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Determination of a Mean Ballistic Coefficient and Decay Predictions for CubeSats

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INTRODUCTION

- Satellites in Low Earth Orbit (LEO) decay due to environmental effects especially atmospheric drag. And it is important to estimate decay of a satellite correctly for the operations and lifetime.
- In this study, a simple equation which calculates decay of a satellite in every orbit is used as reference.

$$\Delta a_{rev} = -2\pi\left(\frac{C_d A}{m}\right)\rho a^2$$

- From above equation, $\left(\frac{m}{C_d A}\right)$ can be expressed as ballistic coefficient. Table below shows change in ballistic coefficient from satellite to satellite.

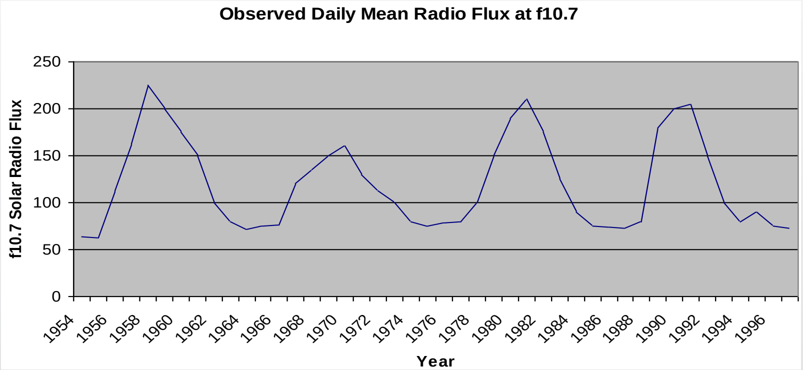
Satellite	Mean Ballistic Coefficient
Oscar – 1	29
Echo – 1	0.515
ERS – 1	73
Skylab	228

INTRODUCTION

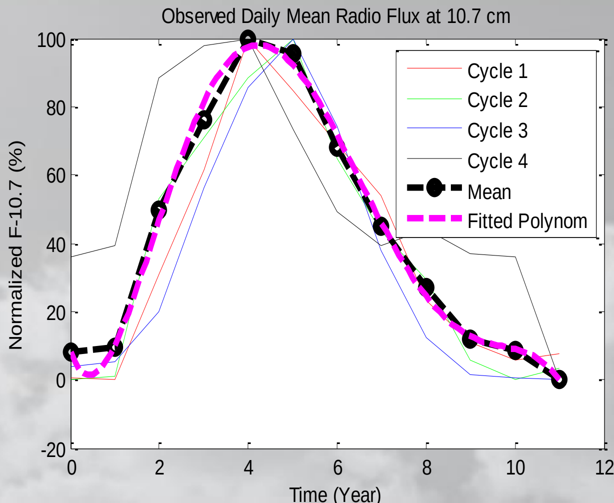
- In order to obtain more realistic results, varying atmospheric density due to altitude and solar activity are considered.
- Solar activity level estimation code is generated to determine atmospheric density more accurate.
- Finally, to determine mean ballistic coeffient, real flight data of 1U CubeSats are investigated.
- Because CubeSats have similar dimension and mass properties, a mean generic ballistic coefficient prediction is more applicable.

Atmospheric Density Model

- To determine solar activity, first, solar flux data and solar cycles between 1954 and 1996 are investigated.

