MARS SAMPLE RETURN - LAUNCH AND DETECTION STRATEGIES FOR ORBITAL RENDEZVOUS

Ryan C. Woolley, Richard L. Mattingly, Joseph E. Riedel, and Erick J. Sturm

Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109

This study sets forth conceptual mission design strategies for the ascent and rendezvous phase of the proposed NASA/ESA joint Mars Sample Return Campaign. The current notional mission architecture calls for the launch of an acquisition/cache rover in 2018, an orbiter with an Earth return vehicle in 2022, and a fetch rover and ascent vehicle in 2024. Strategies are presented to launch the sample into a coplanar orbit with the Orbiter which facilitate robust optical detection, orbit determination, and rendezvous. Repeating ground track orbits exist at 457 and 572 km which provide multiple launch opportunities with similar geometries for detection and rendezvous.

INTRODUCTION

Potential Mars Sample Return (MSR) architectures have been studied for decades. Scenarios range from single-launch, direct-entry, direct-return missions, to multiple-launch, multi-element campaigns spanning many opportunities and requiring multiple rendezvous. In light of recent budgetary constraints and the desire for international cooperation, a three-mission MSR campaign has been proposed as a joint venture between NASA and ESA. The current notional mission architecture, depicted by Figure 1, calls for an acquisition/cache rover in 2018, an Orbiter with an Earth return vehicle in 2022, and a fetch rover and ascent vehicle in 2024.

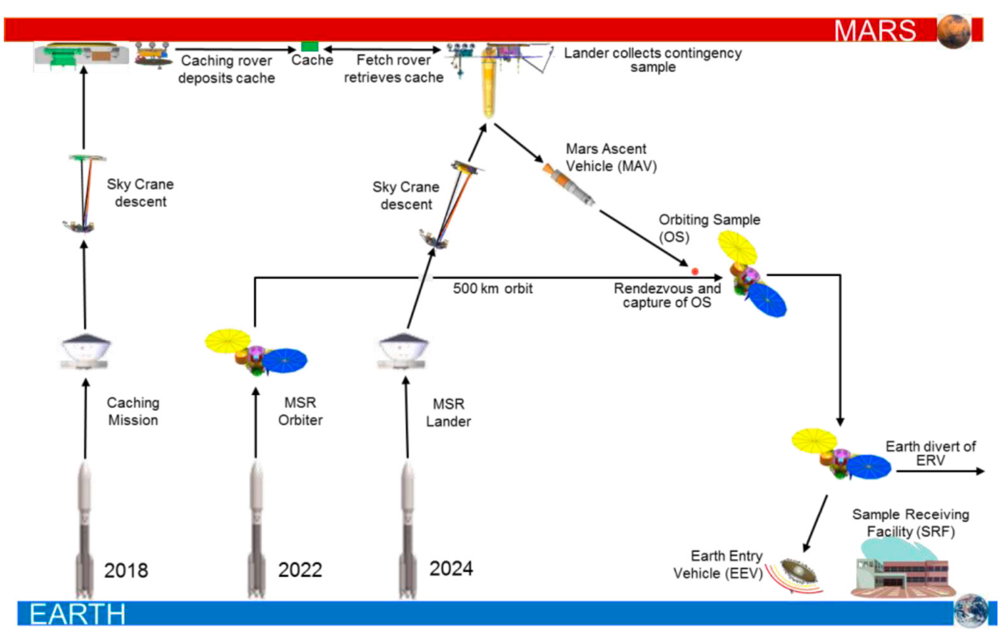

Figure 1 Conceptual Mars Sample Return campaign.

