CROSSINGS OF GEOSTAIONARY ORBIT BY THEMIS SCIENTIFIC SATELLITES

S. Frey (1), M. Bester (2), V. Angelopoulos (3)

(1,2) Space Sciences Laboratory, University of California, 7 Gauss Way, Berkeley, CA 94720-7450

(1) Phone: 510-643-9880 Email: sfrey@ssl.berkeley.edu,

(2) Phone: 510-643-1014 Email: mbester@ssl.berkeley.edu

(3) ESS/IGPP, University of California, Los Angeles, 405 Hilgard Avenue, Los Angeles, CA 90095-1567

Phone: 310-794-7090 Email: vassilis@ucla.edu

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In the first year of the extended mission phase the three THEMIS scientific satellites, on low Earth geosynchronous orbits, were reaching very low inclinations and thus increasing the number of orbits crossing through the equatorial plane at geostationary distance. The THEMIS satellites (a.k.a. *probes*) are equipped with propulsion systems that are utilized to modify size and orientation of the three-probe formation in accordance with the science requirements twice per year. As we were facing an increasing probability of close encounters with geostationary objects we were interested in routinely predicting these equatorial crossings and furthermore investigating whether we could reduce the number of crossings through our frequent orbit refinement. Since it is beyond our resources to perform a detailed conjunction assessment with individual objects we looked at the geometry between geostationary and geosynchronous orbits in the equatorial plane. For this analytical approach the equatorial geosynchronous orbit is a good approximation of the highly elliptical THEMIS orbits that differ slightly in altitudes and inclination. As the number of space objects is growing at a high rate and particularly in the geostationary orbit we believe this study is of general interest to the space flight community.

In the paper we will outline how the argument of perigee can be used to determine the crossings of a geosynchronous orbit through the geostationary orbit without any extensive computational efforts. The peculiarity of this geometry is that the semi-major axis of any geostationary orbit equals the geostationary distance and by definition any spacecraft crossing the geostationary orbit is either at the ascending or descending node. Using standard equations of satellite motion we will show that the eccentric anomaly is 90 degrees at that moment, and the true anomaly is only defined by the eccentricity of the geostationary orbit (Figure 1). We will illustrate, that for any given eccentricity there are four values for the argument of perigee at which the spacecraft crosses the equatorial plane at geostationary distance.

Applied to our THEMIS orbits in 2010-2012 which have on average an eccentricity of 0.76 and corresponding values for the argument of perigee of 220.6, 319.4, and 40.6 degrees, we found three such crossing seasons within 850 days, all at inclinations below 5 degrees. As Figure 2 shows, these crossing seasons are not equally spaced in time since the drift of the argument of perigee is not constant. Inclinations below 3 degrees lead to faster changes of the argument of perigee leaving just about 100 days between crossing seasons. By replacing the simple geostationary circle by a ring structure we were able to estimate the extent and determine the number of orbits of each crossing season. Among the interesting results we will report in the paper is the relation between inclination and density of crossings. Having the long-term knowledge of potential encounters with geostationary objects has been proven to be very beneficial for our long-term operations planning.

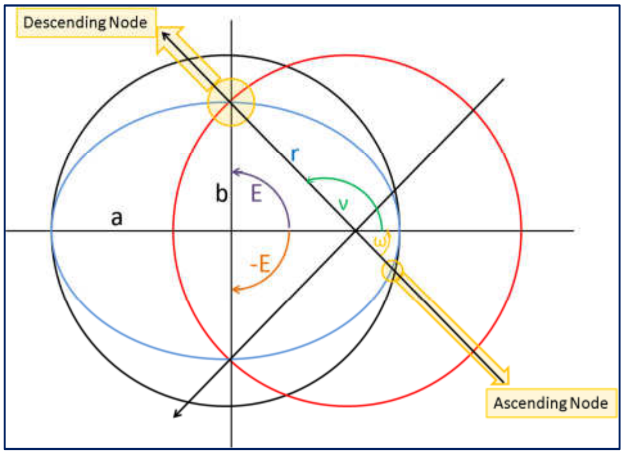

Figure 1: Intersection of geosynchronous orbit (blue) and geostationary orbit (red), not to scale. Keplerian elements are indicated for a spacecraft in the geosynchronous orbit at the descending node.

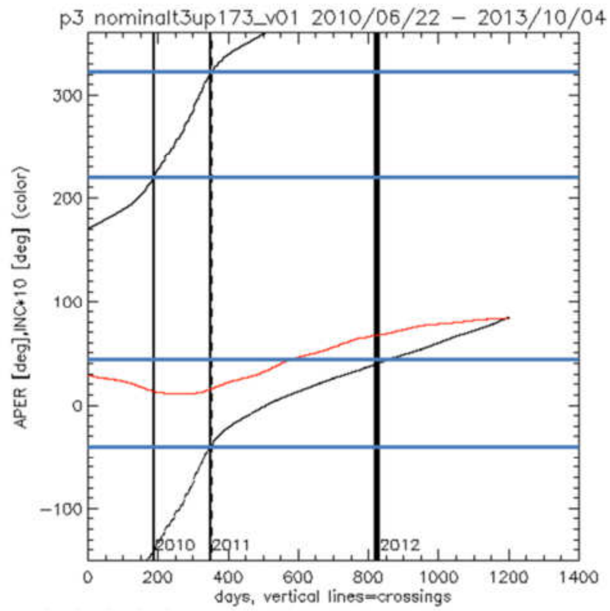

Figure 2: Argument of perigee of a THEMIS probe (black) and inclination (red), enhanced by factor 10, between June 2012 and October 2013. Vertical lines are probe crossings through ring centered at geostationary orbit.

In the final part we report the results of our analysis of how much change of eccentricity or orientation of the orbital plane it will take to influence the timing of upcoming crossing seasons with the focus on whether this is applicable to our specific orbit design which is defined by the science of the extended mission. Although our conclusions and decisions are very THEMIS specific, other missions may find the results helpful in mitigating the risks of crossing the crowded geostationary orbit.