The problem of disposing CubeSats from Low Earth Orbits

José B. Silva Neto[1]; Antônio F. B. A. Prado[1]; Diogo M. Sanchez[1]; Jorge K. S. Formiga[2]

[1]Instituto Nacional de Pesquisas Espaciais – INPE; [2]Universidade Estadual Paulista – UNESP/ICT

Introduction

- In recent years the number of missions with CubeSats has increased, due to the low cost of assembly and launch.
- There is a growing concern about the accumulation of objects in orbit, including CubeSats.
- There is a consensus that objects in low orbits region (LEO) should re-enter in the atmosphere in up to 25 years

Introduction

- A new concept of de-orbit is related to techniques that use solar radiation pressure and atmospheric drag to force the decay of a body in orbit around the Earth.
- These devices are less complex than a solar sail.
- They have variable area (like an inflatable balloon) and variable coefficient of reflectivity that, depending on its design, eliminates the need to control the attitude, which makes them ideal for use in CubeSats.

Introduction

- Such devices would be inactive during the years of the mission and, at the end of the mission, a balloon is inflated. The increase of the atmospheric drag force caused by the increase of the area-to-mass ratio cause the decay of the body.

- The low density of the air in high altitude limits the use of this type of device to low altitudes, or it is necessary the use of a large area increase.

- The solution presented in this study relates the use of devices that are able to change its area, together with devices with the ability to change the coefficient of reflectivity.

Introduction

- A simple theoretical design of this device would be a balloon coated by a fabric able to change its color.

- The paper does not address the constructive aspects of the device. Only the orbital dynamics of a CubeSat is considered.

Mathematical model

- The study was done numerically, via integration of the equation of motion of a perturbed satellite.
- It is considered the masses of the Earth, the Sun, and the Moon, the acceleration due to the geopotential, atmospheric drag and solar radiation pressure.
- The numerical integration is made using the RADAU integrator.
- It was chosen, for our geopotential model, order and degree 8 for the gravity of the Earth.
- The atmospheric drag is assumed to be proportional to the square of the velocity of the spacecraft with respect to the atmosphere of the Earth.

Equation of Motion

- The equation of motion of the satellites, in the equatorial frame if given by:

$$\ddot{\boldsymbol{r}} = -\frac{GM_E}{r^3}\boldsymbol{r} + GM_{\odot}\left(\frac{\boldsymbol{r}_{\odot}-\boldsymbol{r}}{|\boldsymbol{r}_{\odot}-\boldsymbol{r}|} - \frac{\boldsymbol{r}_{\odot}}{|\boldsymbol{r}_{\odot}|^3}\right) + GM_M\left(\frac{\boldsymbol{r}_M-\boldsymbol{r}}{|\boldsymbol{r}_M-\boldsymbol{r}|} - \frac{\boldsymbol{r}_M}{|\boldsymbol{r}_M|^3}\right) + \boldsymbol{P}_G + \boldsymbol{P}_D + \boldsymbol{P}_{SRP}$$

- Luni-solar perturbation
- Acceleration due to the geopotential
- Acceleration due to the atmospheric drag
- Acceleration due to the solar radiation pressure

Solar radiation pressure

$$\boldsymbol{P_{SRP}} = -4.56 \times 10^6 C_r \nu \frac{A}{m} \frac{\boldsymbol{r}_\odot}{|\boldsymbol{r}_\odot|^3} AU^2$$

- C_r - coefficient of reflectivity
- ν – shadow function
- A/m - area-to-mass ratio
- $\boldsymbol{r}_\odot$ - Sun-Cubesat vector
- AU – Sun-Earth distance

Atmospheric drag

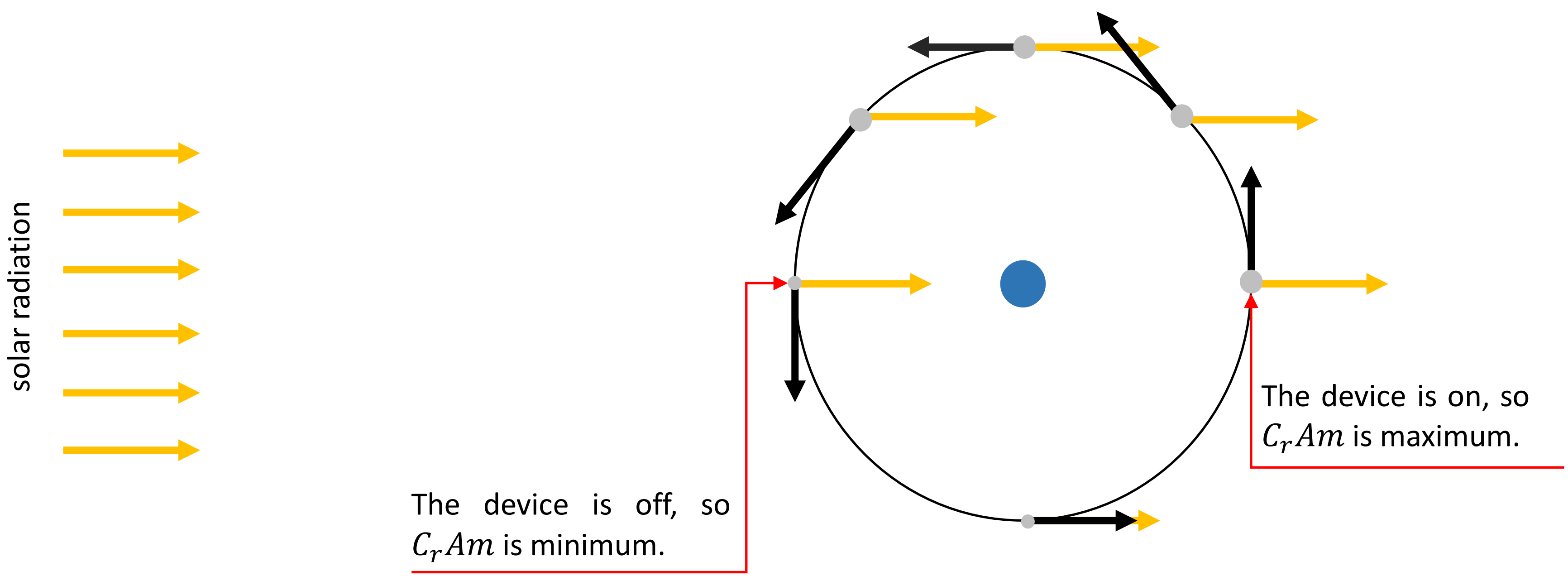
$$\boldsymbol{P}_A = -\frac{1}{2} C_D \rho(r) \frac{A}{m} |\boldsymbol{v}_{\boldsymbol{r}}|^2 \frac{\boldsymbol{v}}{|\boldsymbol{v}|}$$

