Navigation and the Mars Global Surveyor Mission

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Introduction and Overview

The MGS spacecraft was successfully launched from Cape Kennedy by a Delta II 7925 vehicle on 11/7/96, 17:00:50 UTC. Injection into the trans-Mars trajectory went smoothly with the actual or reconstructed injection targeting within 1.3 sigma of the planned targeting.

We are now thirty-eight days into the mission; the first trajectory correction maneuver (TCM-1) was successfully completed on 11/21/96 with the second TCM planned for 3/21/97. Encounter and the Mars orbit insertion (MOI) maneuver shall occur on 9/12/97. 1 he capture orbit is being planned for a 48 hour orbital period, a 3700. km periapsis distance and a descending node at 5:42 pm local mean solar time.

After a cautious '[walk-in" period, this highly elliptical capture orbit shall be nearly circularized by aerobraking (AB). This technique was first utilized for an interplanetary mission by Magellan. l-he interval from MOI to the beginning of the mapping phase is approximately 180 days with AB taking 123 days (i. e. walk-in: 18 days, main part of AB: 94 days and walk-out: 11 days).

With the initiation of the mapping phase on 3/15/98, science data acquisition shall be continuous for one Mars year or 687 earth days. Navigation shall maintain a 2:00 pm, sun-synchronous, low altitude, short periodic and "frozen" orbit throughout this phase. In addition, the ground track coverage shall be nearly uniform in order to maximize data acquisition from the nadir pointed science instruments.

Although this paper deals with the MGS mission, a brief status of the Mars Pathfinder mission will be presented.

Navigation During the Interplanetary Phase

I-we-way, time-delay and coherent doppler data, at an X-band frequency, are being analyzed to navigate the spacecraft. The resultant, reconstructed trajectory and the spacecraft's predicted motion are being used to design the TCMS, provide the DSN with predictions to track MGS, used on-board the spacecraft to determine its location anti provided to other flight teams for planning and analysis. Typical analysis results, showing doppler and time-delay residuals, are given in Figs. 1 and 2. Both are indicative of accurate navigation. 1 he progressive targeting of the spacecraft to its final aimpoint is given in a Mars centered target plane (Fig. 3). Shown are the launch vehicle's planned and achieved targeting as well as the planned and achieved I-CM-I result, In addition, the final targeting prior to the MOI maneuver is indicated. MOI is being planned as a pitch-over maneuver with a velocity-change of 968. m/s resulting in a 48 hour capture orbit period.

Planning for Orbit Insertion and Aerobraking

After capture into the highly elliptical orbit, the plan is to circularize the orbit with AB and arrive at the mapping orbit when the mean sun has drifted into the the 2:00 pm local solar time orientation. 1 hereafter, the orbit precesses at the same rate as the apparent motion of the mean sun around Mars. This produces a sun-synchronous orbit required for science observations. During walk-in, the periapsis altitude shall be lowered cautiously, using propulsive maneuvers. This allows the flight team to estimate atmospheric densities and compare them with estimates assumed during planning. During the main phase of AB, the challenge is to maintain a balance between enough atmospheric drag to achieve the nearly circular orbit and protect the spacecraft from undue heating. Close monitoring of the progress of AB is required. Small propulsive maneuvers, to raise or lower the periapsis altitude, shall provide the control mechanism to achieve the previously mentioned balance. Throughout AB, navigation is required to predict the time of periapsis passage to 225 seconds and the radial distance at periapsis to within 1.5 kilometers. Figs. 4 and 5 show the expected period reduction and variation in periapsis altitude throughout AB.

Mapping Phase and Science Objectives

Navigation is required to establish and maintain the mapping orbit specified in Table 1. From this orbit, the nadir pointed, science instruments shall continuously acquire data which will allow the the science objectives to be satisfied. Maintaining the orbit can be achieved by executing small propulsive maneuvers at monthly intervals. I-his is necessary to counteract the effects of atmospheric drag and gravity perturbations. The mapping phase begins on 3/15/98 and extends until 1/31/2000. A summary of the maneuver (i. e. velocity-change) plan or allocation throughout the mission is given in Table 2.

