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Pocketqube Deorbit Times: Susceptibility to the Solar Cycle

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***Abstract*—Nowadays, as a new kind of femto-satellite with a low cost, Pocketqube has been developed to finish the space research task within the LEO region. During its lifetime the pocketqube is exposed to a high risk of collision with space debris. Taking the solar cycle as a main factor, predicting its deorbit time and evaluating its collision probability before the launch is of great importance for the mission designers to choose a right orbit and determine the proper launch time. This article presents a combined atmospheric density model based on the data from CIRA-2012 to describe the effects of the solar cycle on air density in LEO, and shows how the model is applied to calculate orbital lifetimes of pocketqubes in essentially circular equatorial orbits below 800 km altitude. Then the classical fourth order Runge-Kutta method is utilized in integrating the first order differential equations, which express the rates of change of semi major axis and eccentricity, in order to calculate the orbital lifetimes of pocketqube in LEO. The launch date within the 11-year solar cycle has been chosen as an independent variable to present the influence on lifetime prediction and probability evaluation. The result of lifetime calculation shows that the pocketqube launched at the minimum solar activity year does not necessarily get its longest lifetime. Meanwhile if the pocketqube at some specific starting altitudes is launched at the maximum solar activity year, it may remain in orbit for the longest time period. It also demonstrates how the sensitivity of pocketqube deorbit time to the launch date varies with the initial altitudes. From the figures, it can be obtained that 450 km is the altitude at which the deorbit time is most sensitive to the launch date with the percentage amplitude of 180% over its average value. Furthermore, the collision risk from space debris whose diameter is larger than 1 mm and 10 cm are evaluated by using the same method to integrate through its whole lifetime. It illustrates that for those orbits whose initial altitude is over 700 km, no matter which date is chosen to launch a pocketqube, the debris collision risk grows sharply with the starting altitude rising. Finally, by comparison with the trend of lifetime and collision risk, the interesting thing is that at some orbits with higher altitudes, like 800km, when the lifetime of the pocketqube reaches its maximum, the collision risk inversely reaches its local minimum, which can be useful for its designers to balance these two considerations.**

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1. INTRODUCTION

A Pocketqube as a type of miniaturized satellite for space research was first proposed in 2009 by Professor Bob Twiggs, which has a size of 5 cm cubed, has a mass of no more than 180 grams and typically uses commercial off-the-shelf components for its electronics[1]. It is the most proper way to divide the pocketqube into the femto-satellite, which refers to those satellites with a mass of less than 100 grams, even though it seems a little different in the definition of mass. In order to reduce the costs of Cubesat launches, four pocketqube satellites from different countries were firstly launched in 2013 together. Generally speaking, to some extent, Pocketqube can replace Cubesat to fulfill some specific launch missions and simultaneously play a teaching tool role in some universities, especially for those who have a tight research budget. Usually the orbit of pocketqube is chosen in low Earth orbits (LEO) because naturally a satellite in LEO may experience an orbital decay process into the Earth lower atmosphere at the end of its life to avoid being space debris after its mission. The rate of process nearly depends on the upper atmosphere and determines the orbital lifetime. Predicting the deorbit time of pocketqube before launch would be necessary not only for reasonably arranging its mission plan in orbit but also for scientifically analyzing the risk of space debris during its long term evolutions.

Space debris is any man-made objects in orbit about the Earth which no longer serves a useful function, including non-functional spacecraft, abandoned launch vehicle stages, mission-related debris and fragmentation debris[2]. Since the launch of Sputnik in 1957, plenty of man-made spacecraft have been launched and continue to be launched for scientific, educational, and technological purposes[3]. Space debris has been an increasingly important concern due to the potential risk of causing collisions with operational spacecraft, including pocketqube. The risk is especially high during operation within the LEO region, which is the most concentrated area for space debris. Assessing the risk of potential collisions of the pocketqube with these objects in orbit shows much significance in safely fulfilling its mission.

In the study, taking the effects of 11-year solar cycle into account, a combined atmospheric density model based on CIRA [1] 2012[6] is established within every 20 km at the altitudes from 100 km to 800km, which can be directly applied into the lifetime prediction of pocketqube satellite in LEO. Then the numerical integration model is introduced and classical fourth order Runge-Kutta method is used to calculate the orbital lifetimes. In this way the effects of solar cycle in lifetimes of pocketqube are investigated. The launch date of pocketqube is chosen as an independent variable to describe this effect. According to the results, some launch guidelines is presented for its choice of a better launch time. Next the spatial debris density is described with some specific data by precisely reading figures based on pixels. By integrating the risk increment during a small interval throughout its whole lifetime, the collision risk of pocketqube with space debris is calculated and results are shown in some figures. Similarly, how the collision risk varies with the launch date changing over one solar cycle is discussed. Finally the comparison with the lifetimes and the risk is made to give another clear vision on choosing suitable launch time of pocketqube.

2. A Combined Atmospheric Density Model

Air density model mainly describes the air density of the Earth's upper atmosphere at heights of 100km and above, with emphasis on how to evaluate the specific data at any given heights and any given time in one solar cycle, which can be directly used in lifetime calculation.

According to CIRA 2012[4], some specific air density data for given altitudes has been provided. Part of them is shown in Table 1. From the table, it can be seen that every group of air density data for low solar activity is presented at a height step of 20 km as well as for high solar activity.

Table 1 Part of altitude profiles of air density for low and high solar activity

Altitude(km)	Low activity(kg/m^3)	High activity(kg/m^3)
200	1.47E-10	4.10E-10
220	6.96E-11	2.46E-10
240	3.54E-11	1.56E-10
260	1.88E-11	1.04E-10
280	1.03E-11	7.12E-11

[1] The Committee on Space Research (COSPAR) International Reference Atmosphere

A spherically symmetrical exponential atmosphere model within 20 km

Within these 20 km, a spherically symmetrical exponential atmosphere model is built to describe the variations in air density. Taking the data for low solar activity as example, we assume that at the altitude scale of 20km, the air density ρ depends solely on the distance r from the Earth's center and varies exponentially with r, the density scale height H being constant. Thus the variation of density ρ can be written as

$$\rho = \rho_0 \exp(-\frac{r - r_0}{H}) \quad (1)$$

where ρ_0 is the density at the initial point within 20km, distant r_0 from the Earth's center. Following this model, the air density at any altitude from 100km to 800km could be determined.

