Phobos and Deimos Encounter Experiment during the Viking Extended Mission

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The Viking '75 Mission to Mars permits a truly unique opportunity to explore Phobos and Deimos from distances measured in tens of kilometers. The particular orbital geometry planned for the Viking mission permits the spacecraft to be maneuvered to make repeated passes very close to Phobos and Deimos during the proposed extended mission phase. Multipass images of both satellites will cover approximatey 90% of Phobos and 50% of Deimos. Optical resolution on the order of 50 m is possible. Close encounters will permit mass determination to an accuracy of tens of percent. A preliminary feasibility study has been made which shows that the propulsive requirements are nominal, the orbit determination accuracy is adequate, and the satellites are within the scan platform pointing capability during portions of each encounter.

Introduction

THE first closeup photographs[1,2] of the Martian natural satellites by the MM '71 visual imaging system renewed interest in the satellites discovered almost a century ago. Initial analyses of these pictures indicated that both moons are of irregular shape, very dim, and heavily cratered. Figure 1 is typical of the pictures taken by Mariner 9 while in orbit about Mars. Immediate impressions were that the current surface characteristics are largely determined by cratering and its accompanying fragmentation and spallation. Estimates of the mean radii were 10.9 ± 1.5 km for Phobos and 5.7 ± 0.5 km for Deimos. First estimates of the surface age, based upon crater population, ranged from 10^9 years to as old as the solar system itself.

Recent reports[3] extended the initial analyses by including estimates of the principal axes of the moons and providing additional confirmation of their synchronous rotational periods. Triaxial shapes of the moon were determined using a limb fitting technique. Both moons were determined to have remarkably comparable shapes; the ratios of the three axes of Phobos to the corresponding axes of Deimos are nearly a constant 1.8. The three axes are consistant with hydrostatic equilibrium theory[4,5] for satellites at the current distance of Phobos. In terms of equivalent mean radii, the data yield 11.5 km for Phobos and 6.4 km for Deimos, values slightly larger than first estimates. Estimates of the masses of the moons were given as 19.3 and 3.37×10^{18} gm for Phobos and Deimos, respectively. These were based upon an assumed density of 3 gm/cc. However, no direct measurements of mass or density have been made.

The Mariner 9 experiment has substantially improved our knowledge of the moons; however, many new questions have been raised, particularly on the origin of the moons. The nature and origin of the Martian moons could be the true Rosetta Stone for the origin of the solar system. If these moons were formed from primordial matter, they should, because of their relatively small size, retain their original chemistry and mineralogical composition.[6]

Further investigations and more definitive data on the Martian moons are needed to confirm or reject original theories. A list of the additional science information be be gained by a close Martian moon encounter by the Viking spacecraft includes: 1) Obtain a direct estimate of the mass and an improved figure determination. These new data will provide valuable new information on density which bears directly on origin theories. 2) Obtain improved values on the rotational characteristics of the moons to improve the estimate of the degree of synchronization. These data, combined with the size and mass data, may yield valuable information on moments of inertia and perhaps the density distribution. Further, nonaccountable librations may provide bounds on the probability of asteriod collisions.[6] 3) Provide additional data to improve the ephemerides of the moons. These data, in conjunction with other Mars physical data obtained earlier in the Viking Mission should provide valuable insights into Mars'

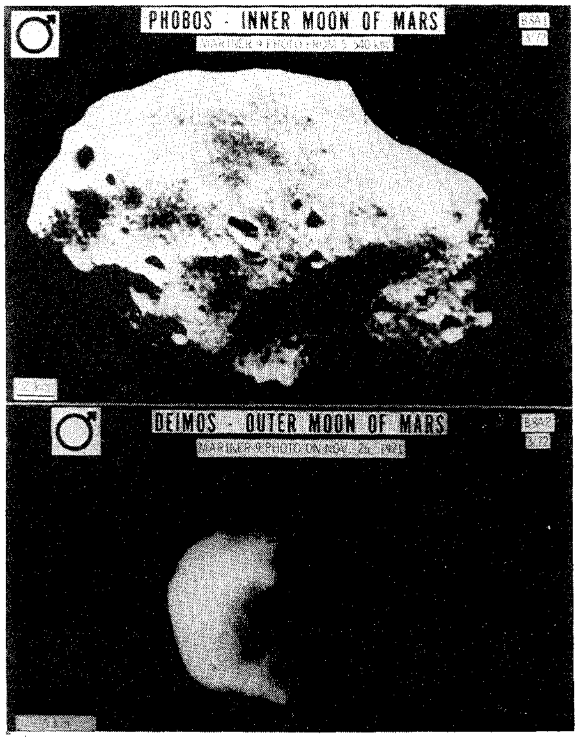

Fig. 1 Mariner 9 computer enhanced pictures of Phobos and Deimos.

