Mars Exploration Rovers Orbit Determination Filter Strategy

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Extended Abstract

The successful delivery of the Mars Exploration Rover (MER) landers to well within the boundaries of their surface target areas in January of 2004 was the culmination of years of orbit determination analysis. The process began with a careful consideration of the filter parameters used for pre-launch covariance studies, and continued with the refinement of the filter after launch based on operational experience. At the same time, tools were developed to run a plethora of variations around the nominal filter and analyze the results in ways that had never been previously attempted for an interplanetary mission. In addition to the achieved sub-kilometer Mars B-plane orbit determination knowledge, the filter strategy and process responded to unexpected error sources by both detecting them and proving robust. All of these facets of the MER orbit determination filter strategy are described in this paper.

Baseline filter selection

The orbit determination process requires the development of correct statistical models for the spacecraft dynamics and the tracking measurement errors. In particular, the choice of the right estimated parameters (along with their *a priori* uncertainties), considered parameters and *a priori* consider uncertainties (which are allowed to affect the covariance without being estimated), and data weights define the filter strategy. The estimated parameters further include both bias and stochastic parameters, the latter of which must have their time update structure defined. The nominal MER filter built on previous missions' use of stochastic range biases and delta-DOR data, but also added stochastic Earth orientation and transmission media modeling after a careful review of the expected error characteristics and latencies of these parameters. In addition, the tracking data was weighted as a function of each pass's RMS and scatter, taking into account expected non-white noise effects.

Filter variations

MER orbit determination marked the first use of automated processes to execute the filter with predefined variations (referred to as filter cases). Some of the variations represented potentially legitimate alternate filter configurations, while others existed purely to expose certain modeling problems or illustrate the content of subsets of the tracking data. In addition to providing the rationale for the various filter cases, this paper describes their organization, which was vital in making the results interpretable.

Statistical tests and presentation

The practical evaluation of an ensemble of solutions, which includes both the internal consistency of each solution, as well as the relative consistency between solution pairs and groups, requires both relevant statistical tests and a set of tools to sufficiently automate their application to the set of solutions. While measuring solution consistency in the B-plane visually has been commonplace, MER orbit determination used a rigorous definition for the consistency of two solutions by computing the required common scale factor to produce tangency of their B-plane error ellipses. In addition, ratios between corrections to estimated parameters and pre- and post-fit uncertainties were computed, and the usual post-fit data statistics were evaluated. While not statistically rigorous, the visual presentation of solutions in the B-plane continues to be important, so important improvements were made to the ease of accomplishing this for an enormous set of computed solutions. The visual presentation was further enhanced by collecting almost all the relevant solution information into an easily navigable web page, which was updated after every extension of the tracking data arc.

Results

During the last two months of the MER cruise trajectory, a total of 12185 orbit solutions were produced, using 108 different filter cases and 7 different data arcs for each vehicle. During this time, while the set of filter cases facilitated the development of a new data model, and helped identify inconsistencies in filter assumptions, the most important result was the high confidence provided to MER project management that the orbit determination process would going to meet the tight delivery requirements. This paper will also analyze the intermediate results in light of the final reconstruction to advance the understanding of the relevance of various tests and the most effective filter settings, particularly when the highly useful delta-DOR data is not available.

Summary

MER orbit determination set a new standard for excellence in interplanetary navigation. The orbit determination filter strategy represents a critical part this result, and forms the basis for use in future missions. Nevertheless, further developments are undoubtedly possible, especially as MER orbit determination marked the first operational use of several new techniques.

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Condensed Abstract

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