Navigation Demonstrations With the *Mariner* Venus–Mercury 1973 Spacecraft Requiring X-Band Receiving Capability at a Second DSN Station

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The opportunities to demonstrate two-station tracking with radio metric doppler and range data calibrated for charged particles by the X- and S-band technique during the Mariner Venus–Mercury 1973 mission are described together with the rationale for undertaking the experiments. The errors which corrupt two-station tracking for single and dual frequency operation are also described.

I. Introduction

The DSN plans to implement one X-band receiver at DSS 14 for the *Mariner* Venus–Mercury 1973 (MVM73) mission and eventually to have X-band receiver capability at the three 64-m antennas for the *Viking* 1975 (VK75) mission. If the installation of one of the second X-band receivers could be accelerated, so that it is operational at some point in the MVM73 mission, then two types of navigational accuracy demonstrations described in this article could be undertaken.

The advantages of the second X-band receiver would be:

(1) An increase in navigational accuracy for MVM73.

(2) Enhancement of the celestial mechanics experiment with the MVM73 spacecraft.

(3) Enhancement of the relativity experiment during superior conjunction of the MVM73 spacecraft.

(4) Demonstration of two-station tracking techniques with X- and S-band (X/S) calibration for use by VK75 and later missions.

(5) Maintenance of JPL technical leadership in ground-based radio navigation.

The accomplishment of these advantages depends on the timing of the implementation of the second X-band station. It is very likely that the second X-band receiver could not be made available for the prime MVM73 mission. However, as shown in Fig. 1, there are other important events after the prime mission which could employ the second receiver.

Figure 1 depicts a function, which is value divided by risks versus MVM73 mission time. Value is defined as the number of opportunities to exploit the two X-band stations with the MVM73 spacecraft times the expected information gained from each opportunity. Risk is included, since the probability of spacecraft failure increases with mission time. There is also factored in the risk the fact that the third Mercury encounter (☿ ENC 3) is being only considered at present and is not an established objective.

The first opportunity in the MVM73 Extended Mission occurs in June of 1974 when the MVM73 spacecraft is occulted by the Sun. The relativity experiments planned for this period could be greatly enhanced by two-station tracking with the charged-particle errors removed by X/S calibration. The next important demonstration opportunity is the time of second Mercury encounter. As shown in Fig. 1, the spacecraft passes through zero declination in early September 1974, and encounters Mercury for the second time late in September. If two-station tracking with X/S can be shown to overcome zero declination and nongravitational force errors, then this technique can heavily influence VK75 and later missions. This will encourage future missions to request the support of the Deep Space Network 64-m subnet which will be eventually implemented with S-band receiving capability.

After the second Mercury encounter, there may be a third encounter. However, zero declination occurs about a month after the third encounter, making this encounter less attractive and, of course, more risky, in terms of spacecraft reliability, than the second.

Even after the third Mercury encounter there is still the value of gaining experience with two-station X/S tracking in preparation for *Viking*.

II. Navigation Demonstrations

The use of X/S with two-station tracking is intended to overcome two types of problems. Problems in the first group are referred to as navigational problems; those in the second are data noise problems. The navigational problems are:

(1) The uncertainty in the solar pressure on the spacecraft.

(2) The gas leaks from pressure tanks on the spacecraft.

(3) The singularity in the determination of declination which occurs as the spacecraft passes through zero declination.

Reference 1 discusses the problem of various navigational errors, such as nongravitational forces on the MVM73 mission. Figure 2 is taken from Ref. 1 and shows the effect of nongravitational accelerations at the 5×10^{-12} km/s^2 level for the Venus encounter. As shown in Fig. 3, the acceleration due to the uncertainty of the solar pressure on the spacecraft could vary from 5 to 20×10^{-12} km^2/s, depending on the actual distance of the spacecraft from the Sun. Figure 3 was calculated (by O. H. von Roos), using the *Mariner 9* spacecraft area and an uncertainty of 5% in the total solar pressure. The actual uncertainties for MVM73 have yet to be determined. However, Fig. 3 is representative of the level of uncertainty.

