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Flyby Error Analysis Based on Contour Plots for Cassini Tour

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The maneuver cancellation analysis consists of cost contour plots employed by the Cassini maneuver team. The plots are two-dimensional linear representations of a larger six-dimensional solution to a multimaneuver, multiencounter mission at Saturn. This realization and the use of the tool itself is just one of the many significant engineering achievements that have come from the Cassini project. After inserting the cost contour capability with an enhancement (taking account of asymptote changes), a tool that was originally only used for analysis could be used for operations once the accuracy of the plots was determined to be acceptable for operations. The plots have been used extensively since the enhancement. By using contours plotted in the B plane with $B \bullet R$ and $B \bullet T$ components, it is possible to view the effects on ΔV for various encounter positions in the B plane. The plot is used in operations to help determine if the approach maneuver (ensuing encounter minus three days) and/or the cleanup maneuver (ensuing encounter plus three days) can be cancelled and is a linear check of an integrated solution. The plots have also been used to bias the targets of encounters to save ΔV.

Nomenclature

B	=	B vector or B plane
$B \bullet R$	=	vertical axis of the B plane
$B \bullet T$	=	horizontal axis of the B plane
$C3$	=	excess velocity or characteristic energy
$G_{x,y}$	=	grid point value on the contour plot for an approach maneuver, m/s
$G_{x,y,c}$	=	grid point value on the contour plot for a cleanup maneuver, m/s
i	=	leg index
$J_{x,y}$	=	ΔV calculation of a B plane grid point for an approach maneuver, m/s
$J_{x,y,c}$	=	ΔV calculation of a B plane grid point for a cleanup maneuver, m/s
K	=	K matrix, a maneuver capability matrix
M	=	the B plane mapping
R	=	R vector of the B plane
r_o	=	nominal trajectory apoapsis maneuver location
S	=	the incoming asymptote
T	=	T vector of the B plane
T_n	=	nth encounter of Titan
$V1$	=	the magnitude of the velocity for a cleanup maneuver, m/s
$V2$	=	the velocity magnitude for an apoapsis maneuver, m/s
ΔB_A	=	asymptote change B plane state vector
ΔB_{RT}	=	grid variation vector
ΔB_{xy}	=	the variations in the B plane with a perturbed trajectory
$\Delta B \bullet R_y$	=	y component of grid points in the B plane
$\Delta B \bullet T_x$	=	x component of grid points in the B plane
Δr	=	difference in the apoapsis maneuver location for a perturbed trajectory
ΔV	=	change in velocity, m/s
ΔV_{REF}	=	change in velocity given in the reference trajectory, m/s

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I. Introduction

THE Cassini–Huygens mission to Saturn launched on 15 October 1997 and successfully entered Saturn's orbit on 1 July 2004. The orbital phase started after Saturn orbit insertion and continued through the prime mission, which ended formally on 30 June 2008 with the extended mission commencing after this date. The primary methods for changing orbital parameters during the Cassini–Huygens orbital segment are the gravity-assist encounters with Titan, Saturn's largest moon. In between encounters with Titan or any other Saturnian moon, there are typically three opportunities for orbit trim maneuvers (OTMs). These three maneuvers, shown in Fig. 1, are named the cleanup maneuver (which takes place approximately three days after an encounter), the apoapsis maneuver or shaping maneuver (which usually takes place around apoapsis of the orbit), and the approach maneuver (which takes place approximately three days before the next encounter). The targets for the maneuvers are $B \bullet R$ and $B \bullet T$ components of the B plane and linearized flight time (LFT) [1]. A description of the B plane is in the Appendix.

During the 11 years since launch, there have been many trajectory correction maneuvers during interplanetary cruise, OTMs implemented throughout the orbital phase, and a number of canceled maneuvers [2]. Preserving the science objectives is one of the navigation team's goals, and so the decision to cancel a maneuver, implement a maneuver, or bias an encounter target has to take account science implications. In order for the Cassini–Huygens maneuver team to provide information for project management to determine if cancellation of a maneuver was the appropriate course of action, tools were developed that would quantify what would happen with and without a particular maneuver. Thus, the maneuver cancellation analysis software was developed [3]. The maneuver cancellation analysis software runs every time the maneuver team designs a maneuver solution for the ensuing encounter. One product of the maneuver cancellation analysis software is the ΔV cost contour plot.

The contour plot is a two-dimensional linear representation of a larger six-dimensional solution to the multimaneuver, multiencounter operation that takes place on the Cassini–Huygens mission at Saturn. The plots show ΔV costs for different B plane encounter