NAVIGATION FLIGHT OPERATIONS FOR MARS PATHFINDER

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Extended Abstract

On July 4, 1997, Mars Pathfinder became the first spacecraft to land on the surface of Mars in 21 years. Pathfinder was launched in December 1996 and spent seven months en route to the red planet. This paper will discuss the navigation flight experience for the Mars Pathfinder interplanetary cruise. In particular, orbit determination and maneuver design and execution results will be presented. Special emphasis will be given to the navigation role during the Entry, Descent, and Landing (EDL) phase.

Part I: Orbit Determination

Spacecraft non-gravitational force modeling was an important aspect of the orbit determination task. One of the first problems encountered in flight operations was the construction of an adequate spacecraft component set for computing solar radiation pressure. Early versions of the model behaved poorly in OD solutions. Another model, featuring two sets of components, the first of which was active up to April of 1997 and the second active thereafter, was found to have unintended and unreasonable consequences in the filter. It was finally decided to use only the second component set of this version, active throughout the entire data arc, for the final critical solutions, including those performed for TCM 4 design and in the last 24 hours leading up to EDL. The paper will give details on why early component models were considered unsatisfactory and the behavior of the two-component set model in filter estimations.

The quality of the radiometric tracking data was critical to obtaining the required navigation accuracy for Mars Pathfinder. Low-noise, high-precision ranging measurements were particularly crucial for meeting the atmospheric entry safety requirements. Variations in Doppler and ranging data quality throughout the mission will be shown and their impact on the orbit determination process will be discussed. The paper will document a series of problems with the ranging system performance and their solutions; special data weighting schemes and bias treatments used to handle these problems in the filter estimations will be presented. The paper will also discuss modeling of the Doppler bias imposed by the spinning spacecraft.

Figures 1 and 2 show successive orbit determination solutions obtained during the last 24 hours before entry as 3-σ uncertainty ellipses in the B-plane and corresponding footprints mapped onto the surface of Mars. The target region, corresponding to a 200 x 100 km footprint on the surface is also shown for comparison. The ellipses range in size from 40 x 8 km to 15 x 3 km in the B-plane or 154 x 52 km to 97 x 13 km on the surface. The final orbit determination solution produced an estimated landing site location only 23 km away from the target site. These results clearly validate the use of the enhanced filter technique for flight operations. The paper will present details of the filter configuration used for these solutions, including the set of stochastic parameters and choices for a priori uncertainties. This will be compared to the pre-launch plans for the enhanced filter configuration.

Part II Maneuver Design and Execution

Four maneuvers were planned and executed during cruise, the first two within 60 days of launch and the last two within 60 days of Mars arrival. The planned and actual maneuver schedule for Mars Pathfinder is shown in the Table 1, while Table 2 summarizes maneuver sizes and execution performance'. The first three columns in Table 2 list the expected magnitude for each maneuver from pre-launch analyses, the overall required magnitude as designed in flight, and the actual magnitude obtained when executed. Execution errors are presented in the fourth column as the percentage difference between the design and actual magnitudes. The paper will discuss the choice of target aimpoints, the computation of required velocity changes, and implementation modes for each of these maneuvers. The breakdown of the overall velocity change vectors into components based on implementation mode will be described. The actual total velocity change implemented for the mission will be compared to the pre-launch budget statistics,

In addition to the four maneuvers in the tables, the possibility of another maneuver -1 CM 5 - to be executed during the last 12 hours before entry into the Martian atmosphere was added as a contingency plan during cruise. TCM5 design and execution strategy will be described as part of the section on navigation activities during EDL.