The acceleration on the spacecraft due to attitude-control gas leaks can be represented by Fig. 4. Figure 4 (supplied by J. W. Zielenbach) shows the magnitude and time of occurrence of random accelerations due to attitude control gas leaks on *Mariner 9* near the time of encounter. Figures 3 and 4 show that the uncertainty ellipse for nongravitational forces shown in Fig. 2 could be much larger.

There are two techniques for solving the navigational problems mentioned above. The nongravitational errors (solar pressure and gas leaks) can be reduced by taking two-way and three-way doppler simultaneously over a very long baseline. Reference 2 describes how this data type can help in this situation. The zero declination problem is corrected by taking range from stations simultaneously or nearly simultaneously over a long baseline where that baseline has a large north/south component.

In both cases, however, the success of the two-station tracking technique depends on the quality of the data. Figure 5 shows error bars for the components that corrupt two-way versus three-way range. The error bars show optimistic and pessimistic levels for each error. Figure 5 also shows the same errors when X-band reception capability has been added. In almost every case, there are improvements due to the additional information provided by the X-band measurement of range. Appendix A of Ref. 3 describes the details of the improvements due to X-band. The improvement in clock synchronization with X/S is based on the supposition that three-way range can be used to solve for clock offset if charged particle errors are eliminated. Three-way doppler will help to maintain synchronization by measuring clock drifts after clock offset is measured. This approach may not work, but if three-way range data is taken with X/S calibration we may find the technique which does measure clock offset and prove the scheme for use by future missions.

III. Charged Particles

The area of greatest improvement with the X-band receiving capability is the charged-particle calibration. Table 1 shows four different techniques for calibrating the charged-particles present in the Earth's ionosphere and the interplanetary space plasma. As indicated in Table 1, X/S removes the charged-particle effect in both media and provides calibration for both range and doppler. The other three techniques are deficient in one aspect or another. Faraday rotation measurements made from geostationary satellites do provide a way for calibrating range and doppler due to ionospheric effects. However, the space plasma is left uncalibrated. Using Faraday rotation in conjunction with two-way minus three-way differences is a complementary technique. Since the space plasma is almost exactly common to the two-way and three-way measurements, their difference eliminates the error. However, the ionosphere is very different, due to the different elevation angles and seasonal conditions over the two tracking stations and must be calibrated by local measurements.

To summarize the advantages of X/S calibration over the other three charged-particle calibration techniques, we take the X/S advantage over each of its competitive approaches. The advantage of X/S over DRVID is that X/S is potentially more accurate, and will provide a range calibration, as well as a doppler. X/S has similar advantages over Faraday rotation in that it is more accurate. Besides this, the X-band receiver will be a fully operational part of the Deep Space Network equipment while the Faraday rotation polarimeter at Goldstone DSCC is only an experimental unit of low reliability, and the Faraday rotation data currently being received from Australia is provided by an outside agency. Finally, X/S has an advantage over two-way versus three-way measurement for removing the space plasma effects. The two-way versus three-way data could be used. However, there are other navigational errors in this data which might make it difficult to distinguish between charged-particle errors and equipment delay differences. Consequently, if the charged-particles are removed by X/S, then the two-way versus three-way can be used to solve for clock offsets and drift rates, free from the charged-particle influence.

IV. Conclusions

The nongravitational forces, charged-particle effects, and occurrences of zero declination shown in Figs. 1 through 6 are intended to show that the MVM73 mission is an excellent opportunity to demonstrate the power of two station tracking with X/S calibration which potentially could improve navigational accuracy for the MVM73 and future missions.

References

1. Jordan, J. F., et al., "The Effects of Major Errors on Planetary Spacecraft Navigation Accuracies," paper presented at the AAS/AIAA Conference, Santa Barbara, Calif., August 1970.
2. Ondrasik, V. J., and Rourke, K. H., "Applications of Quasi-VLBI Tracking Data Types to the Zero Declination and Process Noise Problems," paper presented at the AAS/AIAA, Astrodynamics Specialists Conference, Fort Lauderdale, Fla., Aug. 17–19, 1971.
3. Mulhall, B. D., "Navigation Demonstrations With the MVM73 Spacecraft Requiring X-Band Receiving Capability at a Second DSN Station," IOM 391.3-540, Mar. 10, 1972 (JPL internal document).