- C_D - aerodynamic coefficient
- $\rho(r)$ - atmospheric density – up to 900 km of altitude
- $\boldsymbol{v}_r$ - relative velocity between the satellite and the atmosphere
- $\boldsymbol{v}$ – satellite velocity vector

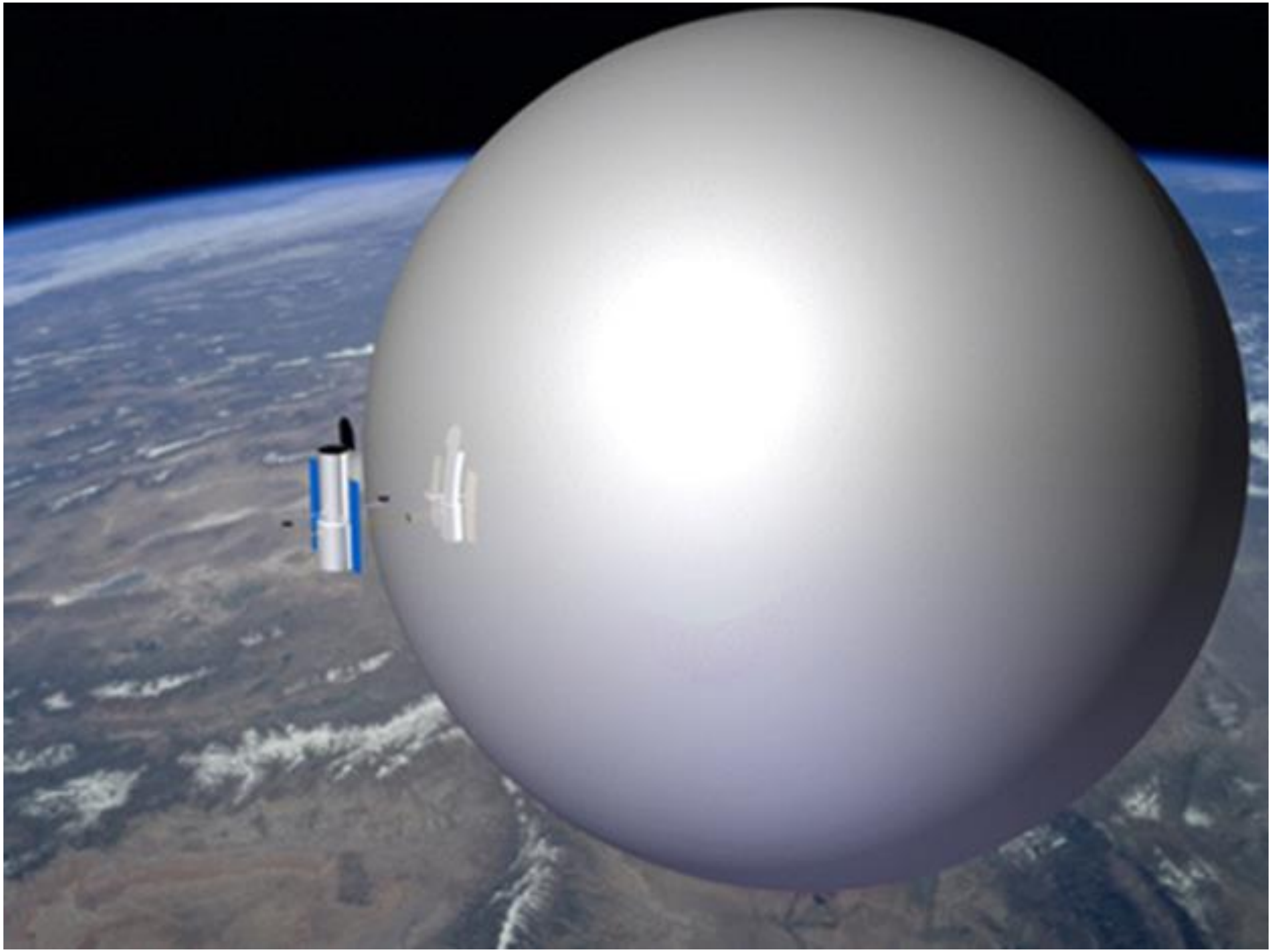
- Control used for the device of the area increase:
  - If the below condition is true, $C_r Am$ has the maximum value:

$$\langle \boldsymbol{P}_{SRP}, \boldsymbol{v} \rangle < 0$$

  - But if the above condition is not true, the $C_r Am$ has the minimum.

