mbits/day], and ops resources.

> **PMIRR and MARCI initializations** occur during this subphase, TBD days after Lander landing. In both cases, this involves turning on the main power and activating onboard instrument software. For PMIRR, this also involves opening the radiator door, and allowing the instrument to cool down. PMIRR must be in its operating mode [main power on], and all significant maneuvers must have been executed by the Orbiter prior to opening the radiator door fully. Other Orbiter activities during this time include standard housekeeping, and instrument health checks. TBD: any remaining Orbiter science D/L capability may be used for MARCI imaging.

Subphase 2: 1/3/00 - 1/31/00 [Overlapping Observations] During this subphase, a coordinated campaign of science observations is planned to occur between the MSP98 Orbiter, MSP98 Lander, and MGS. The MSP98 Orbiter downlink data rate is still 9.9 kbps. During this time, Lander science receives 110 Mbits of the 160 Mbits of science data the MSP98 Orbiter can downlink each day. MSP98 Orbiter science receives the remaining downlink volume [approx 40-50 Mbits/day]. At this point, PMIRR begins observations at its standard data rate (~250 bps, including quaternions), and MARCI begins global mosaics & targeted medium-angle camera imaging.

Subphase 3: 2/1/00 - 2/29/00 [Overlapping Observations] At the start of this subphase, the MSP98 Orbiter D/L data rate drops to 5.7 kbps, and MGS begins its Relay phase. During this time, MGS becomes the primary Lander data relay path. The MSP98 Orbiter payload operates at a moderate level [approximately 70 Mbits/day], and the Lander receives whatever remains of the MSP98 Orbiter D/L data volume capacity [~20 Mbits/day] and ops resources [e.g. U/L planning]. It is requested that MGS delay its planetary protection raise maneuver until 3/1/00, to avoid any interruption in Lander support.

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LANDER SUPPORT PHASE - OVERVIEW

** This page under Change Control **

- **Duration: Nominal Landed Science Lifetime: 12/3/99 - 2/29/00**
  - Assumptions:
    - 34m DSN antennae baselined
      - Use of 70m under review - can significantly improve Orbiter data return, reduce ops complexity [no reliance on MGS in 3rd month of Lander mission]
    - 2/1/00: MGS available for Relay. M98 Orbiter transition to lower data rate occurs.
    - M98 Orbiter **commanding** support of Lander throughout
    - Orbiter payload operations and EMI caused by UHF system TBD

  » **Subphase 1: 12/3/99 - 1/2/00 [Dedicated Lander Relay Support]**
    - M98 Orbiter D/L at 9.9 kbps. M98 Orbiter supports Lander telemetry relay
    - Lander support is highest priority; receives majority of 150-160 Mbits science D/L per day
    - **PMIRR and MARCI initialization** occur during this subphase, TBD days after Lander landing.
      - Main power turned on & onboard instrument software activated
      - PMIRR also requires radiator door to be opened, cool-down interval
        - » PMIRR must be in operating mode [main power on], maneuvers must be finished, before fully opening radiator door
    - M98 Orbiter receives whatever remains in terms of D/L data volume [<10 Mbits/day], ops resources
      - Orbiter housekeeping, instrument aliveness
      - Payload operations [TBD]: Use remaining D/L for MARCI imaging

  » **Subphase 2: 1/3/00 - 1/31/00 [Overlapping Observations]**
    - Coordinated science campaign with Orbiter, Lander, MGS
    - M98 Orbiter D/L at 9.9 kbps. M98 Orbiter supports Lander telemetry relay
    - Lander receives 110 Mbits of the 160 Mbits science D/L per day
    - M98 Orbiter payload operates at reduced level - approx 40-50Mb/day
      - PMIRR begins observations at standard data rate (~250 bps)
      - MARCI begins global mosaics & targeted MA imaging

  » **Subphase 3: 2/1/00 - 2/29/00 [Overlapping Observations]**
    - M98 Orbiter D/L drops to 5.7 kbps
    - MGS supports Lander telemetry relay [MGS now in Relay phase]
    - M98 Orbiter payload operates at moderate level - approx 70 Mbits/day
    - Lander receives remainder in terms of M98 Orbiter D/L data volume [~20 Mbits/day], ops resources [e.g. U/L planning]
    - Request MGS delay PP maneuver until 3/1 [avoids interruption in Lander support]

4.7.2 Data Relay Operations

Overview: There are four cases for relay operations from the Orbiter. They are Lander Telemetry (Lander to Orbiter), Lander Telemetry (Orbiter to Earth), Lander Commands (Earth to Orbiter), and Lander Commands (Orbiter to Lander). The Lander Telemetry case sends science data back to the Earth through the UHF link. The Command case sends a command load to the Lander which goes through the Orbiter, instead of directly to the Lander via the DTE X-band link.