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internal structure. 4) Provide additional and improved knowledge of the secular acceleration of the moons.[3] Accurate Viking image data, taken about 5 years after Mariner 9 should provide further insight into the questionable secular acceleration in the longitude of the moons.[7] These data, with the mass estimates, could also be used to determine additional internal properties of Mars. 5) Obtain high resolution measurements on the surface thermal inertia. Data scans taken with the infrared thermal mapper instrument in conjunction with photographs should provide important surface property information.

It will be shown in this paper that the Viking Mars mission in 1976 provides an unprecedented opportunity to gather important data on Phobos and Deimos at essentially no extra spacecraft design costs. This serendipitous mission can provide data of great scientific value on the satellite masses, and additional data on their figures, surface properties, and rotational characteristics. This study shows that a science mission involving close encounters is technically feasible and within the capabilities of the current Viking design. For a ΔV of about 20 m/s, the Viking orbiter can provide approximately two 40-day periods of close observation of Phobos with the first encounter period in January and the second in March 1977. For an additional 50 m/s Deimos can be observed in Nov. or Dec. 1977. These experiments can be performed in series with the nominal mission, thus providing complementary scientific information without compromising the original mission and scientific objectives.

Celestial Mechanics Considerations

Viking Orbits

The relative orbit geometry in inertial space for the two Viking Orbiters (VO) is depicted in Fig. 2. The mission consists of four vehicles: two landers and two orbiter relay stations. The orbiters contain radio, imaging, and infrared instruments and at different times perform science investigations independent of the landers. However, the orbits have been primarily designed to support landed functions. The orbital shape, period, and orientation have been chosen such that the vehicles can land at the desired latitude, the orbiters can support the landed vehicle, and mutual support from each orbiter to each lander is possible. These requirements translate into an orbital period of 24.61 hr and a periapsis altitude of 1500 km for each orbiter. The selection of landing sites on the Mars surface results in initial inclinations of about 34° for Viking Orbiter A (VO-A) and about 49° for Viking Orbiter B (VO-B). A plane change of approximately 21° is planned for VO-B after landing of Lander B. This inclination of 70% for VO-B is shown on Fig. 2. The initial arguments of periapsis are 44° for VO-A and VO-B, respectively.

Encounter Possibilities

In order for the spacecraft to pass close to Phobos or Deimos, two conditions must be satisfied. First, the orbits of the spacecraft and the natural satellite must intersect in three-dimensional space. The second condition is that the natural satellite and the spacecraft must be at these intersection points at the same time. A mathematical expression for the first condition can be derived from conic equation relating radial distance (r) of the VO to the angular position in orbit[8]

$$r = \frac{a(1-e^2)}{1+e\cos f} \tag{1}$$

where a is the semimajor axis, e is the eccentricity, and f is the true anomaly or angle measured from periapsis to the position in orbit. Since both natural satellites have nearly zero orbit inclinations, the spacecraft passes through the orbit plane of Phobos and Deimos when $f \simeq -\omega$ and $180° - \omega$. Assuming the natural satellites are in circular, equatorial orbits, the orbit paths will intersect when $r = 9380$ km, the semimajor axis of the orbit of Phobos, or 23460 km, the semimajor axis of the orbit of Deimos. Thus the values of ω must satisfy one of the equations

$$\left.\begin{array}{l} \dfrac{a(1-e^2)}{1+e\cos\omega} = \\ \text{or} \\ \dfrac{a(1-e^2)}{1-e\cos\omega} = \end{array}\right\} \quad 9380 \text{ or } 23460 \tag{2}$$

which are necessary and sufficient for orbit path intersection. Assuming the nominal values of a and e, the solutions for ω are

Phobos	±96°	±84°
Deimos	±146°	±34°

The paths intersect as the spacecraft is ascending (south to north) when $\omega = 96°$ for Phobos (146° for Deimos) and descending when $\omega = 84°$ for Phobos (34° for Deimos).

