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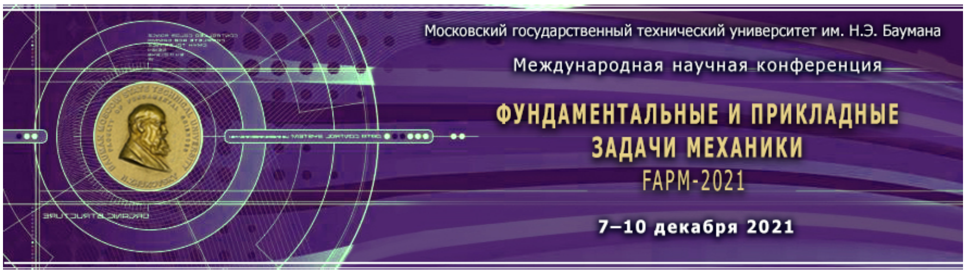
Москва, 7–10 декабря 2021 г.

МАТЕРИАЛЫ КОНФЕРЕНЦИИ

В двух частях

Часть 1

Составители: П.М. Шкапов, М.И. Дьяченко



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THE MATERIALS OF THE CONFERENCE

In two parts

Part 1

Compiled by P.M. Shkapov, M.I. Dyachenko

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Trajectory behavior of high area-to-mass ratio objects in semi-synchronous GPS orbits

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Space Flight Dynamics Laboratory, ISTI/CNR, Pisa, Italy

Abstract. Following the observational discovery of a significant number of objects characterized both by high eccentricity geosynchronous orbits and by extremely high values of their area-to-mass ratios (A/M), whose origin can probably be traced back to the degradation and detachment of the very light specific mass layers used to protect the surfaces of geostationary spacecraft, a thorough investigation was carried out since 2008 to explore the long-term dynamical evolution of fictitious high A/M objects released, with a negligible ΔV, in each of the six orbital planes used by Global Positioning System (GPS) satellites. As for the objects observed and studied in near synchronous trajectories, also in this case long lifetime orbits, with mean motions remaining close to two revolutions per day, but developing large eccentricities together with faster and wider pole precessions, were found possible even for bodies with extremely high A/M. For particularly high values of A/M and favorable initial conditions, the transition from prograde (inclination < 90°) to retrograde (inclination > 90°) motion, and vice versa, would also be possible.

Keywords: *semi-synchronous GPS orbits, high area-to-mass ratio objects, space debris, long-term orbit evolution, solar radiation pressure.*

Optical observations have led to the discovery of a population of faint objects, with mean motions of about 1 revolution per day and orbital eccentricities as high as 0.8 [1] [2] [3]. An obvious explanation for their origin was immediately proposed. In fact, direct solar radiation pressure may significantly affect the eccentricity with small effects on the total orbit energy and, therefore, on the semi-major axis or mean motion. However, this perturbation would be adequately effective only on objects with sufficiently high area-to-mass ratios (A/M).

In order to investigate the long-term dynamical behavior of these peculiar objects in synchronous and semi-synchronous orbits, numerical propagations were carried out since mid-2000s [4] [5] [6] [7] [8] [9] [10]. This paper summarizes some results obtained by the authors since 2008 for high area-to-mass ratio objects released in semi-synchronous GPS orbits [7] [8]. These nearly circular orbits, with a half sidereal day period, semi-major axis close to 26,560 km and inclination of about 55°, are in a deep 2:1 resonance with the Earth's rotation. The ascending nodes of the six constellation planes are separated by 60° in right ascension and each plane is identified by a capital letter, from A to F, while the satellites in each plane are identified by a number. The test objects were propagated for 100 years, taking into account the geopotential harmonics up to the 16th degree and order, luni-solar attraction and direct solar radiation pressure with eclipses. In case of induced high eccentricity orbits with perigee altitude below 1000 km, the perturbing effects of air drag were considered as well, using the 1976 United States Standard Atmosphere. Assuming a radiation pressure coefficient $C_R = 1.2$, area-to-mass ratios up to 100 m^2/kg were simulated.

All the objects analyzed with A/M up to 45 m^2/kg exhibited an orbital lifetime greater than 35 years (very often greater than 100 years), with semi-major axis and orbital period remaining close to the semi-synchronous values. For 45 m^2/kg < A/M < 80 m^2/kg, the exact value depending on the initial conditions, the eccentricity became so large, and the perigee altitude so low, that an orbital decay occurred in a few months.

Regarding the long-term evolution of mean eccentricity and inclination, the results obtained for the objects with the initial orbits of the GPS satellites A3, D1 and F4 are shown, as examples, in Figures 1–6 for a subset of A/M values spanning the investigated range. In general, higher values of A/M resulted in larger amplitudes of the yearly eccentricity oscillation due to direct solar radiation pressure. However, certain initial conditions, coupled with luni-solar resonances, may change this simple behavior, adding to the yearly oscillation a term with a significantly longer period.