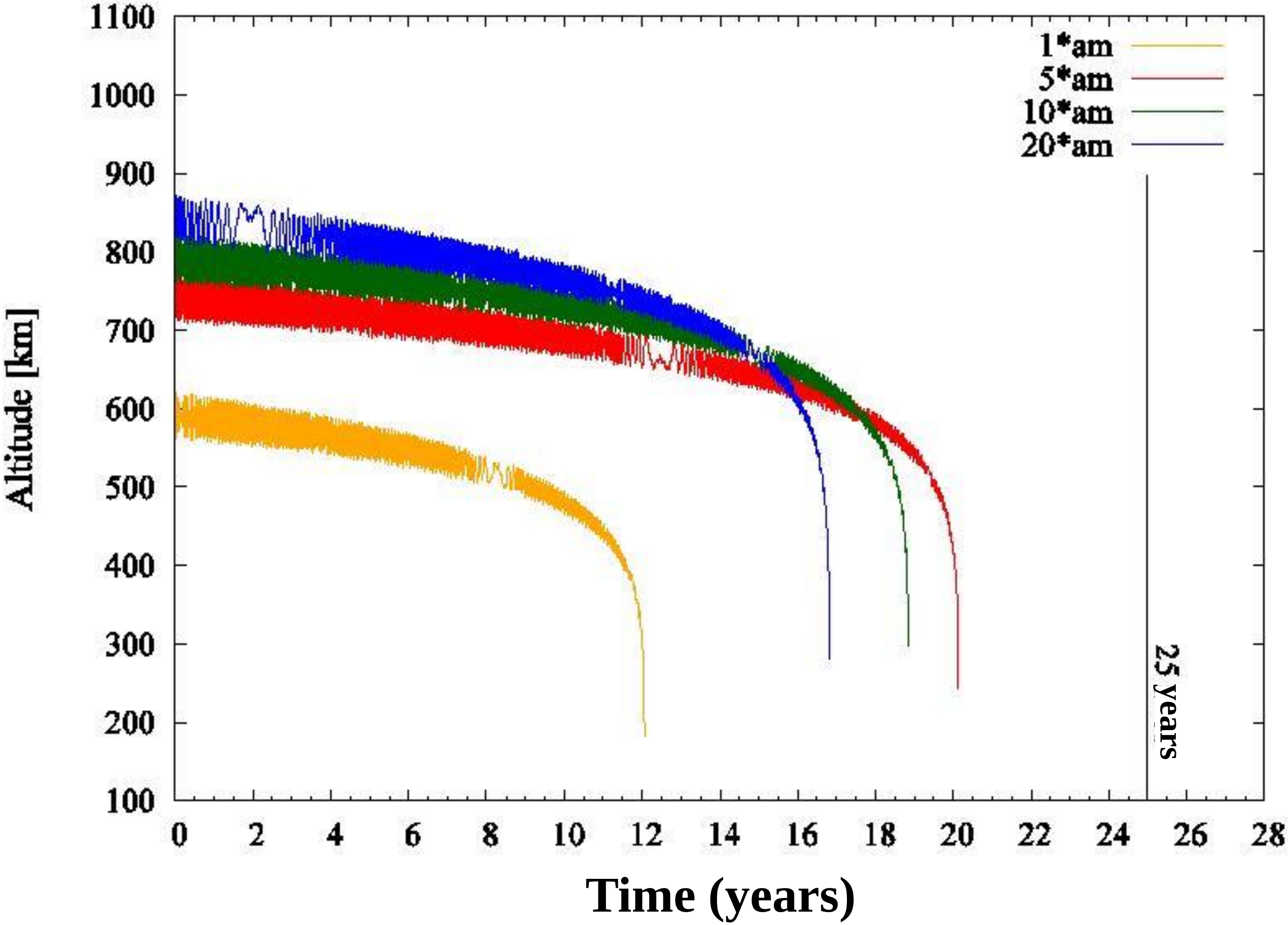


- Balloon type device

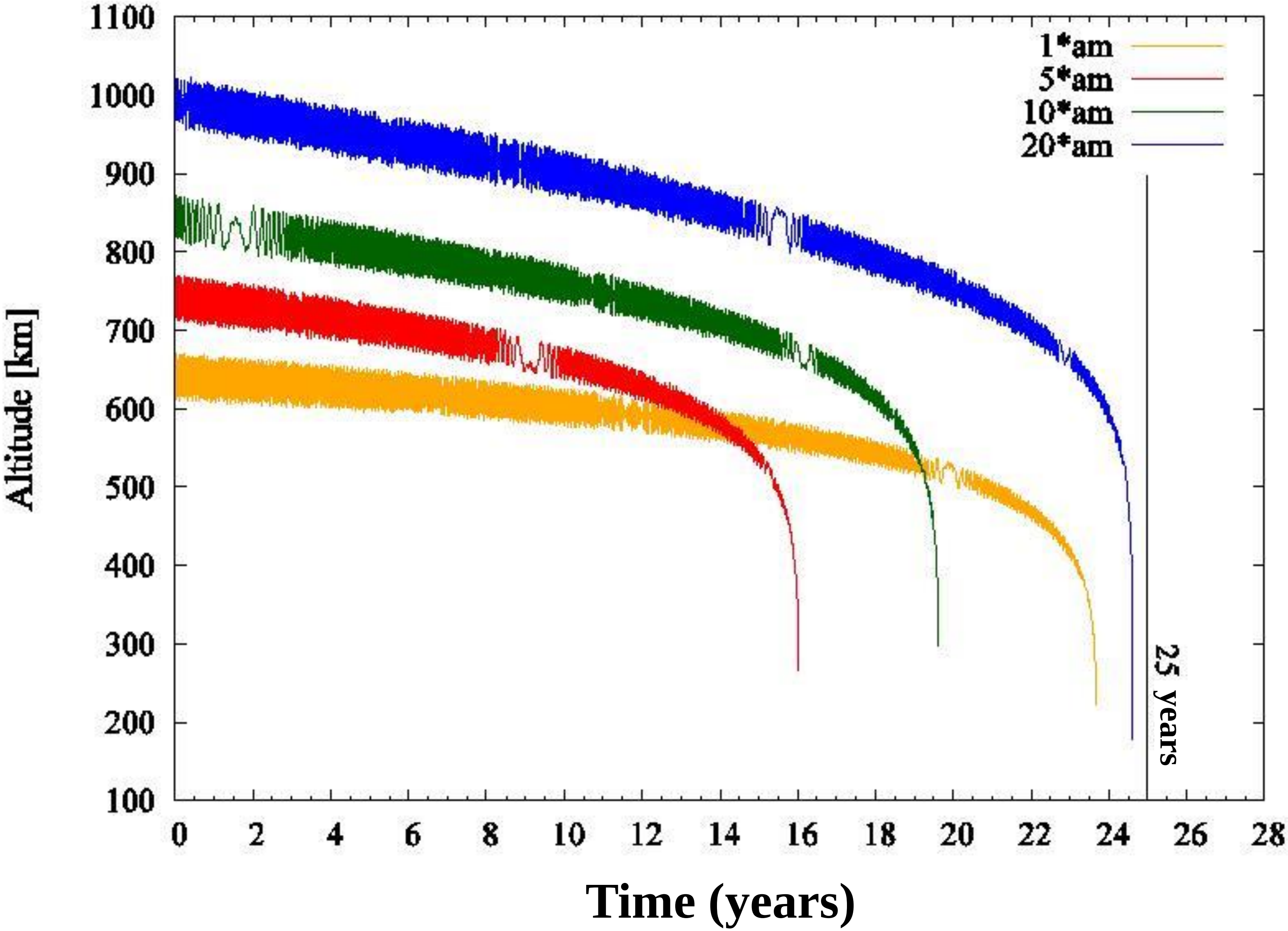


