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ABSTRACT OF PROPOSED PAPER FOR AAS CONFERENCE TO BE HELD IN VICTORIA, B. C., CANADA 16-20 AUGUST 1993

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TITLE: Mars Relay Satellite Orbit Design Considerations for Global Support of Robotic Surface Missions

ABSTRACT:

This paper discusses orbit design considerations for Mars relay satellite (MRS) support of globally distributed robotic surface missions. The orbit results reported in this paper are derived from studies of MRS support for two types of Mars robotic surface missions: 1) the Mars Environmental Survey (MESUR) mission, which in its current definition would deploy a global network of up to 16 small landers, and 2) a Small Mars Sample Return (SMSR) mission, which includes four globally distributed landers, each with a return stage and one or two rovers, and up to four additional sets of lander/rover elements in an extended mission phase.

Mars relay satellites can provide important benefits in the support of such missions. Among the potential benefits are significant improvements in overall communications link performance and global connectivity, use of simpler, lower performance telecom subsystems for the surface mission elements, and reduced demands on Earth-based tracking stations.

The key requirements of the missions studied that are important from the standpoint of MRS orbit design include the following:

- For each of the two missions studied, a single MRS is to be capable of providing the required relay support for the full complement of landed elements deployed by that mission. A second MRS may be included for backup.
- Virtually full global coverage is required for both mission types. The MESUR mission landers may be deployed over the full range of

latitude and longitude. The SMSR lander/rover sets may be deployed anywhere to within 5° of the poles.

- Both missions require a relatively high data return of about 10 Mb/s from every lander each Mars day (sol). In addition, the SMSR mission calls for at least two communications periods/sol for each lander/rover set to allow a full Earth-in-loop operational cycle/sol; one communications period around sunset for data return to Earth for analysis and planning of the next sol's activity, another communications period near sunrise to allow uplinking of commands from Earth.
- The MRS support must be compatible with relatively simple lander design and operations.
- Both missions require that the MRS be launched on a relatively low cost launch vehicle.

Several different types of Mars orbits were initially considered for providing global coverage, including both circular and elliptical orbits with short to long orbit periods and inclinations from about 50° up to polar. Representative candidates of these types of orbits were evaluated with respect to several parameters, which relate directly or indirectly to the mission requirements. The most important of these parameters include: contact times and relative data return capability per sol versus surface location, Earth and Sun occultation frequency and duration, MRS mass delivery capability into orbit for specific launch vehicles, and orbit stability. The paper presents a summary of the results of analysis and tradeoffs of these orbit parameters. ~~Is presented~~. Examples are provided below.

Surface contact times were evaluated by generating data of the types shown in Figs. 1 and 2. Figure 1 illustrates contact times versus longitude during a sol for a particular latitude. This type of data clearly shows the duration and regularity of individual contact times. Plots of the type shown in Figure 2 provide statistical summations of global contact times. The evaluation of contact times clearly demonstrated the regularity of surface coverage provided by inclined circular orbits.

While consideration of contact times by itself is important in the design and operation of a mission, the factor of range must also be taken into consideration to evaluate potential data return capability. In the comparison of data return between the orbit types, a number of telecommunications parameters (e.g., lander transmitter power) could be assumed fixed, but other parameters (e.g., lander and MRS antenna beamwidths) were treated as variables. Figure 3 compares data return results for three types of orbits. In this comparison, variable telecommunications data rate is considered, as variable data rates can be employed to enhance data return when communications range varies. As indicated in Figure 3, the candidate elliptic orbit benefits most from variable data rates; however, variable rates involve design and operations complexities. Another illustration of data return is provided in Figure 4, in which a class of circular, sun-synchronous orbits is compared as a function of site latitude. This type of data permits selection of desired balance between equatorial and polar regions. The class of circular, sun-synchronous orbits compared in Figure 4 was found to include attractive candidates for MRS global support. The periods and inclinations of many of the orbits in this class are shown in Figure 5.

Figure 6 presents comparative results for another important operational parameter, namely MRS-Earth occultations. Data is shown for individual occultation occurrences as well as the aggregate of occultations experienced in a full sol. I-he data of Figure 6 shows very favorable results for example candidates from the circular, sun-synchronous class of orbits (21 and 22 Revs per 5 sols repeat orbits), The paper will also include the results of similar analyses for sun occultations of the MRS.