Table 1. Mapping Orbit Specification

Element	Mean Value
a(km)	3775.1
e	0.0072
Period (min)	117.
Descending node is Sun synchronous at 2:00 pm	
Frozen orbit in order to minimize altitude variation	

Table 2. Strategy For Propellant Usage
Expressed As a Velocity-Change (m/s)

Propulsive Maneuvers Maneuver	Bi-prop	Mono-prop	Attitude Control	Comment
Interplanetary Phase				
TCMs	33.1	2.0	0.5	Targeting
MOI	968.2	0.0	5.9	Capture
Orbit Insertion Phase				
Walk-in	7.5	2.5	0.1	Lower periapsis
Main	0.0	5.0	5.0	Corridor control
Walk-out	0.0	20.0	30.0	Raise periapsis
Pop-up	14.5	2.5	0.0	Emergency
Reserve	5.5	0.0	0.0	---
ABX	67.0	0.0	0.4	Increase periapsis
TMO	18.0	0.0	0.1	Transfer to Map
OTM-1	15.0	0.0	0.0	Frozen orbit
Mapping Phase				
OTMs	0.0	3.9	40.0	Orbit Trims
End map	0.0	22.8	0.0	Quarantine orbit
Relay Phase				
	0.0	1.0	10.0	---
Total	1128.8	**59.7**	**92.0**	Capability: 1280.5

Figure	Caption
1	Navigation analysis result - representative doppler residuals (Hz).
2	Navigation analysis result - representative time-delay residuals (range units).
3	Progressive interplanetary spacecraft targeting.
4	Planned orbital period reduction during aerobraking.
5	Planned variation in altitude at periapsis during aerobraking.