Table 2. Part of altitude profiles of density scale height for low and high solar activity

Altitude(km)	Low activity(km)	High activity(km)
200-220	25.75	39.15
220-240	29.58	43.91
240-260	31.60	49.33
260-280	33.24	52.78
280-300	35.46	56.58

The model can also be applied to fit the data for high solar activity. Then the value of the density scale height in different sections of altitude is been evaluated and part of them are listed in Table 2. Until now the value of air density in any given altitude for a certain solar activity can be easily determined. Figure 1 shows the variation of air density with altitude for heights from 120km to 900km for low and high solar activity.

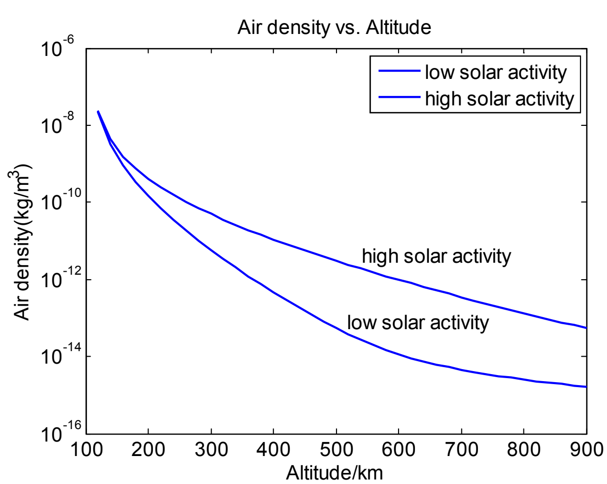

Figure 1. Variation of air density with altitude between 120 km to 900km for low and high solar activity

An air density model describing the effects of solar activity

The important and worldwide variations in upper atmosphere density can be roughly classified into four types as the day-to-night variation, the solar-activity variation, the geomagnetic-field-disturbance variation and the semi-annual oscillation. The day-to-night variation and the geomagnetic-field disturbance are indicators of short-term changes in density. The other two types of variation describe the long-term variation in density. All these variation are difficult to be reliably predicted, especially the irregular solar activity. Until now, neither the timing nor the amplitude of a future cycle has yet been precisely forecast. After removal of the two short-term variations and the semi-annual oscillation, we here only take the effects of solar activity into account and just give a rough-and-ready method to describe the variation.

According to D. King-Hele[5], the best simple analytical representation of the density at the fixed height seems to be

$$\rho_P = \rho_m + (\rho_M - \rho_m)\sin^4(\frac{\pi t}{P}) \tag{2}$$

where ρ_m = the density at perigee height at solar minimum

ρ_M = the density at perigee height at solar maximum

ρ_P = the density at this fixed height at the given time

P = the period of solar cycle

t = the time measured from solar minimum

It is notably pointed out that we should try to ensure the maximum density occurs at the right time, that is, that $t = P/2$ is the time of solar maximum.

A combined atmospheric density model

Then we can put the spherically symmetrical exponential atmosphere model within 20 km and the air density model describing the effects of solar activity together to generate the combined atmospheric density model reflecting the variation in density with altitude and time simultaneously. Based on CIRA 2012, we can easily estimate the air density at any given altitudes and at any given time in one solar cycle after taking the 11-year solar-cycle effects into consideration.

3. Predicting Lifetimes of Pocketqube

Lifetime estimation model

There are two major perturbations groups as gravitational and non-gravitational perturbing forces. In term of pocketqube in LEO, the gravitational perturbations either do not change its semi major axis at all or have a too far smaller effect than the air drag so that they could be neglected during lifetime estimation. Due to its small area (around $2.5\times10^{-3}m^2$ for 1U) exposed to the Sun, the solar radiation pressure, a kind of non-gravitational perturbations is not needed to be taken into account in predicting its deorbit time. The other non-gravitational perturbing force, the air drag acting on the satellite from the upper atmosphere, should be the main force directly leading to its decay.

On the assumption that the atmosphere rotation angular velocity is equal to the Earth's angular velocity, the acceleration produced by the air drag can be expressed in terms of the orbital velocity relative to the Earth's center as follows

$$a_d = \frac{D}{m} = \frac{1}{2}\rho v^2 \delta \tag{3}$$

where

$$\sigma = \frac{FSC_D}{m} \tag{4}$$

where ρ = Density of the ambient air

v = Orbital velocity relative to the Earth center

S = Cross-sectional area

C_D = Drag coefficient

D = Air drag

F = non-dimensional parameter

where

$$F = (1 - \frac{r_p w_E}{v_p}\cos i)^2 \tag{5}$$

r_p refers to the perigee distance to the Earth's center and v_p denotes the orbital velocity in perigee relative to the Earth center. w_E denotes the Earth's angular velocity. i means the orbital inclination.

According to D. King-Hele's theory[5], the rates of change of the semi major axis a and e can be written down as

$$\dot{a} = -\frac{a^2 \rho v^3 \delta}{\mu} \tag{6}$$

$$\dot{e} = -\frac{2}{v} a_d (e + \cos\theta) \tag{7}$$

Then classical fourth order Runge-Kutta method is utilized to solve the first order differential equation.

Details of numerical integration

Before calculating the lifetime of pocketqube for circular orbits, we define the deorbit time as the time that the pocketqube takes when the altitude falls to 140km, since most satellites make only a few revolutions after this time[5].

The descent step of semi major axis is taken as $\Delta a = -10m$. We control the time step by controlling the value of Δa.

Only in this way can we guarantee the accuracy of the lifetime calculation to obtain a much more reliable result. The values of relevant parameters of pocketqube used in estimation are provided in Table 3.

Table 3. Values of relevant parameters of pocketqube

Parameters	Values
Mass m (kg)	0.1
Cross-sectional area S (m^2)	2.5×10^{-3}
Drag coefficient C_D	2.2
Eccentricity e	0
Inclination i (degree)	0
Initial altitude (km)	300-800
Decay altitude (km)	140
Descent step (m)	-10

Taking the solar activity into consideration, the air density varies with altitude as well as time. In different years, the density in some certain altitude may go up and down. We assume that the solar cycle is 11 years, denoted by $P = 11 years$. And when the time $t = 0$ and $t = 11$, it is the very minimum solar activity year. When the time $t = P/2 = 11/2$, it is the very maximum solar activity year.

