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Mars Surface Asset Positioning Using In-Situ Radio Tracking

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Previous Mars lander positioning results relied only upon Direct-To-Earth (DTE) radio metric observations. Accuracy improvements required many weeks of observations and ultimately an accuracy floor of about 100m (1σ) was reached due to limited geometry and uncertainties in the observations. In early 2004, in-situ measurements of the Mars Exploration Rovers will be collected by the Odyssey Orbiter and used to obtain rover position solutions with accuracies of about 10m (1σ) in three days or less. Rover surface operations will benefit from the improved accuracy and timely availability of solutions. Alternative techniques are available, but have disadvantages such as: no assured landmarks (image triangulation), reduced telemetry data return (orbiter-rover DTE ranging), or complex dual station tracking requirements (Same Beam Interferometry). Thus, this paper primarily addresses positioning performance improvements from in-situ orbiter to rover doppler tracking compared to DTE doppler only.

INTRODUCTION

Current Mars Program plans call for landing two rovers around the equatorial region of Mars in early 2004. These Mars Exploration Rover (MER) missions will arrive near the end of the Mars 2001 Odyssey Orbiter science mapping mission. An in-situ radio link between the orbiter and rovers will be available for telecommunication and navigation support.

Two-way doppler measurements, collected by the orbiter during the short (<10 minute) over flights, will be used to determine the rover positions with accuracies sufficient to assist in rover surface operations planning. DTE only observations will also be available; but, due to their weaker navigation information content, they will only be used for initial positioning support.

Alternative surface positioning techniques exist such as: surface feature triangulation from images taken by the rover's camera [1], DTE orbiter-rover doppler plus ranging [2] and Same Beam Interferometry (SBI) [2-4]. These techniques, under ideal conditions, can provide improved positioning performance; however, use of these alternatives can result in reduced telecommunication performance or increased operations complexity and a need for more tracking resources. Figure 1. shows the primary and optional radio tracking measurements.

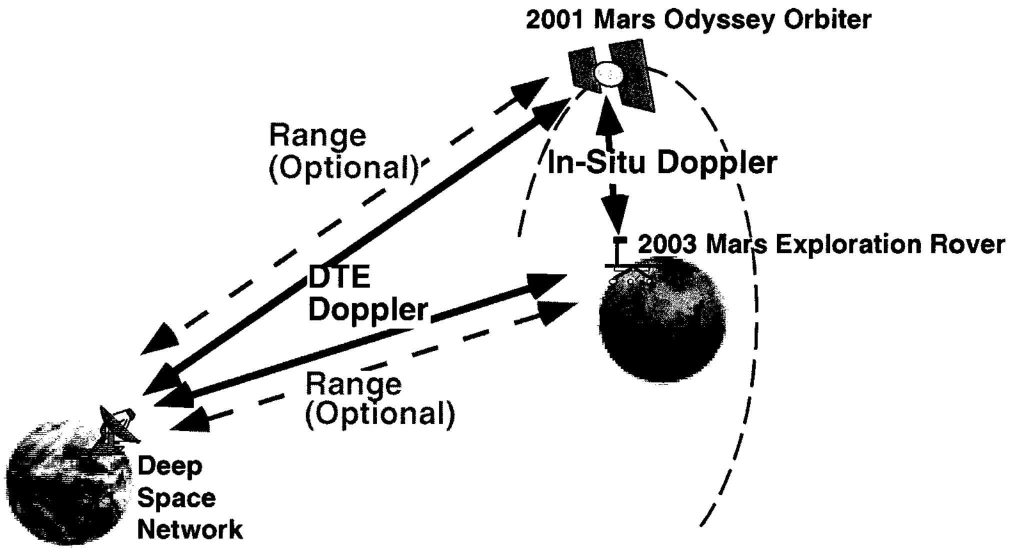

Fig. 1. - Mars Surface Positioning Measurements.

This paper presents results from a linear 'consider' covariance analysis of the expected MER positioning performance using DTE only and in-situ orbiter tracking. The MER position is simultaneously estimated with the Odyssey Orbiter state and maneuvers resulting from momentum wheel desaturations. Additional error sources treated as 'consider' parameters include: Mars gravitational constant, Mars gravitational field (selected terms up to degree and order 50), solar radiation pressure, planetary ephemeredes of Earth and Mars, and Earth troposphere.