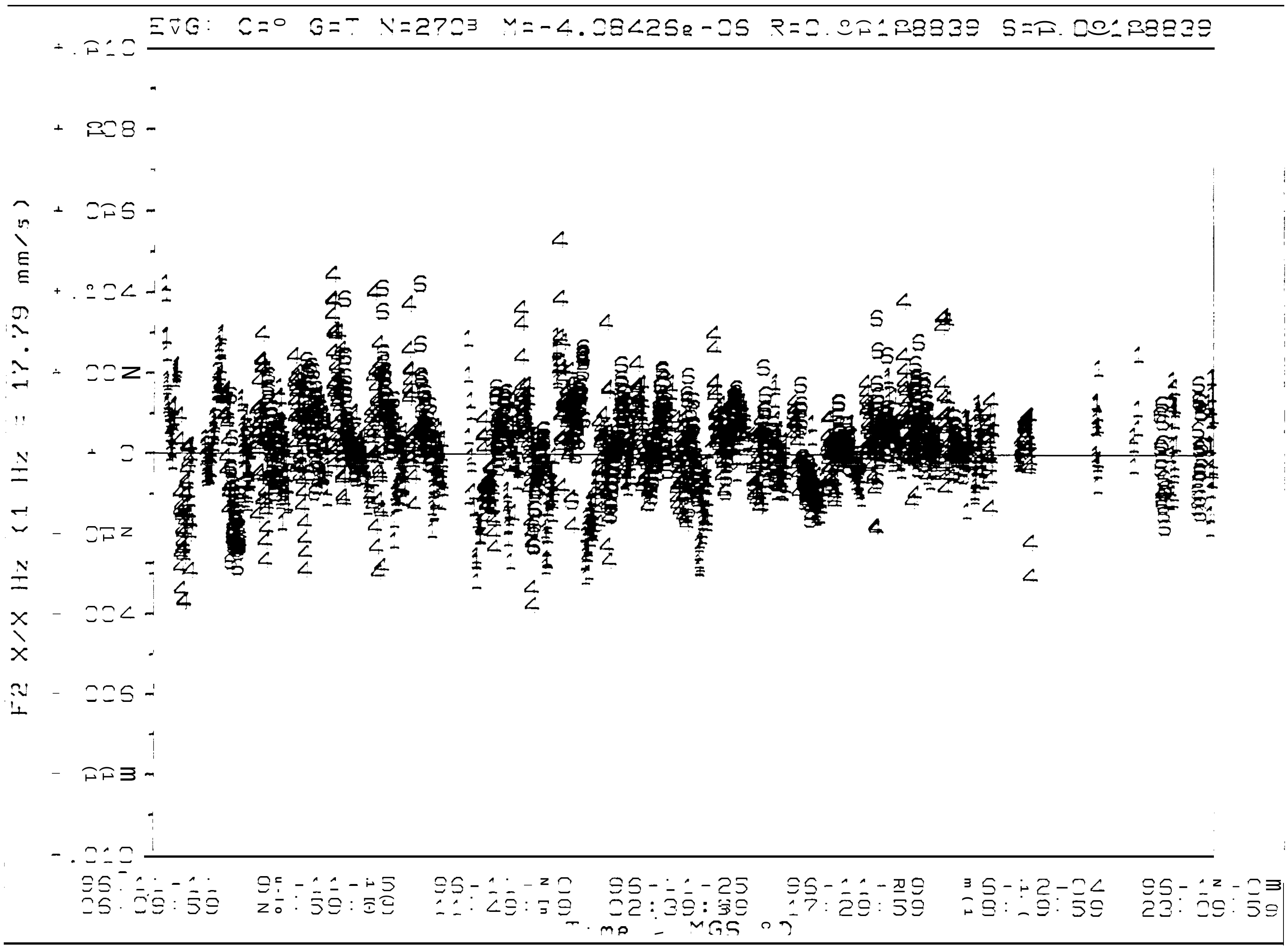


Figure 1

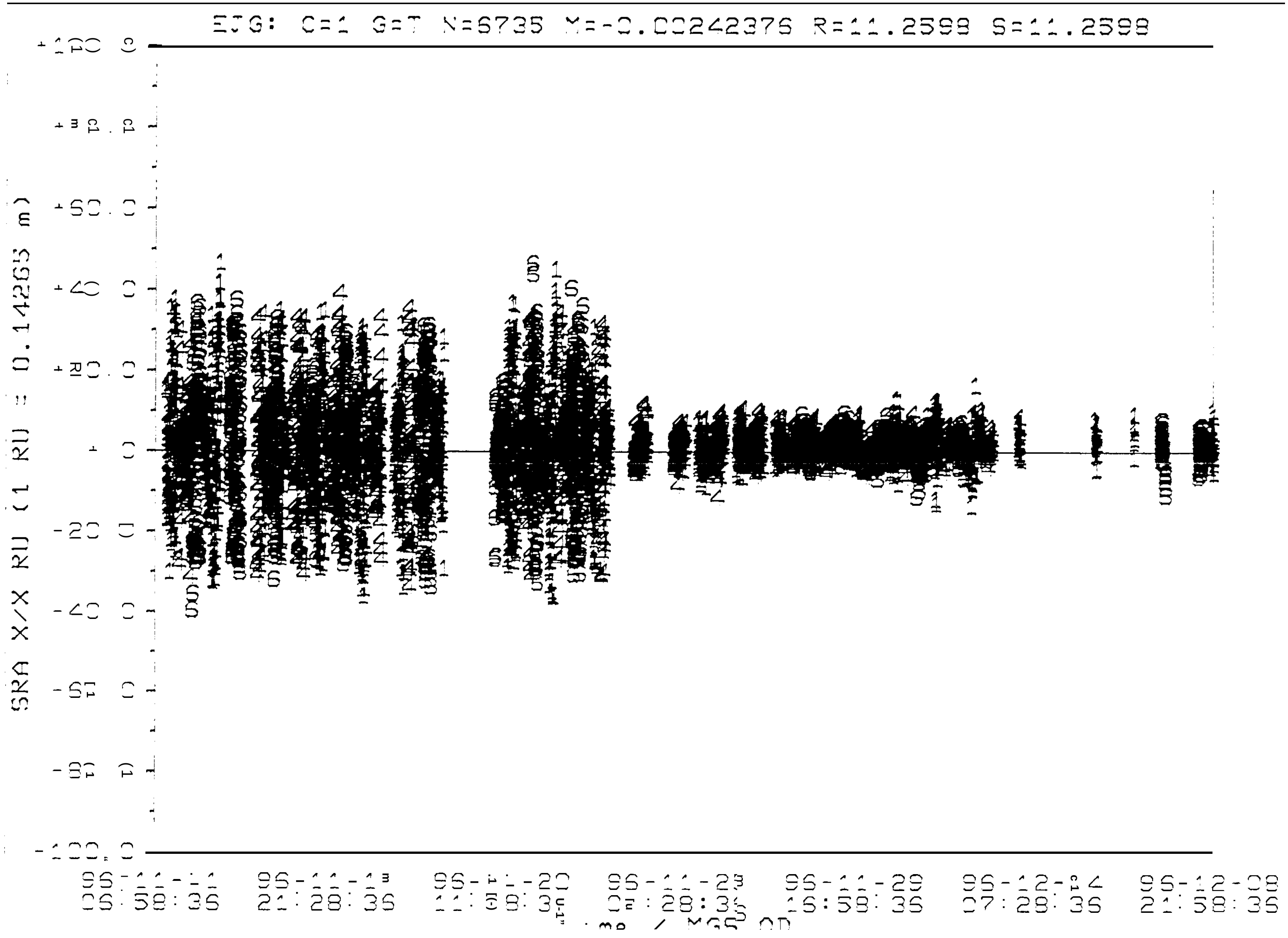

ETG: C=1 G=T N=6735 M=-0.00242376 R=11.2598 S=11.2598
SRA X/X RU (1 RU = 0.14265 m)
+40.0
+20.0
0.0
-20.0
-40.0
-100.0
95-11-11 05:58:35
95-11-13 21:28:35
95-11-20 11:58:35
95-11-23 02:28:35
95-11-29 15:58:35
95-12-04 07:28:35
95-12-08 21:58:35