4.7.2.1 Lander Commanding

During each day of the Lander science mission, 8-10 Orbiter passes occur over the landing site, averaging 6 minutes per contact. Of these, 5-7 occur at solar elevations greater than 20 deg. Currently, four UHF passes are assumed to be supportable by Lander power and thermal limitations at the beginning of the Lander's surface mission, and 3 are assumed to be supportable at the end of the Lander's lifetime. Each UHF pass is a "hybrid" command/telemetry pass. The Lander is always configured to receive commands from the Orbiter at the start of each pass. Once the commands [if any are present] are sent to the Lander, the Lander is autonomously switched to transmit mode for the remainder of the pass duration.

Lander Commands (Earth to Orbiter): The command load for the Lander is double wrapped on the ground before it is sent to the Orbiter. When it arrives at the Orbiter, the Orbiter strips off the CCSDS wrapper with the Orbiter Header on it. It sees the VC 6 (virtual channel indicating it is a Lander command load) and it immediately sends it to a buffer for transmission to the Lander. Nominally, Lander commands will be sent from Earth to the Orbiter twice. The maximum size of a Lander command load x 2 is estimated to be TBD Mbits, requiring TBD minutes to uplink to the Orbiter at 125 bps.

Lander Commands (Orbiter to Lander): The command load for the Lander waits in the buffer on the Orbiter until the ground schedules a command UHF pass with the Lander. At this time the buffer is downlinked to the Lander. The downlink of the buffer is controlled by sequence. The Orbiter powers on the UHF system, sets the UHF system to transmit, and command to the CE protocol. The Reed-Solomon encoding is bypassed and the downlink data mode is set to fill. Then the downlink data mode is set to command relay. After a pre-set delay the command buffer should be empty and the downlink data mode is set to none. The length of transmission time must be set to empty the entire buffer or the buffer will be cleared. It is estimated that the maximum time required for sending a command load from the Orbiter to the Lander at 8 kbps is TBD minutes. Once the commands are sent to the Lander, the UHF mode is switched to receive Lander telemetry. The UHF system is turned off after the pass is finished.

Note: The Orbiter can only send either X-band or UHF. If the Orbiter is in the middle of a DSN contact pass, and an attempt is made to send commands to the Lander from the Orbiter [e.g. a hybrid pass occurs] the X-band link is broken. This must be accounted for in the X-band communications strategy, including potential impact to DSN SOE generation, reaquisition times, etc.

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DATA RELAY OPERATIONS - LANDER COMMANDING

- **Orbiter Passes over MSP98 Lander Site**
  - 8-10 passes, averaging 6 minutes per pass, each day [5-7 in daytime]
    - » Of these, 4 can be supported as UHF passes by Lander thermal/power constraints at start of Landed surface mission, 3 at the end of the mission.

- **Commanding Scenarios**
  - **Orbiter commanding**
    - » Each Lander UHF pass is a hybrid command/telemetry pass
      - **Hybrid:** Commands can be sent to the Lander at the start of any pass
        Autonomous switching to data relay mode, followed by data relay from Lander to Orbiter

- **Lander Commands [Earth to Orbiter]**
  - Command load for Lander double wrapped on ground
  - Upon receipt at Orbiter, commands are identified as Lander commands & sent to buffer for transmission to Lander
  - Nominally, Lander commands sent twice from Earth to the Orbiter. Maximum Lander command load x 2 = TBD Mbits, requiring TBD minutes to send to Orbiter at 125 bps.

- **Lander Commands [Orbiter to Lander]**
  - Buffer containing Lander commands waits on Orbiter until the ground schedules a command UHF pass
    - » Commanding Sequence of Events:
      - UHF system set to transmit, Reed-Solomon encoding bypassed
      - Downlink data mode set to fill, then set to command relay
      - After pre-set delay sized to empty the command buffer, the downlink data mode is set to none and UHF switched to receive Lander telemetry.
      - UHF system turned off after Lander telemetry is received.
      - Time to send the maximum command load at 8 kbps = TBD minutes
  - **Note: Orbiter cannot send data simultaneously via X-band and UHF.** Attempts to send commands to the Lander from the Orbiter during an Orbiter DSN pass will cause the Orbiter's X-band link to be broken, with potential impacts on DSN SOE generation, and usable D/L durations.

4.7.2.2 Lander Data Relay Operations

Lander Telemetry (Lander to Orbiter): The Lander telemetry sequence is straightforward. The Orbiter UHF system is powered up, and set to Receive, using the Cincinnati Electronics (CE) protocol. Once the Lander begins transmitting, the link is established automatically. Once the data are on the Orbiter it is sent off to the FIFO [first in first out] buffer where it is stored for later downlink to Earth. The Lander telemetry has previously been RS [Reed Solomon] encoded on the Lander.

Lander Telemetry (Orbiter to Earth): Once the data are in the buffer, the Orbiter must send it to the Earth. This will be done during the nominal 10-hour DSN contact. Unlike the rest of the Orbiter data, the UHF buffer is not included in any APID table and thus is not automatically sent down with the other spacecraft data. It must be specially commanded to be sent. [Note: onboard the Lander, data can be ordered in its buffer using the Lander's APID tables.] A predetermined time after the beginning of the Orbiter's DSN contact, realtime Orbiter data are sent, until the DSN locks up on the Orbiter's telemetry signal. Interleaved [realtime and stored] Orbiter data are sent next, followed by Lander relay data.