A schematic of the approximate July 1976 orbit geometry for VO-A and Phobos is shown in Fig. 3. The orbit geometry for Deimos is not shown; however, the concepts which are subsequently discussed for Phobos are identical to those for Deimos. For the July orbit, the spacecraft approaches periapsis from beneath the plane of Phobos and intersects the Phobos orbit plane inside the orbit of Phobos. After periapsis passage the intersection occurs outside the orbit of Phobos; however, perturbations on the spacecraft orbit change this initial orbit geometry. The major perturbation, the oblateness of Mars, produces both a nodal regression and apsidal precession given by[8]

$$\dot{\Omega} = -n\left[\frac{3}{2}J_2\right]\cos i\left[\frac{R}{a}\right]^2 / (1-e^2)^2 \tag{3}$$

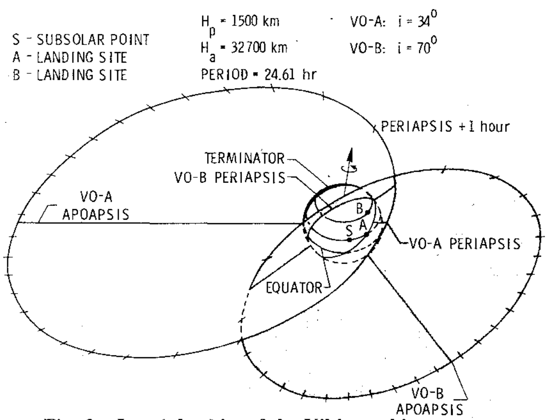

Fig. 2 Inertial orbits of the Viking orbiters

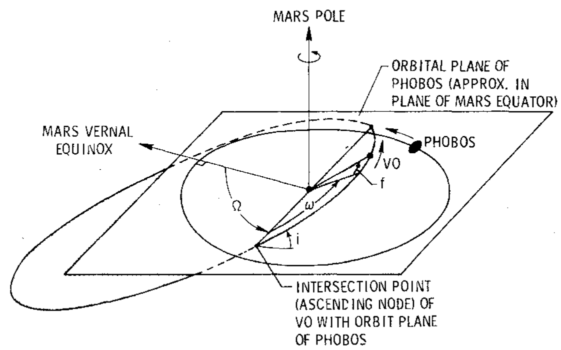

Fig. 3 Relative orbital geometry between Phobos and the Viking orbiter.

$$\dot{\omega}=n\left[\frac{3}{2}J_2\right]\left[\frac{R}{a}\right]^2(2-\frac{5}{2}\sin^2 i)/(1-e^2)^2 \quad (4)$$

where J_2 is 1.96×10^{-3}, $n=351°$/day is the mean motion of the spacecraft, $e=0.76$ is the eccentricity of the spacecraft orbit, $R=3394$ km is the radius of the Mars used as a reference for the gravity field expansion, $a=20420$ km is the semimajor axis of the spacecraft orbit, and $i=34°$ is the inclination.[9] Perturbations from higher order terms in Mars gravitational field, third body effects, radiation pressure and drag are on the order of a few percent of the perturbation produced by J_2. The orbital parameters n, a, e, and i do not change substantially with time; thus $\dot{\Omega}=-0.134°$/day; $\dot{\omega}=0.199°$/day. The argument of periapsis will increase from the initial value of 44° in July to 84° in 201 days and to 96° in 261 days. Consequently, in January and March 1977 the orbit geometry is such that close encounters of the VO-A spacecraft and Phobos are possible. Similar analysis has been performed for potential encounters between VO-A and Deimos and VO-B and both natural satellites. The approximate encounter dates are shown in Table 1. The most realistic opportunities are the two mentioned above and the Deimos encounter in December 1977.

A scale drawing of the orbits of Phobos and Deimos with respect to Mars is given in Fig. 4. Included are the VO-A intersection points with the orbital planes of Phobos and Deimos at various times from July 1976 to December 1977. These inertial intersection points were calculated using a relatively precise definition of the orbital parameters of each moon.[9] The precessing motions of the spacecraft orbit were assumed to be constants throughout and were calculated from the initial Viking orbital conditions mentioned previously. The first possible Mars moon encounter is with Phobos which occurs January 21, 1977, as the spacecraft descends through the Phobos orbital plane. The second encounter is also with Phobos, on March 24, 1977, as the spacecraft is ascending through the Phobos orbital plane. The next encounter is with Deimos on December 25, 1977, with the spacecraft ascending through the plane of the Deimos orbit. Other moon encounters exist but are well beyond the expected operational lifetime of the Viking orbiters and consequently are not shown. The encounter dates are sensitive to the VO orbit geometry and mission timeline; therefore, actual dates during the mission as well as those discussed in subsequent sections may vary a few days from those previously presented.