Lifetimes of Pocketqube at the initial altitude of 500 km vary with the launch date

Setting the initial altitude as 500 km, we can obtain the lifetimes in different launch dates, which varies at a step of 0.5 years from 1st to 11th year in one solar cycle, some of them being shown in Table 4. The complete result is plotted in Figure 4.

As can be seen from Table4, when the pocketqube is launched in the year t with $t/P = 1/2$,which is in the maximum solar activity year, it can only stay in orbit for about 0.3 year, which is the worst situation for the satellite. However, the lifetime would be the longest, about 4.78 years if the pocketqube is launched in the year t with around $t/P = 0.8$, that is about the 9th year in one solar cycle. The reason is that in maximum solar year, the maximum sunspot greatly expands the upper atmosphere so that its density increases sharply, only to accelerate its decay.

Table 4. Lifetimes in different launch date at the initial altitude of 500km

Launch Date	Lifetimes(years)
0	3.05
2	1.25
5.5	0.313
8	2.02
9	4.78
10	3.52

Figure 2 shows how the orbital altitude varies with the time during its lifetime. When the altitude is above 400km, the change of orbit of the pocketqube is at a low rate. Once its height drops below 300km, the pocketqube spirals in extremely quickly.

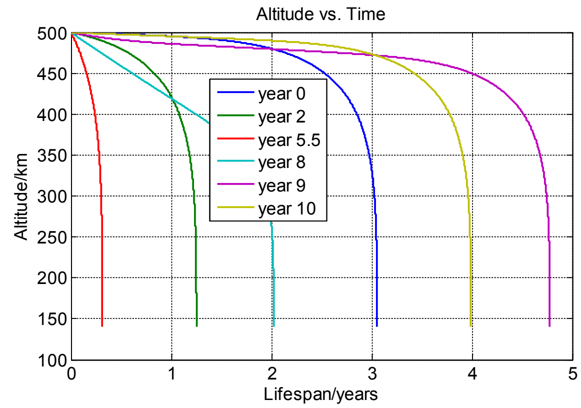

Figure 2. Variation in altitude during the lifetime, 500km

According to the analysis above, some practical suggestions are listed below:

(a) The maximum solar activity year should never be chosen as the launch date. The solar activity would absolutely kill the pocketqube quickly.

(b) If the objective is to make the pocketqube remain in orbit as longer as possible, the best launch date is not the minimum solar activity year, but some year after maximum solar activity. For the initial altitude of 500km, the 9th year may be the best launch date to deploy a pocketqube for the latest decay.

Lifetimes at other initial altitudes

The results for 400 km, 500km, 600 km, 700 km and 800 km, plotted in Figure 3, 4, 5, 6 and 7, respectively. Figure 3 reflects the variation in lifetime of the pocketqube in the 400 km orbit with the launch date. For the orbit of 400 km, it can be seen that the maximum lifetime occurs at the minimum solar sunspot launch year while the launch time that is chosen at the maximum solar sunspot year would lead to the decay in the shortest period. So the approach to prolong its deorbit time is to make the launch date as closer to the minimum solar sunspot time as possible.

It demonstrates that the variation in lifetime of the pocketqube in the 600 km and 800 km orbit with the launch date in Figure 5 and 7, respectively. They have a same trend with the variation in the 500 km orbit, although the launch time when the peaks of lifetimes occur is put forward to about the 7th year within an 11-year solar cycle.

What is interesting is that at the 700km initial altitude, shown in Figure 6, the pocketqube lifetime is longest when it is launched at a time near sunspot maximum. There is a steep increase in lifetime estimation before the maximum solar activity year, which is different from other altitudes. It should be noticed that the longest lifetime is around 11 years. If the pocketqube is sent to the space at the maximum solar year and are able to survive the sunspot maximum, it will last until at least the next solar maximum. In other words, if a pocketqube launched at solar minimum is unlikely to have a lifetime of 11 or 22 years, because that would probably imply decay near solar minimum. It is a conclusion of much importance that decay is much more likely to occur in a year when solar activity is high.

Figure 8 describes how the altitude of the pocketqube at its initial height of 800km drops with the time. Evidently no matter which date is chosen to launch a pocketqube, it can operate in orbit for at least two solar cycles, that is to say, that the lifetime of pocketqube at 800km should be two few decades or more. In terms of the curve with its shortest lifetime, the pocketqube is just launched at a time near the sunspot maximum, which proves the analysis above again.

Also another phenomenon which is worth being discussed is that there are two points of intersection, marked with squares in Figure 8, happening in the 11th and 22nd year within their own lifetime. Precisely speaking, all the lines do not intersect at the same points in the squares because at the same initial orbit, the falling heights of two satellites differ if one pocketqube goes through the maximum solar activity year firstly and the other goes through the minimum solar year firstly. Actually in the 11th year or 22nd year of its own lifetime there is rare little difference in the orbit altitude. In other words, through one or two solar cycles, all the pocketqube launched in different dates descend from the same altitude to the nearly same height. It illustrates that when the orbit altitude is over 700km, there is no significant difference in pocketqubes experiencing the maximum solar year firstly or the minimum solar year firstly.