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LANDER DATA RELAY OPERATIONS

- **Lander Telemetry [Lander to Orbiter]:**
  - Lander telemetry has been Reed Solomon encoded on the Lander
  - Sequence of Events:
    - » Orbiter powers up UHF system, setting system to receive
    - » CE protocol selected
    - » Link established automatically once Lander starts transmission
    - » Data received on Orbiter stored in FIFO [first in first out] buffer for later downlink to Earth.

- **Lander Telemetry [Orbiter to Earth]:**
  - Lander data stored in buffer are sent to Earth during nominal 10 hour DSN contact
  - Downlink of Lander data must be commanded by the ground. It is not automatically sent with the other Orbiter data.
    - » UHF buffer on Orbiter is not included in an APID table.
    - » Data onboard the Lander can be ordered in its buffer using the Lander APID tables.
  - Sequence of Events:
    - » Pre-determined time after start of DSN contact, Orbiter realtime data are sent until DSN locks up on the Orbiter's telemetry signal.
    - » Orbiter interleaved [realtime and stored] data sent next
    - » Lander data sent next

4.8 MAPPING PHASE

4.8.1 Mapping/Relay Orbit

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Index Altitude and Semimajor Axis: Index altitude = 405 km. Semimajor axis = 3802.2 km.

Eccentricity is small but non-zero [mean e = 0.0083], and remains bounded.

Inclination: The inclination of the mapping orbit is chosen for a given value of semimajor axis, to maintain approximate synchrony with respect to the fictitious mean sun. For the chosen semimajor axis of 3802.2 km, the sun synchronous inclination is 92.931°. The final range of acceptable inclinations is TBD; it will depend on the range of sun and earth angles required by the flight system and science payload during the Orbiter science mission, the ΔV required to place the spacecraft in the required range of inclinations, and the sun-relative node location after Aerobraking.

Node: The initial location of the descending node at the end of aerobraking is: 4:14 AM ± 20 minutes [Open of Primary Launch Period] to 4:08 PM, ± 20 minutes [Close of Primary Launch Period], with respect to the mean sun. The evolution of the local mean solar time during the mission will depend on the chosen range of inclinations.

Argument of Periapse: Since the mapping orbit is initially frozen, the argument of periapse starts out at the South pole, and remains within a few degrees of this location over an extended period of time.

Mean Orbit Elements: The following table shows the mean orbit elements chosen for the frozen mapping orbit. Because the node of the mapping orbit at start of mapping operations is uncertain to within ±20 minutes [5 degrees], and because the duration of Aerobraking is also uncertain, the node and epoch chosen for the representative orbit elements is equal to those of the final aerobraking states in the Aerobraking Timeline, Appendix A.5.

Appendix A.6 includes plots of solar and earth geometry for an inclination of 92.93°, and a plot of altitude variation in the frozen orbit.

Orbit Maintenance: No orbit maintenance maneuvers are planned once the mapping orbit is established.

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MAPPING/RELAY ORBIT

- **Semimajor Axis:** 405 km index altitude [3802.2 km semimajor axis]
- **Frozen Orbit - Mean Elements** (Mars Mean Equator and Node of Epoch [IAU]):

	Open of Primary	Close of Primary	Comments
Epoch [ET]	12/1/1999 08:44:41	12/4/1999 17:52:34	Final aerobraking periapse epoch
Semimajor Axis	**3802.2 km**	**3802.2 km**	**405 km index altitude**
Eccentricity	**0.0083**	**0.0083**	**Planetocentric Periapse Altitude = 373.4 km** **Planetocentric Apoapse Altitude = 436.56 km**
Inclination	**92.93°**	**92.93°**	**Acceptable range TBD**
Long. of Asc. Node	**1.17°**	**1.07°**	Final aerobraking node **[DN LMST = 4:14 PM for Open, 4:08 for Close]** **Uncertainty = ±20 minutes**
Argument of Periapse	**270°**	**270°**	
Mean Anomaly	**0°**	**0°**	

- **Orbit Maintenance:** no orbit maintenance maneuvers are planned once the mapping orbit is established.

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4.8.2 Mapping Sequence of Events

Nominal mapping activities consist of two types of orbits: Non-Communication Orbits and Communication Orbits. Orbiter science data and Lander science data are collected during either orbit, but are downloaded to Earth, along with Orbiter engineering telemetry and Lander data, only during the Communication Orbits.

Orbiter Payload Activities: PMIRR data taking proceeds continuously over each orbit, including intervals of eclipse and Earth occultation. MARCI images are taken predominantly over the daylit portion of the planet. The night side may be used for MARCI data management.

