Viking Satellite Orbit Determination

C. E. Hildebrand,* E. J. Christensen,† D. H. Boggs,‡ G. H. Born,§ H. Hokikian,‡ and J. F. Jordan¶
Jet Propulsion Laboratory, Pasadena, Calif.

and

W. B. Howard**
Computer Sciences Corp., Pasadena, Calif.

Abstract

THE Viking missions to Mars have presented and continue to present a number of challenging problems in orbit determination (OD). This paper describes the experiences of the Viking Satellite Orbit Determination Team in support of orbit phase navigation activities. This team is one of five comprising the Viking Flight Path Analysis Group. Included here is a discussion of in-flight OD performance, with reference to preflight analysis in the areas of initial orbit convergence, sensing and evaluation of Mars' gravity field, and Viking Lander position determination.

Contents

On June 19, 1976, and Aug. 7, 1976, the two Viking spacecraft were inserted into orbit about Mars. Each spacecraft consisted of an orbiter-lander combination. The orbiters, which had their own complement of science instruments, also served as communication relays for the landers in their search for Martian life.

The Mariner 9 mission to Mars served as the precursor for Viking and was instrumental in guiding the development of mathematical models and procedures used for Viking OD.[1,2] For example, the gravity field of Mars developed with Mariner 9 data was found to be well within its predicted uncertainty for Viking applications. In general, the initial Viking orbits were near synchronous with Mars rotational period (24.6 h), had large eccentricities ($e \simeq 0.8$), and had subperiapsis points located in the northern hemisphere at 23 and 50 deg for Viking Orbiter 1 and 2 (VO-1 and VO-2), respectively.

After Mars orbit insertion, Flight Path Analysis Group support activities were concerned largely with initial orbit convergence. Immediately thereafter, prior to Viking lander (VL) separation, activities were directed toward the support of 1) acquiring imaging and other scientific observations of candidate landing sites; 2) achieving an orbit from which a safe landing could be effected; and 3) designing the VL deorbit burn, entry trajectory, and descent guidance and control sequences. Postlanding activities shifted to VL/VO relay link design and maintenance, VO science and radio science, and, between VL-1 landing and VL-2 descent design, analysis of the VL-1 descent performance. Specific areas requiring direct orbit determination support during the primary mission include 1) Mars orbit trim design, 2) science sequence design for targeting scan platform instruments, 3) VL descent predictions for VL/VO radio tracking, 4) trajectory predictions for VL/VO radio tracking, 5) provision of VO trajectories and estimates of VL location for VL/VO relay link design, and 6) local orbit estimates and Earth-to-Mars range measurements in support of radio science.

The basic techniques for determining the state of a Mars orbiter were well established during the Mariner 9 mission.[1] The strategy involves processing a single revolution of two-way Doppler to determine the local orbit. Accurate prediction is achieved by using data arcs spanning several revolutions to obtain improvement in the estimate of a spherical harmonic coefficient model of the Mars gravity field. Because of orbital geometry differences, the gravity-sensing techniques used for Viking differed somewhat from those used on Mariner 9. Basically, gravity models associated with a given orbit were developed by first processing two to four revolutions of data estimating harmonic coefficients through sixth degree and order, and then selected "local" models were combined into an ensemble field.

A task that required considerable attention was that of redetermining the orbit after a maneuver. The following methods were employed: 1) processing short arcs of post-maneuver Doppler data; and 2) processing pre- and post-trim data and estimating trim ΔV components (and possibly gravity coefficients), in addition to VO state. A problem encountered with the former technique is that ill-conditioning may lead to slow convergence, or even divergence. However, this can be circumvented by using methods such as the partial step algorithm,[1-3] which is also employed in the process of initial orbit convergence following insertion into orbit about Mars. The problem of rapidly assessing the estimate accuracy also arises. In general, this can be done satisfactorily by processing several intermediate arcs and monitoring the evolution of the estimates of selected orbit parameters. Viking lander position determination involved estimating both the cylindrical coordinates of the VL relative to a Mars-fixed reference frame and the inertial direction of the Mars spin axis from short arcs of two-way Doppler data and a few two-way range points.

Since the Viking orbits were near synchronous with Mars rotational period (24.6 h), the spacecraft orbital periods were perturbed significantly during periapsis passage by resonance perturbations from tesseral harmonics in the Mars gravity field. For example, the change in anomalistic period of VO-1 as a function of areographic node at periapsis is shown in Fig. 1. The actual range of nodal values for periapsis Nos. 2 through 46 also is indicated on this figure. It is seen that VO-1 anomalistic period was reduced by approximately 10 s during each periapsis passage.