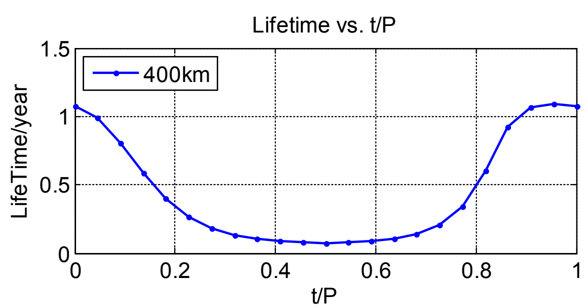

Figure 3. Variation in lifetimes with launch date, 400km

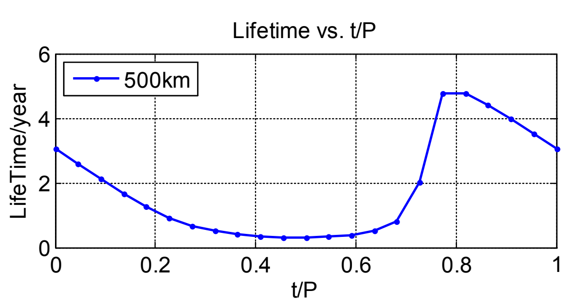

Figure 4. Variation in lifetimes with launch date, 500km

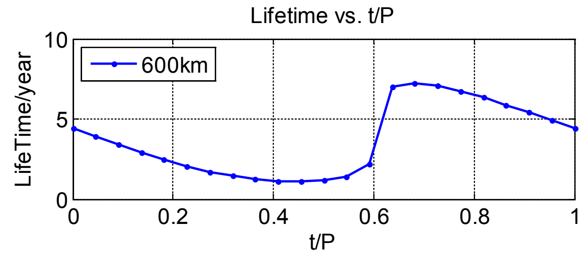

Figure 5. Variation in lifetimes with launch date, 600km

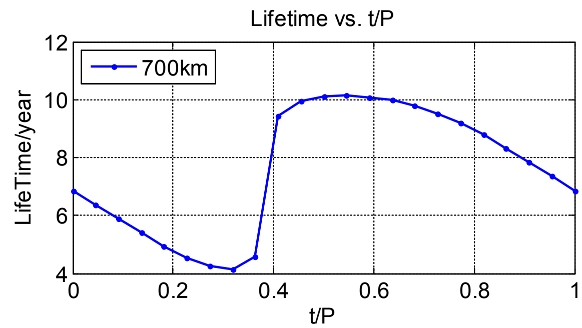

Figure 6. Variation in lifetimes with launch date, 700km

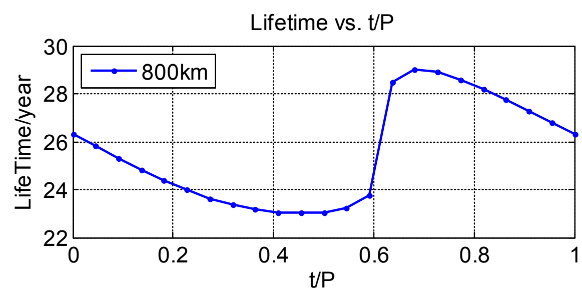

Figure 7. Variation in lifetimes with launch date, 800km

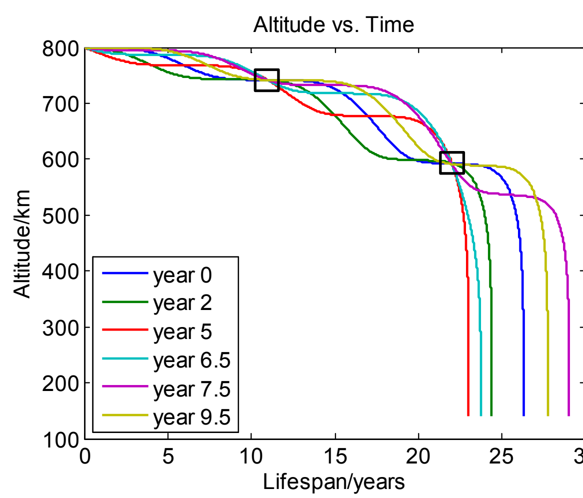

Figure 8. Variation in altitude during the lifetime, 800km

Sensitivity of Lifetimes to the Solar Cycle

Figure 9 illustrates that the ratio of lifetime to its average value changes at different initial altitudes with the launch date. The ratio can be expressed by using the equation

$ratio = L_i / (\sum_{i=1}^{P} L_i / P), i = 1, 2, ..., P$. Obviously, there is a drastic fluctuation with the launch date in the lifetimes of 400km, 450 km and 500 km but the lifetime of 800 km is not so sensitive to the launch date. The percentage amplitude of change of the lifetime in 400 km, 450km and 500km are up to around 150% over its average value. However, the maximum percentage amplitude of change for 800 km is less than 25%. It illustrates that the lifetime of pocketqube in the lower orbits is restricted mostly by the always changing solar activity.

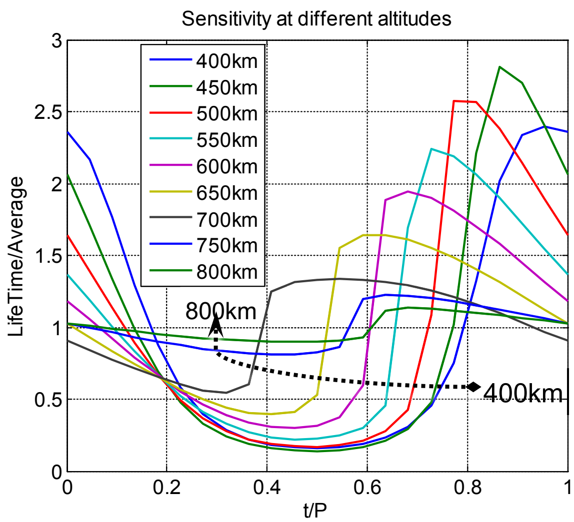

Figure 9. The ratio of lifetimes to its average value

Furthermore, it is clear that the peak of sensitivity happens at some altitude between the altitudes of 400 km and 500 km. The specific relation between the peak sensitivity and initial altitudes is shown in Figure 10. Apparently, 450 km is the altitude at which deorbit time is most sensitive to the launch date with percentage amplitude of 180% over its average value.

4. Assessing Collision Risk of Pocketqube with Space Debris

Data Preparation – Space Debris Density

For the evaluation of collision risk, the first thing we need to deal with is to figure out the space debris distribution in the Earth orbits. The spatial density within LEO regions as a function of altitude is presented. For objects whose diameter is larger than 10 cm, the spatial density is shown in Figure 11, which has a pixel dimension of 967*456 pixels. The horizontal coordinate scale is from 200 km to 2000km, while our focus altitude scale is between 200 km and 800 km. To get the accurate density data from Figure 11, we utilize MATLAB to read the image and take advantage of the pixels information to get positions of some points. The position information can be transferred to the coordinates of points. And then a group of specific density data at an altitude step of 5km from 200km to 800km can be obtained, as plotted in Figure 12.