The results of analysis of MRS delivery capability into orbit will also be included in the paper. An example of results of this type of analysis is provided in Figure 7, in which delivered mass capability is shown for the 2003 Mars launch opportunity with delivery into a circular, sun-synchronous 22-rev/5 sol repeat orbit using a Delta 7925 launch vehicle. Both total dry mass, including propulsion system, and net mass are shown, and an optimum launch period is identified assuming a constant propellant load.

Mars arrival conditions are also an important consideration from the standpoint of orbit orientation. For example, orbit orientation in terms of the ascending node relative to the day/night terminator influences the occultation characteristics and timing of communications periods relative daylight operations. Table 1 is an example of results for orbit orientation analysis. For the case shown in Table 1 (circular, sun-synchronous 22-rev/5 sol repeat orbit), a very small node offset is achieved at arrival without inducing apsidal rotation.

" Fig. 1

Contact Time Characteristics
MRS: Circular, Sun-Synchronous, 37 Revs/5 Sols, Repeating
30 Deg User Elevation Mask
Latitude = 0 deg

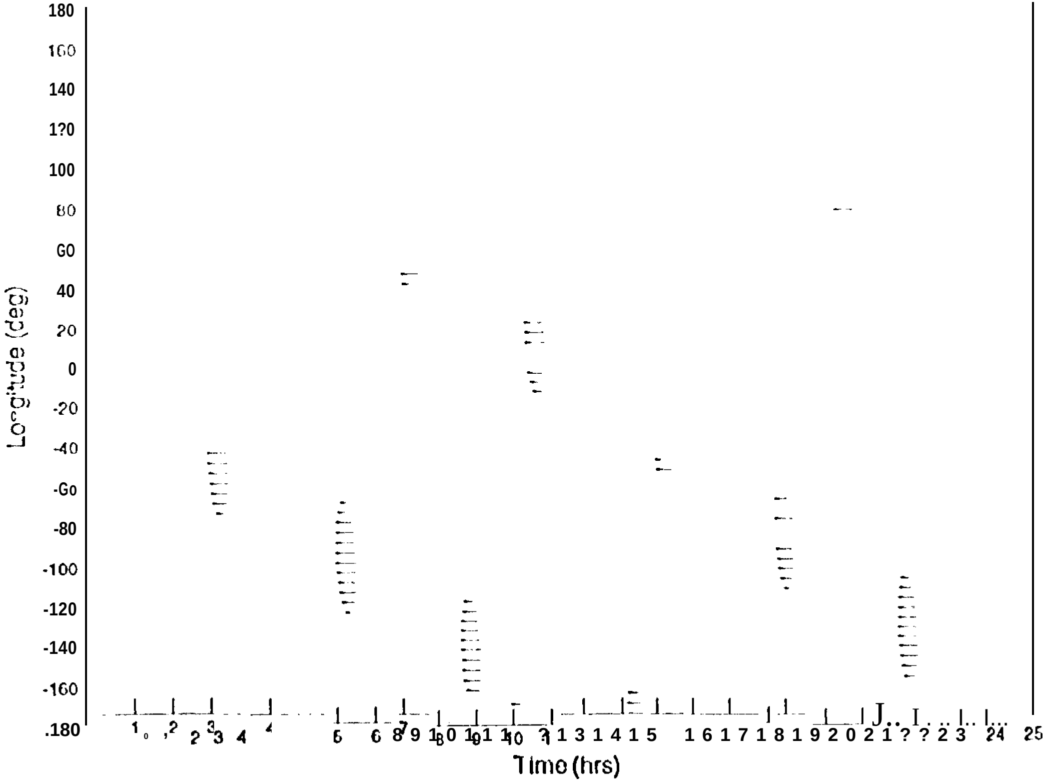


Fig. 2 Surface Contact over 5 Sols
MRS: Circular, Sun-Sync, 37 Rev/5 Sols, Repeating
Lander 30 Degree Elevation Mask