The ability to predict the spacecraft position for relay link and tracking station acquisition is determined predominantly

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*Technical Group Leader.
†Senior Engineer.
‡Member of the Technical Staff.
§Technical Group Supervisor. Member AIAA.
¶Technical Section Manager.
**Computer Analyst.

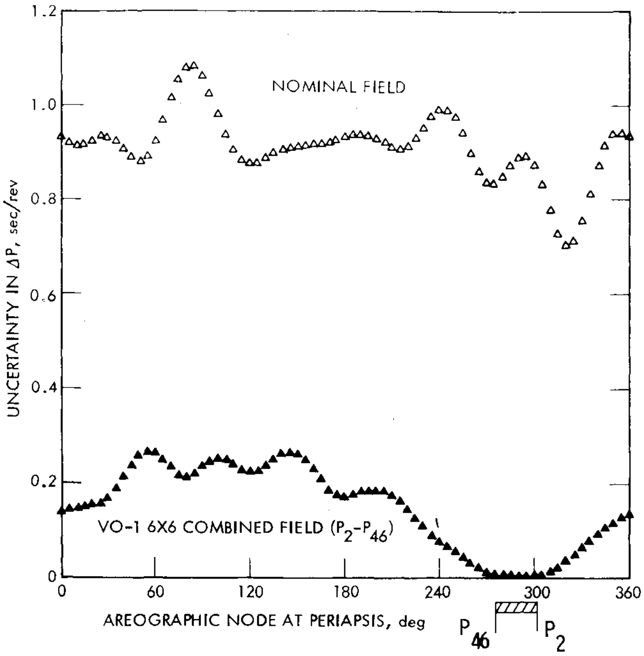

Fig. 1 Change in period as a function of aerographic node at periapsis based on a 6×6 VO-1 combined field determined over P_2-P_{46}.

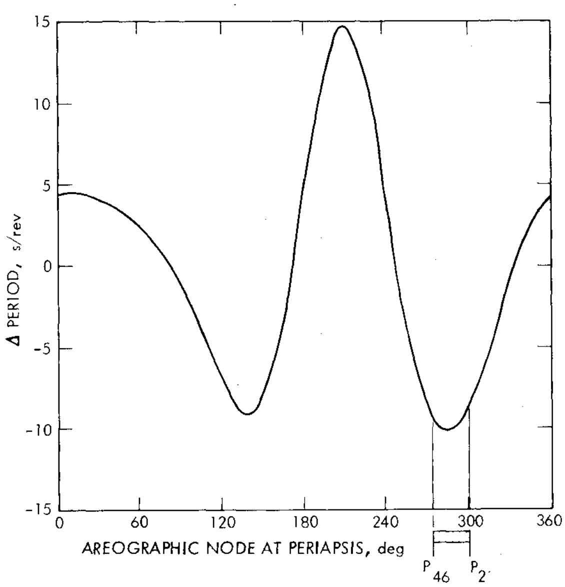

Fig. 2 Uncertainty in the change in period as a function of areographic node at periapsis based on the nominal field and a 6×6 VO-1 combined field determined over P_2-P_{46}.

by the accuracy to which the spacecraft period can be predicted. This is directly related to knowledge of the gravity field. The preflight gravity field for Viking was a fourth-degree and order field based on Mariner 9 tracking data. Figure 2 displays the 1σ uncertainty in the ability to predict the VO-1 orbital period as a function of aerographic node for the nominal preflight gravity field. Also shown is the significant decrease in uncertainty after modeling the gravitational perturbation via a sixth-degree and order field from combined Viking and Mariner 9 tracking data. The initial OD solutions for Viking indicated that the low-degree and order terms of the preflight gravity field were well determined, and the prediction accuracy of the preflight field represented a model error of less than 1σ for both VO-1 and VO-2.

Estimates of the Viking lander position accurate to 0.5 deg were required to be delivered within 5 days after touchdown based on Doppler and range tracking. A Doppler arc of 15 to 90 m duration was obtained on each of the 5 days, and three range points were acquired from each of the landers. The final 5-day position estimates were accurate to better than 1 km. The VL-1 estimated pole was within 0.04 deg of the Viking preflight nominal value determined from Mariner 9 data.

Several experiments that posed interesting orbit determination problems have been carried out successfully during the Viking extended mission. In February 1977, a series of flybys of Phobos to within 80 km of the surface were carried out.[4] High-resolution photographs of the surface, as well as infrared images and a mass estimate of Phobos, were obtained. Another close flyby of Phobos at 300 km occurred in May 1977. An even closer flyby of Deimos to within 26 km of the surface occurred on Oct. 5, 1977. The periapsis of both orbiters has been lowered from 1500 to 300 km. This will allow much higher resolution of the Martian gravity field in the vicinity of the subperiapsis points, as well as higher resolution imaging of the surface of Mars.

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