Fonte: Global Aerospace (2016).

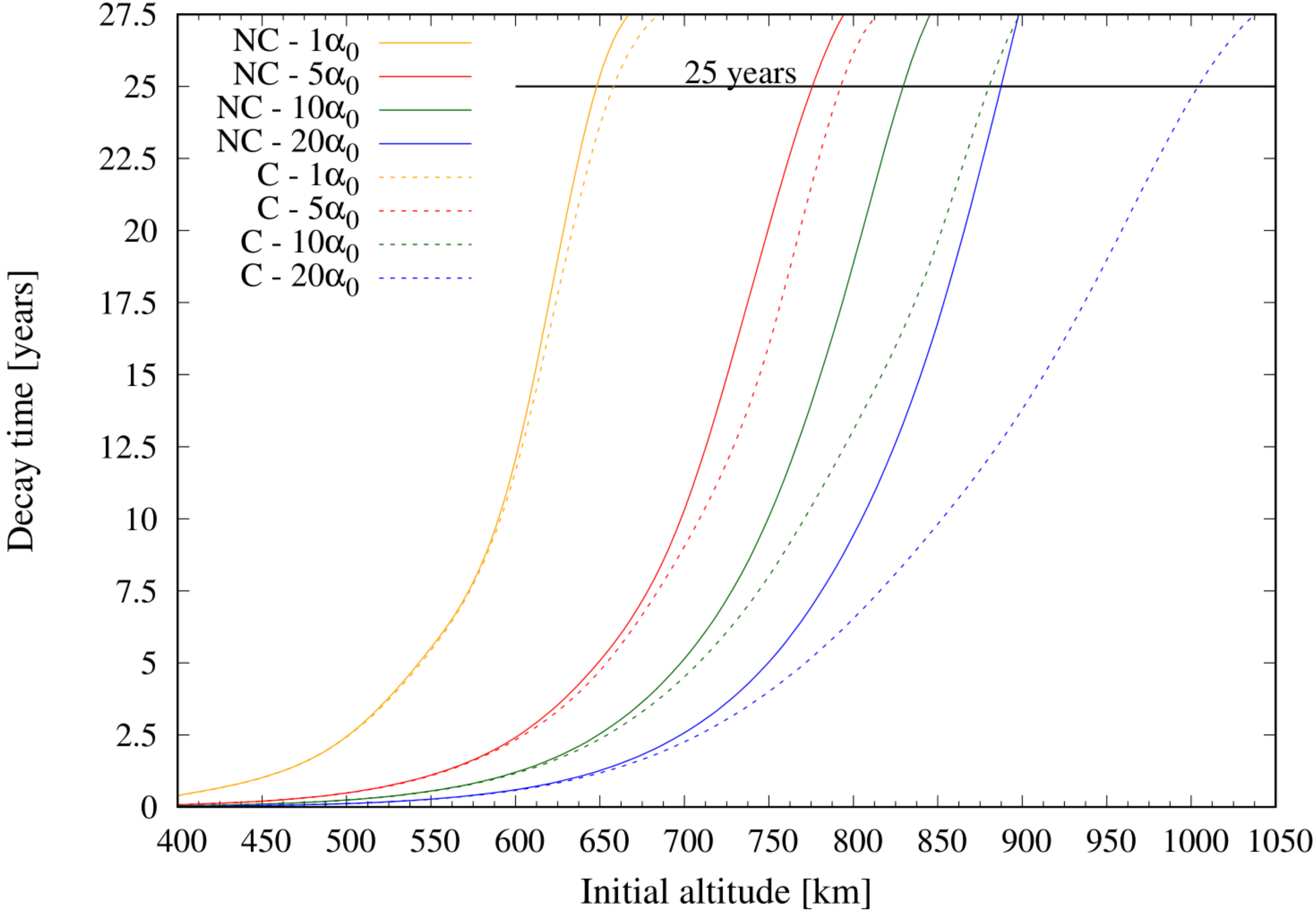
- Results: Inclination of 30 degrees, Cr fixed