Detailed Geometry for January 1977 Encounter

Since ω increases from orbit to orbit by 0.204°, the point where the spacecraft descends through the Phobos orbital plane continually moves inward. The radial change per orbit can be calculated from the differentiation of Eq. (1). This results in

$$\mathrm{d}r=\frac{er^2\sin f}{a(1-e^2)}\,\mathrm{d}f \quad (5)$$

Evaluating the differential with $f=\omega=84°$ and $\mathrm{d}f=\mathrm{d}\omega=0.204°$ gives $\mathrm{d}r=28$ km; consequently, successive piercing points will be 28 km apart radially. Thus, with the proper phasing there will be multiple close spacecraft-Phobos encounters. In order to insure such repeated encounters, the ratio of the orbital periods of Phobos and the spacecraft must be a rational number. The orbital period of Phobos is 7.65 hr and the nominal spacecraft orbital period is 24.61 hr. The ratio is 3.22. Rational numbers close to this ratio are 3, 13/4, and 16/5; however, the latter two ratios do not permit close encounters with each spacecraft orbit. The maximum number of close encounters will occur for a ratio of 3 or a spacecraft orbital period of 22.95 hr. Repeated orbit positions will then occur every spacecraft orbit and every third Phobos orbit. The VO orbit period can be changed from 24.61 to 22.95 hr with a velocity impulse of 12 m/s.

Table 1 Encounter dates of natural satellites and Viking spacecraft

	Phobos	Deimos
VO-A	Jan. 1977	Dec. 1977
	March 1977	Oct. 1978
	1979	1980
	1979	1981
VO-B	1984	Jan. 1978
	1984	1981
	1992	1987
	1993	1990

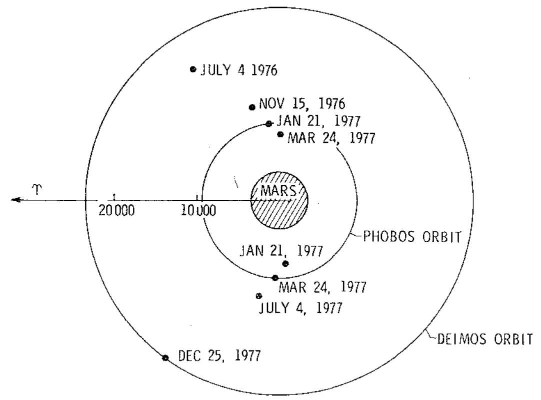

Fig. 4 Phobos and Deimos inertial encounter geometry.

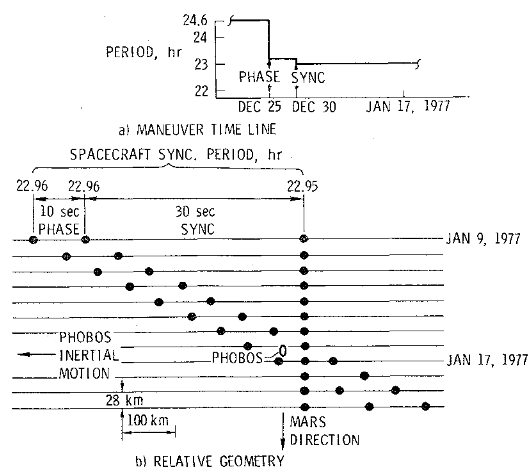

Fig. 5 Encounter maneuver strategy.

The only remaining geometric consideration is to assure that the spacecraft and Phobos simultaneously arrive at the point of intersection. The relative orbital phase of the satellites will depend on the phasing of the spacecraft orbit which will in turn depend on the particular mission profile. The current uncertainties in the physical parameters that enter into the detailed calculations and the complexity of the Viking mission profile make an exact calculation impossible at this time. However, for illustration purposes, it is assumed that the Viking orbit can be described by the initial parameters on July 1 (Fig. 3) plus apsidal precession and nodal regression due to planetary oblateness. With these assumptions, it is possible to calculate phasing and synchronization maneuvers to assure a close encounter in January.

As shown in Fig. 5, the phasing maneuver is assumed to be performed on December 25, 1976, with the synch maneuver on December 30, 1976. The phasing maneuver is scheduled 3 weeks after post-conjunction tracking is resumed, which should be adequate time for orbit determination, maneuver calculation, transmission, and verification. The phasing maneuver has no effect on the total propulsive requirements for the January opportunity since the 12 m/s required to synchronize the two satellites can also be used to phase the satellites. The 12 m/s will produce a 1.7 hr change in period. Over a five-orbit time interval such a change in period will permit more than a 360° change in the relative phase of the satellites. Thus, the first maneuver (phasing maneuver) would be designed to reduce the orbital period from 24.61 to some value greater than 22.95, such that after five orbits the proper phasing is accomplished. The remainder of the 12 m/s will then be used for the second maneuver (synch maneuver) which will synchronize the orbits.

Figure 5 also shows the effect on the encounter geometry of small changes in the phasing and synch periods. The coordinate system is centered at Phobos, and rotating to keep Mars fixed. For a synchronization period of 22.95 hr, the points where the spacecraft pierces the orbit plane of Phobos move essentially in a radial direction toward Mars as illustrated in the figure. Increasing this period by 30 sec causes the points to move in a highly inclined direction as shown. This shift comes about because the time between successive points is increased by 30 sec and the orbital velocity of Phobos is 2.1 km/sec; therefore, Phobos moves about 63 km during this additional time. On the other hand, changing the phasing period by 10 sec causes a 105-km shift without changing the slope. The 105-km is due to the 10-sec change in period, applied over five orbits times the 2.1-km/sec velocity of Phobos. Thus, by making very slight changes in the two periods, the detailed encounter geometry can be optimized for whatever experiments are being performed.