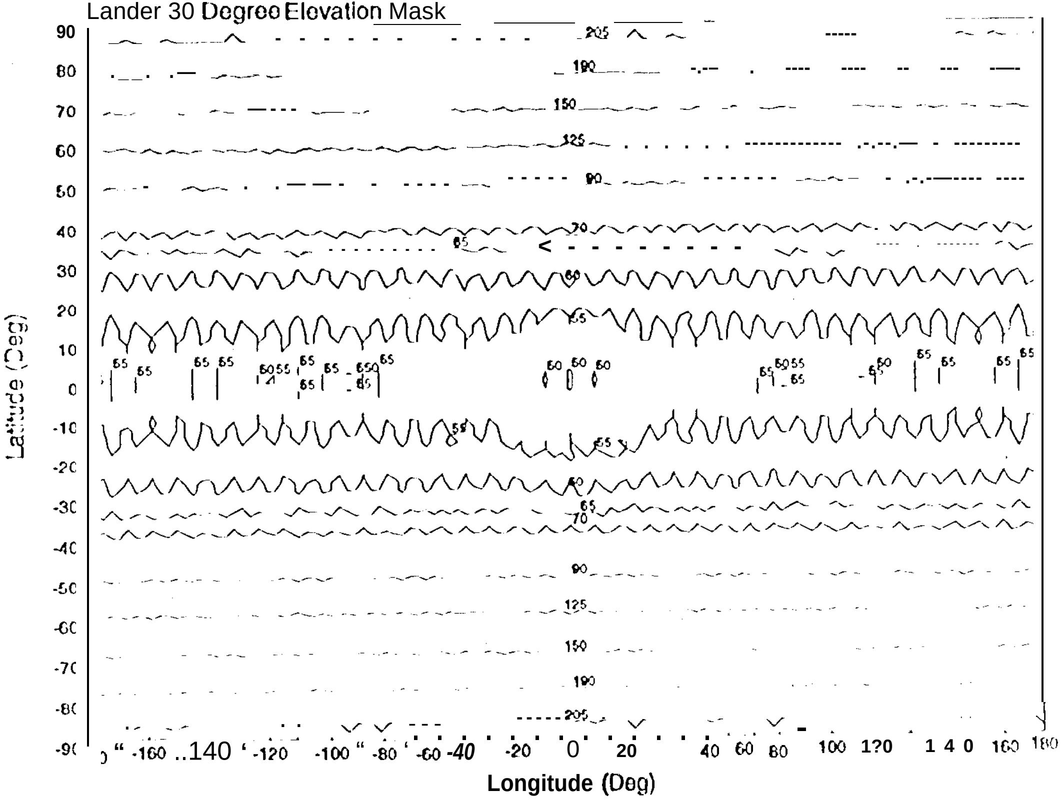


Fig. 3 DATA RATE/QUANTITY COMPARISONS BETWEEN ORBIT TYPES
MRS: 67 DEGREE BEAMWIDTH, LANDER: HEMISPHERICAL ANTENNA, 1 W TX POWER