Table 1. Mars Pathfinder Maneuver Schedule

Maneuver	Nominal Time	Actual Time	Description
TCM 1	Launch + 30 days	January 10,1997 Launch -t 37 days	Remove injection bias, correct injection errors
TCM 2	Launch + 60 days	February 3, 1997 Launch + 61 days	Correct TCM 1 execution errors
TCM 3	Mars - 60 days	May 7, 1997 Mars -58 days	Targets to Mars atmospheric entry point
TCM 4	Mars -10 days	JLint'2!5, 1997 Mars -9 days	Correct TCM 3 execution errors

Table 2. Mars Pathfinder Maneuver Execution History

Maneuver	Pre-Launch Expected ΔV Magnitude (m/s)	In-Flight Desired ΔV Magnitude (m/s)	in-Flight Actual ΔV Magnitude (m/s)	Execution Error
TCM 1	33.3	31.84	30.09	5.5% low
TCM 2	2.08	1.586	1.697	0.7% high
TCM 3	0.432	0.1000	0.112(1	5.7% high
TCM 4	0.138	0.01861	0.01858	0.17% low

Part 111:
Navigation for Entry, Descent, and Landing

Pathfinder's direct entry into the Martian atmosphere from its interplanetary trajectory led to a unique coupling between navigation knowledge, targeting to the atmospheric entry interface and spacecraft activities leading up to and during the descent itself. Orbit determination analyses had shown that the overall uncertainty in the spacecraft's trajectory solutions would remain fairly constant in the last few days before arrival at Mars. A significant improvement in knowledge of the spacecraftrs Mars-relative position would not occur until the last 24 hours before entry when the Doppler data began to sense the planet's gravitational field. During these last few hours it would be possible to refine predictions of the entry conditions and to correct for any unexpectedly large flight path deviations. The development of operational plans and procedures for this critical time period will be discussed. The two major activities to be considered are a possible fifth maneuver (-1 CM5) and updates to flight software parameters controlling various events during descent such as parachute deployment time.

A history of actual orbit determination results and their influence on flight team decisions at key times will be presented. The final, best estimate for the spacecraft's entry state based on all tracking data obtained prior to landing will also be given and compared to solutions available at the earlier decision points. This will also be compared to post-landing solutions for the lander's location generated from imaging data and tracking data taken after surface deployment.

Acknowledgments

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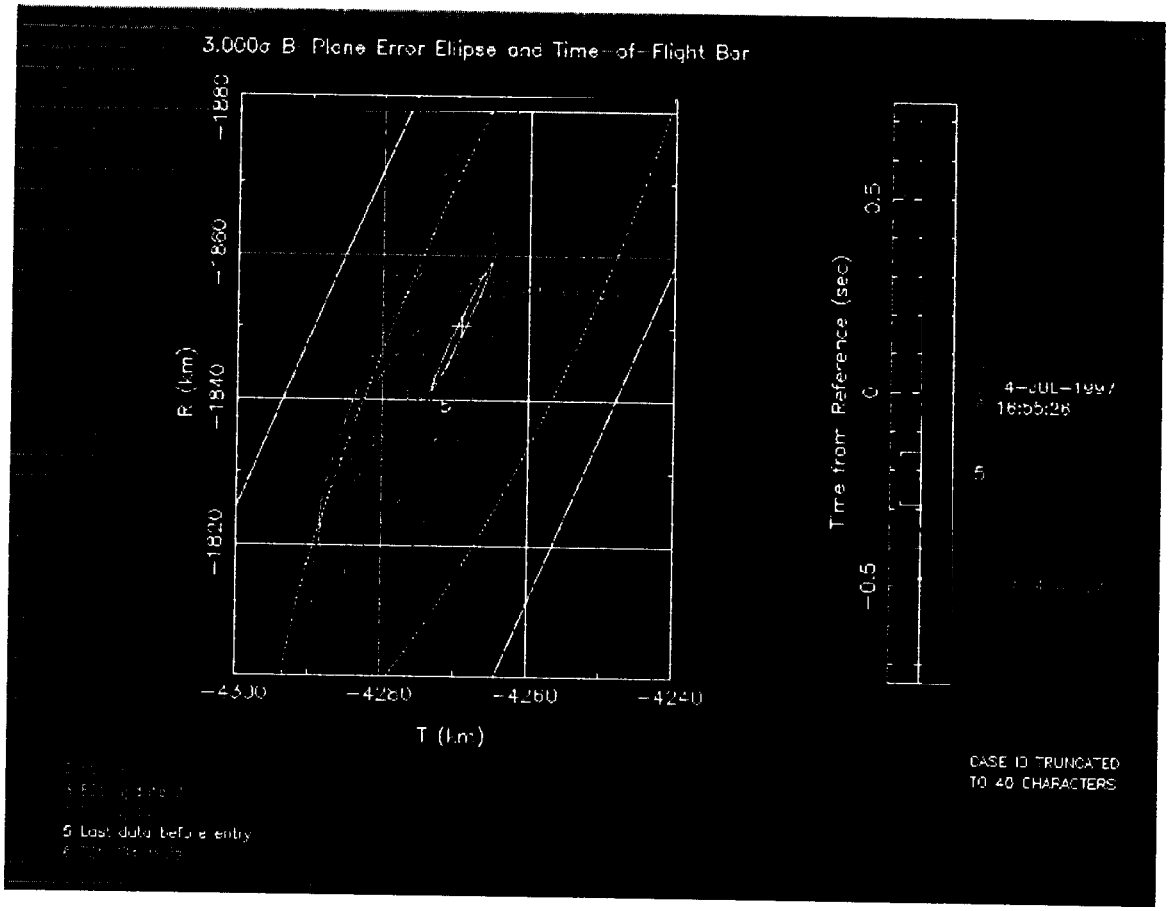