Mass determination and high-resolution imagery will be major considerations in designing the approach geometry. For accurate mass determination it is imperative that the VO pass as close to Phobos as practical for a number of orbits. This maximizes the total change in the VO velocity due to the gravitational attraction of Phobos. In addition, the maximum Doppler signature will occur if the VO passes through the Phobos-Earth line during the particular encounter which has the closest approach; equivalently, the VO orbit about Phobos has a 90° inclination in the plane-of-the-sky coordinate system.

Imagery requirements involve both resolution and surface coverage. The total resolution is calculated by taking the root sum square of the resolution due to a single pixel element (0.025 millirad) and the image smearing. The latter is calculated as the product of the relative tangential velocity and a variable exposure time based on the phase angle. The exposure time is assumed to be 0.05 sec if the phase angle is less than 45° and then increases linearly to 0.250 sec at a 90° phase angle (J.B. Wellman, JPL, private communication). Since the relative velocities are 2 km/s, the image smearing can be between 100-500 m.

Coverage and resolution will depend on the detailed sequences; however, for illustrative purposes the resolution can be obtained independent of the encounter sequence by making

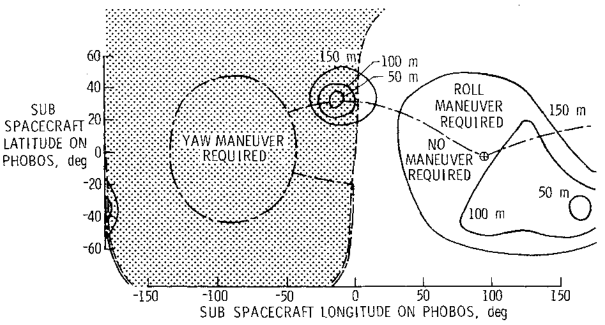

Fig. 6 Resolution and imaging capability contours for Phobos, Jan. 1977 encounter.

the following approximations: 1) the relative velocity of Phobos and the VO does not change throughout the encounter opportunity; 2) the Sun-Mars-Phobos geometry does not change; and 3) the VO-Phobos distance for imagery is 1300 km. This last assumption is to assure that Phobos fills the field of view of the imagery system, approximately 1° square. With these assumptions the resolution is a function only of the latitude and longitude of the VO at the exposure time.

Figure 6 shows resolution contours for the January 1977 encounter. For these calculations, longitude is measured east from the Mars-Phobos line and latitude is measured positive northward from the orbital plane of Phobos. The shaded area is the unilluminated part of Phobos. The subsolar point (⊕) corresponds to closest approach on January 17. The solid lines are the 50,100, and 150 m resolution contours. Also shown by the short-long dotted lines are the scan platform pointing capabilities, along with the type of VO attitude maneuver required to image that particular region of Phobos. For instance, if the VO is passing over the illuminated northern polar region of Phobos, a roll is required to view Phobos. But if the VO is passing over the illuminated southern hemisphere of Phobos a roll is not required. The two high-resolution areas at $-25°$ long, 30° lat and 155° long, $-30°$ lat, correspond to the directions along which the VO approaches and recedes from Phobos. Consequently, the tangential velocity is small and the image smearing is minimal. VO ground tracks for specific encounters will be great circles which originate in the upper left, high resolution area and terminate in the lower right, high resolution area. It is desirable to have the encounter sequence and resulting ground tracks designed to provide global coverage at various phase angles. It should be noted that both the north and south polar regions are illuminated since the Sun is nearly on the equator.

Based on mass determinations and imagery considerations, one possible sequence for the January encounter is illustrated in Fig. 7. The directions to the Earth and Sun and the components of the velocity of the spacecraft relative to Phobos are shown. The Earth and Sun are a few degrees south of the orbital plane. Since this is a descending node encounter, the spacecraft has a velocity component into the Phobos orbital plane of 1.1 km/sec. This figure shows the successive intersection points of the VO with the Phobos orbital plane. The intersection points are designed to move in toward Phobos at about 155° longitude allowing coverage of the northern hemisphere. A small propulsive maneuver decreases the orbital period by 66 sec on January 12 in order to provide 10 encounters within 100 km for the mass determination experiment. A period change of -60 sec on January 21 keeps the spacecraft in the illuminated hemisphere of Phobos during the final part of the encounter sequence and provides southern hemisphere coverage.

