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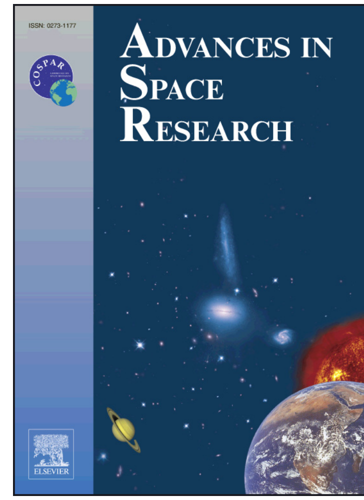

Kinematics effects of atmospheric friction in spacecraft flybys

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Kinematics effects of atmospheric friction in spacecraft flybys

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Abstract

Gravity assist manoeuvres are one of the most succesful techniques in astrodynamics. In these trajectories the spacecraft comes very close to the surface of the Earth, or other Solar system planets or moons, and, as a consequence, it experiences the effect of atmospheric friction by the outer layers of the Earth's atmosphere or ionosphere. In this paper we analyze a standard atmospheric model to estimate the density profile during the two Galileo flybys, the NEAR and the Juno flyby. We show that, even allowing for a margin of uncertainty in the spacecraft cross-section and the drag coefficient, the observed −8 mm/sec anomalous velocity decrease during the second Galileo flyby of December, 8th, 1992 cannot be attributed only to atmospheric friction. On the other hand, for perigees on the border between the termosphere and the exosphere the friction only accounts for a fraction of a millimeter per second in the final asymptotic velocity.

Keywords: Spacecraft flyby, Atmospheric friction, Perturbation theory, Flyby anomaly

1. Introduction

In the sixties of the past century (Flandro, 1966; Anderson et al, 2007) the aerospace engineer G. A. Flandro devised an ingenious proposal for a spacecraft to extract energy from the gravitational field of a planet using a gravity assist or flyby manoeuver. In his idea the planet is seen as a field of force moving relative to the inertial heliocentric or barycentric coordinate system so it can transfer a certain amount of kinetic energy to the passing spacecraft with respect to that inertial system. The transfer can be positive or negative depending upon the particular geometry of the flyby but its main objective was to reduce the required launch energy and the time for arriving at a given destination.

Flandro also foresaw the fact that all major planets from Jupiter to Neptune would be almost aligned on the same side of the Sun during the decades of the seventies and the eighties allowing for the design of a "grand tour" project in which a spacecraft should successively explore Jupiter, Saturn, Uranus and Neptune in a period of twelve years (Flandro, 1966). This project was effectively carried out by the Voyager 1 and Voyager 2 missions launched on September, 5th and August, 20th, 1977, respectively (Butrica, 1998). The flybys of Jupiter gave all the necessary energy boost to travel to Saturn in less than four years from the launching time. Moreover, these manoeuvers also provided an excellent opportunity to take close images of the giant planets as they have never been seen before.

Since then, flybys have become an integral part of space exploration and, in particular, the Juno spacecraft, now in orbit around Jupiter, is programmed to perform a total of 37 close flybys of the planet to gather information about its atmosphere and magnetic field (Matousek, 2007; Bolton and Bolton, 2010; Bolton et al, 2015). Moreover, many missions have included flybys of Venus and the Earth in his way to bodies in the outer Solar System. It was in the analysis of the trajectories of these flybys around the Earth that a team lead by Anderson discovered an unexpected velocity change in the Galileo flyby of Earth that took place on December, 8th, 1990 (Anderson et al, 2008). Fitting the post-encounter residuals for Doppler data they found that a small value, to be interpreted as a velocity increase of 3.92 mm/sec, cannot be attributed to any known perturbing effects considered in the orbit determination program. The anomaly also appeared in the ranging data, so it cannot be dismissed as a systematic error in the Doppler tracking method.

Two years later the same spacecraft performed a flyby with a perigee at an altitude of 303 km over the Earth surface so, it crossed the middle layers of the termosphere were a detectable perturbation by atmospheric friction can be measured. In fact, a decrease of 8 mm/sec was found after taken into account all other sources of perturbations. However, Anderson et al. (Anderson et al, 2008) claimed that only a 3.4 mm/sec velocity decrease could be explained as a consequence of friction. Similar flyby anomalies were found in subsequent flybys by the NEAR, Cassini, Rosetta and Messenger spacecraft but, apparently, they

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