Galileo Europa Mission (GEM) Tour Design

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Abstract

Introduction

The orbital tour trajectory that was selected for the Galileo mission[1] includes ten close flybys of the Galilean satellites Europa, Ganymede, and Callisto, additional distant flybys of those satellites, Io torus observations, and many other events that provide broad opportunities for scientific observations. The last targeted flyby of the baseline tour is an encounter with Europa, scheduled to occur on November 6, 1997. In the fall of 1996, the Galileo flight team predicted that sufficient resources (such as power, propellant, resistance to radiation exposure, health, and instrument lifetime limitations) will remain after the final Europa flyby for as much as two additional years of productive operations. A follow-on mission, designated as the Galileo Europa Mission (GEM), was proposed. The primary objective of GEM is a focused study of Europa; however, a close flyby of Io at the end of the follow-on mission is also desirable. An orbital tour for GEM has been designed that accomplishes both objectives by providing eight additional encounters with Europa, four close flybys of Callisto, and two Io flybys to end the GEM in December of 1999, nearly two years beyond the planned end of the baseline Galileo mission.

Mission Profile

Although the scientific opportunities that would be possible from an Io flyby are of substantial importance to many of the Galileo science teams, the potential catastrophic deterioration in the health of the spacecraft due to the radiation exposure incurred by such a flyby requires that any Io encounter be postponed to the end of the follow-on mission. The desire to focus on Europa and then to return to Io suggests a three phase tour. The first phase, denoted as the "Europa study phase," involves a series of Europa encounters that are designed to provide favorable scientific flyby conditions, without drawing the spacecraft so far from the orbital plane of the other satellites as to preclude the opportunity of returning to Io. The second phase of the tour, which includes four Callisto encounters, is designated as the "pump-down" phase since its purpose is to reduce the perijove of the orbit to approximately the radius of Io's orbit. The final phase of GEM is the "Io encounter phase." As of the writing of this paper, the characteristics of the Io flybys have not been selected; however, the tour has been designed to allow repeated flybys of Io in the event the spacecraft survives the first (GEM) Io encounter. Thus, multiple Io flybys may be possible, and, at this time, the design of the Io phase is proceeding with the assumption that two favorable Io encounters should be included in the nominal trajectory design.

A table that includes several characteristics of the flybys in the GEM is attached. The first letter (E, C, or I) of the code in the first column represents the first letter of the satellite being encountered; the digits indicate the orbit number on which the flyby occurs; an "A" following the orbit number indicates a "non-targeted encounter" – that is, an additional distant encounter on the same orbit, above 10,000 km altitude, whose aimpoint will not be specifically targeted. Also

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attached is a petal plot that shows the projection of the orbits onto a plane normal to Jupiter's pole; the direction to the Sun is toward the top of the plot.

Issues

The design of the tour for GEM involved several related challenges. One problem that is faced during any orbital tour design for a spacecraft such as Galileo, where the science instruments have diverse and often conflicting requirements, is to achieve a set of encounters that satisfies as many of the desired flyby characteristics as possible. In addition, each encounter must serve the dual purpose of providing acceptable conditions for science data collection while also providing an appropriate gravity assist to continue the orbital tour. This problem is particularly present in the design of a follow-on mission where the only propellant that is available is that remaining at the end of the primary mission. The tour that was selected achieves the first twelve GEM encounters with a total deterministic ΔV cost of 12.3 m/s. (See the ΔV column in the attached table.) Although the analysis of the available propellant will continue throughout the mission, the spacecraft has a high probability of completing a tour that requires a deterministic propellant cost of this order of magnitude.