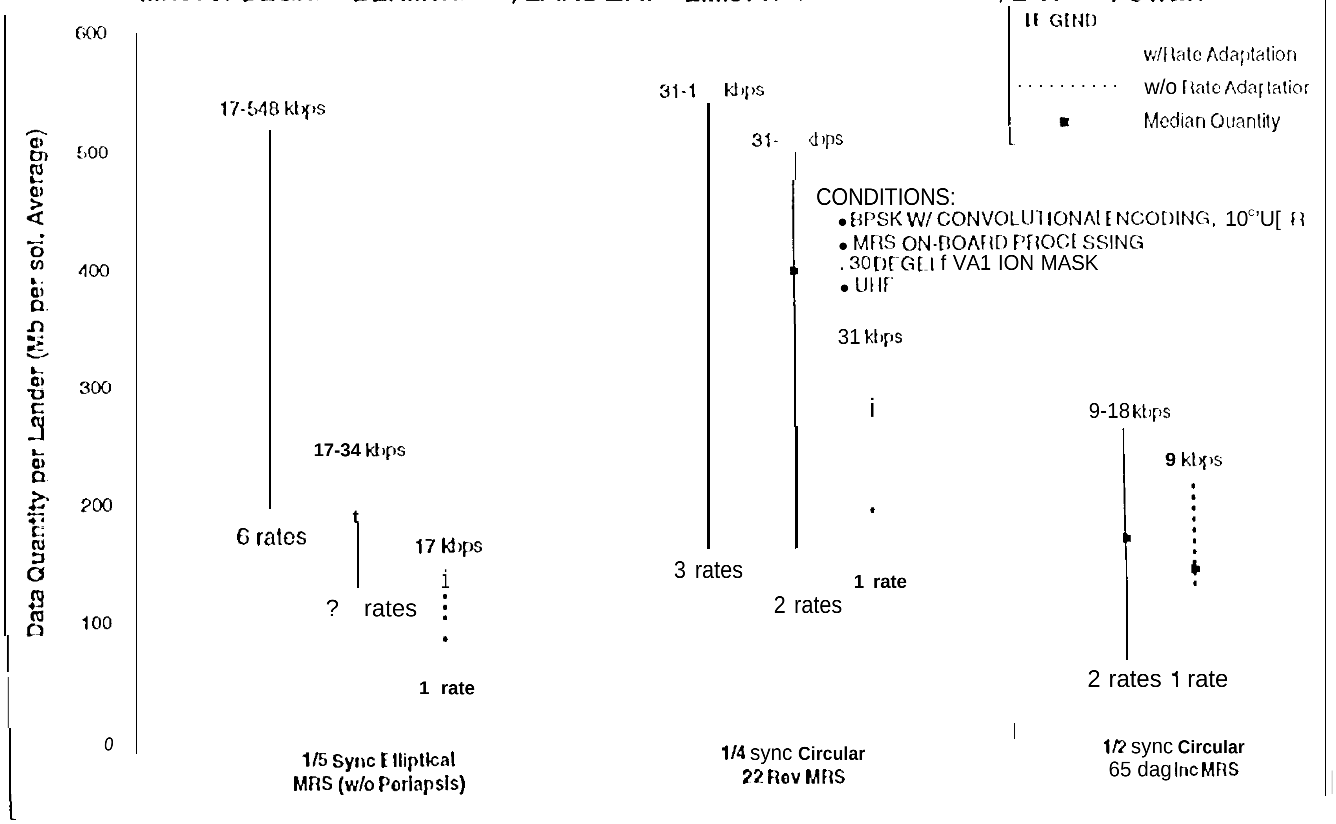
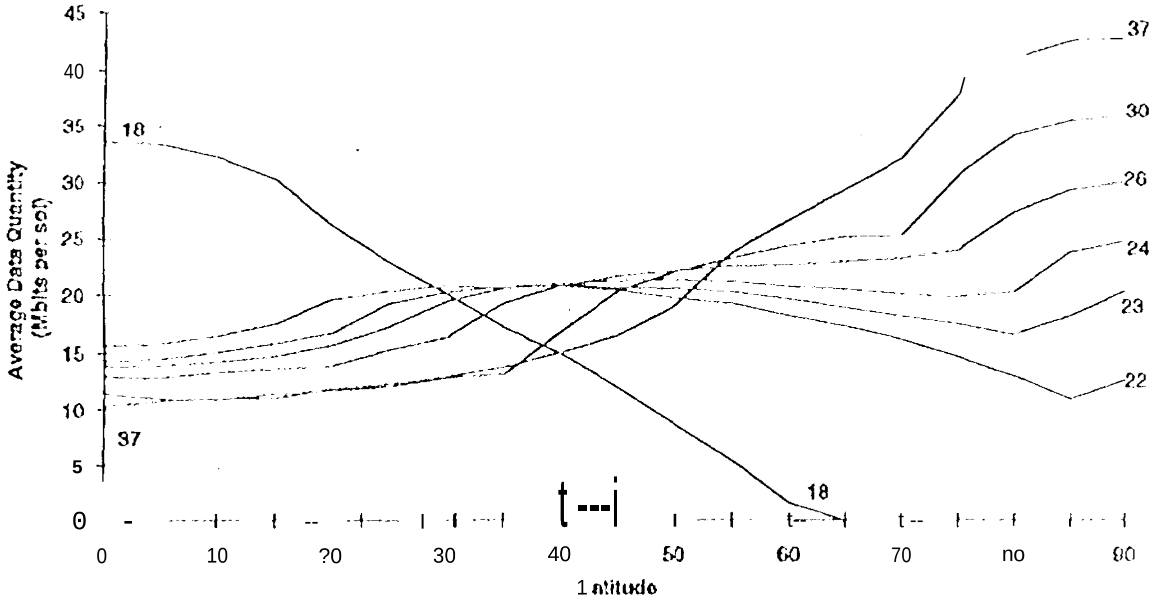