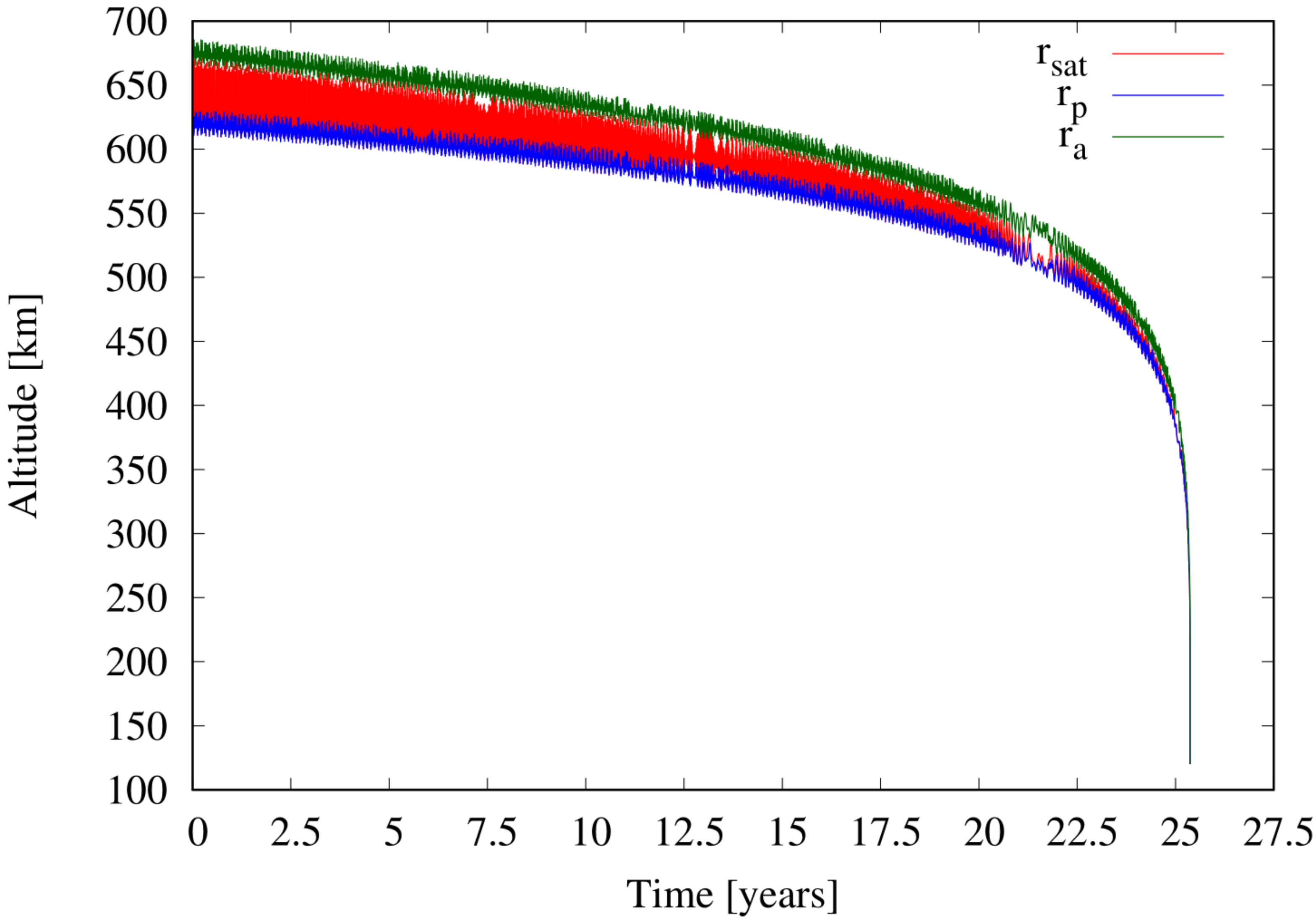
- Results: Inclination of 30 degrees, Cr not fixed



