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ATMOSPHERIC INFLUENCE IN CUBESAT´S ORBITAL DECAY

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Abstract. *It is estimated that more than 18.000 objects are in orbit around the Earth, with a total mass above to 7 Ton. The objects in orbit around the Earth that are non-operational bodies without control, are also known as orbital debris. Recently, the development and increment of CubeSat´s missions increase the low Earth orbit population. Due the low operational time of these satellites, they rapidly are turning into debris. The debris are hazards to operational satellites and aerospace operations because they increment the probability of collisions and reduce the operational space in orbit. Due to the interaction of the debris with the atmosphere of the Earth, the solar activity and other factors, the debris and operational satellites began to lose energy and decay. These phenomena is easily observed in the LEO, due to the increase of the atmospheric density. It is important to determine and quantify the influence of the variation in the atmosphere and the aerodynamic forces acting in the non-operational CubeSat´s (debris) to propagate the trajectory, to determine the decay time. Research in this area are necessary to understand the decay with more accuracy, useful in space debris mitigation. To obtain a better approximation of the atmospheric influence during the decay in CubeSats, in this case, it is implemented a computational code to integrate the equations of motion with the Cowell´s method and to propagate the dynamics of 1U CubeSat´s. A panel method is implemented to determine the Drag coefficient as a function of the CubeSat attitude, in this case, in 2D, the incident angle is constant at 90°. The mathematical model consists of a Runge Kutta 7/8 integrator, the atmospheric models NRLMSISE-00 and JB2008, Earth Gravitational Model EGM-08. Results are validated with data from the TLE of historical CubeSat´s missions. The results from the simulations show a good approximation with observational data.*

I. INTRODUCTION

The implementation of satellite data to calibrate and study the influences of the atmosphere has been studied by Pardini and Anselmo (2003; 2004; 2012) and Vallado and Finkleman (2016). To calculate the influence of the atmosphere in the satellite orbital decay, it is necessary to known the satellite cross-area, mass and his attitude. Due to the low availability of these specific data, the area-mass ratio and Drag Coefficient are estimated in a single variable called Ballistic Coefficient. The coefficient is adjusted to determine, the semimajor axis decay from the Two Elements Data and the propagations. These adjusted coefficients don’t represent the physical Drag coefficient and include the uncertainly in the Area to Mass ratio, rotation, atmospheric and solar activity influence. They need to be periodically calibrated. Usually, to determine the models of Drag in satellites, the coefficient is calculated from the TLE in satellites with spherical geometry (Pardini et al., 2006). The Cubesat´s data from the TLE, the standard mass and geometry, make possible the implementation of the Drag analysis and atmosphere calibration of a specific atmospheric model. Because a large number of CubeSats are been deployed in the last years, the quantity of data is large, so it is possible to reduce the uncertainly of the Drag model and obtain a better adjust with the model. In this way, it is selected the atmospheric model with lower residual. Some advantages in the use of CubeSats are:

- Low lifetime, generally placed in LEO, where the atmospheric density accelerate the decay rate. Results from previous researches detected that the error of the Drag increases with the altitude.
- The Principal forces acting in the Body at low altitudes are the Two body gravity, J2, J4 and Drag. The other perturbations are of inferior order (Dell’Elce et al., 2015).
- Most of the CubeSats do not present mass variations due to propellant use and maintain the same geometry along the trajectory.
- Cubesats do not perform long-time maneuvers.
- Due to the low operational time, the CubeSats become Debris rapidly.

