MARS ORBITER MISSION DESIGN AND ANALYSIS

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Abstract

Mars orbiter mission (MOM) is India's first interplanetary mission. MOM was planned to be launched by PSLV into an Earth elliptic parking orbit (EPO) in Oct-Nov 2013 utilizing the 2013 opportunity to rendezvous with Mars. This paper covers the mission design and analysis carried out for the MOM/PSLV mission. MOM mission scenario is unique, involving transfer of the spacecraft from earth parking orbit phase to Mars transfer trajectory phase in several perigee burns using the main 440 N liquid engine and after nearly ten months of interplanetary cruise, Mars orbit insertion (MOI) employing the same engine. New software tools were designed and developed to design interplanetary trajectories, to generate total impulsive maneuver strategy from earth EPO to target Martian orbit, to generate operational finite maneuver plans, to design trajectory correction maneuvers in interplanetary cruise phase targeting to desired B-plane parameters and to design Mars orbit insertion maneuver. The launch opportunities were studied, the launch period was identified in Oct-Nov 2013 and the launch window and optimum EPO requirements were generated for each launch date in the launch period and provided to PSLV. The target Martian orbit was selected as a retrograde orbit of size 500 x 80000 km, with 151 deg inclination, right ascension of ascending node of 61 deg and argument of perigee of 206 deg in Mars IAU frame of reference, after detailed analysis of various Martian orbits covering the full range of achievable inclinations, considering all the specified s/c platform and payload constraints. Maneuver strategies were designed to transfer the s/c from earth EPO to cruise phase, to perform a deterministic trajectory correction maneuver (TCM#1) in cruise phase to achieve desired Martial arrival conditions and finally to capture into desired target Martian orbit, considering operational constraints. The major constraints considered in maneuver design were:- to minimize total mission delta-V; ensure ground station network visibility for each Liquid Engine Burn (LEB) to the possible extent; ensure perigee stability in Earth orbiting phase considering all perturbative forces; limit number of passes through radiation belts in Earth phase; MOI in common visibility of two JPL DSN stations of Goldstone and Canberra; de-conflict MOM MOI with NASA's MAVEN MOI time. Finite maneuver simulations were carried out for each burn and the attitude steering profiles analyzed for each burn. Total mission profiles were studied comprising ground station visibilities, eclipse predictions in Earth and Martian orbit phases and occult of Earth-satellite line of sight by Mars in Martian phase. The variation of the earth-satellite-sun angle, satellite-sun distance and solar intensity factor, satellite-earth distance and signal round trip time were all studied and results were provided to Project, Power, Communications and Thermal sub-system designers for their studies and for finalizing the s/c configuration. Non-nominal mission scenarios were studied, comprising worst case launcher dispersions, missing any of the earth phase burns including Trans-Mars Injection (TMI) burn and backup maneuver plans generated. A detailed propellant budget was generated. MOM was launched on 2013 Nov 5 at the time specified by the launch window into the expected EPO. MOM was injected into Mars transfer trajectory on 2013 Nov 30 after a series of seven perigee burns. Three TCM's were carried out on 2013 Dec 11, 2014 Jun 11 and 2014 Sep 22, to precisely achieve the desired arrival conditions. The first two TCM's were executed with eight

and four 22 N engines respectively. During the cruise phase, Propulsion team specified that the main 440 N Liquid Engine will have to be operated in blow down mode as they had found that pressure regulation would not be possible after the long cruise period of nearly ten months. The final TCM was executed with the main engine with the purpose of testing its performance before MOI. It was decided to augment the main engine with eight 22 N engines operating in off-modulation mode and this was called MOI operation Plan A. MOI simulations were carried out considering blow down and augmented mode of operation of the main engine and 8 22 N engines, using thrust and mass flow performance prediction data provided by Propulsion team and effect of performance deviations was analyzed. Analysis was carried out on stability of capture orbits with different apoapsis altitudes and the minimum stable capture apoapsis altitude and associated delta-V required to be imparted was worked out. MOI analysis was also carried out considering various non-nominal arrival periapsis altitudes. The nominal Plan A MOI execution commands sequence was uploaded to the spacecraft ten days before MOI assuming nominal performance of the final TCM which was scheduled 41 hours before MOI. Contingency maneuver design studies were done to correct for effects of unplanned thruster firings due to any s/c contingency occurring after MOI sequence uplink. In preparation for a contingency case of failure of the main engine, MOI design and analysis was done considering only the eight 22 N engines in blow down mode of operation, which was called MOI operation Plan B. MOI strategy for Plan B was finalized after optimizing the burn arc to get maximum energy change for the delta-V imparted and propellant spent, maintaining the minimum altitude during the burn above 150 km. Some interesting closed orbits with varying stability were found to be achievable for this case. To everyone's delight, the main engine performed flawlessly when it was fired for nearly 4 seconds for the final TCM at 9 UT on 2014 Sep 22. Mars orbit insertion was executed as per the uploaded sequence around 2 UT on 2014 Sep 24 and MOM was captured into the desired Martian orbit with periapsis altitude of 419 km, apoapsis altitude of 76872 km and inclination of 150 deg, achieving the main technological objective of the mission in India's first interplanetary endeavor.