Detailed Geometry for March 1977 Opportunity

The phasing and synchronization maneuvers for the March opportunity will require additional propulsion. Referring to Fig. 4, during the January opportunity the satellites are simultaneously in the vicinity of the descending node of the VO orbit, whereas the March encounter requires that both be at the ascending node. The spacecraft takes about 2 hr to pass from the ascending to the descending node and Phobos takes 3.8 hr. Therefore, the total phasing correction is 1.8 hr. If phasing is performed over a 5-day period, the total propulsive requirements for a two-maneuver transfer will be 6 m/s.

The resolution plot for the March 1977 Phobos encounter is shown in Fig. 8. This figure is based on the same assumptions used to obtain Fig. 6. The best resolutions are at $-165°$ long, $-40°$ lat and 15° long, 30° lat. The Sun has moved into the southern hemisphere of Phobos, therefore, the north polar region is not visible. A roll maneuver is not required to cover most of the illuminated southern hemisphere and the South

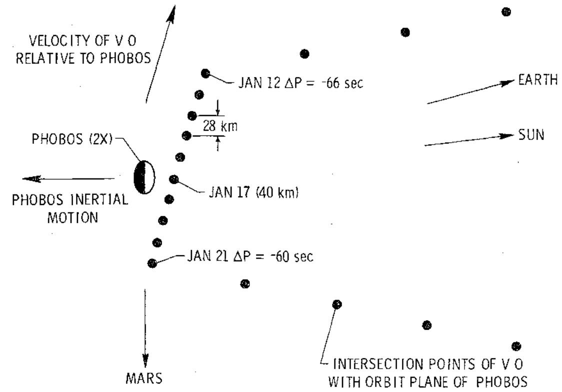

Fig. 7 Detailed encounter geometry in Jan. 1977.

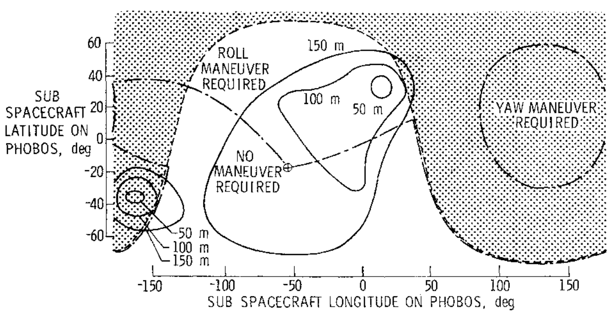

Fig. 8 Resolution and imaging capability contours for Phobos, March 1977 encounter.

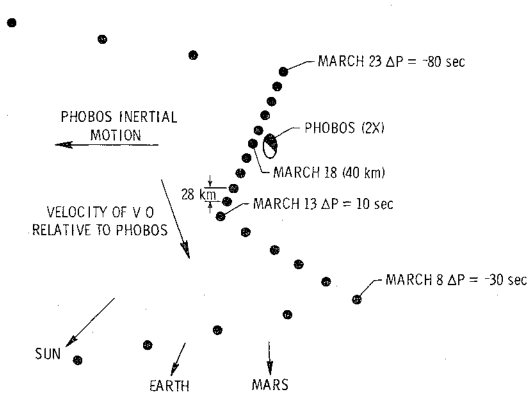

Fig. 9 Detailed encounter geometry in March 1977.

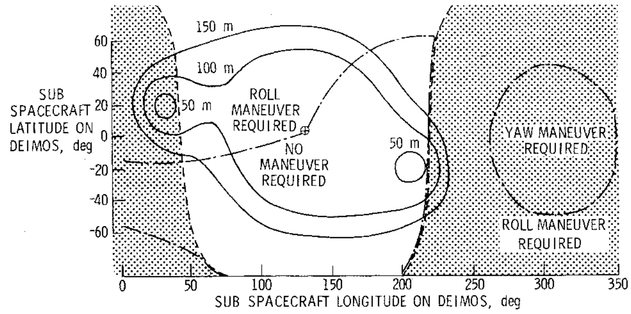

Fig. 10 Resolution and imaging capability contours for Deimos, Nov. 1977 encounter.

Pole. Considering Figs. 6 and 8 from the standpoint of coverage, it is seen that the January encounter will cover the eastern hemisphere and the March encounter covers most of the western hemisphere. Thus, coverage of Phobos should be at least 90%.

Figure 9 shows a possible encounter sequence for the March opportunity. The Earth and Sun are now about 20° south of the Phobos orbital plane and the spacecraft is ascending through the orbital plane at 1.1 km/sec. The total relative velocity is again 2 km/sec. The intersection points approach Phobos near the center of the illuminated portion and provide south polar coverage. A small change in period on March 8 is designed to position the spacecraft for the mass determination maneuver on March 13. A period change of -80 sec on March 23 completes the coverage of the illuminated hemisphere by providing north polar images.