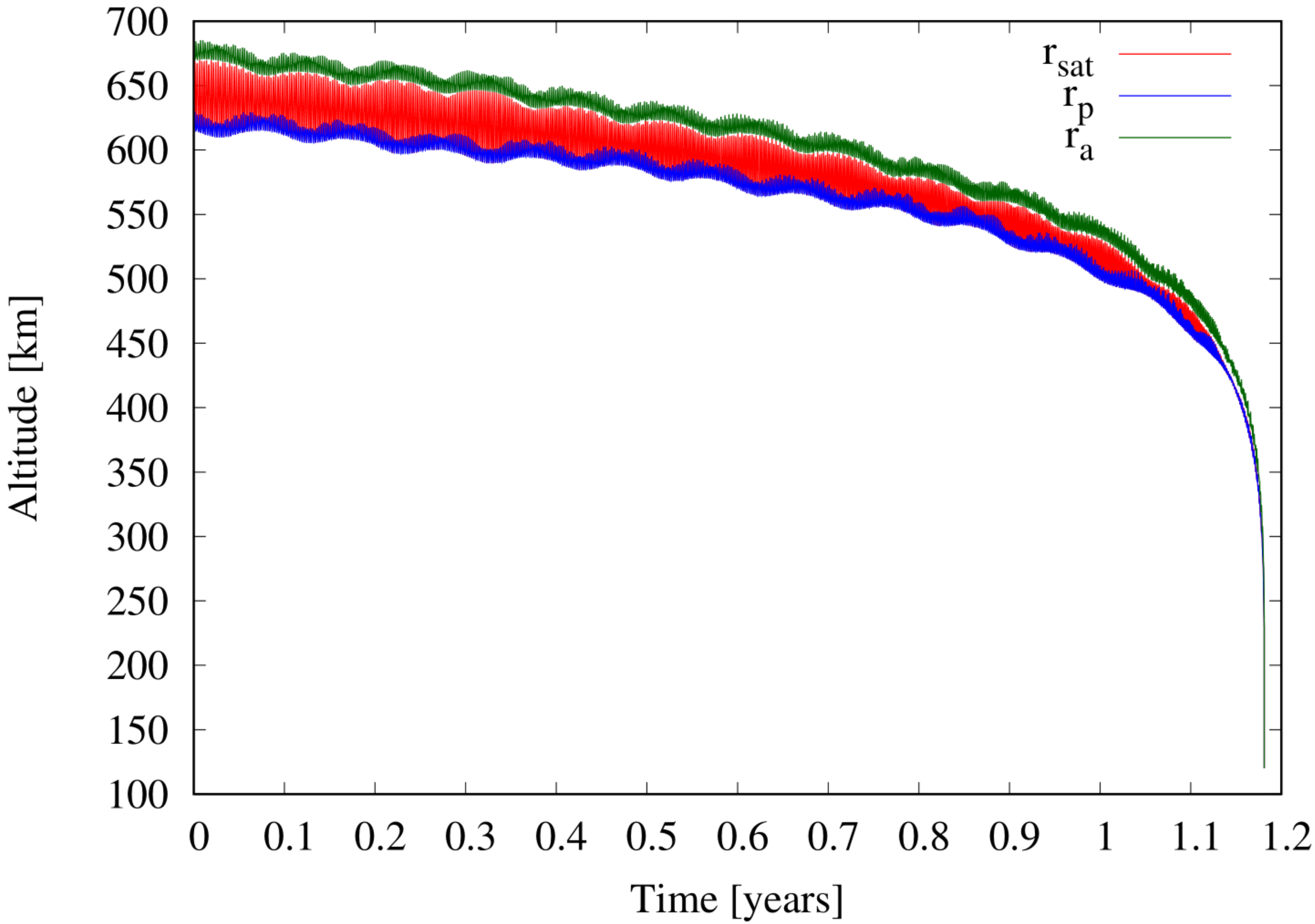
- Results: All cases for 30 degrees



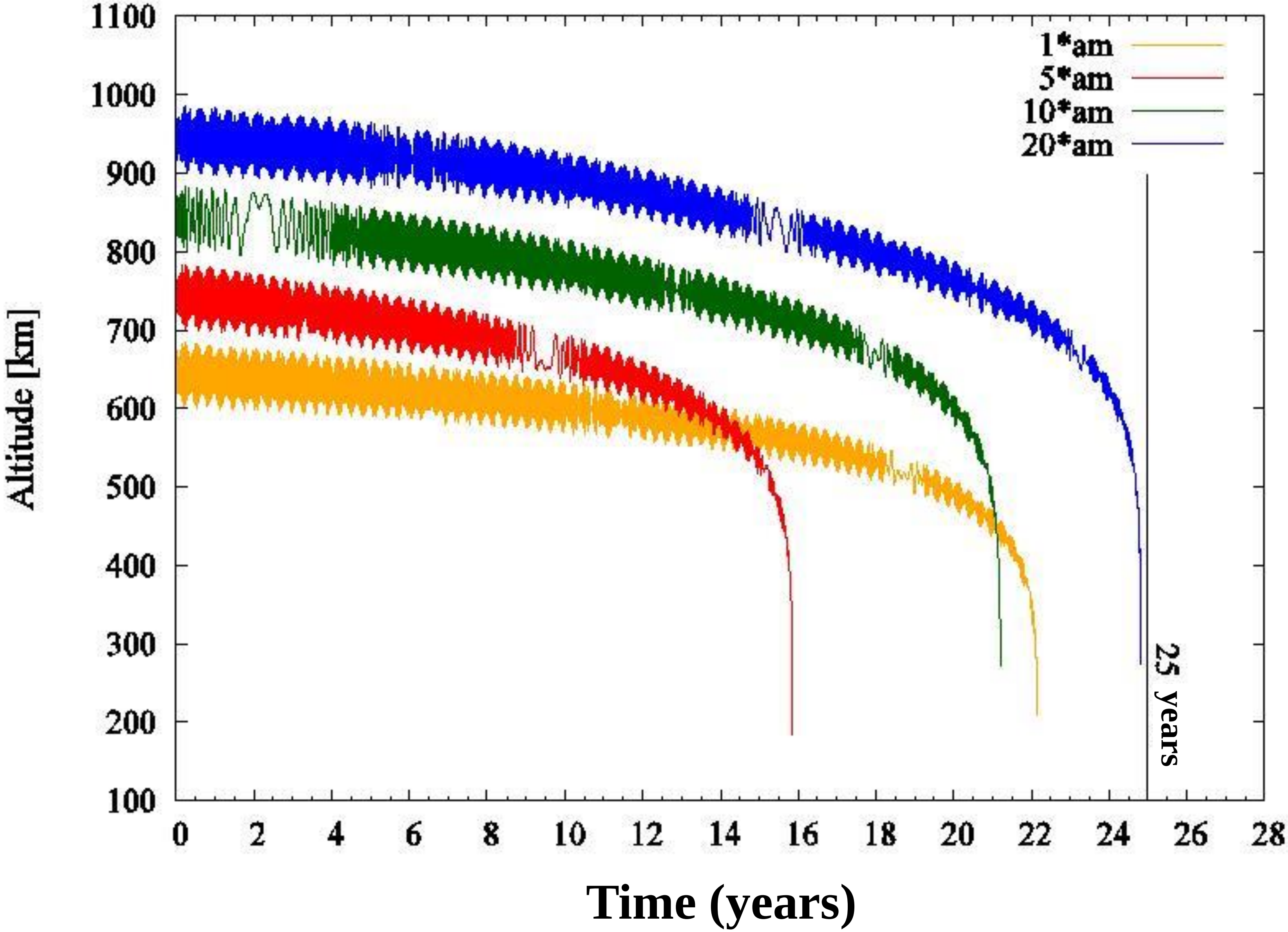
- Results for altitute initial of 650 km and without device and $C_r Am = 0.007$ m²/kg:



