A First Look at Orbit Determination for the Cassini Mission

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Abstract

This paper summarizes orbit determination analysis accomplished to date as part of navigation studies for the Cassini mission. The thrust of the analysis has been to characterize orbit determination accurac y to first order for selected phases of the mission and to identify problems that must be addressed in future studies.

The Cassini orbiter with its Huygens probe is scheduled for launch in October of 1997. Its "VVEJGA" trajectory carries the spacecraft through two gravity assist encounters with Venus and single encounters with Earth and Jupiter before arrival at Saturn in June of 2004 for the beginning of a 4-year tour of the Saturn system. The probe separates from the orbiter during the first orbit around Saturn and subsequently enters the atmosphere and impacts the surface of the satellite Titan. The orbiter then continues the tour, with numerous close encounters with Titan and several encounters with the smaller icy satellites.

Each of these mission phases presents different challenges to the traditional orbit determination process of using radiometric tracking and onboard optical data to estimate accurate spacecraft trajectories in the presence of errors. "This paper will present the results of analysis for three phases: a Venus flyby, the Huygens probe delivery to Titan, and representative orbits from the Saturn tour. Simulations will be described for each of these phases including selection and scheduling of data types and modeling of spacecraft dynamics and filter configuration. Current estimates of orbit determination accuracy will be given along with suggestions for future improvement. Sensitivities to various error sources in the data and in the spacecraft modeling will also be di scussed.

Early analysis of an approach to Venus for the CRAF mission [1] has some applications to Cassini, including a demonstration that the use of two-station differenced range data can make a significant contribution to accuracy, approaching the accuracy achievable by use of ΔDOR (Spacecraft-Quasar wideband VLBI) data. A newer data technique referred to as "Precision Ranging" is discussed, and promises results similar to those with difference ranging except with simpler operations and calibrations requirements. Data taking strategies for different radiometric data types including Differenced Doppler and ΔDOR will be discussed. Results from a current Venus study just beginning will also be discussed if time permits.

The Huygens probe delivery was simulated[2] with the result that optical centerfinding error was confirmed as a major contributor to Titan-relative orbit determination. Target plane delivery errors for both the probe and the orbiter were determined as a function of data cutoff time before the Titan encounter. Results for the probe delivery are shown in Figure 1. The error ellipse for the probe delivery to Titan's atmosphere was found to be highly elongated in the satellite's equatorial plane. The Titan ephemeris was estimated, and the error is found to be maintained at the 20 30 km level after a few days of Titan optical data arc processed.

The Cassini orbiter will travel through many orbits of widely varying geometries during its Saturn tour. Recent studies[3,4] investigated low inclination orbits relative to Saturn's equatorial plane, and found different results for two types of Titan encounters. Inbound encounters, occurring two days before the spacecraft passes through Saturn periapsis, have typical delivery errors of 15–20 km for a data cutoff 4 days before the encounter (Figure 2), while for outbound encounters, occurring 2 days after periapsis, delivery errors are typically 25–35 km. The two types of encounter exhibit somewhat different sensitivities to errors in modeling for optical data and non-gravitational accelerations. Titan delivery accuracies are strongly influenced by the treatment of the optical data which provides target-relative measurements. The paper will recommend strategies for handling the optical data weights and error sources. Experimentation with enhanced radiometric data types (e.g., ΔDOR weighted to an accuracy of 1 cm, range weighted at 0.1 m) with typical media and data platform noise removed show that Titan relative orbit determination is not improved despite extremely optimistic assumptions. The use of stochastic modeling of non-gravitational accelerations is found to lead to numerical problems when more than one Titan flyby is included in a single data arc, thus necessitating a change in an original operations strategy which included two encounters per arc.