Communication Orbits: Each day, five consecutive orbits during a contiguous 10 hour interval are planned for downlink of data to Earth. In order to support Lander commanding, it will in general be necessary for this 10 hour interval to be correlated with the Lander's operational "day". Because the rotation periods of Mars and Earth differ by 40 minutes, this produces a secular drift in the Earth-relative times of the 10 hour DSN contact period, during the Lander Support Phase. The 10 hour interval is not tied to Mars rotation after the end of the Lander Support Phase. A portion of the contact period is used for Orbiter commanding and radiometric tracking to support position predicts. All communications during this time are two-way coherent. Earth contact durations during each orbit are limited by Earth occultations, HGA gimbal limits, obscuration of the HGA by the spacecraft body itself, and the Orbiter energy balance. Orbiter data rates, Earth contact times, and daily data volumes are indicated in Appendix A.10

Autonomous momentum management is enabled throughout, for both Communication and non-Communication orbits. As the spacecraft enters sunlight, the solar array tracks the Sun and the HGA tracks Earth to maintain DSN contact. As the spacecraft enters eclipse, the solar array motion is stopped. During eclipse the array is rewound in preparation for re-emergence into the sunlight. The HGA continues to track the position of the Earth even during eclipse and occultation.

The sequence repeats as the spacecraft moves again into sunlight.

Transition to Non-Communication Orbit: At the end of the 10 hour DSN pass, the HGA is parked in a position which minimizes principal axis misalignment, thus reducing RCS fuel usage during mapping and relay.

Non-Communication Orbits: Seven of the twelve orbits the Orbiter experiences every day are non-communication orbits. As the spacecraft moves into sunlight, the solar array tracks the sun until eclipse, or until it enters a hardware keepout zone, at which point the solar array movement is stopped. The solar array is then unwound in preparation for exiting eclipse, at which point the sequence repeats.

Transition to Communication Orbit: At the end of the 14 hour interval of the non-communication orbits, the HGA is moved to the DSN contact attitude.

The Orbiter CPU is set to 20 Mhz throughout.

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MAPPING SEQUENCE OF EVENTS

- **Orbiter Payload Activities:**
  - **PMIRR** data taking proceeds continuously over each orbit, including intervals of eclipse and Earth occultation
  - **MARCI** images taken predominantly over the daylit portion of the planet. [Night side may be used for MARCI data management]

- **Communication Orbits:**
  - Each day, 5 consecutive orbits during a contiguous 10 hour interval are planned for downlink of data to Earth
  - To support Lander commanding this 10 hour interval must in general be correlated with the Lander's operational "day" during the Lander Support Phase.
    - » Different rotation periods of Earth and Mars leads to 40 minutes/day secular drift in 10 hour DSN contact period.
  - All communications are two-way coherent.
  - Earth contact durations during each orbit are limited by Earth occultations, HGA gimbal limits, obscuration of the HGA by the spacecraft body, Orbiter energy balance.
  - Orbiter data rates, Earth contact times, and daily data volumes are indicated in Appendix A.10
  - Autonomous momentum management enabled [Comm and non-Comm orbits]
  - **As s/c moves into sunlight:** solar array tracks the Sun, HGA tracks Earth to maintain DSN contact.
  - **As s/c enters eclipse**: solar array motion is stopped
  - **During eclipse:** solar array is rewound. HGA continues to track the position of the Earth even during eclipse and occultation.
  - The sequence repeats as the spacecraft moves again into sunlight.

- **Transition to Non-Communication Orbit:** At the end of the 10 hour DSN pass, the HGA is parked in a position which minimizes principal axis misalignment, reducing RCS fuel usage during mapping and relay.

- **Non-Communication Orbits:**
  - 7 orbits per day are non-communication orbits.
  - **As s/c moves into sunlight:** solar array tracks the sun
  - **As s/c enters eclipse:** solar array movement is stopped [also if it encounters a hardware keepout zone]
  - **During eclipse:** solar array is unwound in preparation for exiting eclipse, at which point the sequence repeats.

- **Transition to Communication Orbit:** At the end of the 14 hour interval of the non-communication orbits, the HGA is moved to DSN contact attitude.

- **CPU setting:** 20 Mhz throughout.

4.8.3 Mapping Orbit Navigation

Mapping Orbit Prediction Capabilities: Preliminary estimates of orbit prediction capabilities during Mapping are summarized in Appendix A.11. The dominant influence on the accuracy of downtrack orbit prediction is atmospheric density uncertainty at orbital altitudes. Because the Lander Support Phase and the start of Mapping occur at a time in the solar cycle of high flux, and near Mars perihelion, density at the mapping altitude is at its highest during this time, yielding the worst prediction capabilities for the mission. Position prediction requirements during the Lander Support Phase are those needed for adequate prediction of UHF passes. Position prediction accuracies required by the Orbiter science payload will be accommodated on a best efforts basis during the Lander Support Phase. Prediction requirements for Mapping are listed in the Project Policies, Requirements, and Capabilities Document.

Ranging may not be needed during the Mapping Phase.