Detailed Geometry for November 1977 Deimos Encounter

The orbital period of Deimos is 30.3 hr. Assuming that after the March opportunity, the spacecraft has been returned to a synchronous orbit with a 24.61 hr period, it will take about 50 m/s of additional propulsion to synchronize with Deimos in a 1-to-1 ratio, thereby providing the maximum number of encounters. However, a 4-to-5 ratio can be obtained for 3 m/s but this would only provide one close encounter for mass determination. The resolution plot for the Deimos encounter in November is given in Fig. 10. The best resolutions are near 40° long, 20° lat and 220° long, $-20°$ lat. The pointing capabilities of the scan platform permit imaging Deimos if the VO is passing over the southern hemisphere including the south polar region. Since only one encounter sequence with Deimos is feasible, then coverage will be limited to approximately half the entire Moon.

A possible encounter scheme is shown in Fig. 11. The Earth and Sun are about 12° north of the orbital plane, the relative velocity is about 1.4 km/s, and the spacecraft is ascending through the orbital plane at 0.4 km/sec. Because of the greater size of the Deimos orbit, the radial distance between two successive points of passing through the orbital plane is now 96 km instead of 28 km. Thus, there will be fewer opportunities for very close encounters; in fact, only five encounters pass within 100 km. The early encounters provide south polar coverage. A decrease in the orbital period of 20 sec on November 26 provides a nearly radial approach to Deimos for mass determination. Finally, a 50-sec period increase provides northern hemisphere coverage after December 3.

Although now shown in Figs. 6, 8, and 10 higher resolutions are possible for the Phobos and Deimos encounter experiments. The scan platform can move in two directions at three speeds 0, 0.25, and 1 deg/sec. Analysis of the possible resolutions using the motion of the scan platform to reduce image smear, shows that resolutions of 1 or 2 m are possible on at least two passes of each encounter experiment.

Mass Determination

As the spacecraft passes Phobos or Deimos the gravitational fields of these bodies will perturb the spacecraft orbit about Mars. An approximation to the amount of bend-

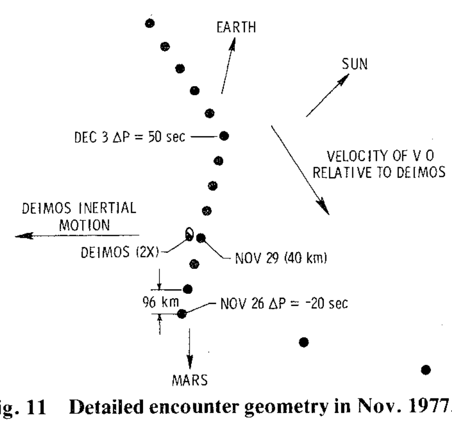

Fig. 11 Detailed encounter geometry in Nov. 1977.

ing is obtained by assuming that the relative motion of the spacecraft and the natural satellites can be represented by hyperbolic conic motion. If Phobos and Deimos have the same density as Mars, the change in velocity due to bending of the spacecraft trajectory will be about 42 and 6 mm/s, respectively, for an encounter distance of 40 km. The effect varies inversely as the distance of closest approach. A second effect is a change in the total velocity as the spacecraft approaches and recedes from Phobos or Deimos. The energy integral shows that the change in velocity would be 21 and 3 mm/s, respectively, for an encounter distance of 40 km and again the effect drops off inversely as the distance. The geometry is nearly optimal in January to view the total effect of the bending in the Doppler data. In March or November about an equal amount of the change in velocity magnitude and the bending effect will be seen in the Doppler data. The noise on the Doppler data is a proximately 1 mm/s; thus, the signals for Phobos will be easily detectable, whereas the effect due to Deimos will be much closer to the noise level. Detailed error analyses are required to examine the effects of corrupting influences such as the Mars gravity field, encounter geometry uncertainties, and so forth. Mass accuracy in the tens of percent can probably be attained. Applying an expression developed for asteriod flybys[10] yields a comparable mass accuracy estimate. Optical tracking of Phobos and Deimos will probably play an important role in eliminating the errors due to uncertainties in the relative geometry.