Table 1. Charged-particle calibration

Area	Calibration			
	X/S	DRVID	Faraday rotation	2-way — 3-way
Ionosphere	Range and doppler	Doppler	Range and doppler	Not calibrated
Space plasma	Range and doppler	Doppler	Not calibrated	Range and doppler

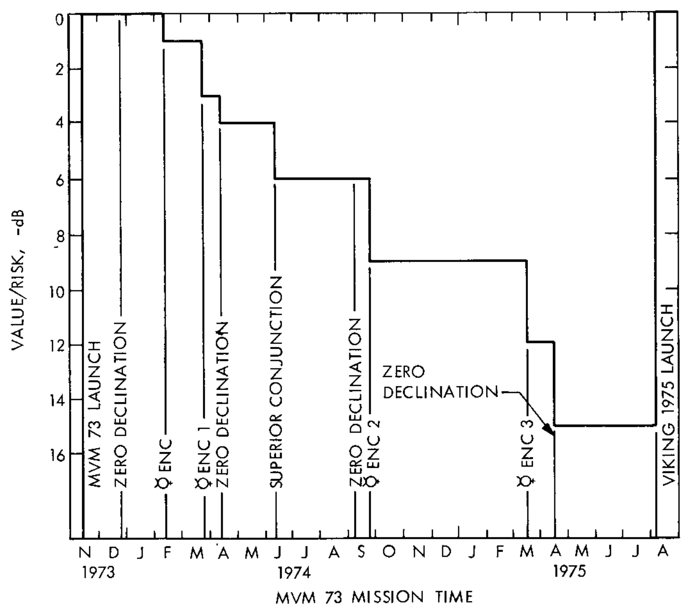

Fig. 1. Two-station tracking opportunities

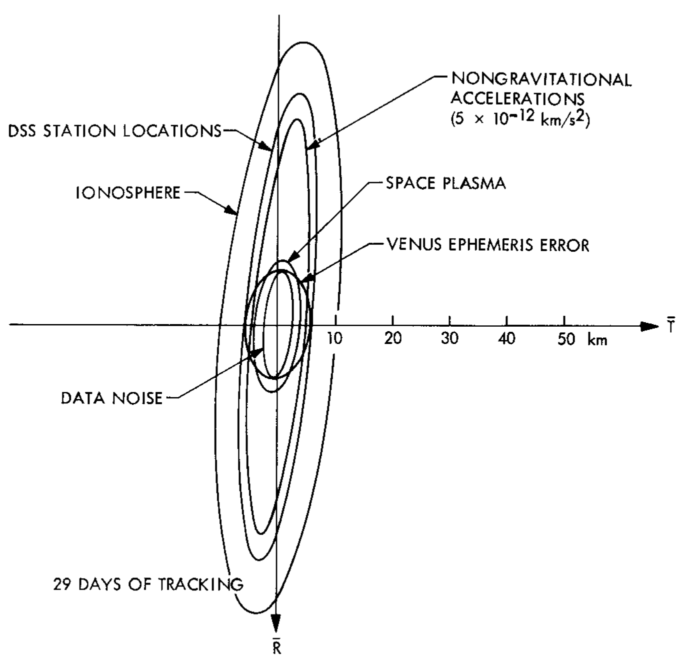

