Satellite Ephemerides Update Schedule for the Cassini Mission

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Condensed Abstract

The Cassini mission will arrive at Saturn in July 2004 to explore the Saturnian system including the satellites. The navigation team will update the ephemerides of 9 of these satellites to improve spacecraft navigation and provide information on satellite location for pointing of the spacecraft. This paper outlines the approach used to predict pointing uncertainty when pointing information is generated with a spacecraft prediction and older satellite ephemerides. This modeling is then used to choose times when the satellite ephemerides need to be updated to meet requirements.

Extended Abstract

Introduction

The Cassini spacecraft will arrive at Saturn in July 2004 to conduct a 4 year exploration mission. As part of the navigation effort, the ephemerides of the nine satellites of Saturn will be improved using optical and radiometric data. These satellites are Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Iapetus, and Phoebe. Improvements in the ephemerides will need to be communicated to non-navigation members of the Cassini flight team for refinements of spacecraft pointing vectors, event timing, and other products. Two major factors in this process are the pointing uncertainty due to ephemerides errors and the labor involved outside of navigation to incorporate ephemerides changes. This labor requires that the navigation team not deliver every update to the satellite ephemerides; only updates that are required to meet pointing requirements will be delivered to the flight team. The one-sigma pointing requirements allocated for navigation are 0.79 mrad for ranges above 30,000 km and 1.02 mrad for ranges above 20,000 km. The navigation team will continue to adjust the satellite ephemerides but will generally only deliver a new ephemerides to the flight team when the projected pointing uncertainty exceeds requirements. This study will determine the minimum set of satellite ephemeredes updates to be delivered to the flight team.

Problem Definition

The pointing uncertainty is driven by two major factors: uncertainty in the location of the spacecraft and uncertainty in the location of the satellites. The spacecraft uncertainty is dictated by the orbit determination analysis performed a few days before pointing information is uplinked to the spacecraft. Orbit determination will be performed prior to each maneuver and this is a logical time to update the spacecraft ephemeris and perhaps update the satellite ephemerides. For each maneuver, a covariance analysis was conducted to predict the spacecraft position errors associated with the pre-maneuver orbit determination analysis.

The uncertainty in the location of the satellites is determined by the previous delivery of the satellite ephemerides. The covariance analysis for each maneuver includes an estimation of the satellite states and predicted position error. Whether these ephemerides needs to be delivered to the flight team or not is the focus of this study.

Solution Approach

The covariance analysis for each of the 159 maneuver deliveries provides a different prediction of the spacecraft and satellite position errors. The analysis tool SIGMA was used to output predicted state errors in two coordinate frames at 5 day intervals during large spacecraft-satellite ranges or 15 minute intervals during times of satellite close approaches. One frame is satellite centered and oriented along the radial, transverse, and normal (RTN) directions. The software computes the one-sigma relative position error of the spacecraft with respect to each of the nine satellites in this frame. How this relative position error is translated into a pointing error is discussed later. This frame includes cross correlations between the spacecraft and the satellite and incorporates the current spacecraft and satellite ephemerides. This case is used when a new satellite ephemerides is delivered along with a new spacecraft ephemeris.

The second coordinate frame used was the Saturn barycentric frame. The spacecraft and satellite state one-sigma errors are predicted in this frame. This frame is then used to combine predictions that are the products of two separate analysis runs. A predicted spacecraft ephemeris from one maneuver design can be combined with a predicted satellite ephemerides from a previous maneuver design to compute the spacecraft position error with respect to a satellite.

The covariance matrices of the spacecraft and satellite position error are both rotated into satellite radial, transverse, and normal directions and then statistically combined.

The use of both of these approaches results in a satellite centered uncertainty of the spacecraft position in the RTN directions. The pointing uncertainty is determined by first computing the maximum error in the perpendicular radial direction from the error in the transverse and normal directions. The radial distance used for pointing is the reference radial distance minus the satellite's radius and the uncertainty in the radial direction. The perpendicular error is then divided by the radial distance to yield a conservative pointing uncertainty.

Results

The Cassini mission at Saturn is readily divided into the approach and tour phases and this analysis was also separated along these phases. For the approach the pointing requirements are dominated by the flyby of Phoebe. Two or three satellite ephemeris updates are needed during the approach phase with the final update based on data 4-5 days before the Phoebe flyby.

The tour analysis is much more involved because of Titan flybys, maneuvers, and different times of close approaches to various satellites. For each of the 159 maneuvers the most recent spacecraft prediction was used with a previous satellite prediction. If the requirements are not met, then the satellite ephemerides associated with the maneuver are used for this and subsequent maneuvers. The satellite ephemerides from the first maneuver, Saturn Orbit Insertion (SOI) Cleanup at two days after SOI, was used for the first ephemerides delivery. To meet or almost meet the flyby requirements the following satellite updates were required:

Table 1: Satellite Ephemerides Update Times	
Maneuver Number and Event	Time
5 Pre-Titan A maneuver	October 26, 2004
12 Pre-Titan B maneuver	December 13, 2004
18 Post-Titan C maneuver	January 16, 2005
27 Pre-Enceladus 2 maneuver	July 5, 2005
95 Post-Titan 24 apoapse maneuver	February 7, 2007

These update times show that the majority of the updates are in the early phases of the mission. After the first three updates in three months, the next updates are then six months and 18 months apart.

This analysis also indicates the times when the pointing requirements are not being met and adjustments need to be made. These times can be classified into 4 types of events. The maneuver plan may not include a maneuver for an extended period of time and additional spacecraft ephemeris updates need to be added. Second, the requirements for a targeted satellite may not be met. Maneuvers are designed based on targeted satellites and some adjustments in tracking schedule, data cutoff times, or other areas may be needed. Third, the pointing error may grow quickly after a Titan flyby and exceed the requirements before the post-flyby maneuver design satellite update is ready. Finally, the pointing error for a non-targeted satellite flyby may not be met. These events are typically a few days before or after a targeted flyby. A maneuver is typically designed before a flyby but this updated spacecraft ephemeris may not be ready for a pre-flyby non-targeted satellite. The concerns for a post-flyby non-targeted satellite flyby are another case of the third type of events.

Concluding Remarks

This analysis is one approach to the problem of combining spacecraft and satellite ephemerides to compute spacecraft pointing uncertainty. An exhaustive search of satellite ephemerides update times was not conducted nor was there a minute-by-minute examination of pointing errors. In addition, the satellite ephemerides update times need to be iterated with the flight team to evaluate the labor dictated by these times. This analysis does show various regions of time and events when pointing requirements are in jeopardy and basic causes. Some causes, such as an extended period with no maneuvers, can be easily remedied. Others will require discussions with the flight team.