Viking Orbit Trim Maneuvers

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Abstract

THE Viking missions to Mars provided significant navigation challenges. This paper describes the maneuver analyses performed in response to real-time requirements for orbit modification for the first Viking spacecraft prior to landing. Included is a discussion of the propulsive maneuver strategies and operational techniques that were developed to allow for examination and certification of proposed landing sites, to provide for safe entry and descent of the lander, and to cope with hardware failures.

Contents

Viking was the first United States project to send soft-landers to the surface of another planet. Each spacecraft consisted of an orbiter with an attached lander. Following the delivery of this combination to Mars, the spacecraft was inserted into planetary orbit to reconnoiter proposed landing sites. Once a site was certified, the lander separated from the orbiter to descend to the Martian surface. The orbiter's task in this mission phase was to provide the proper orbit geometry and timing to certify the site and prepare for landing.

Site reconnaissance specified viewing angle requirements on early spacecraft revolutions about the planet. The dominant angular constraint was considered in terms of an equivalent timing offset which measured how far the spacecraft missed overflying the landing site.

Orbit requirements for a safe entry and accurate landing were specified for the spacecraft revolution on which the lander separated from the orbiter (separation orbit). The navigation task was to position the spacecraft so that the downrange and crossrange (DR and XR) capability of the lander could easily acquire the desired site within the entry environment constraints imposed on the lander. The separation orbit also had to guarantee lander-to-orbiter communications at overflight for several orbits after landing.

Many trim maneuver strategies were considered[1] to obtain a satisfactory trajectory while coping with several error sources, notably the interplanetary navigation delivery, orbit determination,[2] and maneuver execution errors. A strategy consisted of a sequence of propulsive maneuvers designed to shape and orient the orbit and to time the spacecraft to allow imaging of proposed landing sites under proper lighting and to achieve a specific separation orbit which changed often as the site selection process continued. Each maneuver consisted of a sequence of turns, followed by a motor burn to achieve the desired velocity correction ΔV at the ignition time t_{ign}. The operational timeline required the turns to be specified (with estimates for ΔV and t_{ign}) well before the motor burn. The ΔV and ignition time were updated later to account for changes in the orbit estimate.

By launch time, a strategy had been selected which involved delivering the spacecraft to the planet in the vicinity of the preselected landing site and then inserting it into a Mars synchronous orbit (1 Mars day = 24.6 h). Thus, the craft would continue to overfly the site, providing early reconnaissance. Trims would be required only to correct errors. Opportunities for maneuvers to correct errors in specific orbit parameters were scheduled on the 2nd and 5th revolutions (revs) near periapsis and on the 8th and 11th revs.

The planned Mars encounter sequence was disrupted by a propulsion system gas leak which required two large motor burns before Mars orbit insertion to reduce propellant tank pressures. These two burns delayed the arrival at Mars by about 7 h, making it impossible to insert directly over the landing site. To return to the original operational timeline as soon as possible, insertion was made into an orbit having a 42 h period so that the first periapsis would occur at the same time that the second periapsis would have occurred on the planned timeline. Then the period was reduced to 24.6 h at the first periapsis. Thus, the number of revs before lander touchdown, planned for July 4, 1976, was reduced by one.

The first trim maneuver was designed now in real-time to adjust the timing offset relative to the site known as A1 at 19.5°N and 34.0°W. The target value for the offset was not exactly zero, reflecting the method for correcting DR and XR geometrical errors at touchdown and the fact that the lander would lead the orbiter as it descended to the planet. All downrange error for landing was to be removed by this trim, while crossranging would be performed by the lander deorbit maneuver to conserve orbiter propellant. This initial trim maneuver was to change period only, where the target period was selected to set DR = 0 at landing. The velocity change was made at periapsis directly opposite to the velocity vector to minimize fuel usage and the effects of pointing errors.

Following the execution of this trim, reconnaissance proceeded as planned and A1 was soon shown to be unsatisfactory for landing. Another point was selected northwest of A1 at 23.4°N, 43.4°W, requiring two more spacecraft maneuvers. First, the orbit period was increased to be greater than 24.6 h to move, or time-phase, the spacecraft to the west. Second, a synchronizing maneuver was designed to stop this migration over the site. Thus, the longitude change could be produced by relatively fuel-inexpensive period adjustments, but the latitude change required altering the orbit orientation. A timing offset plot for this two-maneuver strategy is shown in Fig. 1. Three positions are shown for the synchronizing maneuver corresponding to further changes in the landing location. This strategy delayed the landing from rev 15 (July 4, 1976) to rev 27 or later. It also allowed reconnaissance of the candidate sites and postponement of final site selection as late as possible. The last opportunity to land before the start of encounter activities for the second spacecraft was on rev 35.