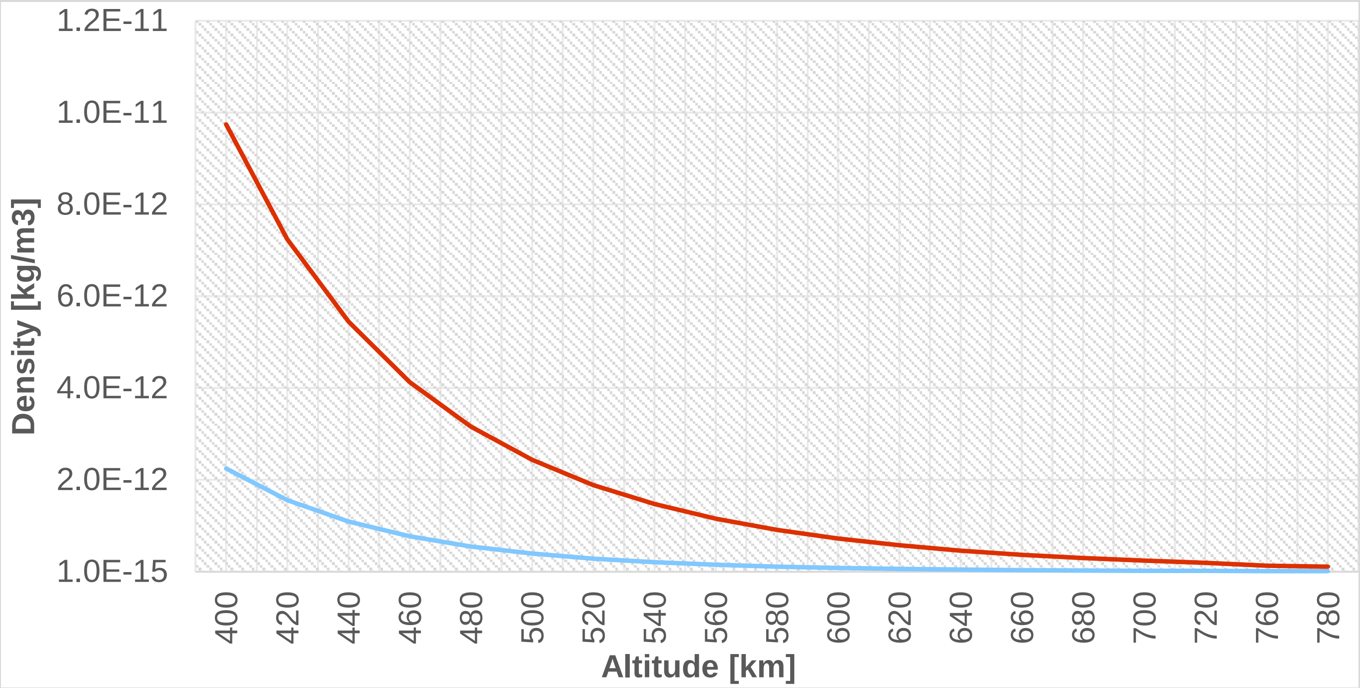


- These cycles were normalized to 100 to find the activity level percentage in a cycle. A polynomial is fitted to the data and it gives the percentage of solar activity for a given date in its own cycle.



Atmospheric Density Model

- Harris-Priester model was taken as reference, because it is valid for LEO altitude range and gives both minimum and maximum density values for a specific altitude.

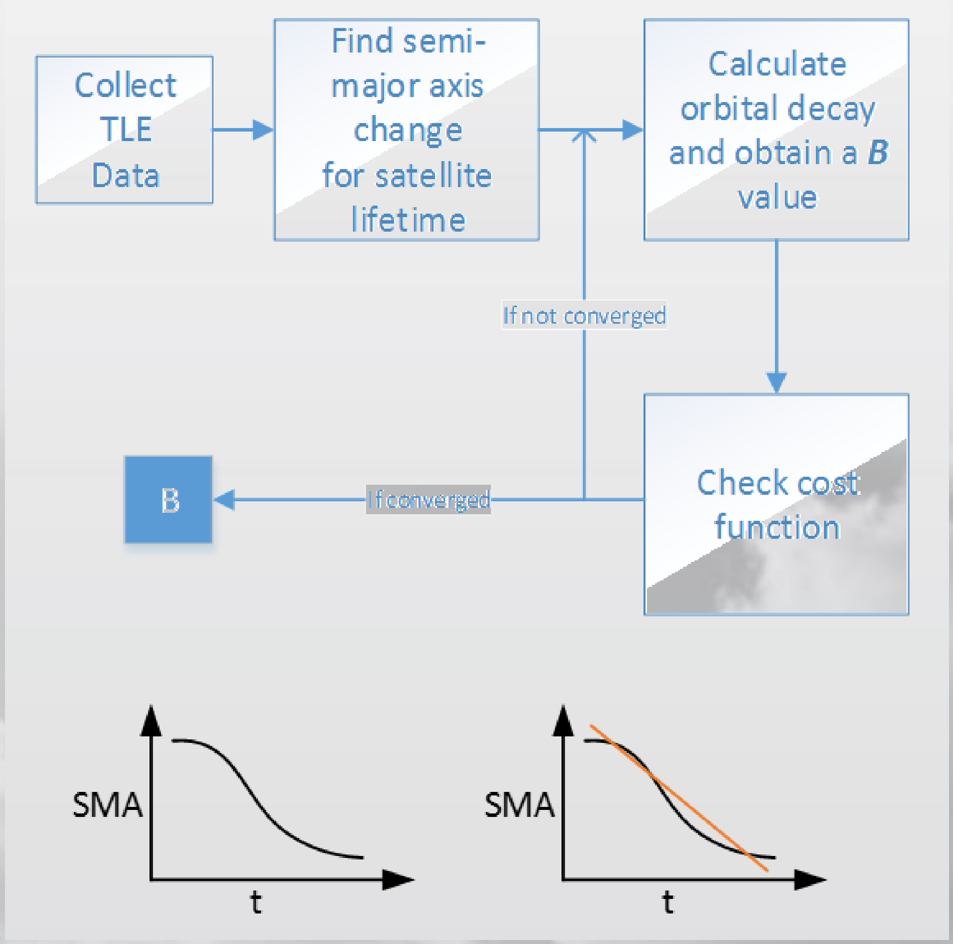


- The real density depending on the solar activity level is:

$$\rho_{sa} = \rho_{min} + \frac{\rho_{max} - \rho_{min}}{100} \times (\%Activity)$$