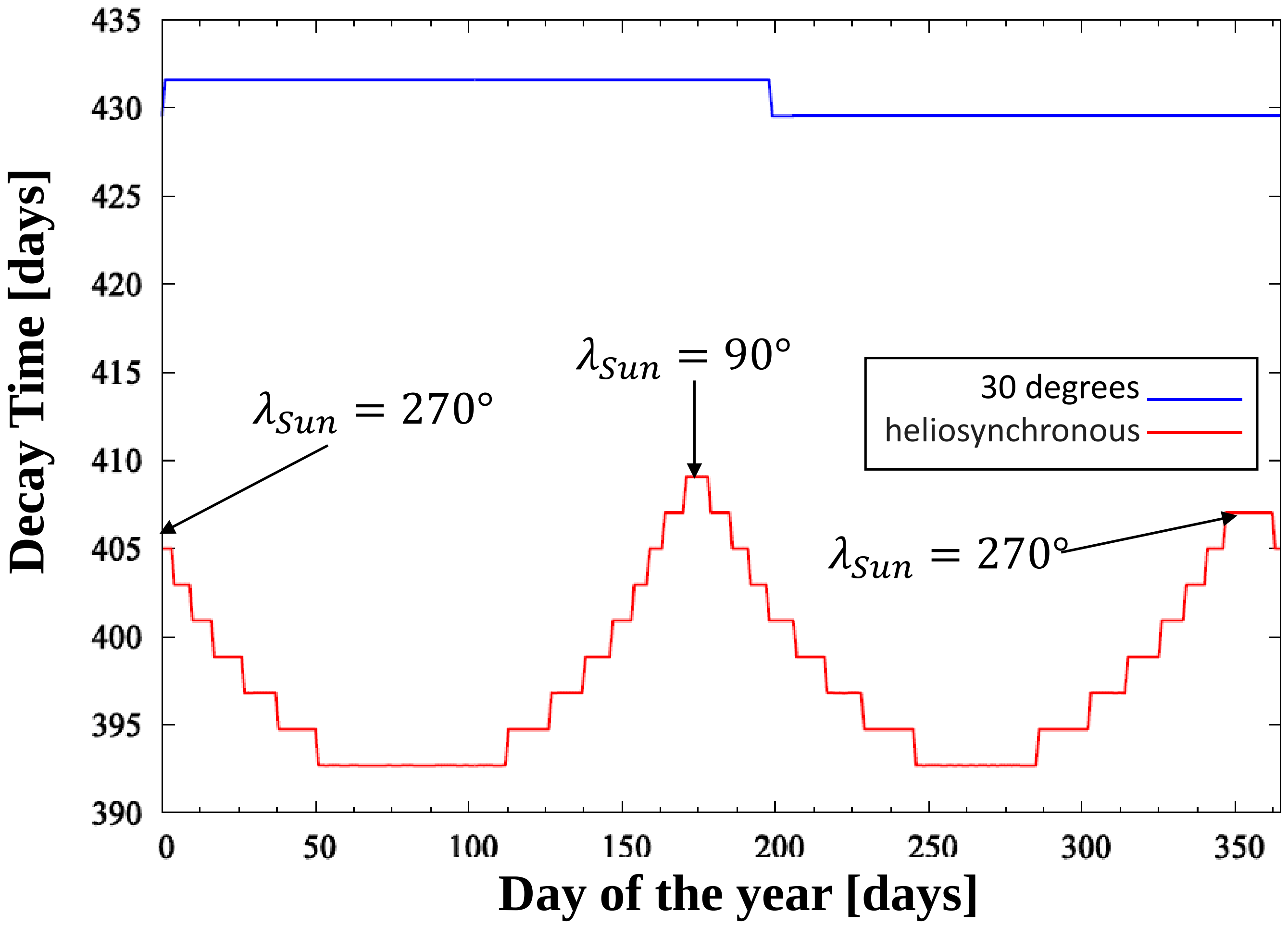
- Results for altitute initial of 650 km and with device and $C_r Am = 0.14$ m²/kg :



