Extended Abstract – AAS/AIAA Astrodynamics Specialist Conference
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Big Sky, Montana

CASSINI TOUR NAVIGATION STRATEGY

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The purpose of the Cassini mission is to study Saturn and its satellites, rings, and magnetosphere. To accomplish this mission, the combined Cassini orbiter and Huygens probe will be injected into orbit around Saturn on 1 July 2004. Prior to the third flyby of Titan, the Huygens probe will separate from the spacecraft and descend through Titan's atmosphere to the surface. The Cassini orbiter will continue on a four year tour of the Saturn system, with multiple close flybys of Titan and several flybys of selected icy satellites.

Cassini's tour trajectory is shaped by 45 Titan gravity assists. The icy satellites are not massive enough to provide significant gravity assists to the orbiter, so flybys of these satellites must be obtained on orbits which have been targeted to return to Titan. The trajectory may be described in terms of four general orbit orientations, or phases, chosen to achieve specific science objectives that would otherwise be mutually exclusive in any single geometry. The first phase achieves occultations of Saturn and its rings as viewed from the Earth and Sun. The line of nodes is nearly perpendicular to the Saturn to Earth direction, and the orbit is inclined by an amount equal to the declination of Earth with respect to Saturn's equatorial plane. The quality of the occultation measurements degrades significantly as the ring tilt angle relative to Earth decreases. The tilt of the rings is 24 degrees at Saturn Orbit Insertion, and decreases to nearly zero degrees by the end of the mission. Therefore, this geometry must be achieved early in the tour. The second phase achieves passage of the orbiter through the Saturn magnetotail region. The spacecraft must pass within 20 degrees of local midnight at a distance greater than or equal to 40 Saturn radii (R_S). The orbit orientation is about 90 degrees from the first phase orientation. The third phase allows for Saturn atmospheric observations. These observations must be taken from distances greater than 40 R_S and phase angles of less than 45 degrees. By taking observations from a large distance, Saturn's disk fits entirely within the Wide Angle Camera (WAC) field of view. The WAC images then provide context for the Narrow Angle Camera (NAC) images. The orbit orientation is 180 degrees from the second phase orientation. The fourth phase achieves an orbit inclination of nearly 76 degrees. From this orbit, observations of the ring plane, high latitude aurora and kilometric radiation, and radio occultations through the polar regions of Saturn's atmosphere are obtained.

To maintain the orbiter on this trajectory, a maneuver strategy has been developed. There are three maneuvers between flybys: a cleanup maneuver as soon as possible after a flyby, a deterministic trajectory shaping maneuver near apoapsis, and a final targeting maneuver three days before an encounter. The Cassini program has developed software to automate maneuver design and command sequencing such that the whole maneuver design process can be completed in two days. Due to the short time interval between flybys, a chained two impulse maneuver strategy will be implemented. The cleanup maneuver is designed such that the sum of its cost and the predicted cost of maneuvers for the next four or more encounters is minimized. This minimization is constrained such that the trajectory shaping and final targeting maneuvers both achieve the nominal flyby aimpoint. With this strategy, there is usually no need for a deterministic component to the final targeting maneuver, leaving room for the opportunity to cancel some these final targeting maneuvers in flight.

Orbit determination shall be performed in support of maneuver design, mission planning, and science data reduction. Because of numerical precision limitations and nonlinearities in the estimation process, orbiter arc lengths are limited to 1.5 revs with epoch states for each arc occurring near each apoapsis. Successive arcs will therefore have half a rev of overlap. In addition to solving for the orbiter ephemeris, the orbits of Saturn and nine of its satellites, (Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Iapetus, and Phoebe) shall be determined. When transitioning to successive orbiter arcs, satellite ephemeris information is retained by updating the ephemeris and covariance with all tracking observations preceding the orbiter state epoch. Tracking observations shall include radiometric (range and two-way Doppler) and optical navigation (images of the satellites against a stellar background) data types. Parameters to be estimated within each arc include the orbiter, Saturn, and satellite states, Saturn and satellite masses, Saturn gravity field parameters and pole orientation, ΔV vectors associated with attitude control activity and maneuvers executed within the arc, and a non-gravitational acceleration imparted to the spacecraft by the radioisotope thermo-electric generators. Because the direction of the non-gravitational acceleration is dependent on the spacecraft orientation and because the spacecraft orientation is expected to change frequently (Cassini does not have a scan platform), this acceleration will be modeled as process noise.

As the orbit determination process improves the satellite ephemeris, a re-optimization of the reference trajectory becomes desireable. While the re-optimization results in significant ΔV savings, the workload involved with not only updating the trajectory, but also with updating the command sequences, limits the frequency of updates. Therefore, the reference trajectory will be updated about a half dozen times during the tour. Most of these updates will occur near the beginning of the orbital mission when relatively large satellite ephemeris errors will be quickly reduced with optical navigation images and radiometric data acquired during satellite flybys.

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Upon injection into orbit around Saturn in July 2004, Cassini will spend the next four years conducting investigations of Saturn and its satellites, rings, and magnetosphere. A strategy to navigate Cassini through 45 Titan flybys, seven icy satellite flybys, and a constantly changing orbital geometry has been developed. A brief overview of the trajectory is presented first, followed by a description of the maneuver strategy developed to maintain the nominal flyby aimpoints. Orbit determination of the spacecraft and nine Saturnian satellites is characterized next. Finally, as the satellite ephemeris is improved, the process and ΔV savings associated with updating the reference trajectory is discussed.