According to the previous assumptions, the goal of this research is to implement the Cubesat´s historical data to compare the results of propagations from two atmospheric models JB08 and NRLMSISE-00 and observe the semimajor axis variations. Similar results were observed in previous research implementing satellites with different geometry and Ballistic parameters (Picone et al. 2002). Previous analysis of atmospheric models were made with the J60, 70, 71, MSIS-86, 90 and NRLMSISE-00 model in Vallado and Finkleman (2016) and Emmert et. al. (2017), and the JR-71, TD-88 and MSIS-86 in Pardini and Anselmo (2003; 2004). In 2012, Pardini et al. present the analysis of drag fitting with six thermospheric density models used in spacecraft operations. They analyzed the models: JR-71, MSISE-90, NRLMSISE-00, GOST-2004, JB2006 and JB2008, during the 23th Sunspot maximum. A calibration of the scale in the NRLMSISE-00 was presented by Shi et. al. in 2015.

II. MATHEMATICAL MODEL

The system is formed by the Earth central body (M) and the CubeSat second body (m) moving in orbits around the center of mass. The equations of motion are derived from the perturbative satellite problem with the influence of the Drag acceleration (a_D). The dynamic equation is:

$$\ddot{\vec{r}} = \nabla\vec{U} - \vec{a}_D, \tag{1}$$

Where $\nabla\vec{U}$ is the Earth´s geopotential. The Drag force acts in the direction opposite to the motion of the satellite. Density models decays are functions of the altitude increment. The satellite is moving around the Earth with a inertial velocity, in the atmosphere with a relative velocity vector $\vec{V}_\infty$, that includes the Earth’s rotation. In the TLE data is used the Ballistic Coefficient term, that includes the drag coefficient and the inverse of the spacecraft mass/area ratio $(B = AC_D/2m)$ (Vallado & Finkleman, 2016). The acceleration due to the Drag is:

$$\vec{a}_D = \frac{\vec{D}}{m} = \rho V_\infty^2 B \frac{\vec{V}_\infty}{2|\vec{V}_\infty|}, \tag{2}$$

III. METHODOLOGY

Two atmospheric density models were selected, JB08 and NRLMISISE-00. The selection was made according to the availability of the models. The atmospheric models JR-71 and MSISE-90 were compared with the Drag of spherical satellites (Pardini et. al., 2006).

To compare the results, it was selected the historical TLE from CubeSats at LEO, because the influence of the atmospheric density is more important due to the low altitude. An initial epoch was selected to calculate the semimajor axis decay, and the orbital elements from the epoch were selected to propagate the trajectory using the two atmospheric models. The results are compared to determine the model with better results.

The propagator implement the Cowell´s method, including the gravitational model EGM-08 with 50x50 (Kuga & Carrara, 2013; Pavlis et. al. 2012). The predominant perturbation is the Drag force. The numerical integrator is a RKF 7/8 (Fehlberg, 1968) with numerical tolerance lower than 1.1E-16. The step-size is 1/2000. To propagate the trajectory it is assumed that the body maintain the cross-area constant, without variations in the Drag coefficient due to spin. The mass is well known and constant. Eleven 1U satellites with lower decay times were selected to observe the influence of the atmospheric model.

