

# GALILEO ORBIT DETERMINATION RESULTS DURING THE SATELLITE TOUR<sup>§</sup>

P.G. Antreasian, T.P. McElrath, R.J. Haw, G.D. Lewis, T. Krisher

Members of the Technical Staff  
Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, CA 91109

The Galileo spacecraft and its approach to the planet Jupiter are well documented in the literature. In this paper we shall describe the navigation accuracies achieved so far in the satellite tour.

Following its arrival at Jupiter in December, 1995, the Galileo spacecraft embarked on a series of frequent encounters with the major satellites of Jupiter, starting with the first Ganymede encounter in late June, 1996. During this phase of the mission, orbit determination accuracy plays a critical role in enabling the spacecraft trajectory to be controlled for an acceptably low propellant cost. In addition to determining and predicting the spacecraft trajectory, the orbits of the Galilean satellites must also be adjusted and their accuracy improved, due to the major role of satellite encounters in shaping the spacecraft trajectory.

This paper will describe the operational methods used to determine the spacecraft and satellite orbits from the available Doppler tracking and optical navigation data, as well as compare the actual results against the predicted delivery accuracies. In addition, some of the methods and results from the determination of the satellite gravity fields in support of operational orbit determination will be presented.

Over the four encounters to date, the average pre-encounter orbit determination error (compared against the post-encounter reconstruction) was  $0.46 \sigma$  in B•R,  $0.77 \sigma$  in B•T, and  $0.85 \sigma$  in encounter time, with the largest single error being  $1.5 \sigma$ . As knowledge of the spacecraft and satellite orbit dynamics improves during the rest of the satellite tour, the predicted accuracies will improve and the statistical behavior of the errors should become more regular.

A representative B-plane diagram of the first satellite encounter (Ganymede) is shown in Figure 1, and illustrates the navigation effort to achieve the desired flyby conditions. In this

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diagram, orbit determination solution, OD118, was used to design the last pre-encounter maneuver, Orbital Trim Maneuver 6 (OTM-6) which centered the  $1-\sigma$  delivery ellipse at the G-1 aimpoint. After the flyby, a reconstruction solution, OD123, is shown in Figure 1 to be within the  $1-\sigma$  OTM-6 delivery ellipse.

Determination of the four major satellites' orbits have undergone steady improvement since the launch of Galileo, in anticipation of the spacecraft's arrival. These ground-based observations acquired in support of ephemeris development prior to the tour reduced the expected error in the positions of the Galilean satellites to about 40 km in the downtrack direction ( $1-\sigma$ ) -- a magnitude approximately representative of each of the major satellites. Thus the first encounter of the tour in June 1996 marked a significant event in ephemeris development, for as a result of the spacecraft's combined data set of optical and Doppler measurements of each satellite, knowledge of the satellite ephemerides has improved substantially. Figure 2 (a,b,c) indicates the changes occurring as a result of the first encounter. The differences in Ganymede's position with respect to the latest ground-based ephemeris at that time (labeled Jup088 in Figure 2) are plotted along each orbit-relative Cartesian component for 20 months, the length of the nominal tour.

A progression of ephemeris errors over the span of the mission for each major satellite also will be discussed (showing ephemeris improvement versus time). The Jupiter ephemeris has been refined in this process, and these results will be discussed too.