The time-phase maneuver was designed to adjust the period and correct the orbit orientation for minimum ΔV while holding the periapsis altitude fixed. The site latitude and longitude changes that could be accommodated with a late update (fixed maneuver attitude) are shown in Fig. 2. This

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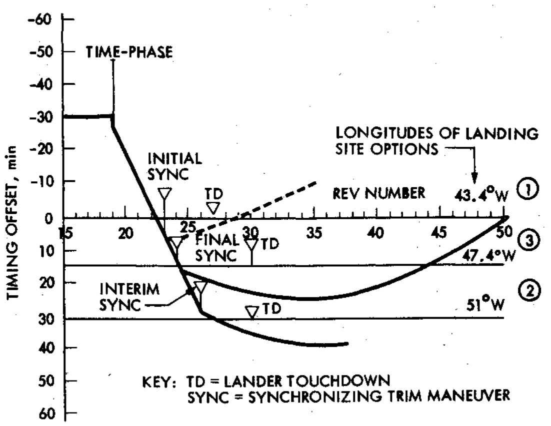

Fig. 1 Site acquisition strategy changes.

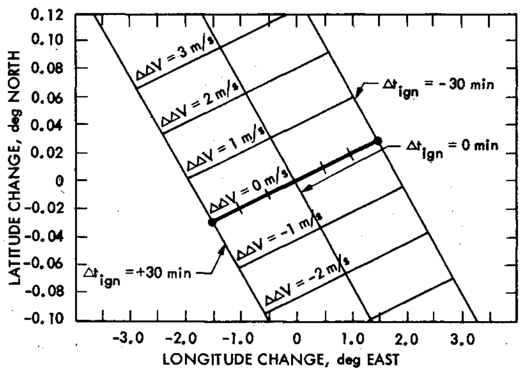

Fig. 2 Late update capability for adjusting the landing site with the time-phase maneuver.

information on retargeting capability was of great interest at this point in the mission because an intense search for the final landing location was still in progress. Before the time-phase maneuver was implemented, another site was selected at 23.5°N and 51.0°W (A1WNW—see Fig. 3).

After the time-phase maneuver was redesigned and executed for A1WNW (see Fig. 1), another candidate, A1WNWSE, was located at 22.5°N, 47.4°W. The remaining trim was then modified to acquire this site. This new design involved a tradeoff of several factors: 1) the need for accurate period control, 2) timing offset constraints on the touchdown orbit and five revs later, 3) a favorable geometry for communications, and 4) no change in the periapsis altitude. This problem required a four-dimensional optimization. To simplify the analysis, the constraint to fix periapsis altitude was ignored initially and the problem was considered in a flight plane velocity space. This space is defined in terms of the three orthogonal reference vectors: $\hat{V}_M$ (unit vector along the spacecraft velocity direction), $\hat{V}_N$ (unit vector along the angular momentum), and $\hat{V}_G(\hat{V}_M \times \hat{V}_N)$. A ΔV_M component was needed to decrease the period by 6 min 40 s. A normal component ΔV_N was added to satisfy a constraint on the communication angle between the Earth vector and the low-gain antenna. The required magnitudes of ΔV_M and ΔV_N are

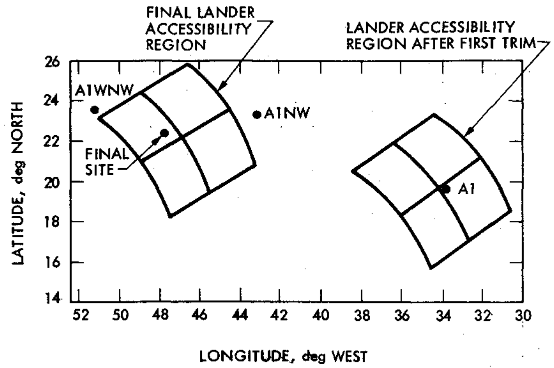

Fig. 3 Landing site adjustments.

functions of the true anomaly at which the maneuver is executed. The period sensitivity to ΔV_M is symmetric about apoapsis, but maneuver locations after apoapsis were more favorable for communications. A maneuver at apoapsis would have changed periapsis altitude by 120 km. The ΔV cost is largest and period accuracy is best here because of the relative insensitivity of period to velocity changes. As a tradeoff, the maneuver at the true anomaly of 262.5 deg was selected, where the change in periapsis altitude caused by the ΔV_M component was cancelled by adding a ΔV_G component. One more update finalized the landing site at 22.4°N and 47.5°W. As shown by Fig. 3, this new site is well within the region that the lander could achieve so no more changes were needed in the maneuver design. This last prelanding trim was executed successfully on rev 24, followed by lander separation and landing on rev 30.

These strategies for orbit trim selection and design were used to provide stationkeeping capabilities, orbiter mapping excursions, and other science requirements. Application of these navigation techniques is continuing in the extended Viking missions and other projects for planetary exploration.

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