IV. RESULTS

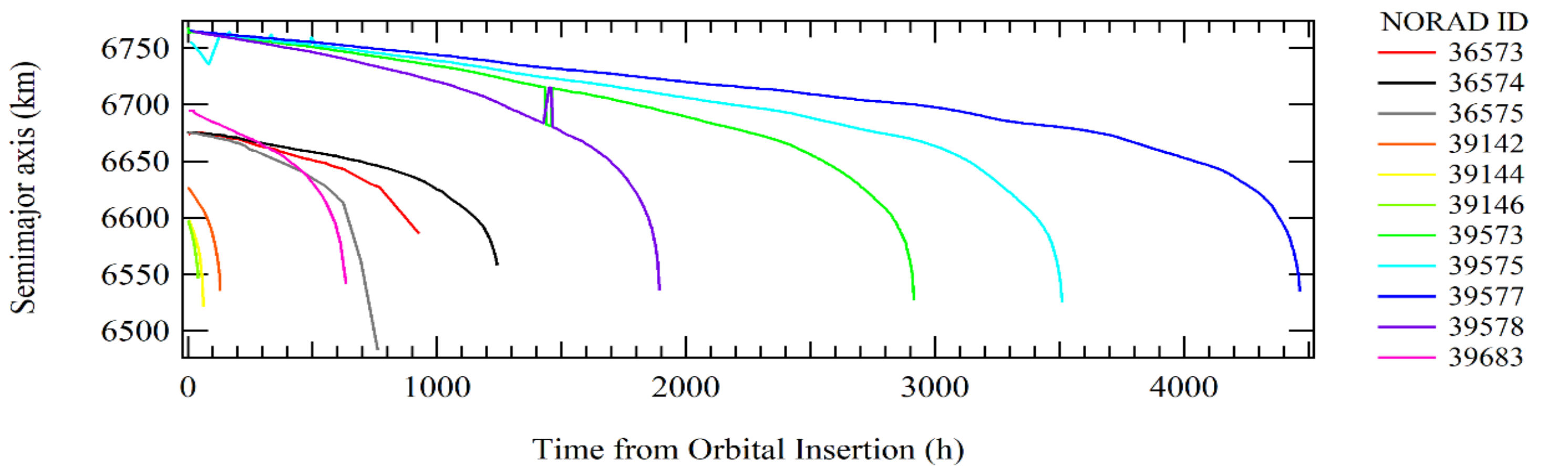

Figure 1. Satellites semimajor axis vs lifetime.

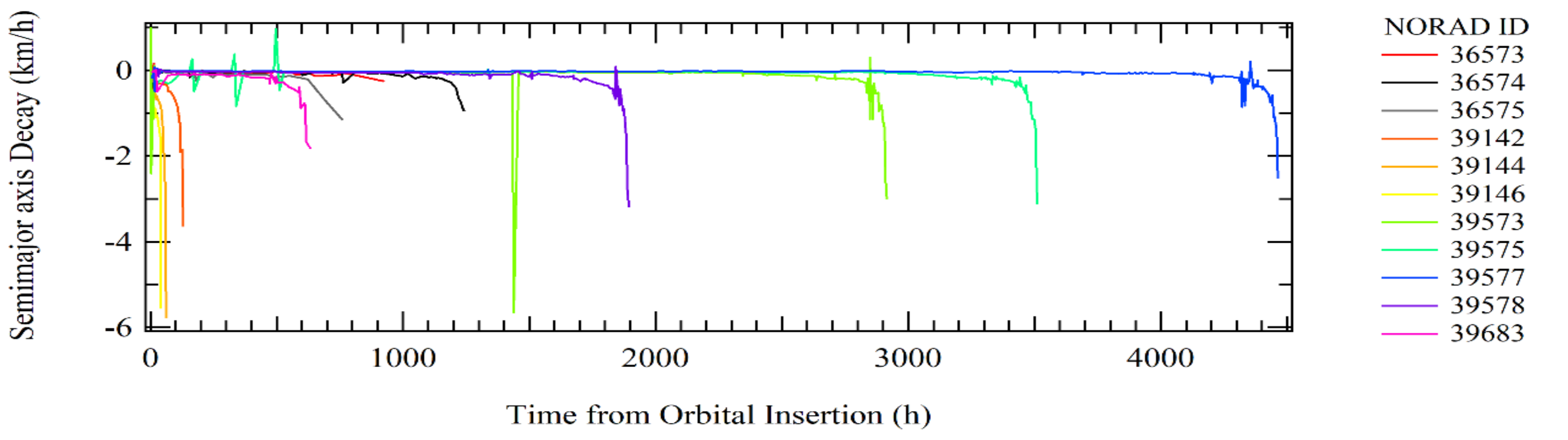

Figure 2. Satellites semimajor axis decay vs lifetime.