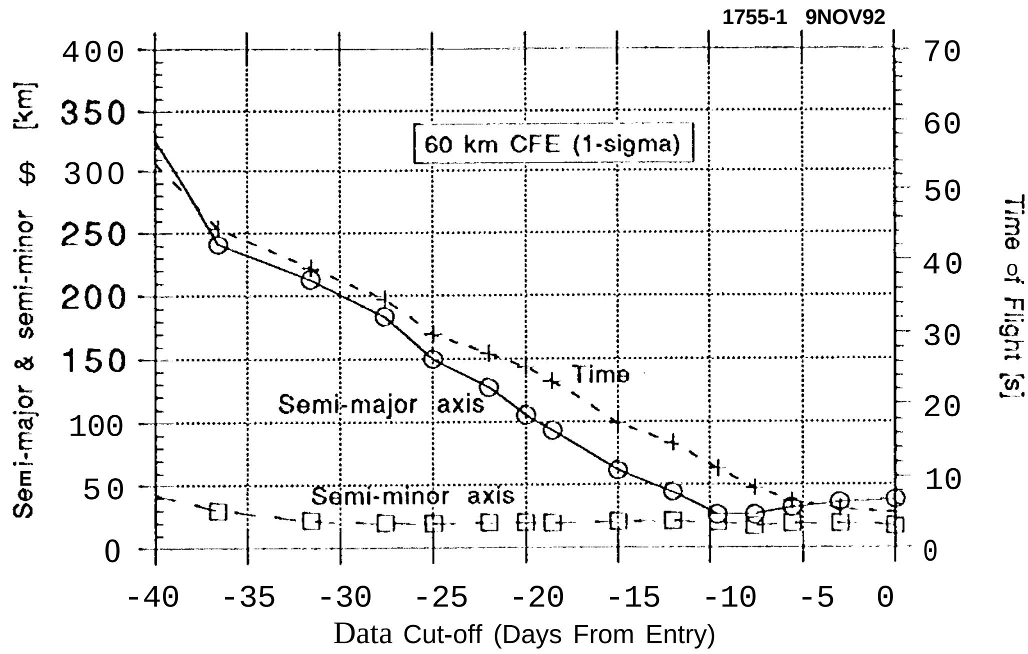

Figure 1: Orbit determination delivery errors for the Huygens Probe at Titan. 1-sigma B-plane enor ellipse and Time of Flight uncertainties as a function of data cutoff time relative to Titan entry time.

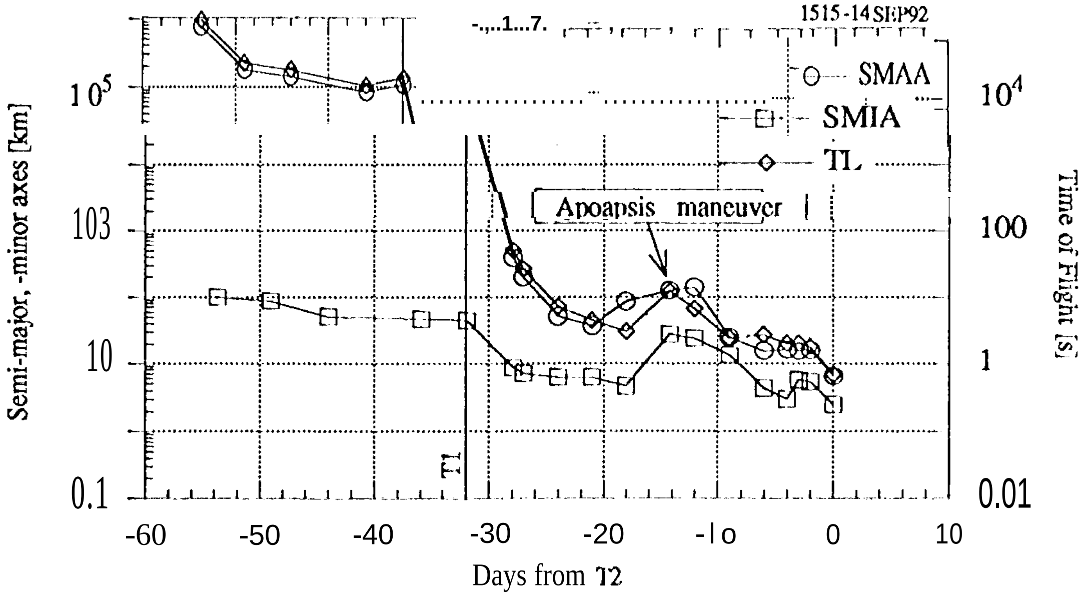

Figure 2: Orbiter B-plane delivery errors to Titan closest approach as a function of data cutoff time.

References:

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