The spatial density of objects whose diameter is larger than 1mm is given as the red line in Figure 13 with 967*459 pixels, which is a rather rough image but the clearest one on

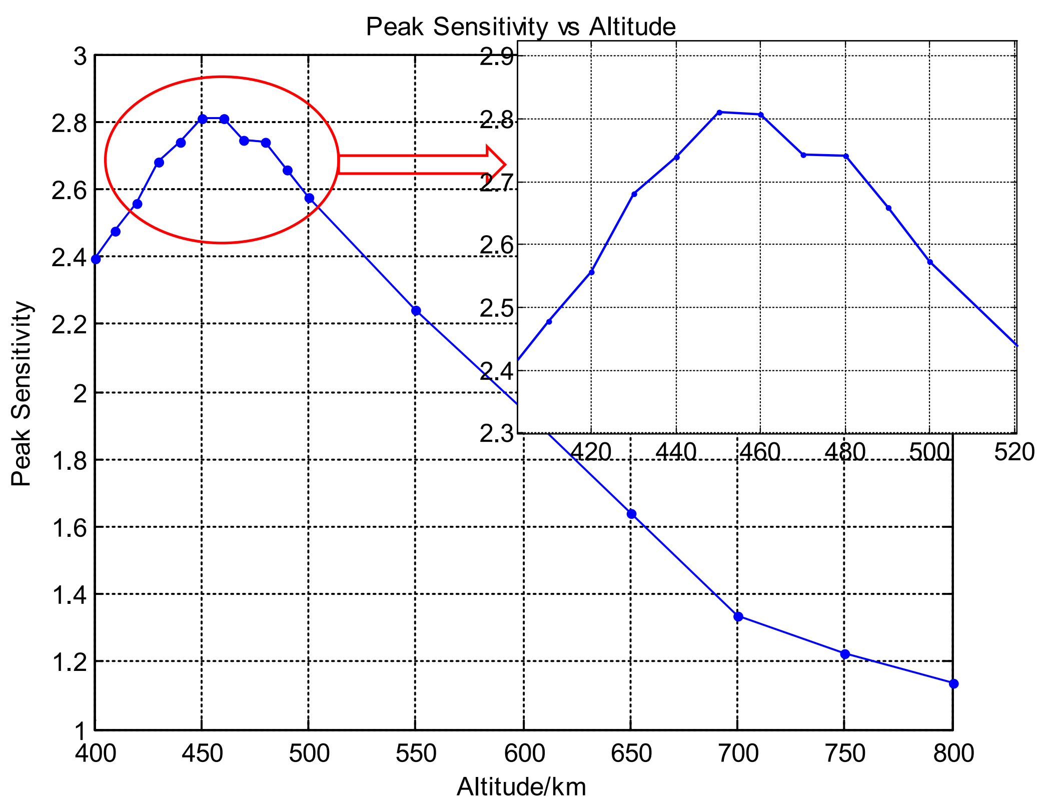

Figure 10. Relation between peak sensitivity and the initial altitudes

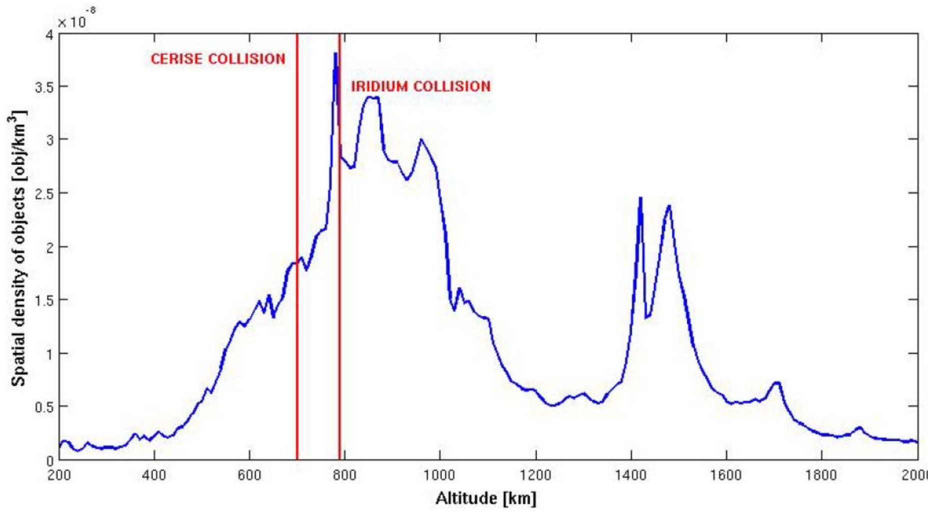

Figure 11. Spatial density of objects with diameter larger than 10cm in LEO[6]

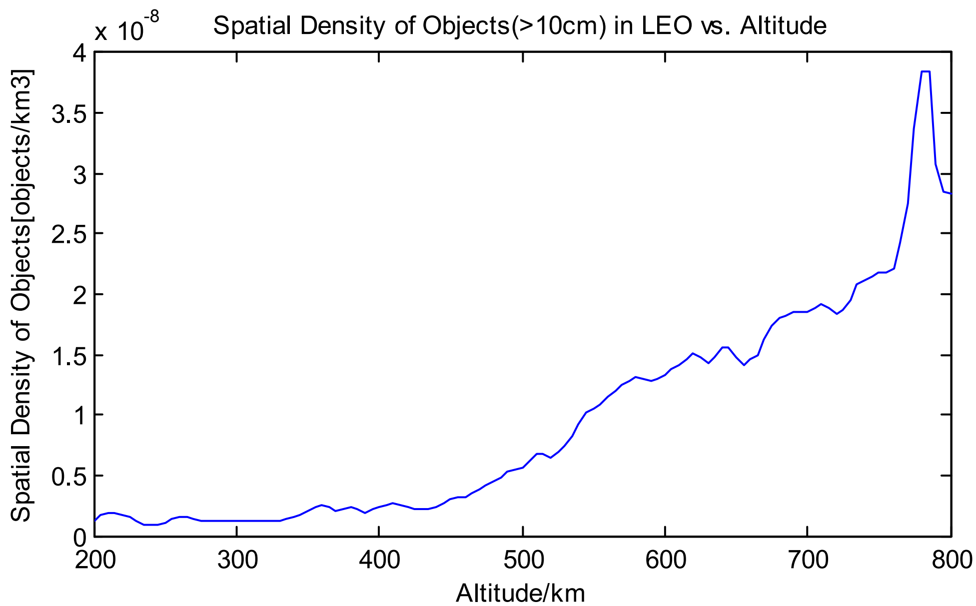

Figure 12. Spatial density (>10cm) vs. Altitude from 200km to 800km

the Internet. Using the same method, we can pick up some points at an altitude step of 50 km and plot them in Figure 14. The spatial density data plotted in Figure 12 and 14 can be directly used in calculating the probability of collision of pocketqube with space debris.