Fig. 4 Average In Situ Return Data Quantity per Sol per Lander versus Latitude
Average over 5 Sols, for Various Circular, Sun-Synchronous MRS Orbits
(Results are Symmetrical about the Equator)



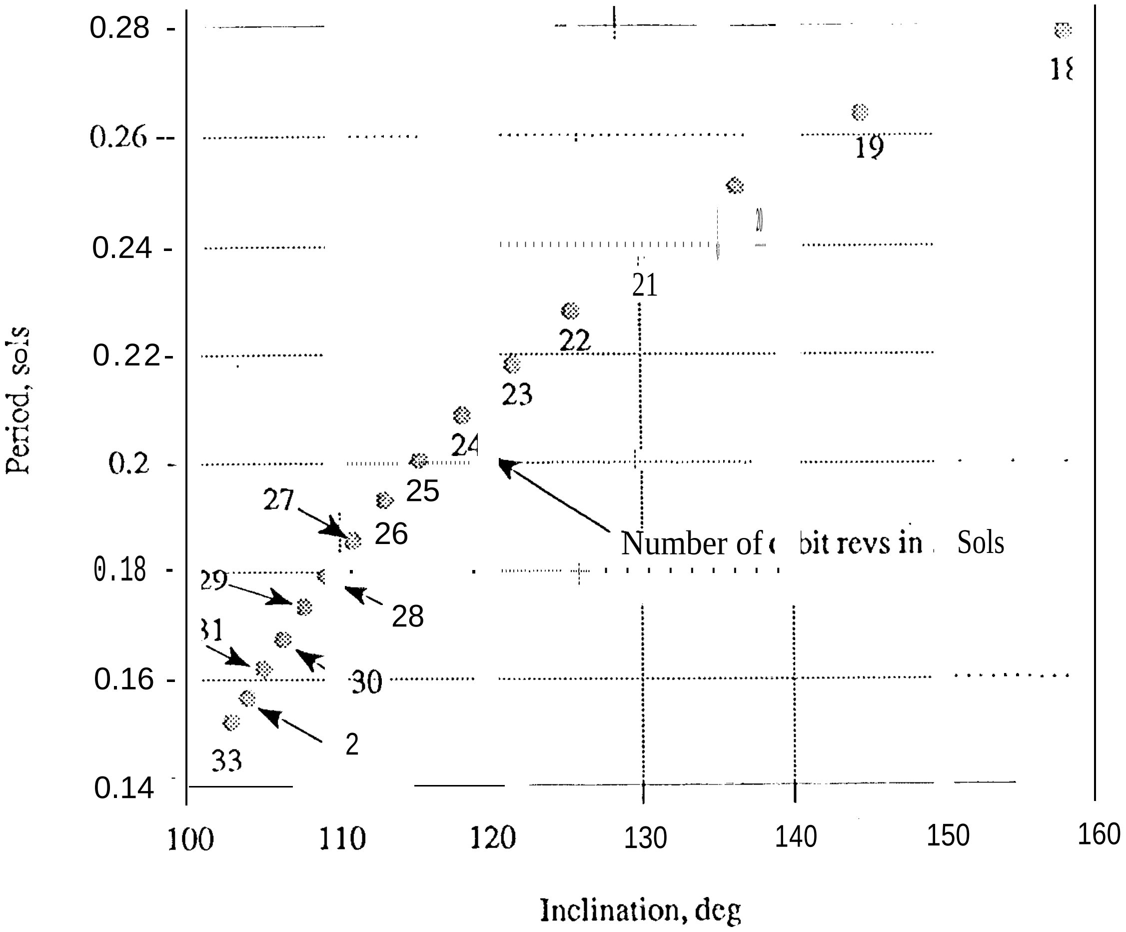
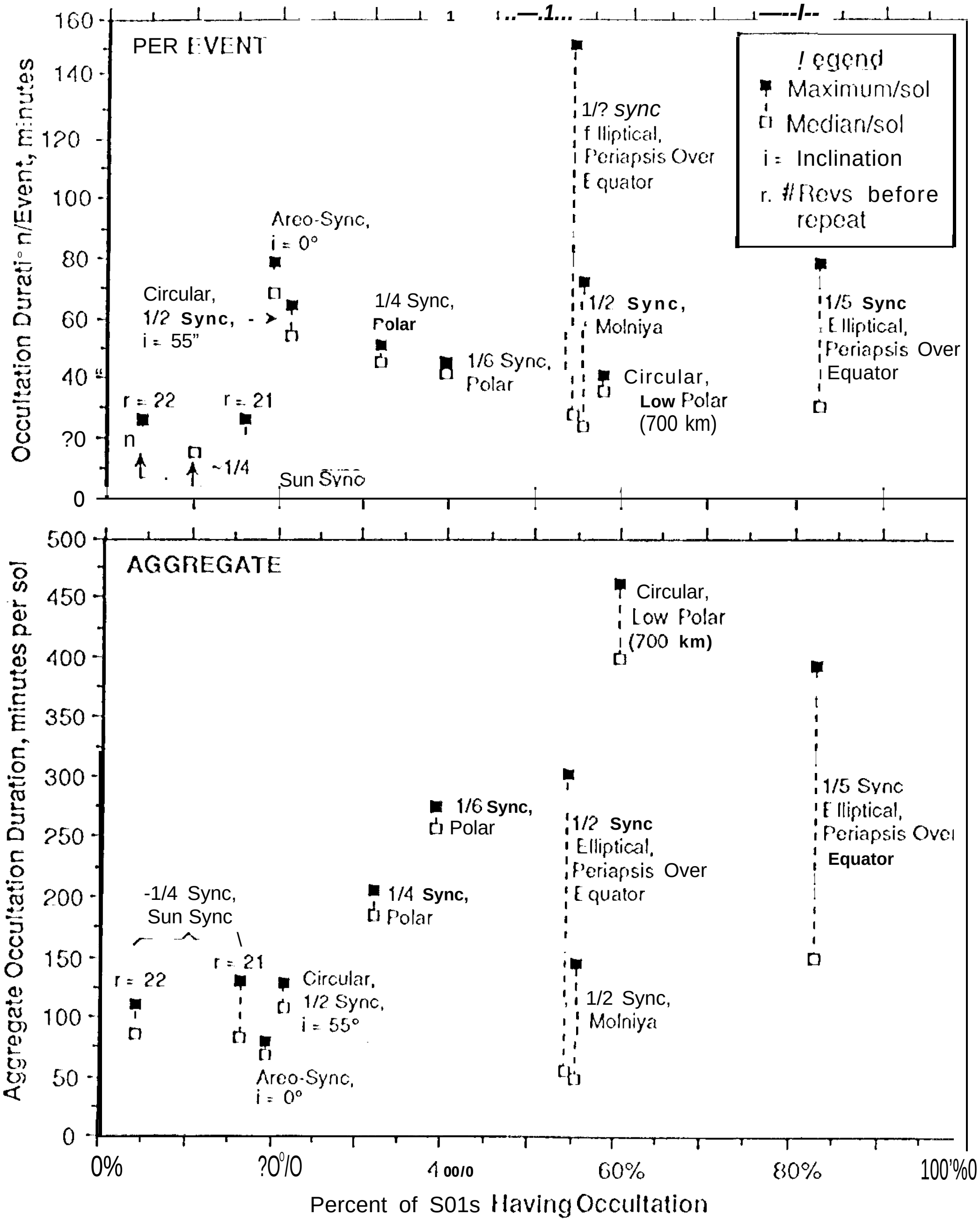