Error Analysis

The accuracy with which encounters can be planned and controlled is an important consideration, and a preliminary analysis is given here. There are three distinct considerations: 1) How well can the orbit of the spacecraft be determined? 2) How well can the orbits of Phobos and Deimos be determined? and 3) How well can the orbit of the spacecraft be controlled? The major orbit determination errors influencing the knowledge of the spacecraft orbit will be the orientation of the orbit and the orbital period.[11] The spacecraft orientation errors[12] will be about 0.1° which could produce a displacement of 15 km and 10 km relative to Phobos and Deimos, respectively. The period uncertainty is important because it produces a secular increase in the error from one orbit to the next. The expected period uncertainty of about 0.1 sec means that the spacecraft passes through the orbital plane 0.1 sec later (or earlier) in each orbit. After 30 orbits this error would accumulate to 3 sec. Thus, Phobos would be about 6 km farther along the orbit than expected when the spacecraft passes through the orbit plane of Phobos; whereas, Deimos would have only moved 4.5 km. These errors are the same order as the contribution from the orientation uncertainty discussed above; however, both estimates may be slightly conservative because the spacecraft will be in a 2.95- or 30.3-hr orbit and the periapsis will be at a new latitude, so the spacecraft will be experiencing a new Mars gravitational environment. In any case, the total orbit determination error is probably less than 25 km.

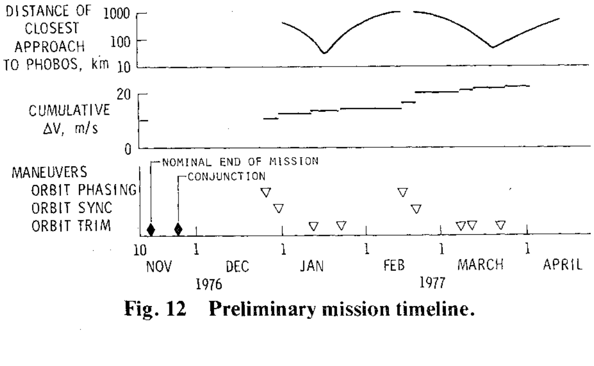

Fig. 12 Preliminary mission timeline.

The error in our knowledge[9] of the orbital periods of Phobos and Deimos are negligible over a few months. Optical tracking of Phobos and Deimos during the approach phase should reduce the along-track errors to a few kilometers and the orientation angles should be known to 0.1°.[9] These errors produce position uncertainties in the orbit of Phobos that are the same order as the uncertainties in the spacecraft orbit.

The only other source of error to be considered is that introduced by the phasing and synchronizing maneuvers themselves. Since these maneuvers cannot be performed perfectly, they will introduce errors in the orbit of the VO. For such small maneuvers, the major effect will be to produce an error in the orbital period. For example, a 12-m/s maneuver with a 1.0% proportional error will produce a period error of about 6 sec. This error will have the same effect as an orbit determination error in the period of the VO. However, a 6-sec period error is unacceptable if very close encounters are required. Therefore, several small propulsive maneuvers may be required to assure proper encounter geometry during the most critical phase of the experiment. With such small trim maneuvers, control of the orbit geometry should be about 1 to 2 sec in period; thus, during the few most critical orbits the control error will be below 20 km. Considering all three error sources, encounters as close as 40 km should be relatively safe

Mission Overview

A preliminary mission time line for the Phobos part of the experiment is illustrated in Fig. 12. The nominal end of the Viking mission for Viking '75 is November 14, 1976. Mars solar conjunction occurs on November 24, 1976, and it is expected that all spacecraft communication will be lost ten days on either side of conjunction. It is assumed that 20 days after conjunction the communications will be adequate to determine the VO orbit so that the phasing maneuver can be made on December 25, 1976. This maneuver will take about 10.5 m/s and will change the VO orbital period from 24.611 to 23.318 hr. The synchronizing maneuver will occur on December 30 and will use approximately 2.1 m/s. The closest approach distance continually decreases to a minimum of about 40 km on January 17, 1977. Orbit trims on January 12 and 21, 1977 optimize the imagery and mass determination experiments. The March opportunity starts with a phasing maneuver on February 14. An orbit synchronization on February 19 and trims on March 8, 13, and 23 serve the same purpose as those in January. The total ΔV requirements for both experiments will be approximately 20 m/s.

A mission timeline for the Deimos encounter would be similar to one of the Phobos encounters shown in Fig. 12. However, a 50 m/s impulse is required for a one-to-one synchronization with Deimos in late 1977. This insures five encounters within 100 km. If propulsive capability is limited, a four to five synchronization is possible for 3 m/s. However, this will give only one encounter within 100 km.

Conclusions

It has been shown that a science mission involving close Phobos and Deimos encounters is technically feasible and within the capabilities of the current Viking design. Multi-encounter experiments with Mars' moons can be performed in series with the nominal missions, thereby providing complementary scientific information without compromising the original mission and scientific objectives. The data obtained from multi-Phobos and Deimos encounter experiments will add significantly to our total understanding of Mars, the environment of Mars, and the origin of the solar system.

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