Figure 2

MGS DELTA II INJECTION AND TCM-1 ASSESSMENT

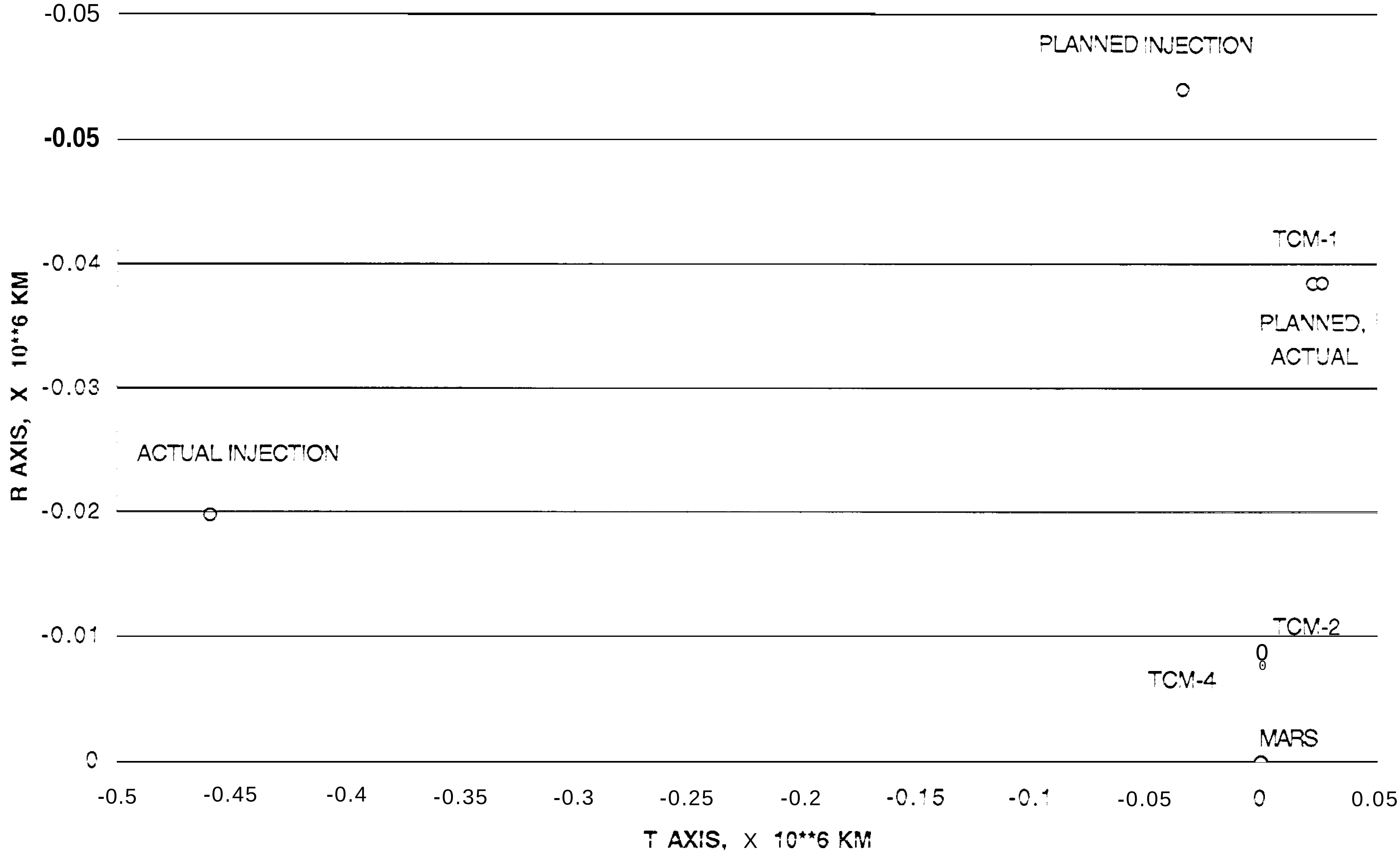