ANALYSIS ASSUMPTIONS

Tracking schedules for radio metric observations are based on mission operations scenarios developed for both the Odyssey orbiter and MER missions. DTE observations for MER are planned for one hour each morning and 1.5 hours each evening. For the Odyssey Orbiter, DTE doppler only is assumed to be available for about 4 hours per day [5]. The location of Odyssey Orbiter can be predicted during the time period of the later MER missions since strict orbit phase requirements ensure known sun relative geometries. Orbit determination assumptions for both the rover and orbiter are provided in Table 1.

Rover DTE only performance is calibrated to reflect results achieved for the Mars Pathfinder lander [6-8]. Geometric constraints such as minimum elevation angles, range limits and planetary occultations are included. Concurrent observations between the in-situ orbiter, the Deep Space Network (DSN) and Mars rover are assumed. This allows for realistic (fully correlated) in-situ orbiter errors to be incorporated in the lander uncertainty estimates. Uncertainties are derived from the linear covariance analyses updated in one-hour batches as observation become available.

When radio metric range observations are used via the alternative techniques, the Earth and Mars ephemeris uncertainties contribute significantly to rover position errors. An updated 'DE405' planetary ephemeris covariance, provided by Myles Standish, is used and includes Mars pathfinder observations. These ephemeris uncertainties are treated as 'consider' parameters. To reduce this conservative assumption, a constant range bias is estimated to reduce the line-of-sight component that is highly observable in the range measurements.

Table 1. Orbit Determination Assumptions

	Odyssey Orbiter	Rover
*Estimated **Considered		
Initial Epoch		
	1/1/04	1/4/04
Lander Location		
Latitude, Longitude		2° 15' S, 6° W
Orbital Parameters		
Altitude	396x404 km	
Semi major Axis	3794.2 km	
Eccentricity	0.008	
Inclination	93 deg	
Period	2 hours	
Data Arc Length		
	11 days	7 days
Tracking		
DSN (Goldstone,Canberra)	4 hours/day	1 hours/day
In-Situ (Odyssey Orbiter to MER)		10 minutes/day
Data Types/Quality		
DSN 2-Way Doppler Weight (1σ) @60sec	0.1 mm/s	0.1 mm/s
In-Situ 2-Way Doppler Weight (1σ) @60sec		1.0 mm/s
DSN 2-Way Range Weight (1σ) @60sec	5 m	5 m
DSN 2-Way Range Bias (1σ)	100 m	100 m
In-Situ 2-Way Range Weight	none	none
Gravity Perturbations		
Mars GM** (10σ)	.08581 km^3/s^2	
Mars Oblateness Terms** (10σ)	Selected 50x50	
Planetary Ephemeris** (includes Pathfinder data)	DE405+	DE405+
Spacecraft Configuration		
Momentum Wheels?	Yes	
Balanced Thrusters?	No	
Non-grav Accelerations		
Stochastic Acceleration* (1σ)	none	
Solar Pressure**	20% of area	
Small forces model* (1σ)	none	
Earth Station Locations and Calibrations		
Station Locations (1σ)	0 cm per	0 cm per
Troposphere** (1σ), wet/dry	5 cm / 0 cm	5 cm / 0 cm
Ionosphere (1σ), night/day	0 cm / 0 cm	0 cm / 0 cm
Polar Motion (1σ)	0 cm	0 cm
Timing UT1-UTC (1σ)	0 cm	0 cm
Momentum Wheel Desaturation Maneuvers		
Location	Every 6 hours	
Fixed pointing (3σ), per axis	spherical	
Total* (1σ)	1.0 mm/s	

RESULTS

Odyssey Orbiter state uncertainty estimates are consistent with current performance achieved with the Mars Global Surveyor mission [3]. Figure 2 shows estimates of the Odyssey radial, along track and cross track orbit components. Odyssey orbit uncertainties, predominantly in the along track, are caused by uncertainties in the orbiter momentum wheel desaturation maneuvers and the gravity field of Mars as seen in Figure 3.