Evaluation Model and Method

As shown in Figure 15, during a small time interval Δt, it is reasonable to assume that the value of the flying velocity of the pocketqube is a constant. The volume it pass through can be get and then be multiplied by the spatial debris density to obtain its risk of collision in this interval. The risk increment denoted by ΔC can be written as

$$\Delta C = \rho_{debris} S v \Delta t \tag{8}$$

where ρ_{debris} means the spatial density at some altitude and S denotes its cross-sectional area.

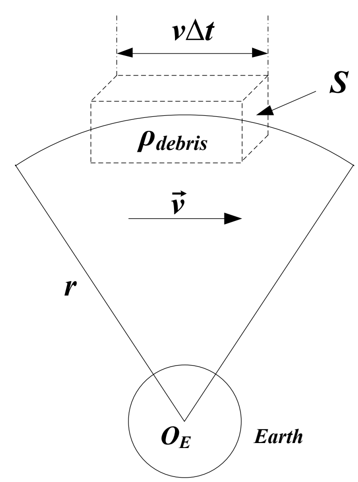

Figure 15. Diagram of risk calculation

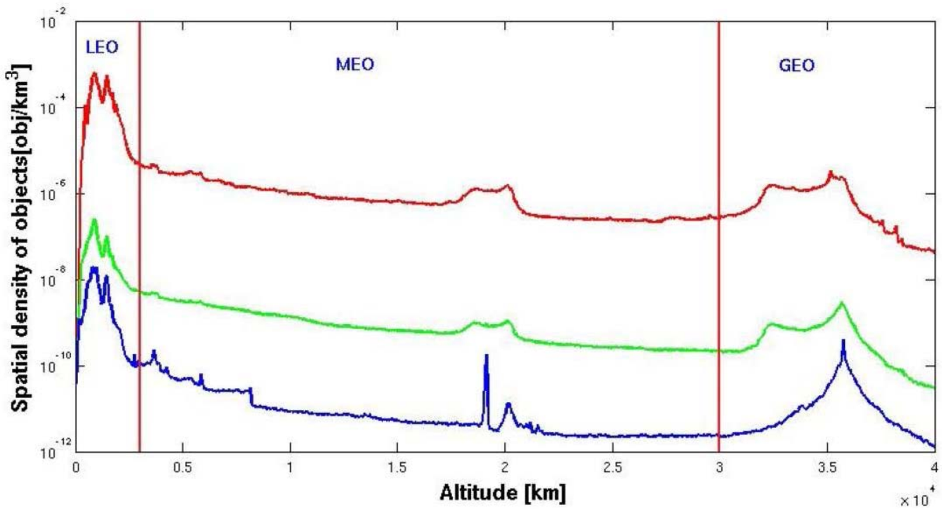

Figure 13. Spatial density of objects with diameter larger than 1mm (the red line)[6]

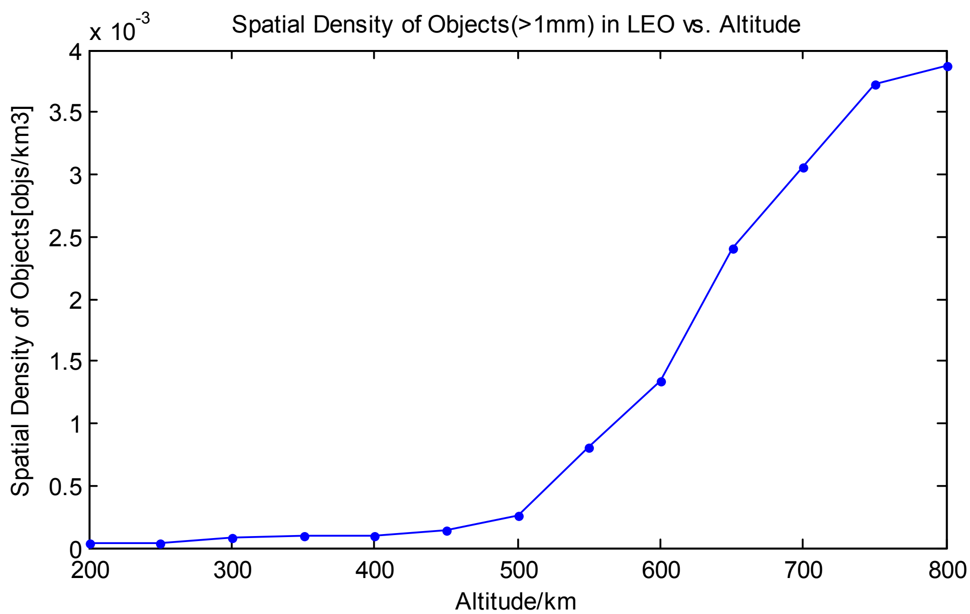

Figure 14. Spatial density (>1mm) vs. Altitude from 200km to 800km

By utilizing the 4th order Runge-Kutta method, we integrate equation (6) and (7) throughout the whole lifetime of the pocketqube to acquire the total collision risk.

Variation in collision risk with altitude at different launch dates

The variation in collision probability of pocketqube with the initial altitude is plotted in Figure 16 for 10cm and Figure 17 for 1mm. The red line of Year 6 in Figure 16 or 17 means that the collision risk the pocketqube launched at the maximum solar activity year suffers increases with the initial altitude of orbits rising.

The curve trend in Figure 16 or 17 shows that no matter which date is chosen to launch a pocketqube, the initial orbit altitude where there is a steep climb in the probability of collision is around 750km. It reflects that plenty of space fragments gather around at this altitude and expose the in-orbit pocketqube to much more dangers. As is shown in Figure 16 and 17, the pocketqube launched at the 8th year within a solar cycle are exposed to the maximum collision risk at any initial altitudes. The 8th year is when usually the pocketqube may get a longer operation time, just two and a half years after the maximum sunspot. It illustrates that longer the pocketqube stay in orbit for, the higher the probability of collision with space objects.

By comparison with Figure 16 and 17, it is obvious that the collision risk from objects whose diameter is larger than 1mm is far too greater than that from objects whose diameter is larger than 10cm. The maximum probability for 10 cm is around objects while the maximum probability for 1 mm is up to 0.05.