Fig. 5 Sun synchronous S-sol repeat orbits

Fig. 6 STATISTICS OF MRS-TO-EARTH LINK OCCULTATION



Note: Median is taken over all sols in which some occultation occurs

Fig. 7 MAXIM(JM DRY MASS vs I. AUNCl 1 DATE for a CONSTANT PROPELLANT LOAD

2003 Opportunity - Circular 22 Revs / 5 Sols Orbit

Delta 7925 Performance

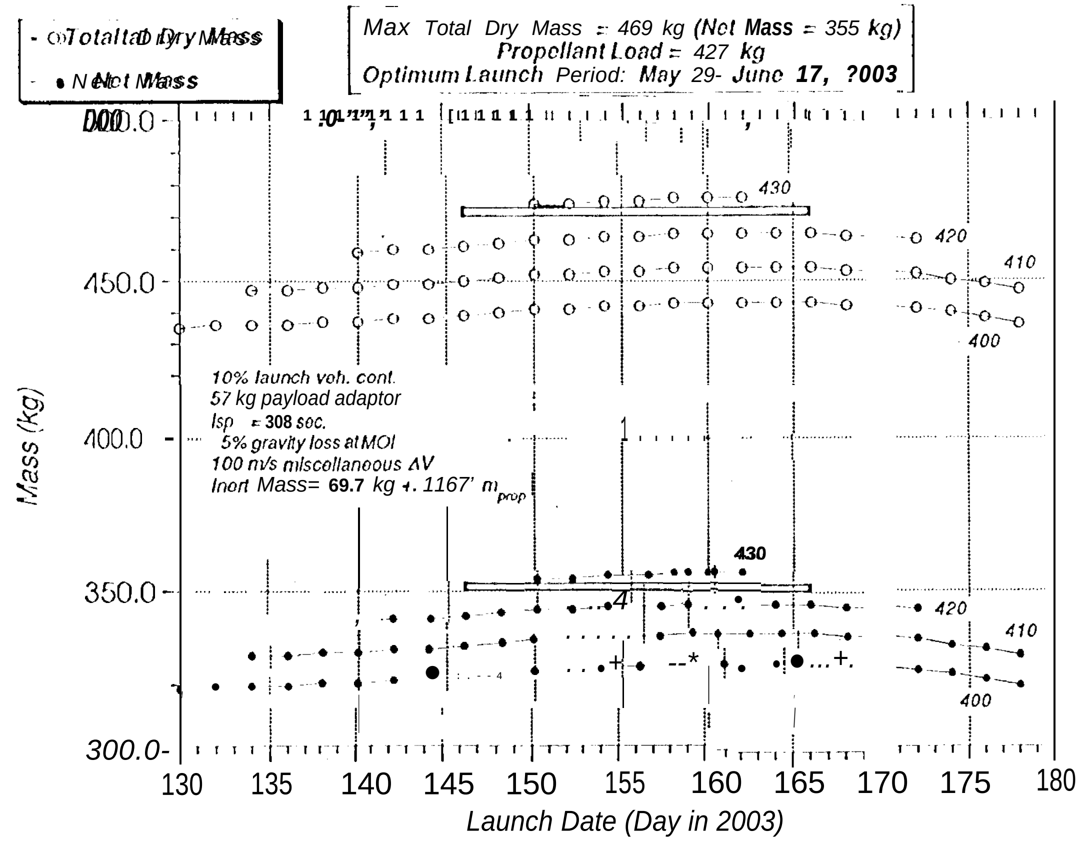


Table 1. 2003 LAUNCH PERIOD and ARRIVAL CONDITIONS

Launch Date	Arrival Date	C3 (km²/s²)	DLA	VHF' (km/s	Insertion	Node O//set'
5-29-2003	12-24 -?003	9.228	-6.100	2.716	South	7.0" East
6-.2-?003	12-25-2003	8.955	-5.700	2.708	**south**	6.3" East
6-6-?003	12-27-2003	8.825	-5.500	2.702	**south**	5.4 " East
6-10-2003	12-31-2003	8.6'51	-5.500	2.699	South	4.3" East
6-74-2003	1-1-2004	9.048	-5.700	2.698	**south**	3.0" East
6-18-2003	1-3-2004	9.432	-5.900	2.702'	**south**	**1.4°** fast

' Angle from 6 PM point to Ascending Node

No broken plane maneuvers

Launch Vehicle	Max Total Dry Mass	Max Net **Maw**	Propellant load
Delta 7925	469 kg	355 kg	469 kg
Atlas IIAS	870 kg	701 kg	792 kg