Mapping Orbit Prediction Frequency Profile [TBD]: Based on preliminary estimates of prediction accuracies required to satisfy payload needs, navigation updates will be required at least weekly during the Lander Support Phase, and during the early portion of the Mapping Phase, until approximately 6/19/00. From 6/19/00 through 5/6/01 predictions every 2 weeks are required. From 5/6/01 through end of mapping, weekly or more frequent predictions will again be required as Mars nears perihelion again.

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MAPPING ORBIT NAVIGATION

- Preliminary position prediction capabilities shown in Appendix A.11
- Lander Support and start of Mapping phases occur at highest density during mission [high solar flux, perihelion]
  - Worst prediction capability during mission
- **Lander Support Phase:**
  - Prediction needs based on UHF pass support.
  - Position prediction required by Orbiter science payload accommodated on best efforts basis
- **Mapping Phase:** prediction requirements listed in PPRDC
- **Position Prediction Frequency Profile [TBD]:**
  - At least weekly during the Lander Support Phase and until 6/19/00 during Mapping.
  - Every 2 weeks from 6/19/00 through 5/6/01.
  - Weekly from 5/6/01 through end of Mapping.
- Ranging may not be needed during the mapping phase.

4.8.4 MARCI Science Campaigns

Two MARCI science campaigns are planned to occur when the True Solar Time at the descending node is at its earliest, enabling the best multispectral imaging during the mission. During these intervals, 70m support is requested to increase data return.

MARCI Science Campaign #1: The first MARCI Science Campaign occurs in March/April 2000. At this point, the True Solar Time is approximately 3:25 PM and the data rate using the 70m antenna is 9.9 kbps [5.7 kbps on the 34m]. Earth range is approximately 2.3 AU. 70m support during this campaign accommodates downlink only. Uplink support still requires use of the 34m antennae. Duration of this campaign is approximately 10 days, from 3/26/99 - 4/4/99.

MARCI Science Campaign #2: The second MARCI Science Campaign occurs in December/January 2002, at the very end of the MSP98 Orbiter mapping mission, during another period of low True Solar Time. The Earth is closer to Mars [1.4-1.6 AU] than it is during the first science campaign, yielding a 33.2 kbps data rate on the 70m [9.9 kbps on 34m]. Also, by this time, uplink capability is scheduled to be available on the 70m subnet, eliminating the need for dual 34m/70m coverage to support both uplink and downlink. This science campaign occupies the final 30 days of the Mapping mission, from 12/18/01 - 1/16/02. True solar time varies between 3:28 and 3:39 PM for launch at the open of the Primary launch period.

The following graphic illustrates the relationship between data rate, local true solar time of the descending node [LTST], and earth range during the mapping mission.

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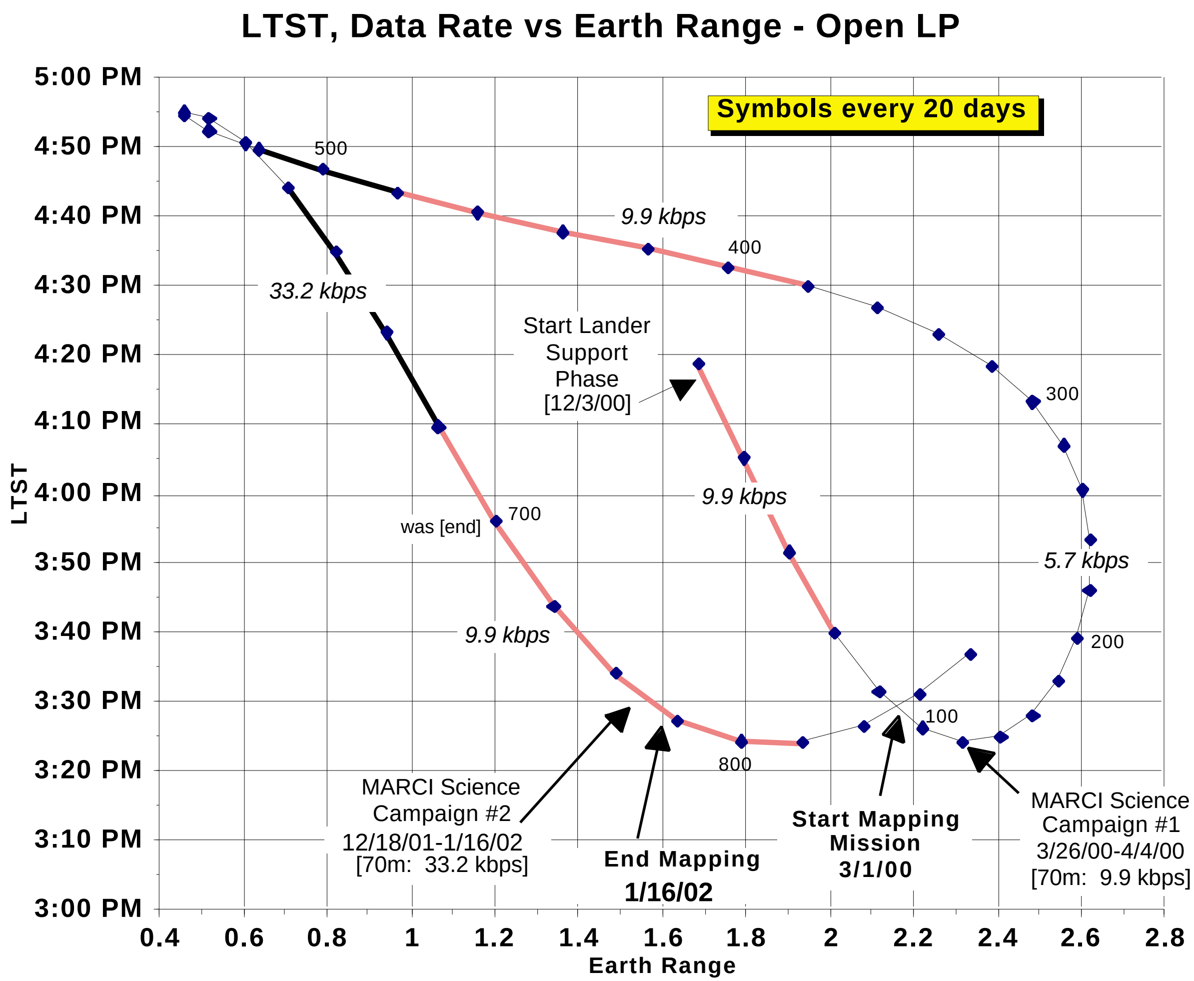
MARCI SCIENCE CAMPAIGNS