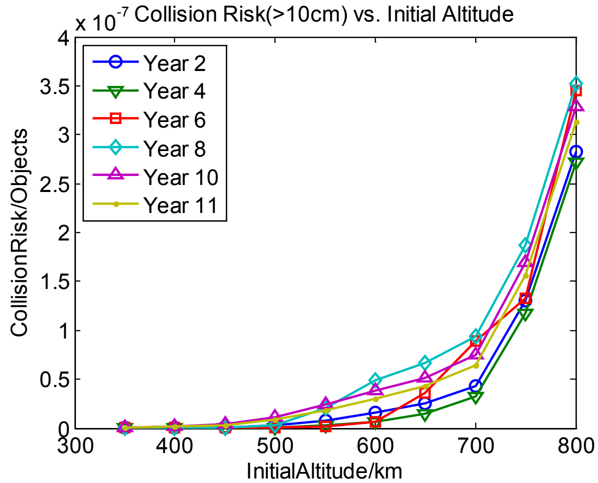

Figure 16. Collision risk (>10cm) versus initial altitude of pocketqubes launched in some selected years in one solar cycle

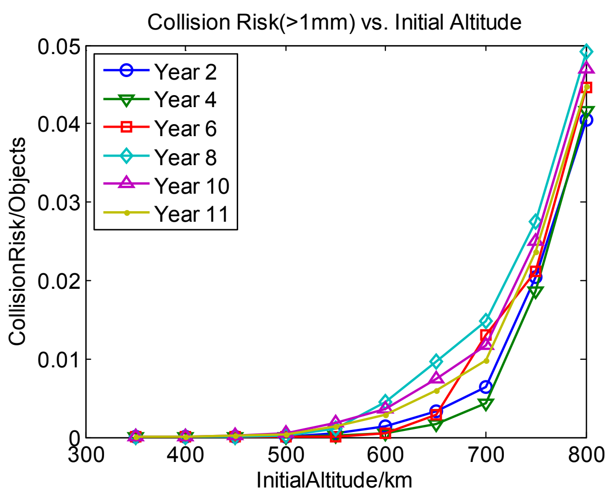

Figure 17. Collision risk (>1mm) versus initial altitude of pocketqubes launched in some selected years in one solar cycle

5. Comparison of the Variation in Lifetime and Collision Risk with the Launch Date within a Solar Cycle

The lifetimes and the collision risks at altitudes of 400 km, 500km, 600 km, 700km and 800km for 10cm and 1mm are plotted in Figure 18, 19, 20, 21and 22, respectively. In the horizontal coordinate, both $t/P=0$ and $t/P=1$ stand for the sunspot minimum year, which is year 0 or year 11, while $t/P=1/2$ means the maximum solar activity year, which is year 5.5. In terms of Figure 19, if the pocketqube is launched at about the 9th year, its lifetime would be around 5 years and the collision risk from objects whose diameter is larger than 10 cm and 1mm would be around 1.2×10^{-8} and 6×10^{-4} objects, respectively.

For the orbit with an initial altitude of 500 km, the collision risk of the pocketqube with space debris is almost proportional to the lifetimes. The general trends of variation in lifetime and collision risk with launch date are similar. As can be seen in Figure 19, the longer the lifetime is, the more danger the pocketqube is exposed to. However, for those orbits with a starting altitude of 700 km and 800 km, shown in Figure 21 and 22, the lifetime may be relatively shorter while the pocketqube would suffer a higher risk of collision with space objects. The lifetime and collision risk seem not to keep a synchronous path. There is a sharp climb in the variation of lifetime through all launch dates. By contrast, the collision risk of the pocketqube with debris ranges slowly and smoothly.

From Figure 21, when t/P is nearly 0.6, correspondingly year 7.5 within one solar cycle, the lifetime almost is the maximum value of all but the collision risk reaches its local minimum, either for 10 cm or for 1 mm. This phenomenon can be used to guide the pocketqube mission designers to consider the best launch date to balance its lifetime and collision risk.

In Figure 22, when the pocketqube is launched to the 800 km orbit at maximum sunspot year, correspondingly $t/P=1/2$, its lifetime almost reaches its lowest, while the probability of collision with space objects share the same level with the pocketqube launched at minimum sunspot year, correspondingly $t/P=0$. It implies that at some higher starting height, the pocketqube would not face less danger due to its shorter lifetime.

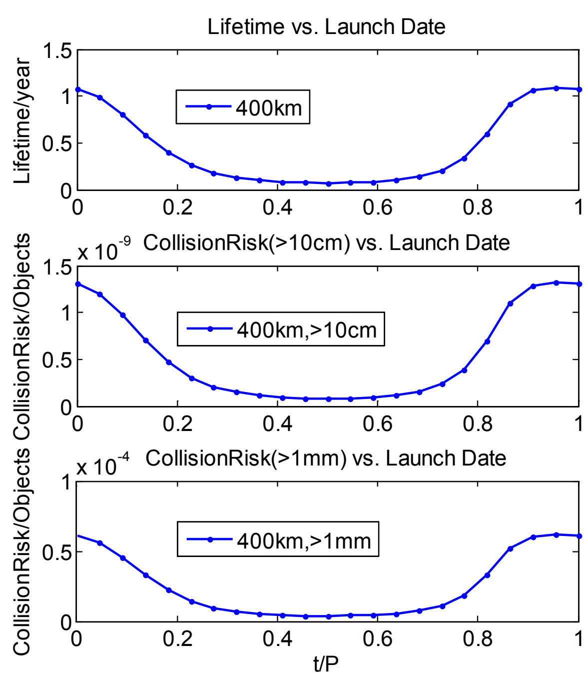

Figure 18. Comparison with the lifetime and collision risk for 10 cm and 1mm, 400km

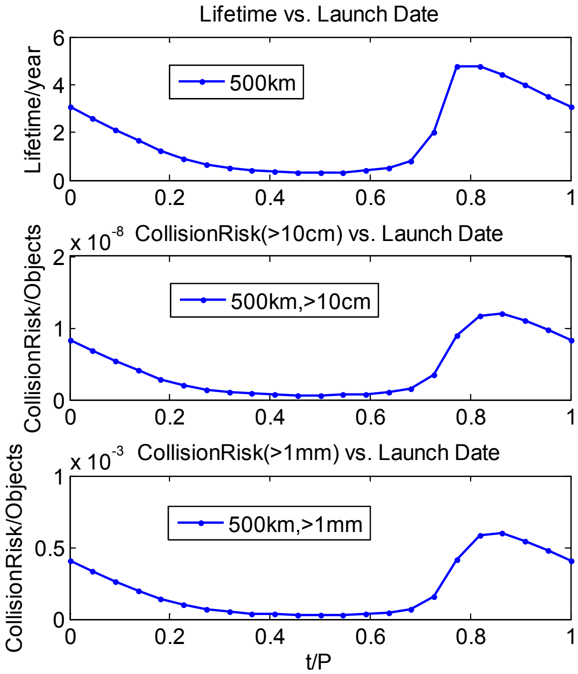

Figure 19. Comparison with the lifetime and collision risk for 10 cm and 1mm, 500km