The geometric benefit of in-situ doppler observations is evident in Fig. 4. With only two short passes, the rover position uncertainty is reduced to below 1km (1σ). Within two days the uncertainty is reduced to a level of 10's of meters. In contrast, the DTE doppler only observations produce a much slower rate of uncertainty improvement. This is primarily due to the lack of geometry variation between the Earth tracking stations and the rover.

Figure 4 also shows the effect of a rover traverse at day eight of up to 100m. Again, the position uncertainty can be reduced to below 10m (1σ) after two Odyssey orbiter over flights.

The total rover position uncertainty is dominated by errors in the 'z-height' or perpendicular distance from the Mars equator. Since both MER missions will land near the equator, the 'z-height' uncertainty will be mapped almost entirely into the latitude component of the positions.

Figure 5 shows the contribution of uncertainties in dynamic and measurements models to the rover position uncertainty. The dominant errors are caused by uncertainties in the Odyssey Orbiter position caused by the Mars gravity field.

Rover observations from the in-situ orbiter are nominally constrained to be above 20 degrees and assume a doppler noise weighting of 1mm/s over a 60 second count time. Figures 6 and 7 shows the performance variations resulting from lower and higher elevation limits and different doppler weighting.

Including radio metric range observations can significantly improve rover positioning performance. Figure 8. shows improvements from including range to the rover only and then to both the rover and Odyssey orbiter. Table 2. provides a comparison of the relative advantages and disadvantages of the various techniques.

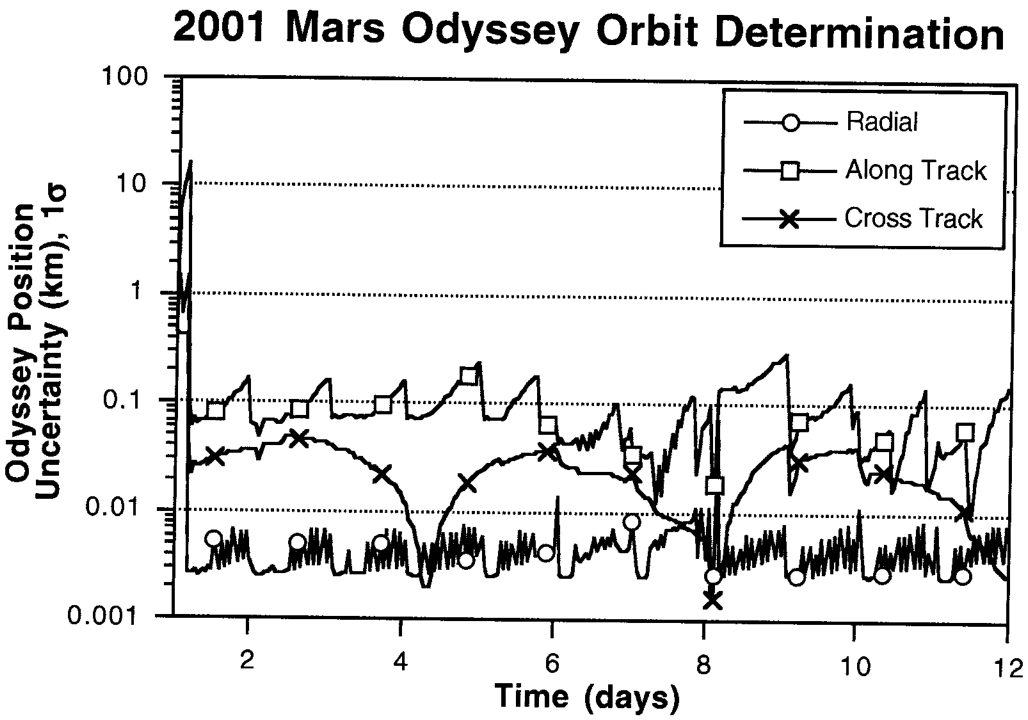

Fig. 2. – Components of Odyssey Orbiter position uncertainties.