Figure 3

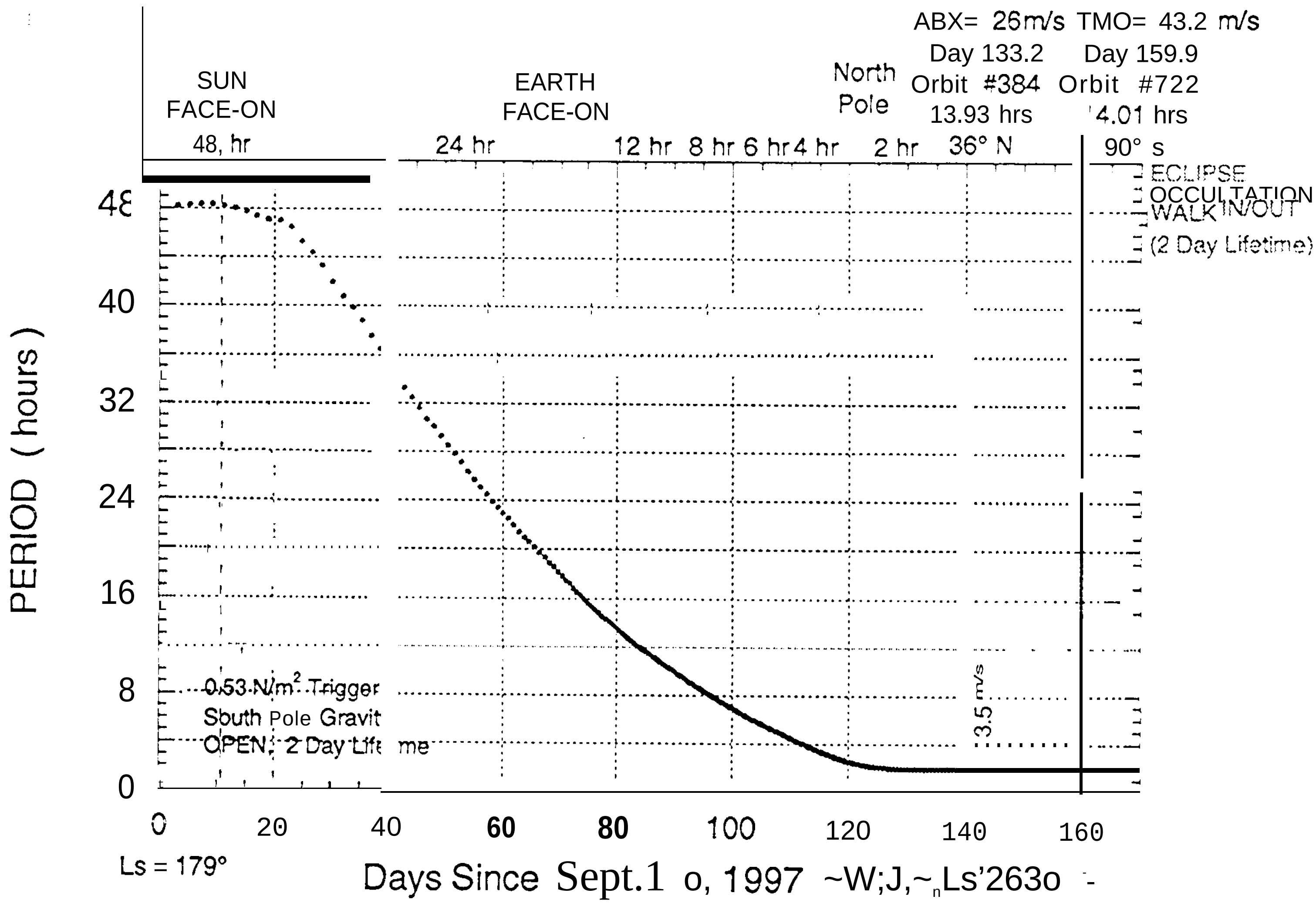
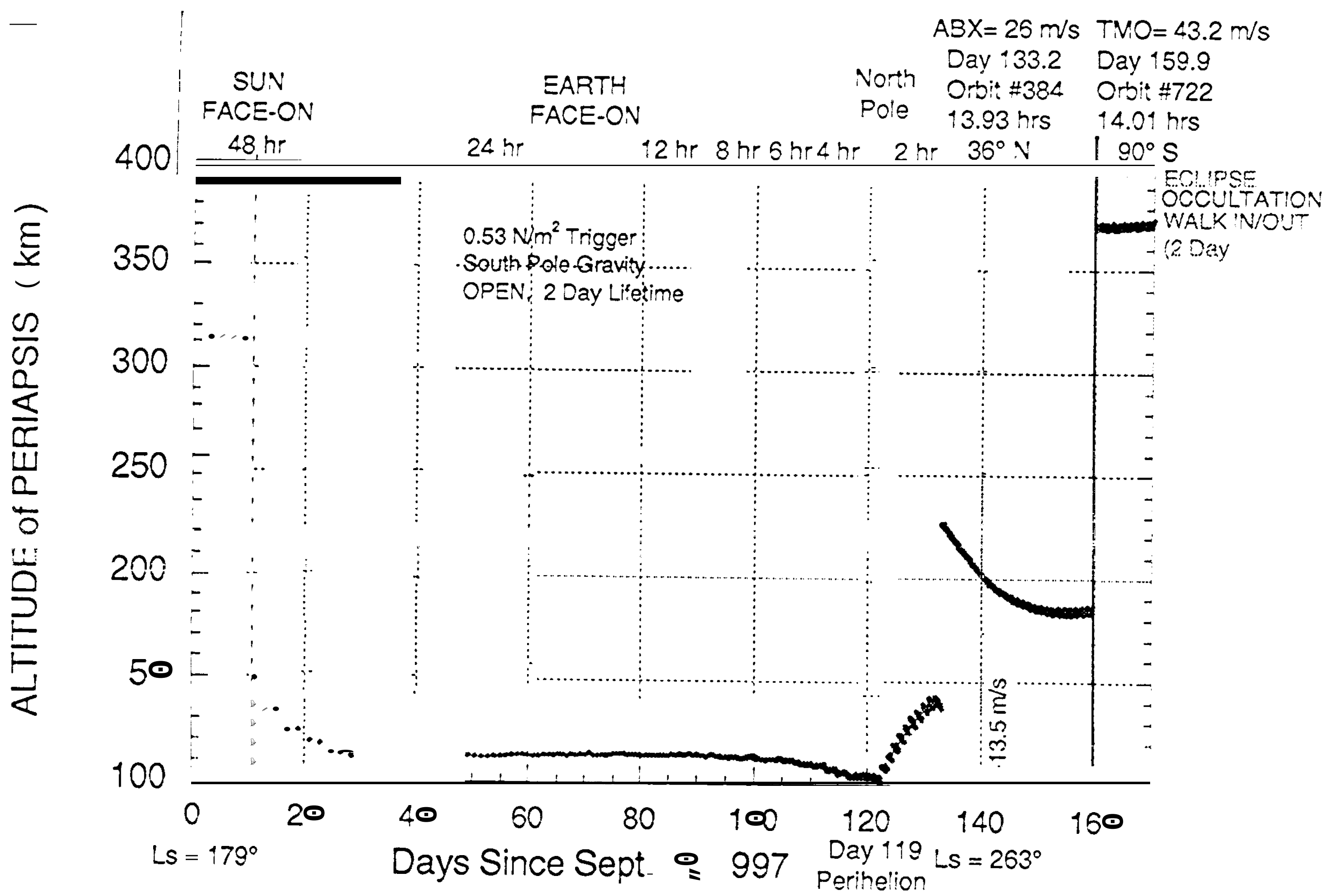