A critical element to this proposed architecture is the successful launch, detection, and rendezvous of the orbiting sample (OS). A feasibility study was conducted with a notional set of assumptions and requirements to develop a proof-of-concept and to determine the feasibility of optical detection. The notional set of assumptions for this study includes:

- The Orbiter is in a circular, 45° inclined orbit.
- The Mars Ascent Vehicle (MAV) shall have the capability to launch the OS to a circular orbit with an altitude between 400 – 600 km with an accuracy of +/-50 km.
- The launch shall occur between 9am and 3pm local solar time (LST), due to thermal constraints on the MAV.
- The Orbiter shall be available (clear Line-of-Sight, LOS) for critical event telemetry coverage during MAV launch through OS separation.
- The Orbiter shall provide at least 4 opportunities to launch over a 7-day period which also satisfy the previous two requirements.
- The Orbiter shall have the ability to detect the OS optically and to determine its orbit.
- The optical telescope is limited to searching in the forward, down-track direction only.

There are two key drivers that distinguish the current launch geometry design from those that have been done in the past. The first is the requirement that the Orbiter be available for critical event coverage. This would require that the Orbiter have LOS visibility during MAV launch, thus restricting launch timing and driving the launch opportunity strategy. The second driver would be that the MAV is launching into a coplanar orbit with the Orbiter with a small down-track separation so as to aid in optical detection and orbit determination (OD) of the OS. The combination of these two factors would place much larger restrictions on launch strategy than have been needed in past mission designs.

STUDY METHODS

The nominal mission timeline was broken into six phases between the lander's entry, descent, and landing (EDL) and the Orbiter's trans-Earth injection (TEI): surface operations/orbiter relay, MAV launch period, preliminary rendezvous (detection and OD), intermediate rendezvous (orbit matching), terminal rendezvous, and TEI phasing. This study focuses on mission design constraints to meet the notional requirements (set forth above) during MAV launch and preliminary rendezvous.

Sample Return Orbiter Orbit Selection

In order to facilitate optical detection and rendezvous with the OS, it would be desirable to launch the MAV into a nearly coplanar orbit with the Orbiter. Coplanar launch opportunities occur twice daily (one ascending and one descending) as the MAV launch site would pass through the orbit plane. However, these launch opportunities occur at varying local times and with the Orbiter in varying positions (true anomaly) within the orbit. Since launch is notionally required to occur during daylight hours (9am-3pm) with the Orbiter visible, the majority of these launch opportunities must be ruled out. Providing multiple launch opportunities (four in seven days) with suitable launch geometries would require that the Orbiter be placed in a ground track repeating (GTR) orbit.

Table 1 Ground-Track Repeat orbits at Mars between 400-600 km (i = 45º).

Altitude (km)	Repeat (sols)	Orbits to Repeat	Grid Sep. (deg)	Actual Repeat (sols)	Sun Cycle (sols)	ΔLST/ Repeat (hrs)
401.7	4	49	7.35	3.91	44.90	-2.09
412.5	5	61	5.90	4.89	45.34	-2.59
419.8	6	73	4.93	5.87	45.64	-3.09
425.0	7	85	4.24	6.85	45.85	-3.59
456.6	**1**	**12**	**30.00**	**0.98**	**47.14**	**-0.50**
488.9	7	83	4.34	6.86	48.45	-3.40
494.3	6	71	5.07	5.88	48.67	-2.90
501.9	5	59	6.10	4.90	48.98	-2.40
513.4	**4**	**47**	**7.66**	**3.92**	**49.45**	**-1.90**
521.7	7	82	4.39	6.86	49.78	-3.31
532.8	**3**	**35**	**10.29**	**2.94**	**50.24**	**-1.41**
548.5	5	58	6.21	4.90	50.87	-2.31
555.2	7	81	4.44	6.87	51.15	-3.22
572.2	**2**	**23**	**15.65**	**1.96**	**51.84**	**-0.91**
589.4	7	80	4.50	6.87	52.54	-3.14
596.3	5	57	6.32	4.91	52.82	-2.23