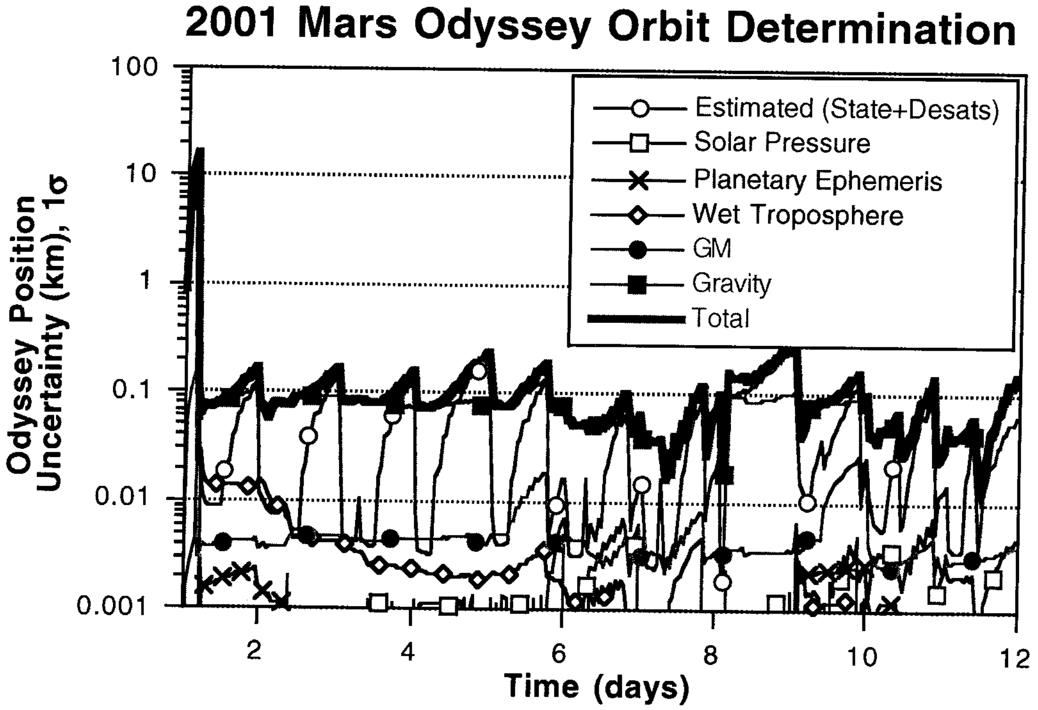

Fig. 3. – Uncertainty in Odyssey Orbiter position due to uncertainties in dynamic and measurement models.