Fig. 2. Target-plane 1-sigma position dispersion

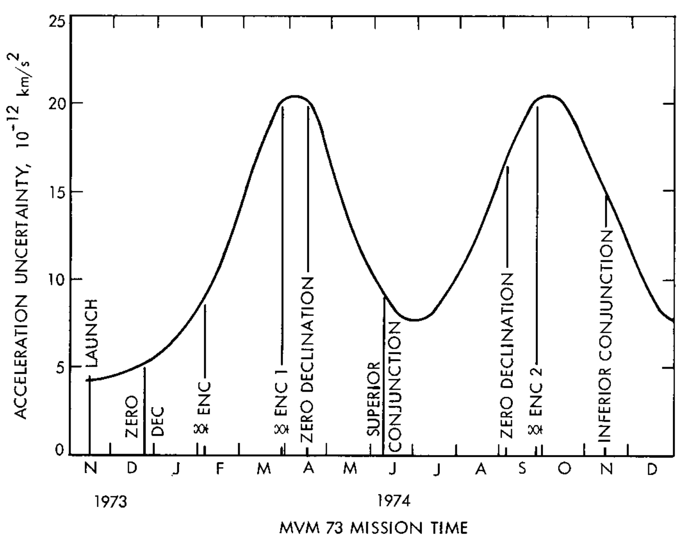

Fig. 3. Acceleration uncertainty due to solar pressure

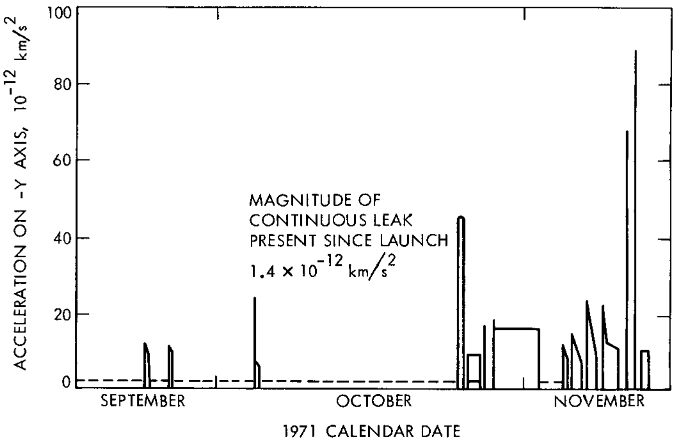

Fig. 4. MM'71 spacecraft accelerations due to attitude-control gas leaks

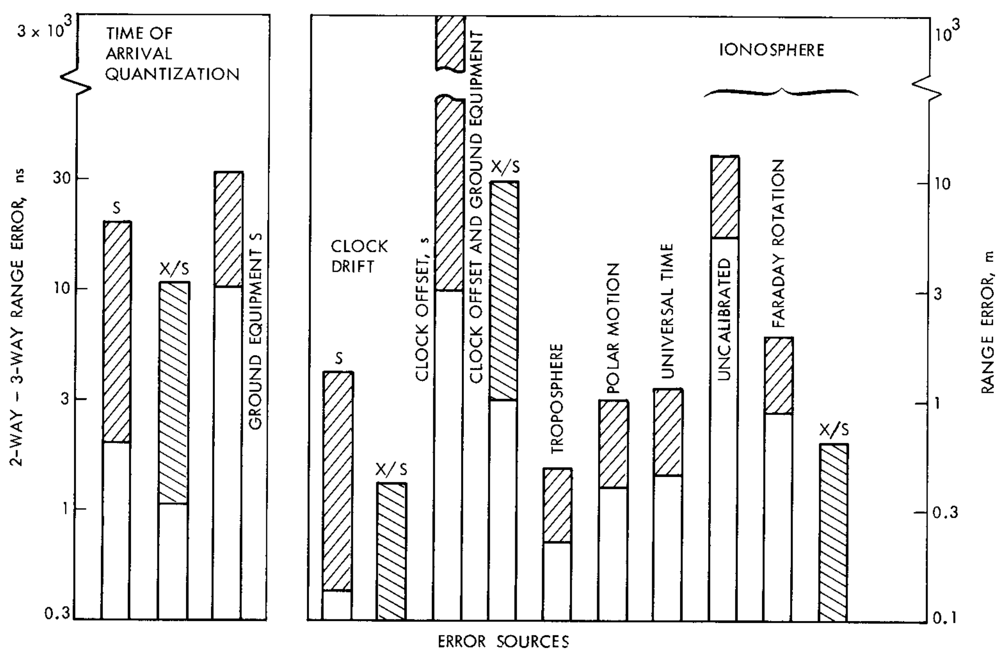

Fig. 5. Two-station tracking error sources