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Control of Node Crossing Points in Saturnian Gravity-Assist Tours

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Abstract

In the Saturnian system, the control of the node crossing point is important to avoid debris in Saturn's ring plane and to target flybys of moons other than Titan. This paper describes how to use Titan gravity assists to control the spacecraft's node crossing point.

1 Introduction

Unlike Jovian tours, gravity-assist tours at Saturn have only one gravity-assist body available, Titan. All of Saturn's other moons are not massive enough to provide a useful gravity-assist. Flybys of Saturn's other moons may be designed by finding Titan to Titan transfers which happen to pass close to a moon. Finding satellite encounters can be especially difficult when a spacecraft is in an inclined orbit, as the spacecraft must cross the radius of a moon's orbit in that moon's orbit plane.

The techniques that I will develop in the paper assume that Titan's orbit is circular and in the same plane as Saturn's rings. I will also assume that the icy satellites: Mimas, Enceladus, Tethys, Dione, and Rhea are also in circular orbits in the ring plane. These assumptions are not valid for Saturn's other icy satellites: Hyperion's orbit is elliptic, and Iapetus and Phoebe are in orbits inclined relative the ring plane.

For an inclined orbit, a Titan encounter must occur at one of the node crossing points in the spacecraft's orbit. If the spacecraft's orbit is not inclined, the longitude of the ascending node can be chosen so that a Titan encounter occurs at a node. The node crossing point without a Titan encounter can be referred to as the *vacant node* as shown in Figure 1.

By calculating the location of the vacant node, we can compute whether or not a spacecraft will cross the orbit of one of the icy satellites mentioned above, or whether or not a spacecraft will cross through one of Saturn's rings.

2 Results

In the paper, I will derive the following equations for the radius of the vacant node:

$$r_{vac} = \frac{p}{2-p} \tag{1}$$

$$p = \left(\frac{3 - \frac{1}{a} - v_\infty^2}{2\cos(i)} \right)^2 \tag{2}$$

These equations are non-dimensional, with the following variables: r_{vac} is the radius of the vacant node divided by Titan's orbit radius, a is the spacecraft's semi-major axis divided by Titan's orbit radius, v_∞

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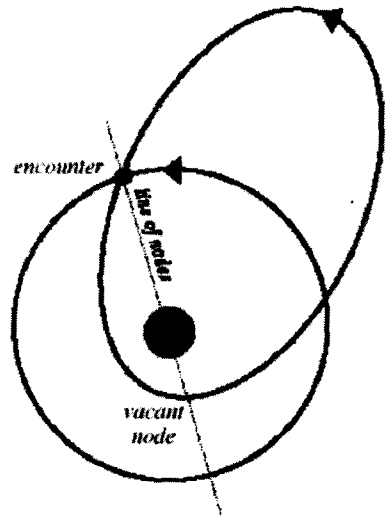

Figure 1: Illustration of the Vacant Node

is the spacecraft's v-infinity with respect to Titan divided by Titan's orbit velocity, and i is the spacecraft orbit's inclination.

Unless a maneuver is used, the spacecraft's v-infinity at Titan is fixed. So, we can control the radius of the vacant node crossing by varying either the semi-major axis or the inclination of the spacecraft's orbit (i.e., either by pumping or cranking).

If the spacecraft's orbit is inclined, it must be resonant with Titan's (π-transfers or blackflip transfers are an exception that will be covered in the paper). In Figures 2 and 3, for $v_\infty = 1$, I've plotted node crossing radius vs. inclination for a variety of resonant orbits. In these figures, the radius of the vacant node is in the units of Saturn Radii and the resonance of each curve is labeled as *Titan revs:spacecraft revs.*

Figure 2 compares the locations of these node crossings to the orbits of the inner icy satellites. Mimas's orbit is labeled *Mi*, Enceladus is labeled *En*, Tethys is labeled *Te*, Dione is labeled *Di*, and Rhea is labeled *Rh*. With such a figure drawn for the appropriate spacecraft v_∞, it is possible to plan Titan to Titan transfers that cross an icy satellite's orbit and may have a flyby.

Figure 3 shows the vacant node crossing compared to the location of Saturn's rings. Saturn's D, C, B, A, F, and G rings are shown as well as possible debris fields near the orbits of Janus and Epimetheus (labeled *J/E*) and the orbit of Mimas. Such a plot can be used to either avoid rings debris or to plan orbits that fly through gaps in Saturn's rings.