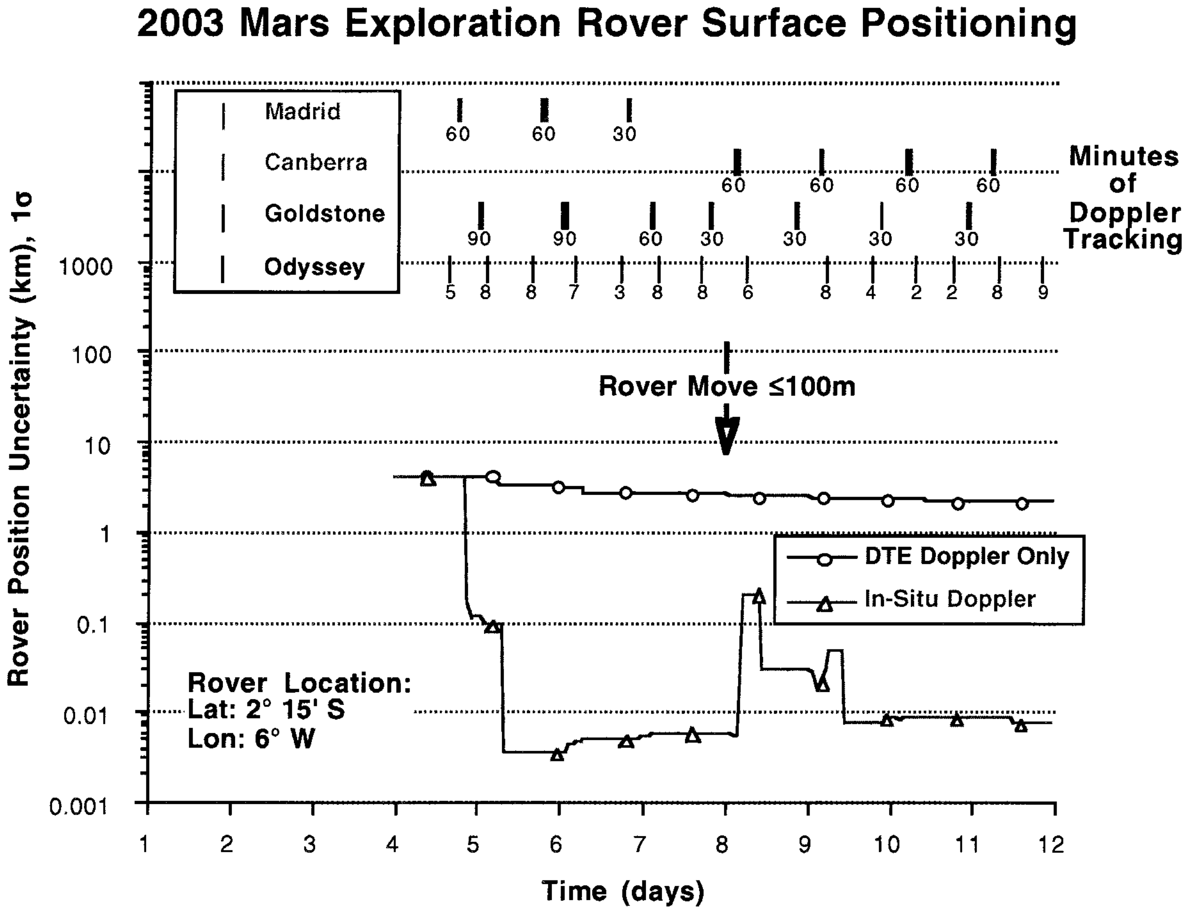

Fig. 4. – Doppler only surface positioning performance.

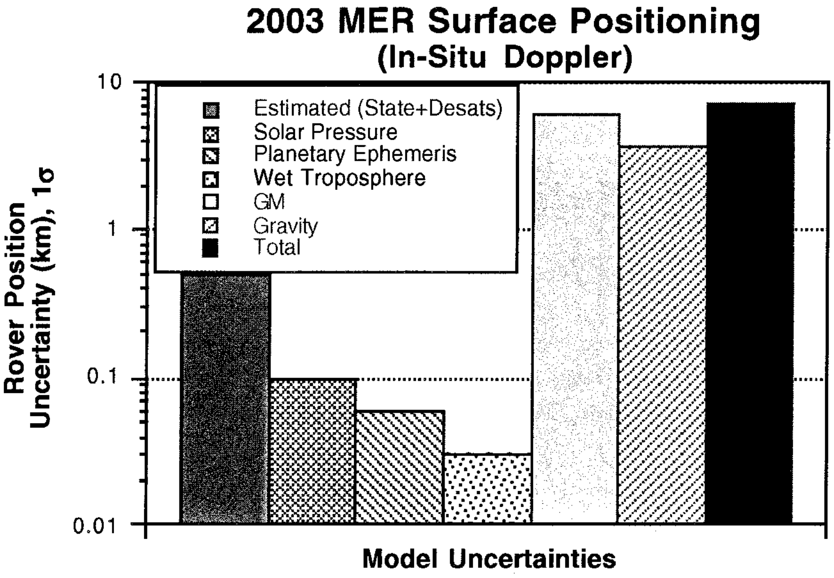

Fig. 5. – Uncertainty in rover position due to errors in dynamic and measurement models.