Figure 1. 3-σ B-plane error ellipses for MPF EDL orbit determination solutions

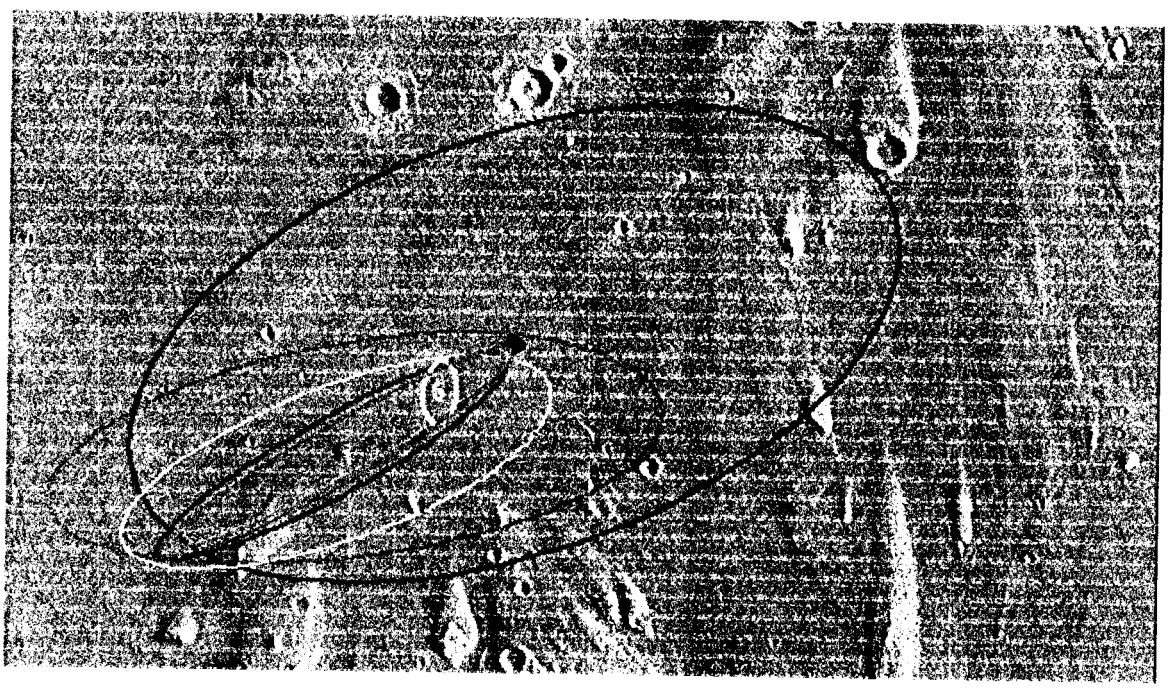

Figure 2. 3-σ landing error footprints for MPF EDL orbit determination solutions