- Planned for lowest True Solar Time at descending node [better multispectral imaging]
- 70m support requested [increased data return.

- **MARCI Science Campaign #1: 3/26/99 - 4/4/99 [10 days]**
  - True Solar Time = 3:25 PM
  - Earth range = 2.3 AU
  - **70m data rate = 9.9 kbps**
    - » 34m data rate = 5.7 kbps
  - 70m supports D/L only. 34m required for uplink.

- **MARCI Science Campaign #2: 12/18/01 - 1/16/02 [30 days]**
  - Final 30 days of Mapping
  - True solar time = 3:28 - 3:39 PM [Open of Primary]
  - Earth range = 1.4-1.6 AU
  - **70m data rate = 33.2 kbps**
    - » 34m data rate = 9.9 kbps
  - Uplink now available on 70m.



4.9 RELAY PHASE

4.9.1 Overview

The Relay phase starts with the termination of mapping operations and continues for approximately three Earth years, terminating approximately 5 Earth years after the transfer to map orbit. [Note: this is an estimate of the likely usable lifetime for the Orbiter. Propellant loading is based on contractual requirements to maintain orbit attitude control and spacecraft operability for a total of 3 Earth years from the start of Mapping.] During this interval, the Orbiter acts primarily as a command and data relay asset for other landed surface stations, as needed.

4.9.2 End-of-Mission Planetary Protection Activities

In accordance with the provisions of the Planetary Protection Plan [3-2001] and related documents, the Project must demonstrate the ability to satisfy the following impact probabilities for the Orbiter, assuming no special bioburden control is effected:

> The probability of entry into the martian atmosphere shall not exceed the following levels for the specified time periods: 1% for the first 20 years from date of launch, 5% for the period of 20 to 50 years from date of launch.

The MGS Project has determined that, in order to satisfy these requirements, MGS shall be raised to an index altitude of 427 km at the end of its mapping phase. Equivalent altitudes for the MSP98 Orbiter range from approximately 396-449 km, depending on the drag factor at which the uncontrolled Orbiter would stabilize. Because the baseline index altitude of 405 km for the mapping orbit lies between these extremes, some action at the end of the Relay phase may be required to satisfy planetary protection. If sufficient propellant is available at end of mission, the spacecraft will be placed into a circular orbit at a higher altitude. [Note: this requires a maneuver of approximately 19 m/s. Feasibility and/or max size of maneuver after HGA deployment is TBD.]Approximately 3.5 kg of Hydrazine is required to place the Orbiter into a circular orbit at 449 km; the probability that this amount of propellant will be available three years after transfer to the map orbit is approxmately 97%. If, however, no end-of-mission propellant remains for translational maneuvers, the Orbiter may be reconfigured and/or turned to present a smaller drag area for increasing orbit lifetime. Options include: turning to a passively stable low-drag attitude, “feathering” the solar array, and deliberately tumbling the spacecraft.

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RELAY PHASE

- **Overview**

  - Begins with termination of mapping operations, terminates ~5 Earth years after start of Mapping
    - » Note: propellant loading based on 3 Earth years operability from start of Mapping
  - Primary Orbiter mission is command and data relay support for Mars landers, as needed.

- **End-of-Mission Planetary Protection Activities**

  - Planetary Protection Plan [3-2001] requirements: probability of entry into the martian atmosphere ≤ 1% for the first 20 years from date of launch, ≤ 5% for the period of 20 to 50 years from date of launch.