- Results: Sun-synchronous orbit, Cr not fixed

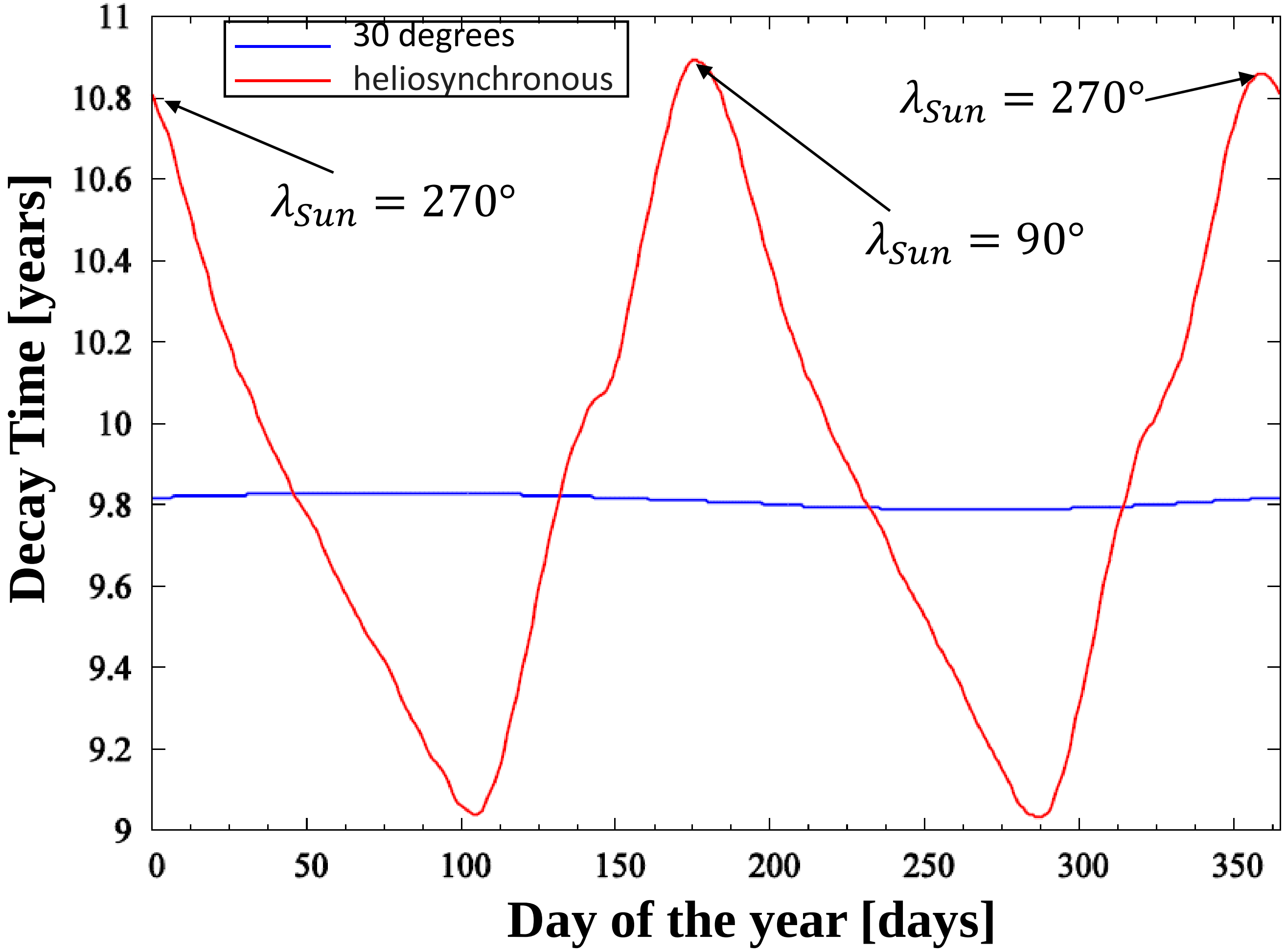


- Results - Correct day in the year to start de-orbit for altitude of 650 km



- Critical Angles of Heliosynchronous Resonance:
  - Ecliptic longitude (λ_{Sun}) = 90 degrees and 270 degrees

- Results - Correct day in the year to start de-orbit for altitude of 850 km



- Critical Angles of Heliosynchronous Resonance:
    - Ecliptic longitude (λ_{Sun}) = 90 degrees and 270 degrees

Conclusions

- The results show the advantages of using the device proposed here.
- The current missions of CubeSat are subject to the rule of the 25 years, which limits the altitude of the mission.
- Now, with the use of devices to expand the area and to vary the coefficient of reflectivity in missions, it is possible to reach higher altitudes.
- It includes even regions where the atmospheric density is not enough to bring down a CubeSat.

Conclusions

- The solar radiation pressure can to bring down the satellite using the variation of the coefficient of reflectivity and a simple control of this variation.
- At the end of the study we can say that missions where the area-to-mass ratio can have a value greater than the one considered in the present study or it is considered the highest values of the coefficient of reflectivity, higher altitudes can be desired.

Conclusions

- It is noteworthy that, with this device, for the model used in the present study, it was possible to raise the maximum limit from 600 km to 1000 km.
- Future stages will make a broader analysis of the use of different coefficients of reflectivity and more area-to-mass settings, to try to increase even more the maximum altitude for missions of CubeSats, with respect the rule of the 25 years.

References

- Everhart, E. (1985). An efficient integrator that uses Gauss-Radau spacings. *Dynamics of comets: their origin and evolution*, pages 185–202.
- Hull, S. M. (2011). End of mission considerations. In Wertz, J. R. and Larson, W. J., editors, *Space Mission Analysis and Design*, page 976. Microcosm.
- IADC (2002). *IADC space debris mitigation guidelines*. Inter-Agency Space Debris Coordination Committee.
- Lokcu, E., Ash, R. L., and F., T. A. (2011). A de-orbit system design for cubesat payloads. In *Proceedings...*, pages 470–4. 5th International Conference on Recent Advances in Space Technologies (RAST).
- Montenbruck, O. and Gill, E. (2001). *Satellite orbits*. Springer.
- Qiao, L., Rizos, C., and Dempster, A. G. (2013). Analysis and comparison of cubesat lifetime. In *Proceedings...*, pages 249–260. 12th Australian Space Conference, Sydney, Australia.
- Sanchez, D. M., Prado, A. F. B. A., and Yokoyama, T. (2014). On the effects of each term of the geopotential perturbation along the time I: Quasi-circular orbits. *Advances in Space Research*, 54(6):1008–1018.
- Silva Neto, J. B. d. (2016). Estudo da influeˆncia da pressa˜o de radiac¸a˜o solar na remoc¸a˜o de sate´lites em ressonaˆncia. Master’s thesis, Instituto Nacional de Pesquisas Espaciais (INPE), Sa˜o Jose´ dos Campos.