3 Conclusion

These techniques will be useful for the design of future gravity-assist tours at Saturn, including Cassini's extended mission. Plots such as Figures 2 and 3 greatly improve the ability of a tour designer to find icy satellite flybys and avoid ring debris.

These methods may also be applied to Neptunian tour design where there is also only one gravity-assist body available. Future work may also extend these methods to systems with multiple gravity-assist bodies (i.e. Jupiter and Uranus) to design high-inclination multiple moon tours.

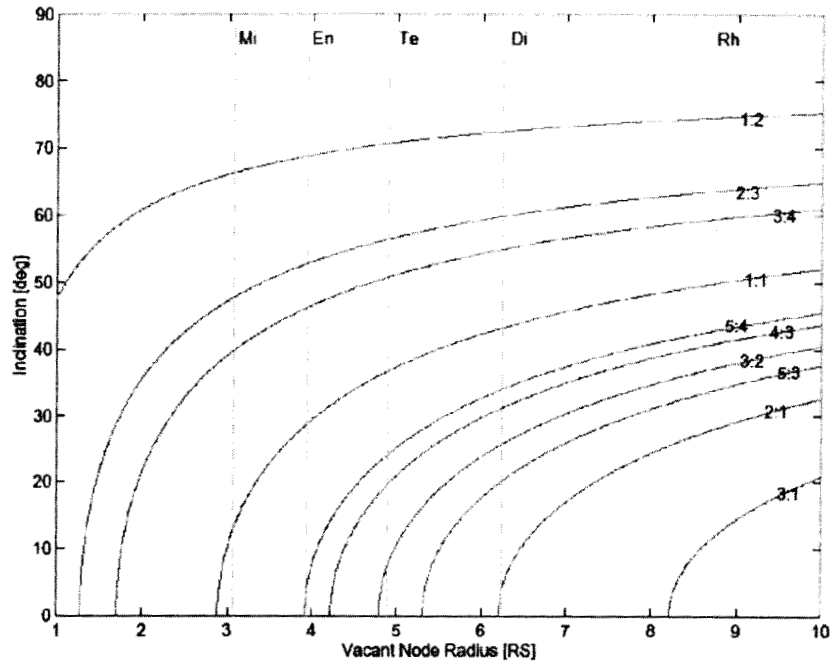

Figure 2: Vacant Node Crossings and Icy Satellites

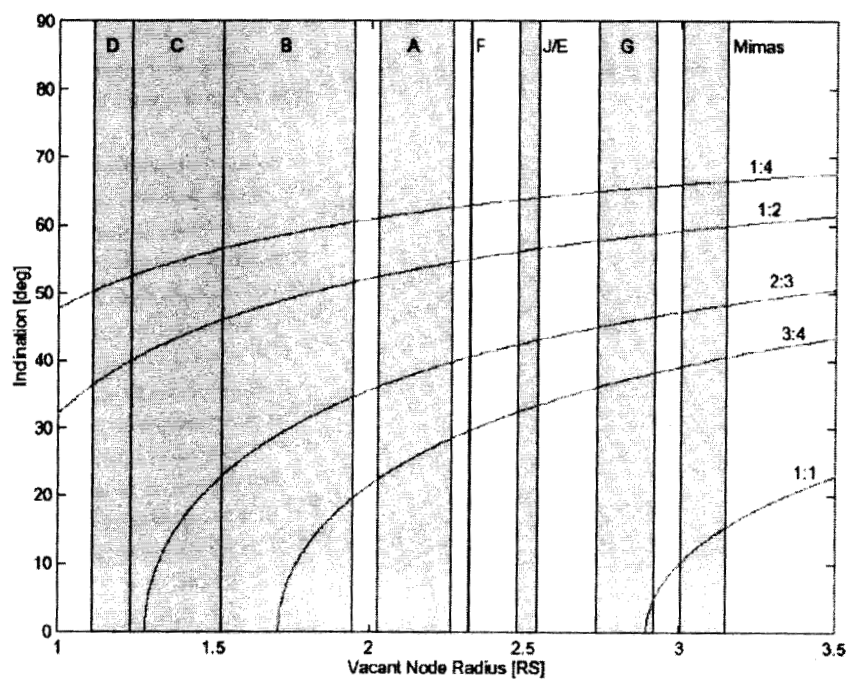

Figure 3: Vacant Node Crossings and Rings