  - MGS Planetary Protection altitude = 427 km
    - Equivalent altitudes for MSP98 Orbiter: 396 km [lowest drag area] - 449 km [highest drag area]

  - **At End of Relay - Only Phase:**
    - If sufficient propellant is available, Orbiter is placed into a higher altitude orbit
      - 3.5 kg required to place Orbiter into 449 km circular orbit. The probability that this amount of propellant will be available 3 years after transfer to map orbit, is approximately 97%.
      - Requires 19 m/s w/ deployed HGA. Feasibility &/or max size of maneuver after HGA deployment TBD.
    - If no propellant available for translational maneuver, Orbiter may be reconfigured and/or turned to present a smaller drag area for increasing orbit lifetime. Options include:
      - Turn to passively stable low-drag attitude
      - "Feather" solar arrays
      - Deliberate tumbling of s/c

4.10 ORBITER DESIGN REFERENCE MISSIONS

4.10.1 Overview and Assumptions

** This page under Change Control **

Design Reference Missions have been developed for the Orbiter, to measure mission and spacecraft performance during critical or stressing situations, and assess effects of changes in the sequence of events. These scenarios are:

DRM #1: MSP98 Lander Relay Support Phase
DRM #2: Mars Aphelion
DRM #3: Minimum Earth-Mars Distance

Orbit Geometry: It is assumed that Aerobraking operations place the orbit node at its nominal expected position with respect to the sun [i.e. descending node at 4:14 PM for the open of the Primary Launch Period, and 4:08 PM at the end of Primary].

Payload Operations: MARCI runs continuously at 4 Watts per camera (8 Watts total). PMIRR runs continuously at 40.4 watts plus 4.1 watts for auxiliary power at aphelion.

Communications, CPU utilization: Five comm orbits and 7 non-comm orbits are baselined per day, consistent with the 10 hours per day allocated for contact with Earth. Use of 34m HEF dishes is assumed. The spacecraft operates at 20 MHz throughout. During non-comm intervals, 3 MHz is allocated to science payload operations. Science payload CPU allocations during a DSN contact (i.e. during actual transmit times) are: 2.8 MHz at 9.9 kbps, 2.5 MHz at 33 kbps, and 1.7 MHz at 110 kbps. The remainder of the 20 MHz must accommodate all spacecraft bus operations and 25% system margin.

Bus Data Management: Maximum data transfer rate across the RS-422 is 1 Mbit/sec. The processor utilization for obtaining this rate is allocated against science; it is not in the spacecraft portion of the budget. DRAM buffer size for MARCI data is as per the MARCI ICD (330 Mbits work space, 512 Kbytes software, 24 Kbytes DSP init, etc.). DRAM buffer size for PMIRR data is as per the PMIRR ICD (small compared to MARCI).

Orbiter Data Volume estimates are contained in the file "orbitermapdatavol_revA1.97" on the MSP collaborative server in LMA Distributed/System Engineering and Integration/System Tools/. [See Also Appendix A.10]. Science data volume indicated on these files is for science data plus science packet overhead. Engineering data, RS encoding, CCSDS frame and transfer overhead have been removed from these estimates. Science packet overhead is dependent on the length of the science packets. [E.g. if each science packet is 11 bytes then the overhead is 100% since the telemetry packet overhead is 11 bytes. If the science data packets are 1000 bytes long then the overhead is 1.1%.] DSN lockup time and some margin for modeling uncertainty have also been removed. Some additional system margin has been withheld at Mars Aphelion to support potential variations to the power budget.

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ORBITER DESIGN REFERENCE MISSIONS - Overview and Assumptions

- **Purpose:** Design Reference Missions measure mission and spacecraft performance during critical or stressing situations, and assess effects of changes in the sequence of events.

- **Scenarios:DRM #1: MSP98 Lander Relay Support Phase**
  DRM #2: Mars Aphelion
  DRM #3: Minimum Earth-Mars Distance

- **Orbit Geometry:** nominal post-aerobraking descending node: 4:14 PM [open Primary Launch Period], 4:08 PM [end of Primary].

- **Payload Operations:**
  - MARCI runs continuously, 4 Watts per camera (8 Watts total).
  - PMIRR runs continuously, 40.4 watts plus 4.1 watts for auxiliary power at aphelion.

- **Communications, CPU utilization, Margins:**
  - 5 Five comm orbits, 7 non-comm orbits per day, using 34m HEF antennae.
  - S/c operates at 20 MHz throughout.
  - Science CPU allocations:
    - » Non-comm intervals: 3 MHz allocated to science payload.
    - » Comm intervals [during actual transmit times]: 2.8 MHz at 9.9 kbps, 2.5 MHz at 33 kbps, and 1.7 MHz at 110 kbps. Remainder must accommodate spacecraft bus operations & 25% system margin.