The requirement to return to Io at the end of GEM was an influential factor in many aspects of the tour design. As mentioned above, returning to Io led to a three phase structure for the GEM tour; however, the return to Io was also a factor in the design of the individual encounters in each of the three phases. First, although the design of the primary mission did accommodate the possibility of additional Europa encounters at the end of the tour, it did not provide the opportunity to encounter other satellites without the use of a relatively large propulsive maneuver. Thus, returning to Io in the GEM requires a modification to the end of the baseline mission and also limits the flexibility in the choice of the flyby characteristics in the Europa study phase. Second, in order to encounter Io, the perijove of the orbit must be near the radius of Io's orbit. Thus, following the Europa study phase, the perijove must be reduced; however, reductions in the perijove are also accompanied by reductions in the orbital period. Following the Io encounter, the data collected during the flyby must be relayed to Earth at a relatively low data rate using the low gain antenna. Relaying all of the data may require more than 50 days; therefore, it is desirable to have a relatively long post-Io period in order to playback the Io encounter data before the spacecraft returns to the harsh radiation environment that exists at the low perijove distances required for the Io encounter. Given the reduction in period that accompanies the required perijove reduction, achieving the long post-Io period necessitates an even longer period at the end of the Europa study phase. It also requires the use of flybys of Callisto during the pump-down phase (as opposed to using Ganymede, for example) since Callisto flybys generally reduce perijove with less loss in period than encounters with other satellites.

Flyby Characteristics

The individual satellite encounters within each phase of GEM were selected to satisfy a list of desirable characteristics. For many of the instruments and experiments, relatively low altitudes (ideally less than 1,000 km) on the lit side of the satellite are preferable. As shown in the table, the Europa encounters of the GEM tour range in altitude from a minimum of 200 km (one month after the end of the primary mission) to a maximum of 3,600 km. Also, in order to provide coverage of as much of Europa as possible during the Europa study phase, it is useful to vary the latitudes of the encounters. The latitudes of the Europa flybys range from –42° to +42°, with encounters at a wide variety of latitudes between those extremes. This characteristic was one of the primary reasons this particular tour was selected. The characteristics of the Io encounters are still being studied; however, at least one polar flyby of Io (perhaps on the twenty-fifth orbit) is a possibility.

Summary

The paper includes a detailed description of the orbital tour, the design considerations and constraints, and the rationale for various decisions.

References

1. Wolf, Aron A. and Dennis V. Byrnes, 'Design of the Galileo Satellite Tour,' AAS/AIAA Astrodynamics Specialist Conference, Victoria, B.C., Canada, August 16-19, 1993, AAS 93-567.

GEM Flyby Summary

		DATE	TIME	ALT km	LAT deg	LON W deg	PHASE deg	TA deg	PER days	INC deg	Rp Rj	ΔV m/s
		971018	120000						49.0	0.4		11.8
E11	EUROPA	971106	203116	2178	22.2	140.2	31.4	-24.0	39.2	0.3	9.0	0.0
G12A	GANYMEDE	971215	100123	14315	-6.2	92.6	11.0	-85.3				
E12	EUROPA	971216	120748	200	-8.4	225.1	10.8	30.5	56.6	0.5	8.8	0.0
E13	EUROPA	980210	175739	3558	-8.8	131.9	26.4	-30.5	46.3	0.6	8.8	0.1
E14	EUROPA	980329	132546	1648	12.0	228.3	14.9	31.1	63.7	0.4	8.8	0.1
E15	EUROPA	980531	211245	2519	14.9	133.7	22.0	-31.3	49.9	0.3	8.8	0.0
E16	EUROPA	980721	50934	1837	-25.7	226.0	31.9	28.0	67.2	0.7	8.8	0.0
E17	EUROPA	980926	35032	3601	-42.5	138.6	45.7	-27.1	56.9	1.0	8.9	0.0
E18	EUROPA	981122	115025	2279	41.9	220.3	45.1	24.8	70.8	0.5	8.9	0.0
E19	EUROPA	990201	20924	1506	31.3	329.8	146.2	-18.3	91.4	0.1	9.1	0.0
C20	CALLISTO	990505	141315	1310	2.5	102.0	165.2	115.2	59.5	0.2	9.3	0.0
C21	CALLISTO	990630	75009	1052	-0.8	74.1	49.3	-121.6	41.3	0.2	7.3	0.1
I21A	IO	990702	51108	123489	0.5	137.2	6.2	0.7				
C22	CALLISTO	990814	84523	2288	-3.4	107.7	164.9	127.7	33.4	0.1	7.3	0.1
C23	CALLISTO	990916	174124	1051	-0.8	110.5	158.8	133.5	26.2	0.2	6.5	0.0
I24	IO	991011	44002	848	-19.5	225.0	66.2	29.6	42.4	0.6	5.5	0.0
E25A	EUROPA	991122	14815	62039	-0.2	89.3	46.8	-82.1				
I25	IO	991122	93251	1741	-85.7	0.4	94.2	-24.0	40.7	1.4	5.6	0.0