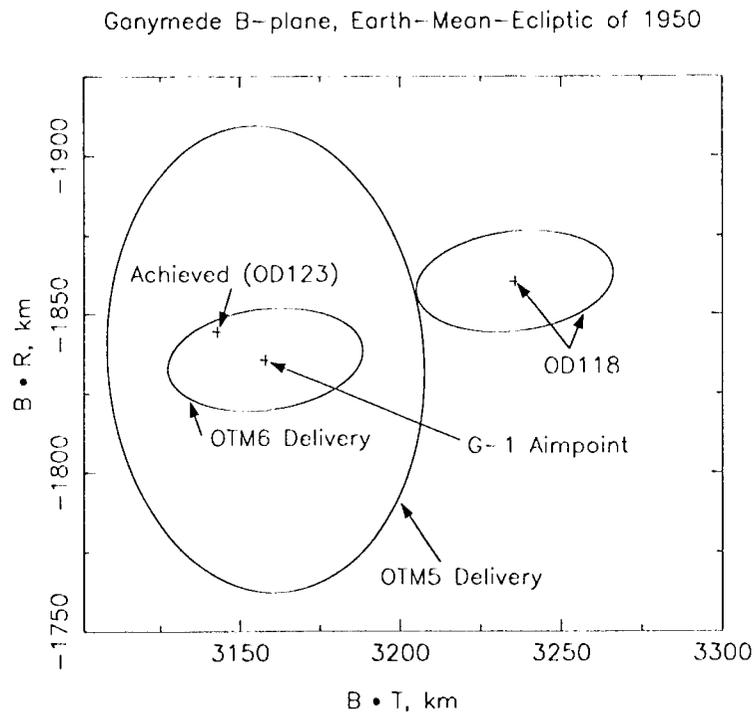


Figure 1: B-plane diagram of first Ganymede encounter.

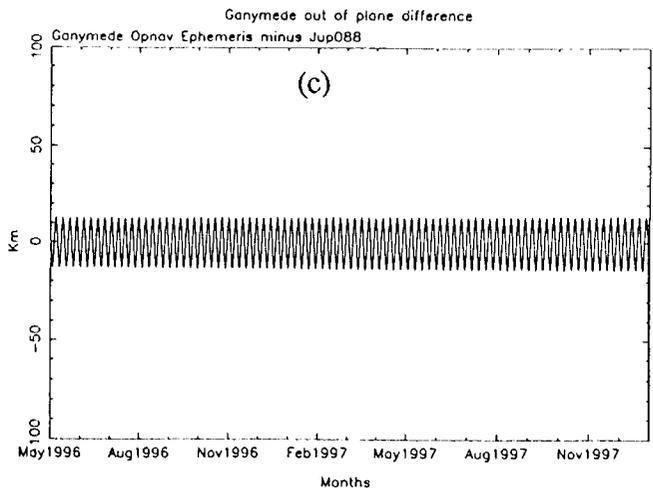
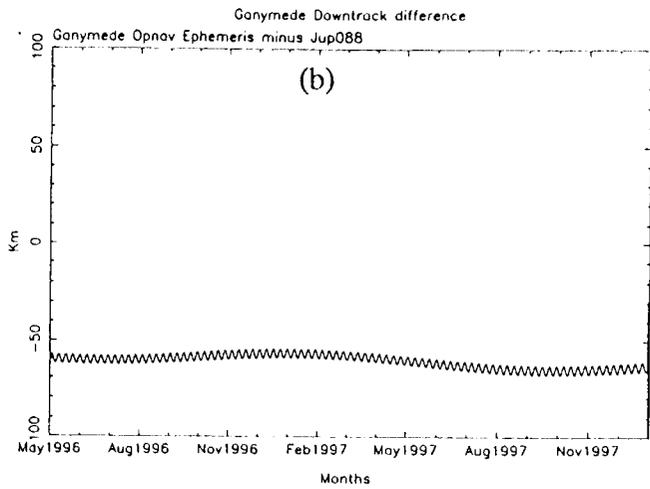
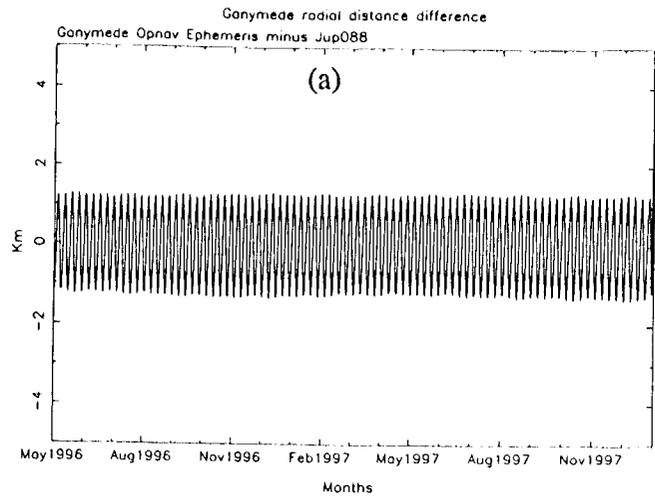


Figure 2: The differences between the last ground-based and recent spacecraft-based Ganymede ephemerides in (a) radial, (b) downtrack, and (c) out-of-plane orbit-fixed components.