Mission Design and Navigation Analysis of the ESA ExoMars program

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Keywords: *ExoMars, Mission Design, Navigation, Planetary Protection*

ABSTRACT

This paper presents the mission design and the navigation analysis for the 2016 and 2018 missions of the ExoMars program. Both missions are conducted jointly by the European Space Agency ESA and the Russian Space Agency Roscosmos. The significantly different mission objectives are reflected in equally significant differences in the mission design.

The ExoMars 2016 mission comprises a large Mars orbiter and a landing craft. The orbiter is called “Trace Gas Orbiter” (TGO) and carries scientific instrumentation for the detection of trace gases in the Martian atmosphere and for other atmospheric and surface science. The landing craft is called “Entry, Descent and Landing Demonstrator Module” (EDM). Its mission is to demonstrate and evaluate European Mars landing technology. The 2018 mission will deliver a surface platform and a mobile rover to the Martian surface. The rover’s task is to perform surface science including the search for traces of extant or former life.

The design of the 2016 mission is optimised to deliver the TGO with a defined dry mass into a low circular Mars orbit with an inclination of 74 deg inclination. The TGO will carry the EDM on the interplanetary transfer and deploy it during Mars approach for a landing in Meridiani Planum. The spacecraft composite will be launched and placed into an Earth escape trajectory by a Proton M/Breeze M launcher provided by Russia. A large Deep Space Manoeuvre (DSM) is performed during the 9-month transfer.

Release of the EDM will take place 3 days before the Mars arrival in October 2016. After EDM release the TGO will perform a deflection manoeuvre to prevent the TGO from also entering the atmosphere. During Mars Orbit Insertion (MOI), the TGO is foreseen to receive and store data transmitted via UHF radio signal by the EDM during entry, descent and landing (EDL). This constrains the inclination of the TGO’s highly eccentric insertion orbit, requiring an inclination change manoeuvre (ICM) at the first apoares. A further manoeuvre reduces the orbit period to around 1 sol, from where aerobraking is employed to reach the low target orbit.

The 2016 mission launch window optimization takes into account the entire series of manoeuvres from launcher separation until the start of aerobraking. The transfer resulting from launch on each date of the 21-day launch window is optimised individually; the window is placed such that the available delivered mass is maximized for the worst case. The same arrival date is assumed for every all days in the launch window to facilitate the planning of ground segment resources and operations.

Compared to the 2016 mission, the 2018 interplanetary transfer is simpler. No major manoeuvre is required after escape. Deployment of the descent module takes place from hyperbolic approach. The launch window also spans 21 days and the delivery mass is also maximised.

The paper gives details on the optimization of the launch period for both missions.

Navigation analysis is performed for both the 2016 and 2018 missions. The main challenge of the interplanetary navigation is to deliver entry craft (2016: EDM, 2018 descent module) to the defined atmospheric entry interface points sufficiently accurately to ensure that landing on the surface takes place within the required uncertainty ellipse. The driving parameter is the entry corridor, expressed via the entry flight path angle dispersion.

Another important output of the navigation analysis is the expected size of Trajectory Correction Manoeuvres (TCMs). The simulated navigation campaign is based on an assumed TCM orbit determination timeline.

Additionally, the probability of the launch vehicle upper stage entering the Mars atmosphere is assessed to ensure compliance with planetary protection requirements. If necessary, Earth escape must be off-targeted; the trajectory is then retargeted towards the correct arrival point via a Launcher Injection Correction (LIC) manoeuvre. For the 2016 mission, the LIC only corrects the launcher injection dispersion but there is no need for deterministic retargeting, as the presence of a large DSM during interplanetary transfer already ensures that the upper stage will miss Mars. Conversely, for the 2018 mission, which has no DSM, Earth escape off-targeting is a must and an LIC inclusive of deterministic retargeting is mandatory. This constitutes a major contribution to the navigation delta-v budget for the 2018 mission.

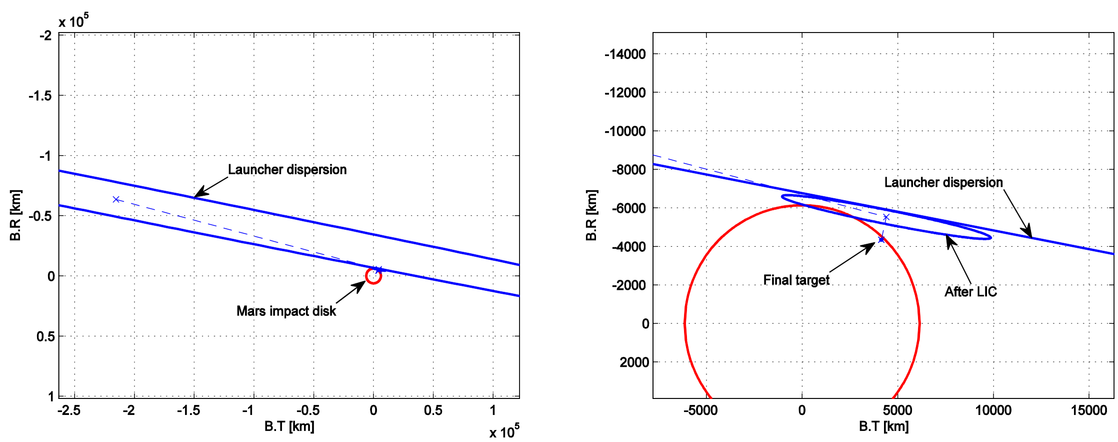

Fig. 1. EXM 2018 mission B-plane error ellipse with escape off-targeting to comply with planetary protection requirements