ABX= 26m/s TMO= 43.2 m/s
Day 133.2 Day 159.9
Orbit #384 Orbit #722
13.93 hrs '4.01 hrs
SUN FACE-ON
EARTH FACE-ON
North Pole
48, hr
24 hr
12 hr 8 hr 6 hr 4 hr
2 hr
36° N
90° s
ECLIPSE
OCCULTATION
WALK IN/OUT
(2 Day Lifetime)
0.53 N/m2 Trigger
South Pole Gravit
OPEN, 2 Day Lifetime
3.5 m/s
PERIOD (hours)
48
40
32
24
16
8
0
0
20
40
60
80
100
120
140
160
Ls = 179°
Days Since Sept.1 o, 1997 ~W;J,~nLs'263o

Figure 4



ALTITUDE of PERIAPSIS (km)
400
350
300
250
200
50
100
0
20
40
60
80
100
120
140
160
Ls = 179°
Days Since Sept. 0, 997
Day 119
Perihelion
Ls = 263°
SUN
FACE-ON
48 hr
EARTH
FACE-ON
24 hr
12 hr
8 hr
6 hr
4 hr
North
Pole
2 hr
ABX= 26 m/s
Day 133.2
Orbit #384
13.93 hrs
36° N
TMO= 43.2 m/s
Day 159.9
Orbit #722
14.01 hrs
90° S
ECLIPSE
OCCULTATION
WALK IN/OUT
(2 Day
0.53 N/m² Trigger
South Pole Gravity
OPEN, 2 Day Lifetime
13.5 m/s

Figure 5