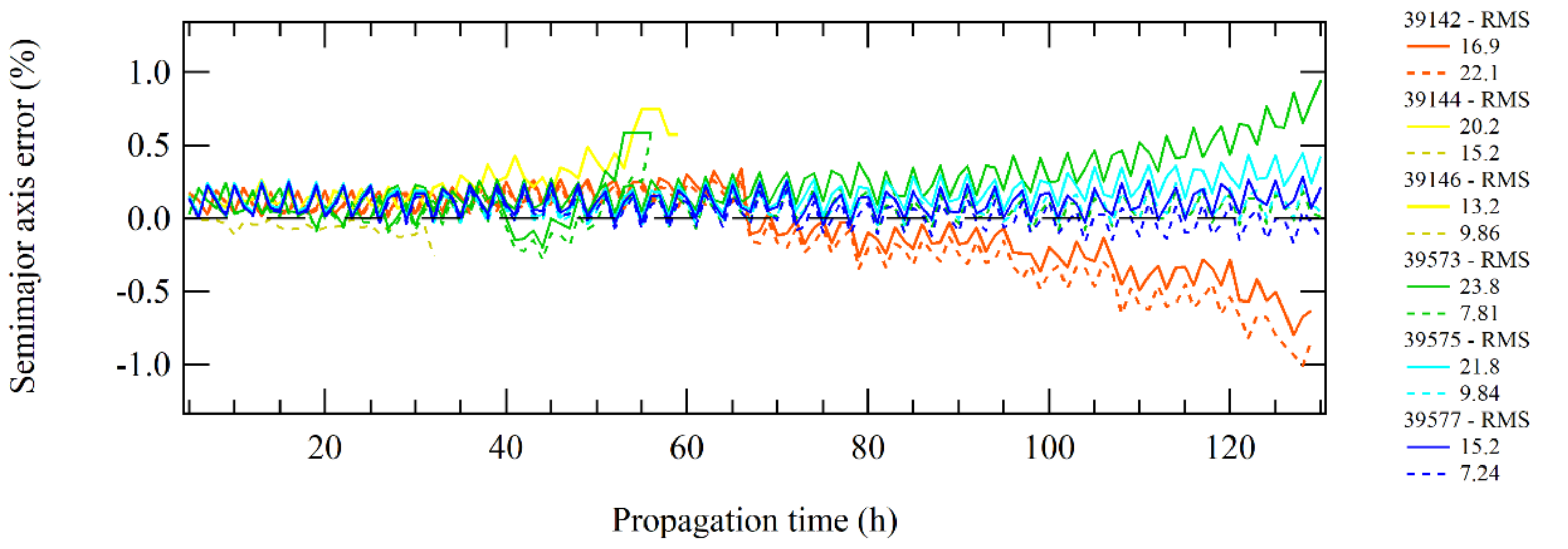

Figure 3. Satellites semimajor axis error vs propagation time.
NRLMSISE-00 (lines) and JB08 (dots).

V. FUTURE WORKS

- Application of the methodology in CubeSats at higher altitudes.
- Increase the number of satellite data to analyze, including all the CubeSat´s missions to obtain a better adjustment with the atmospheric models.
- Apply the third-body, radiation pressure and albedo in the mathematical model.
- In the case of satellite spin, it is necessary to adjust the Drag coefficient and Cross-Area variation as a function of time. To calculate these changes it is necessary the application of a more accurate method, like DSMC in the Drag calculation.

CONCLUSIONS

To determine the influence of the atmospheric model in the 1U CubeSat´s decay, it was propagated the evolution of the semimajor axis with two models, the JB08 and the NRLMSISE-00. The short lifetime of the selected satellites and the low altitude in LEO, allows to observe the decay in short periods. Results of the propagations were compared with the observed values from the historical TLE´s to determine the error propagation and the residual. In these case, it was implemented the physical Drag coefficient with a area to mass constant, remaining the same B for all the cases. The results from the propagations show good agreements with the observed data. In this case, booth models presented similar results. The implementation of the two models is recommended for future propagations in LEO. For future works it is recommended to use more satellites to analyze the problem at different altitudes.

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