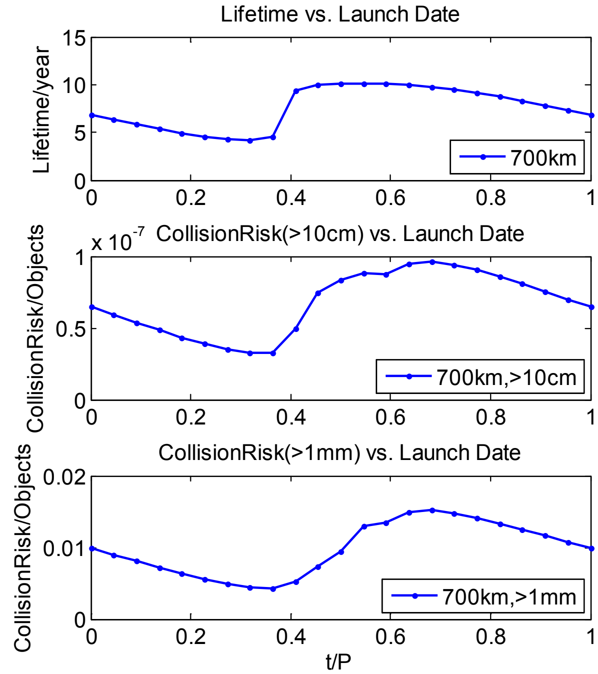

Figure 21. Comparison with the lifetime and collision risk for 10 cm and 1mm, 700km

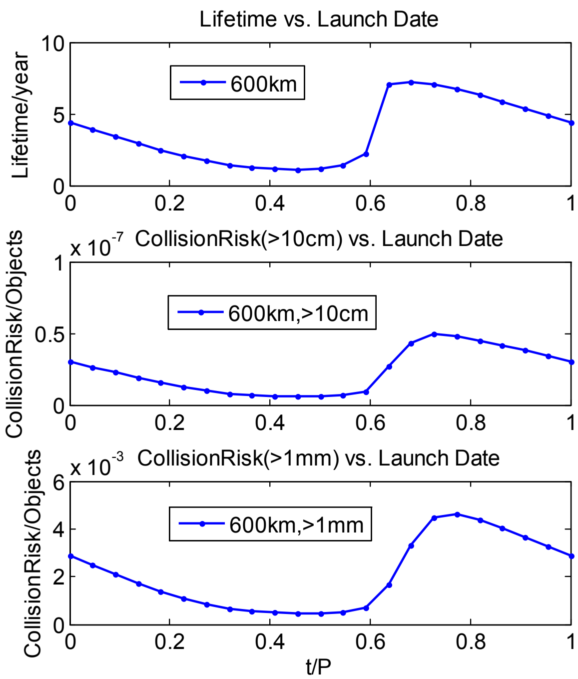

Figure 20. Comparison with the lifetime and collision risk for 10 cm and 1mm, 600km

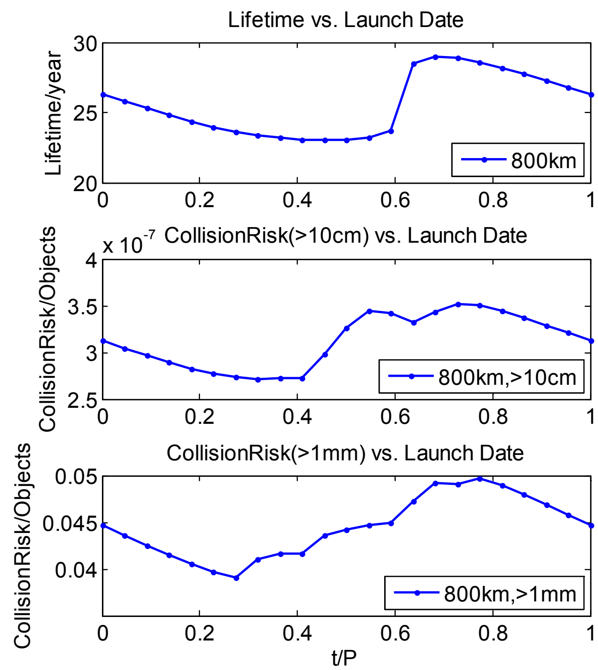

Figure 22. Comparison with the lifetime and collision risk for 10 cm and 1mm, 800km

6. Conclusions

The combined atmospheric density model describes the variation in air density with the altitude and the time within 11-year solar cycle in a simple way. It is used to demonstrate the effects of solar activity in lifetime prediction of the pocketqube in different starting altitudes. Usually, the lifetime of the pocketqube launched at maximum solar activity year would be shortest. However, in turn, the lifetime for minimum solar activity year does not mean the longest one. For most orbits in LEO, the launch date for the longest lifetime is some year after the maximum solar activity year, which is determined by the specific initial altitude. There exists an exception that if the longest lifetime is right around solar cycle or multiples of solar cycle, that is 11, 22 years or more, the launch date for the longest lifetime should be chosen at the maximum solar activity year, such as the pocketqube at the initial altitude of 700km. In terms of the sensitivity of deorbit time, between 400 km and 800 km, 450km is the starting altitude at which the deorbit time of the pocketqube is most sensitive to the solar cycle.

The risk from space debris whose diameter is larger than 1mm is far too higher than that from those whose diameter is larger than 10 cm. As concerning initial-altitude variation in collision risk, there is a consistent climbing trend. The higher the initial altitude is, the more quickly the risk increases, especially for 750km with a sharp growing. In general, the variation in collision probability with the launch date shares the same trend with the lifetime. The longer time it survives for, the higher the collision risk is. It should be noticed that at some orbits with higher altitudes, there is also an asynchronous phenomenon between collision risk and lifetime with launch date within one solar cycle. Like at an 800 km starting altitude, when the lifetime of the pocketqube reaches its maximum, the collision risk inversely reaches its local minimum, which can be useful for the pocketqube designer to balance these two considerations.

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