Table 1 lists the possible GTR orbits between 400 and 600 km at 45º that repeat in 7 sols or less. Attractive orbits exist at 457 km and 572 km with 1- and 2-sol repeats, respectively. Due to the precession of the orbit plane with respect to the sun, the LST of the ascending node decreases by about 30 minutes per sol. This means that for a 2-day GTR, successive launch opportunities may occur at 3pm, ~2pm, ~1pm, and so on, spaced at two-sol intervals. This gives up to 7 launch attempts over 12 days with similar geometries and meeting the notional requirements. Figure 2 shows the progression of launch opportunities for a 572 km orbit with the LST's given for each launch azimuth (ascending or descending). If the MAV is unable to launch during the north-east (NE) launch period, but is capable of launching to either azimuth, it must wait another ~12 days for the south-east (SE) launch period to open, where 7 more opportunities exist. This also presupposes that the Orbiter's node may need to be adjusted slightly between periods in order to preserve the desired launch geometry.

Figure 2 Launch window sequence for an Orbiter in a 2-sol GTR orbit. Each arrow represents an opportunity to launch with the specified geometry. The yellow boxes limit the launches to 9am - 3pm LST.

Mars Ascent Vehicle Launch Geometry

A nominal two-stage MAV ascent to orbit would take around 12 minutes and travel about 1000 km downrange. During this time the Orbiter would travel about 2300 km in its orbit. This means that the MAV must launch when the Orbiter is no higher than 10-15º above the horizon if the OS is to remain ahead of the Orbiter. Since the Orbiter would have forward-facing cameras, it would be necessary to place the OS into an orbit at or below the altitude of the Orbiter. Recall that the notional MAV for this study would have injection errors of +/- 50 km, which means that a nominal orbit 50 km below that of the Orbiter's should be targeted to ensure that the OS does not drift behind the camera's FOV.

Figure 3, below, shows the relative launch geometry for an orbiter at 572 km with the OS being injected into a 522 km orbit. When the Orbiter reaches 10º above the horizon, a signal would be sent giving a launch confirmation command. Thirty seconds later, the MAV would lift off in an optimized 2-burn launch profile. Almost 12 minutes later the OS would separate from the MAV 270 km in front of the observing orbiter. The targeted offset in semimajor axes of 50 km would ensure that the OS will drift away from the Orbiter at a nominal rate of ~500 km per orbit. If the OS reaches the highest end of the dispersion range, equal to the Orbiter's altitude, it would remain "stationary" in front of the Orbiter. If it is sent to the low end of the dispersion range, 100 km below, it would move away at ~1000 km per orbit.

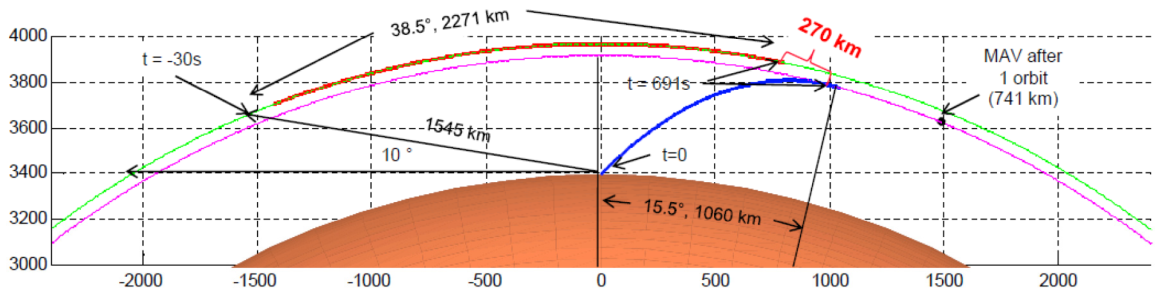

Figure 3 Projected launch geometry for a MAV injecting the OS into a 522 km circular orbit and the Orbiter at 572 km. Launch would occur when the Orbiter is 10º above the horizon, +30 seconds.

Detection and Orbit Determination

For this study a notional optical telescope was chosen with a 5º x 5º FOV. A mosaicking pattern with 5-10 second exposure times would be necessary to image the region where the OS is to be located. Detailed simulations were performed to demonstrate the robustness of optical detection techniques under specified conditions. Plots of estimated signal-to-noise ratios (SNR) versus time were created over a large range of varying conditions in order to show that sufficient observations of the OS would be acquired before the OS is occulted by the limb of Mars. This occurs nominally in 17 hours and as fast as 8 hours for the lowest-orbit case.