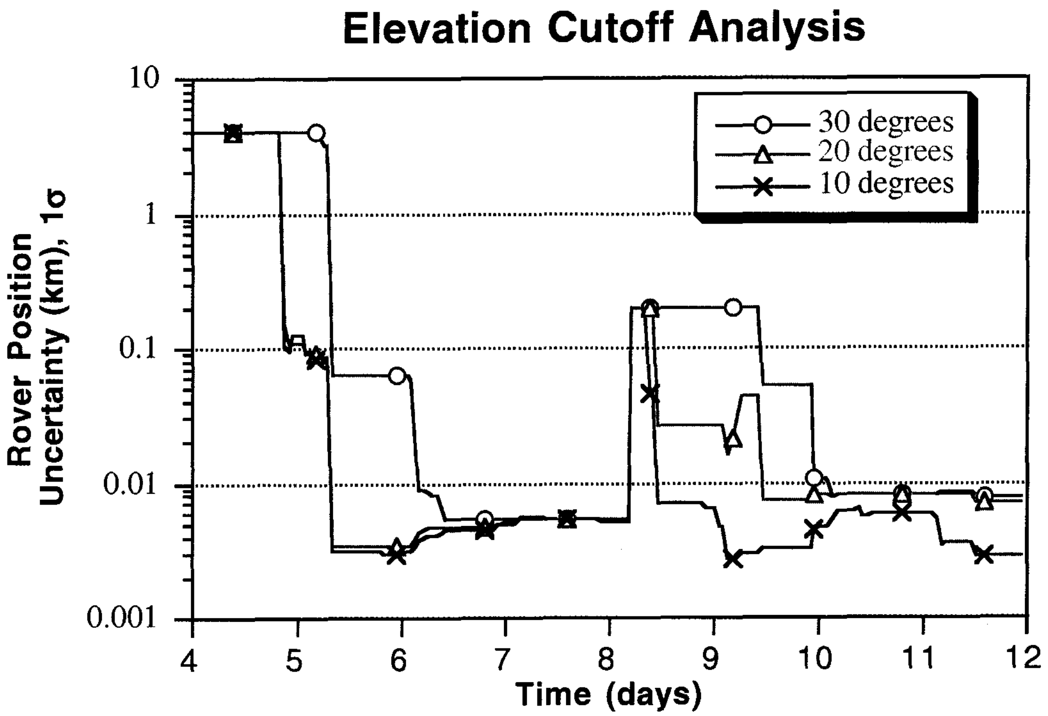

Fig. 6. – Rover positioning sensitivity to in-situ doppler elevation cutoff.

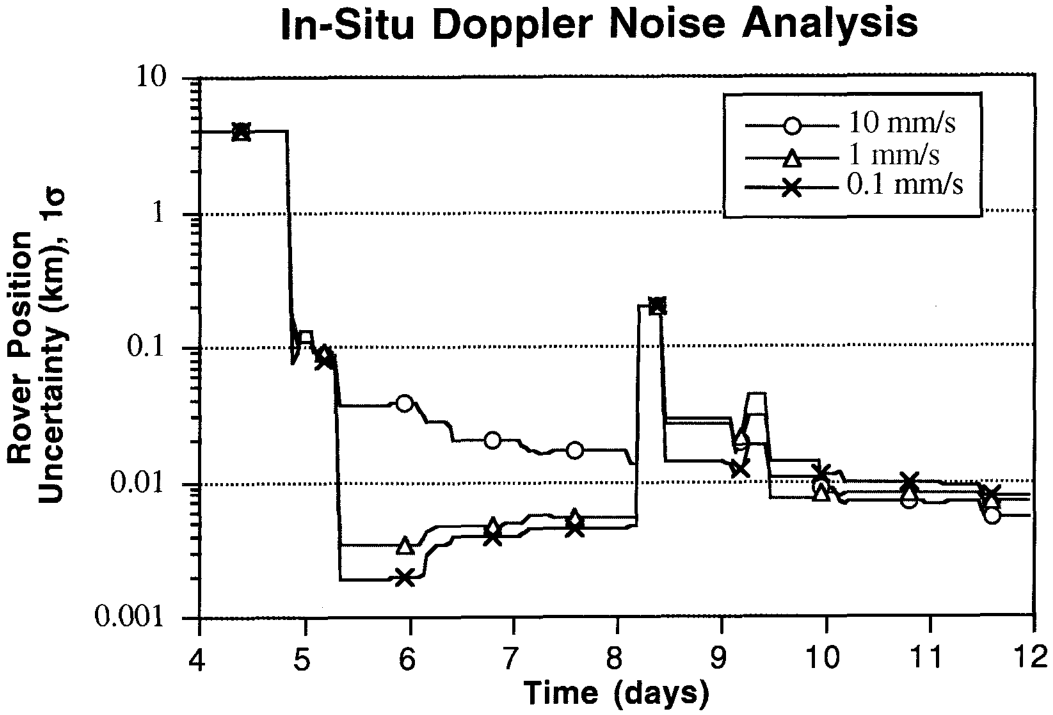

Fig. 7. – Rover positioning sensitivity to in-situ doppler weighting.