11.8+.5=12.3

Table 1

PETAL PLOT: GALILEO EUROPA MISSION 96-04

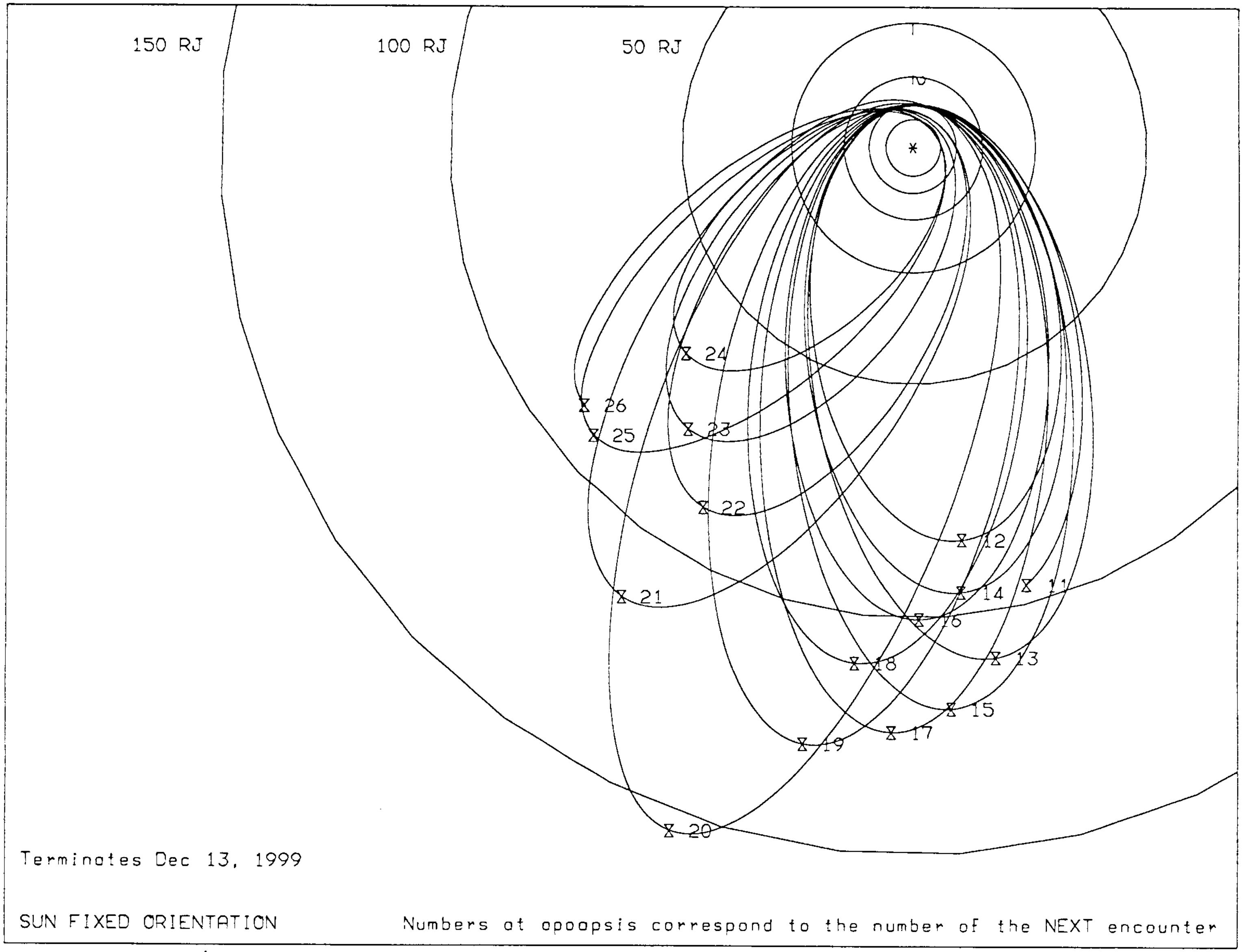

Figure 1