RESULTS

Figure 4 shows the SNR function vs. time for the nominal case. Each segment of the plot represents the portion of the orbit where the OS would be illuminated by the sun. The OS would get brighter as the phase angle increases. Near maximum illumination the Orbiter would follow the OS into eclipse. The peak SNR of each orbit would gradually decrease as the OS drifts away. At approximately 4000 km the OS would be occulted by Mars and the Orbiter must wait 3 days for the OS to emerge from the other side. Of course, this time scale would vary as the OS is placed in different orbits throughout the MAV dispersion range.

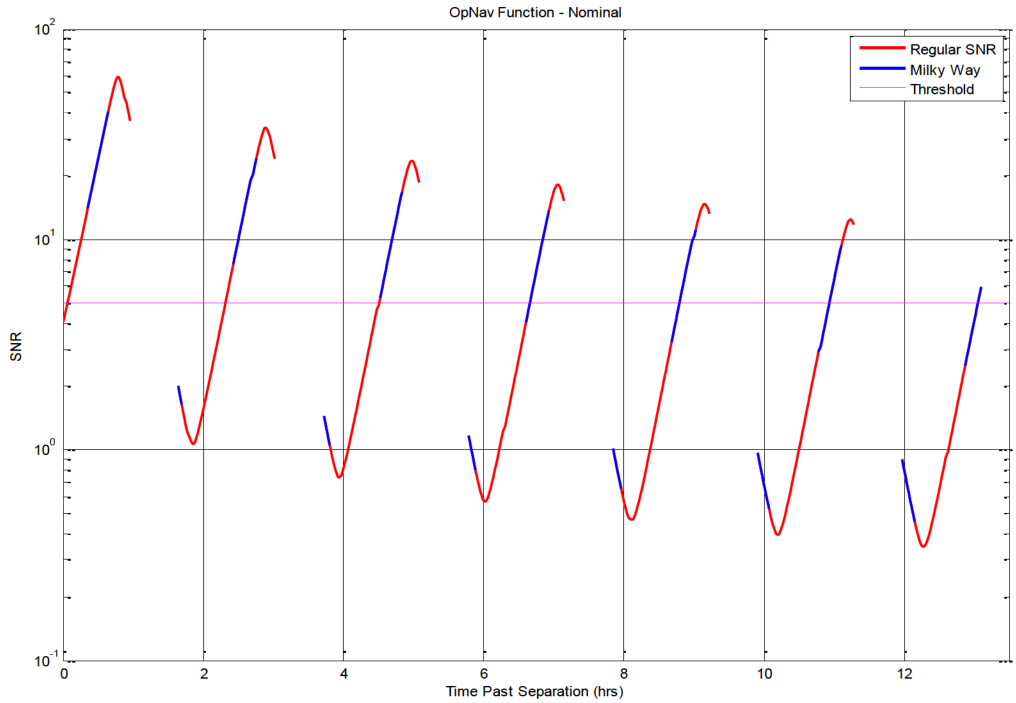

Figure 4 Signal-to-Noise ratio vs. time for the Orbiter tracking the OS. T = 0 corresponds to OS orbit injection. Each segment represents the illuminated part of one orbit. The sequence ends when the OS is occulted by the limb of Mars.

Some of the conditions that were varied in this study include: Orbiter altitude, OS altitude, initial separation range at injection, launch latitude, LST of launch, Mars L_s (season) at launch, and launch azimuth. Hundreds of permutations of these parameters were simulated in order to characterize the trade space and to identify best and worst case scenarios for optical detection. Under the assumptions and ranges set forth in this study, it was found that optical detection and orbit determination would be a viable option for the proposed Mars Sample Return campaign.

ACKNOWLEDGMENT

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.