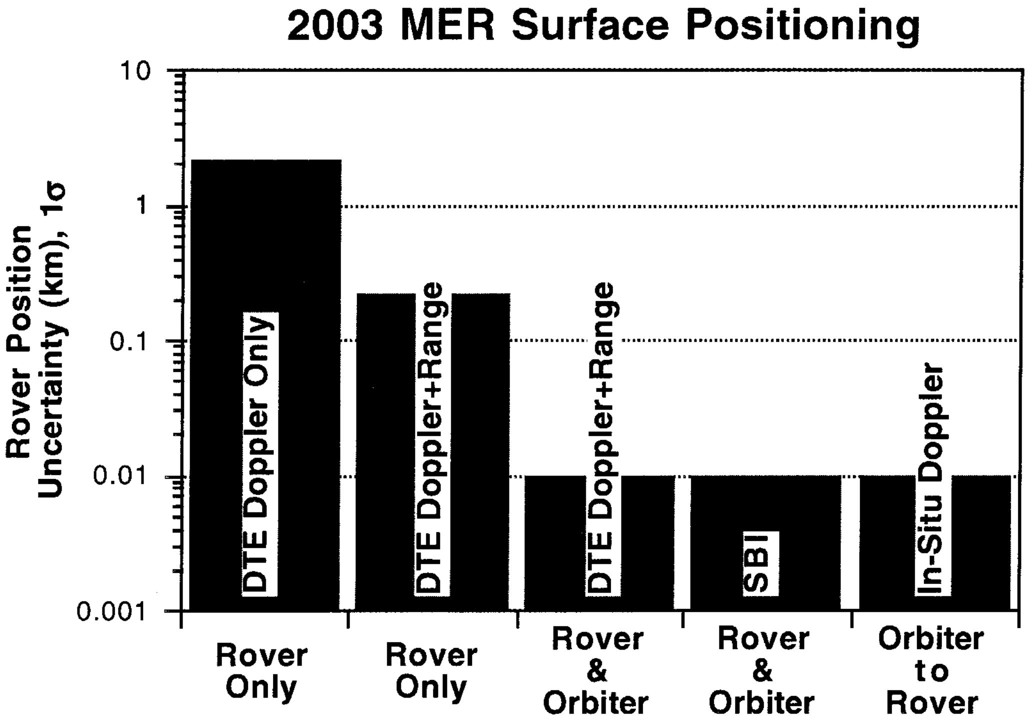

Fig. 8. – Alternative rover positioning performance comparisons.

Surface Positioning Technique	Strengths	Weaknesses
DTE Doppler Only (Rover Only)	• Proven performance • Operational experience • Telecom unaffected	• Z-Height not well determined due to poor geometry
DTE Doppler+Range (Rover Only)	• Proven performance • Operational experience	• Reduces telecom • Earth & Mars ephemeris uncertainties contribute to poor Z-Height determination
DTE Doppler+Range (Rover & Orbiter)	• Excellent performance	• Reduces telecom for both Rover and Orbiter
Same Beam Interferometry	• Excellent performance	• Unproven performance • Complex Tracking
In-Situ Doppler (Orbiter to Rover)	• Excellent performance • Telecom improved	• Unproven performance

Table 2. – Alternative rover positioning technique comparisons.

CONCLUSIONS

Significant accuracy and time-to-solution improvements are available for rover positioning using in-situ orbiter radio metric measurements. The improved positions are useful for rover operations planning and for cartographic improvements.

Given that the rovers will be tracked by an in-situ orbiter primarily for telecommunication purposes, the in-situ doppler observations are essential free. Also, considering the disadvantages of using radio metric ranging and/or SBI, the in-situ technique provides the best cost/performance solution for Mars surface positioning.

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