At low area-to-mass ratio, the evolution of the orbit plane is dominated by the interaction between J_2 and the third body attraction, with a nodal regression period of nearly 26 years and an inclination oscillation amplitude of about 2°, superimposed on a longer term trend driven by luni-solar perturbations. An increase of A/M induces a faster nodal regression and wider amplitude of the inclination excursion, depending on the initial conditions. For sufficiently high A/M values and specific initial conditions, the orbit can become periodically retrograde (i.e. with inclination > 90°) for some time. For instance, this is shown in Figure 4 for the D1 initial conditions and A/M = 60 m^2/kg.

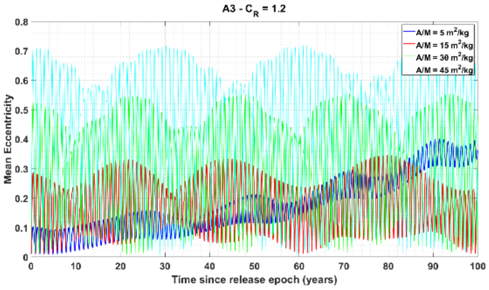

Fig. 1. Mean eccentricity evolution for initial conditions A3 (since 2007-04-17)

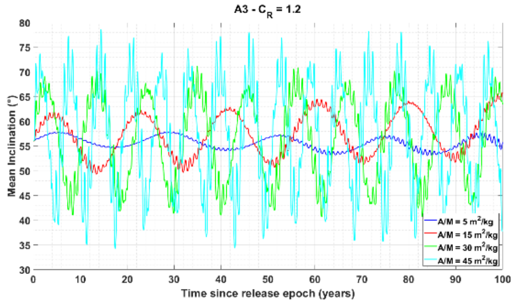

Fig. 2. Mean inclination evolution for initial conditions A3 (since 2007-04-17)

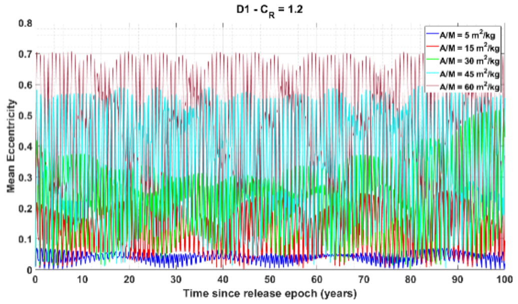

Fig. 3. Mean eccentricity evolution for initial conditions D1 (since 2007-04-17)

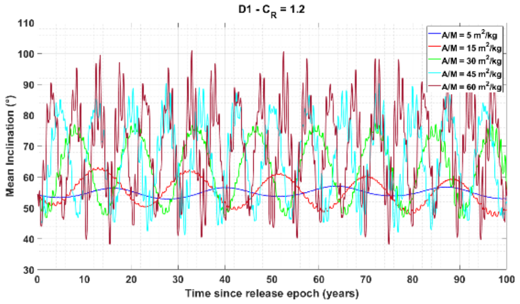

Fig. 4. Mean inclination evolution for initial conditions D1 (since 2007-04-17)

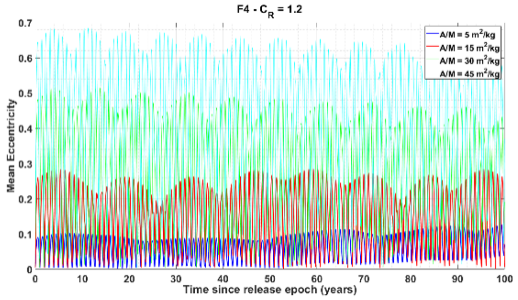

Fig. 5. Mean eccentricity evolution for initial conditions F4 (since 2007-04-17)

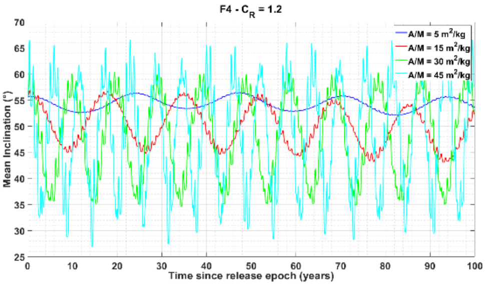

Fig. 6. Mean inclination evolution for initial conditions F4 (since 2007-04-17)

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Институт автоматизации проектирования РАН, Москва, Россия
E-mail: i_nikitin@list.ru, nikitin_alex@bk.ru