- **Bus Data Management:**
  - Maximum data transfer rate across the RS-422 = 1 Mbit/sec. [Processor utilization for obtaining this rate is allocated against science; it is not in the spacecraft portion of the budget.]
  - MARCI: DRAM buffer size per MARCI ICD (330 Mbits work space, 512 Kbytes software, 24 Kbytes DSP init, etc.).
  - PMIRR: DRAM buffer size per PMIRR ICD

- **Orbiter Data Volume estimates: see Appendix A.10**
  - Science data volume is for science data plus science packet overhead.
    - » Engineering data, RS encoding, CCSDS frame and transfer overheads, DSN lockup time, & margins for modeling uncertainty have been removed.
    - » Aphelion only: additional system margin withheld to accommodate potential variations to the power budget.
  - Science packet overhead dependent on length of the science packets.

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4.10.2 Orbiter Design Reference Mission #1 - Lander Support Phase

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Orbiter Design Reference Mission #1 consists of 3 cases, appropriate for stressing conditions during each of the 3 major subphases of the Lander Support Phase [See Section 4.7 - Lander Support Phase].

Case 1.a [Suphase 1]: During this subphase, the majority of the science D/L capability of the Orbiter is assigned to Lander data relay. Remaining D/L capability is available for Orbiter housekeeping, instrument aliveness tests, and payload operations. The comm time per obit is approximately 63 minutes, at 9.9 kbps. Daily data volume [not including packet overhead or X-band pass interruptions due to lander commanding via UHF] = 160 Mbits. Maximum eclipse duration during this subphase is approximately 31 minutes. It is assumed that the Orbiter supports 4 UHF passes of the Lander per Lander day.

Case 1.b [Subphase 2]: During this interval, the Lander receives approximately 110 Mbits of the total D/L volume. PMIRR and MARCI operate at a reduced level [approximately 40 Mbits/day]. The comm time per obit is approximately 67 minutes, at 9.9 kbps. Daily data volume [not including packet overhead or X-band pass interruptions due to lander commanding via UHF] = 163 Mbits. Maximum eclipse duration during this subphase is approximately 32-33 minutes. It is assumed that the Orbiter supports 4 UHF passes of the Lander per Lander day.

Case 1.c [Subphase 3]: During this subphase, eclipse time is approximately 32 minutes per orbit for the open of the Primary launch period, and 33 minutes at the close of the Primary launch period. True solar time of the descending node is 3:28 p.m. for open of Primary, and 3:20 at the close of Primary. The communications time per orbit is approximately 65 minutes at 5.7 kbps. Total Science data volume returned by the Orbiter (not including packet overhead) is 90 Mbits per day, of which approximately 70 Mbits/day are allocated to Orbiter science. One daily UHF communication with the Lander is allocated for the MSP98 Orbiter during this time, primarily for the purpose of commanding the Lander. Although some telemetry from the Lander to the Orbiter may be sent up during this pass, the primary data relay path during this time is the MGS orbiter. There is some additional overhead on total data volume returned each day because of the interruption to the X-band pass on the Orbiter during the UHF contact with the Lander.

The CPU processor utilization for science is limited to 3 MHz for non comm periods [i.e. whenever the X-band transmitter is not powered on, approximately 57 minutes per orbit]. CPU processor utilization for science is limited to 2.8 Mhz for comm periods [63 minutes per orbit].

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ORBITER DESIGN REFERENCE MISSION #1 - LANDER SUPPORT PHASE

Timeline To Be Supplied

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4.10.3 Orbiter Design Reference Mission #2 - Mars Aphelion

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The Mars Aphelion Design Reference Mission examines Orbiter operations at aphelion [11/3/2000] a time of reduced power output. Eclipse time is approximately 21 minutes per orbit at open of the Primary launch period and 23 min. at close of Primary. True solar time of the descending node is 4:23 PM at the open of Primary, and 4:16 at the close of Primary. The communication time per orbit is approximately 42 minutes @ 5.7 kbps. The total Science data volume per day (not including packet overhead) is about 57 Mbits. CPU processor utilization for science is limited to 3 MHz for non comm periods and 2.8 MHz for comm periods.

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ORBITER DESIGN REFERENCE MISSION #2 - MARS APHELION

Timeline To Be Supplied

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4.10.4 Orbiter Design Reference Mission #3 - Minimum Earth-Mars Distance

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The Minimum Earth-Mars Distance Design Reference Mission examines Orbiter operations at 6/22/2001. It is assumed that the Orbiter operates at its maximum data rate of 110 kbps. At this point in the mission the orbiter is in constant sunlight, but the solar arrays are off-sun approximately 10 minutes per orbit while the panel unwinds. Thermal limits on the SSPA limit the communications interval to 75 minutes per orbit. True solar time of the descending node is approximately 4:54 p.m. for launch at the open of the Primary launch period, and 4:47 p.m. at close of Primary. Total Science data volume per day (not including packet overhead) is approximately 2090 Mbits. CPU processor utilization for science is limited to 3 MHz for non comm periods and 1.7 MHz for comm periods.

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ORBITER DESIGN REFERENCE MISSION #3 - MINIMUM EARTH-MARS DISTANCE

Timeline To Be Supplied

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