ABSTRACT

Mars Approach Navigation using Mars Network based Doppler Tracking

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Introduction

Recent scientific discoveries at Mars have heralded an unprecedented commitment and focus by NASA and its international partners towards further exploration of Mars. As part of this effort NASA has an on-going project, called the Mars Network, to examine communication and navigation infrastructure requirements needed to support Mars exploration. This could potentially consist of a small constellation of satellites to provide in-situ communication relay and navigation services for other missions at Mars. A critical service that the network will provide is the formation of Doppler tracking measurements between a Mars approaching spacecraft (of particular interest are Mars landers) and a Mars Network orbiter. These observations can be used to augment standard direct-to-Earth (DTE) Doppler and range data taken by the Deep Space Network (DSN) in support of approach phase trajectory correction maneuver planning for approaching spacecraft. The data can also be used for trajectory knowledge updates after the TCMs to support Mars lander entry guidance. The Mars Network transceiver is currently envisioned to have a 1-Way X Band receive capability via the network orbiters high gain antenna. Using this link to formulate a Doppler observable requires both spacecraft to carry ultra stable oscillators (USO) and, operationally, to point their respective antennas towards each other. Doing so represents a significant operational activity that should be minimized so as to not interfere with the landers DTE communications. Recent experience with Mars approaching spacecraft has also revealed that low level accelerations introduced by spacecraft attitude control systems can significantly impact trajectory knowledge. The impact of these real world issues on approach navigation must be understood in order to fully characterize the viability of the Mars Network Doppler data in aiding approach navigation.

Current Study Results

The present study will examine the performance of the Mars Network at providing approach navigation services given realistic assumptions on tracking capabilities (i.e., maximum ranges, short pass length, USO stability) and major error sources affecting approach vehicle trajectories (i.e., unmodelled nongravitational accelerations). The study will focus on approximate analytical modeling to characterize significant factors affecting approach trajectory uncertainties and numerical simulations illustrating expected knowledge performance for specific lander scenarios. Comparisons of Mars Network Doppler data will be made between alternative observations data at providing approach navigation services. In particular, these are DTE only data, and DTE data augmented with optical navigation data or double differenced one-way range (ΔDOR) data. The analytical study will extend the work done by prior authors [1,2] by incorporating issues relevant to the current Mars Network baseline architecture.

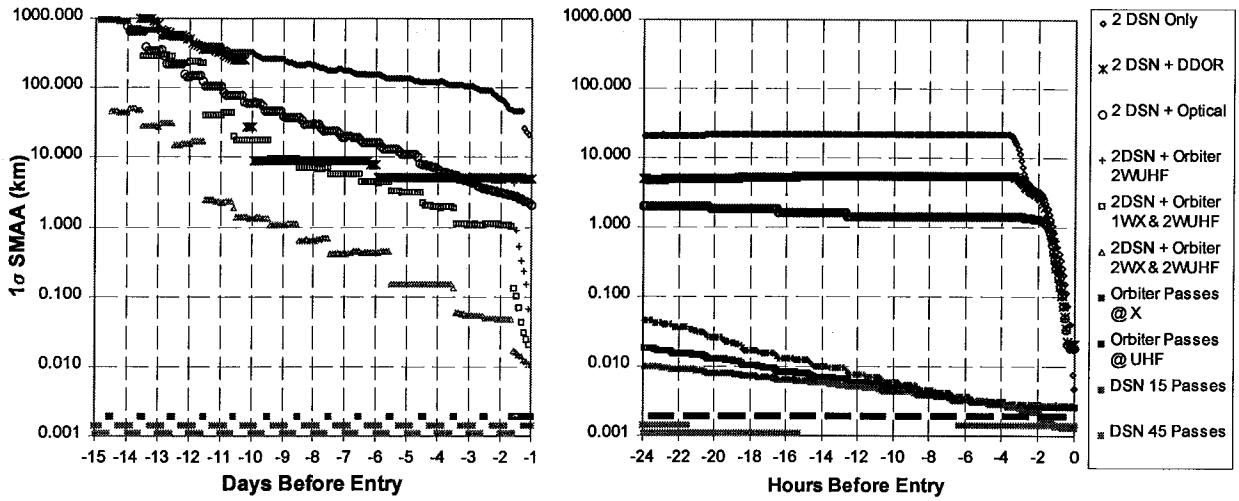

Figure 1: Semi-major axis of approach vehicle B-Plane error (1 σ) as function of days before atmospheric entry at Mars. Figure shows results using, in the same order as the legend: 2 Way DSN Doppler and range only data, 2 Way DSN with DDOR data, 2-Way DSN data with optical navigation data, 2-Way DSN with 2-Way Mars Network UHF-band based Doppler data (UHF link maximum range at 380,000 km), 2-Way DSN data with 1-Way Mars Network X-band Doppler data (X-band link maximum range at 6.3 million km) and 2-Way Mars Network UHF-band Doppler, finally, for comparison, 2-Way DTE data and 2-Way Mars Network Doppler (X-band and UHF). The pass structure is highlighted at the bottom of the figure illustrating the Mars Network orbiter passes and the DSN passes.

Current numerical performance studies suggest that the Mars Network Doppler is a robust data type and can improve trajectory knowledge by orders of magnitude versus DTE Doppler and range data only. An example approach scenario illustrating the potential of the Mars Network Doppler is illustrated in Figure 1. The figure shows results for a Mars lander on a candidate trajectory for the 2007 opportunity being tracked by 2 DSN stations and a Mars Network orbiter. The vertical axis is the 1-σ semi-major axis associated with approach vehicle aim-point uncertainity, and the horizontal axis is days (hours for the pane at the right) prior to atmospheric entry. Details of the scenario will be described in the full paper, but clearly the relative performance of the different tracking data types illustrates the merits of the Network orbiter data at improving approach trajectory knowledge in sufficient time support final trajectory maneuver correction planning (where these maneuvers typically occur anywhere during final 10 days to 12 hrs prior to entry).

Acknowledgements

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References

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2. THURMAN, S. W., ESTEFAN, J. A., Mars Approach Navigation Using Doppler and Range Measurements to Surface Beacons and Orbiting Spacecraft, Paper No. AAS 91-118, AAS/AIAA Spaceflight Mechanics Meeting, Houston, Texas, February 11-13, 1991.