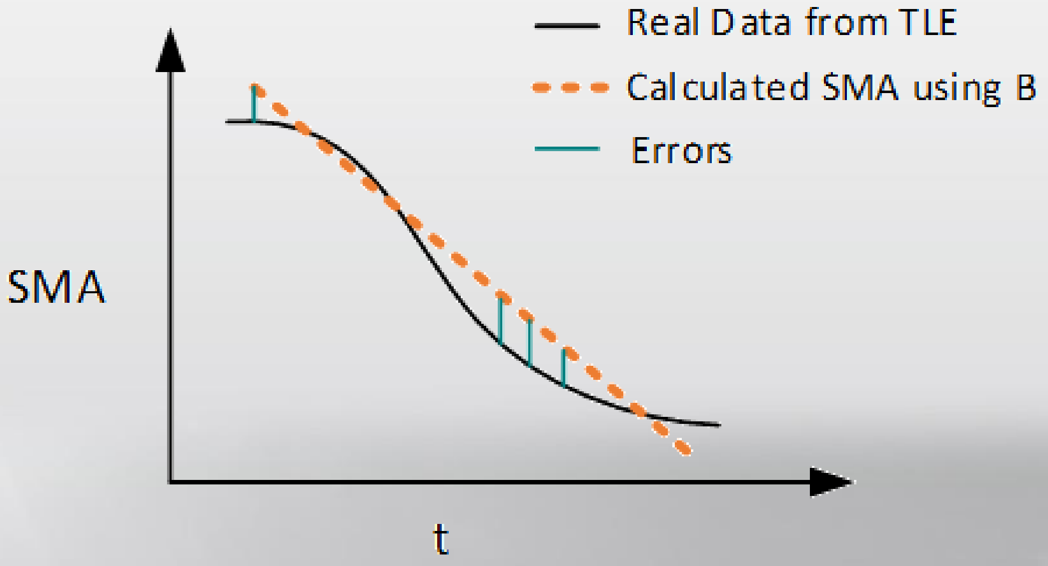
Determination of B

- Backward TLE data was downloaded for 1U CubeSats and was solved as an optimization problem for each CubeSat. The method is illustrated below.



Determination of B

- Optimization cost function is created as below for the solution of B. Where e_n is the error between real and calculated SMA data and T is time.

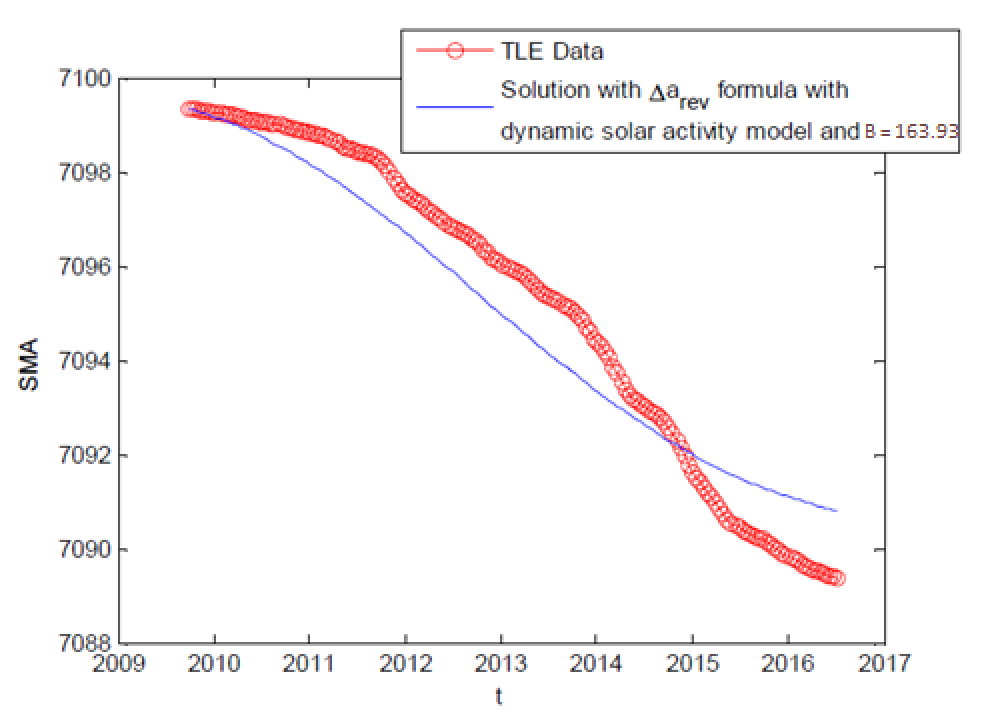


$$J = \frac{{e_0}^2 + {e_1}^2 + \cdots + {e_n}^2}{T}$$

- Dividing the cost function by T makes cost function and fitting performances comparable between satellites that have different data and time span.

Example Analysis

- An example analysis is performed for ITUPSAT-1 with modified B which is obtained via the method proposed in the paper.
- In ITUPSAT-1 case, best B value for satellite is obtained as 163.93. Δa_{rev} is solved with a step size of 15 days by recalculating the new atmospheric density with respect to solar activity.



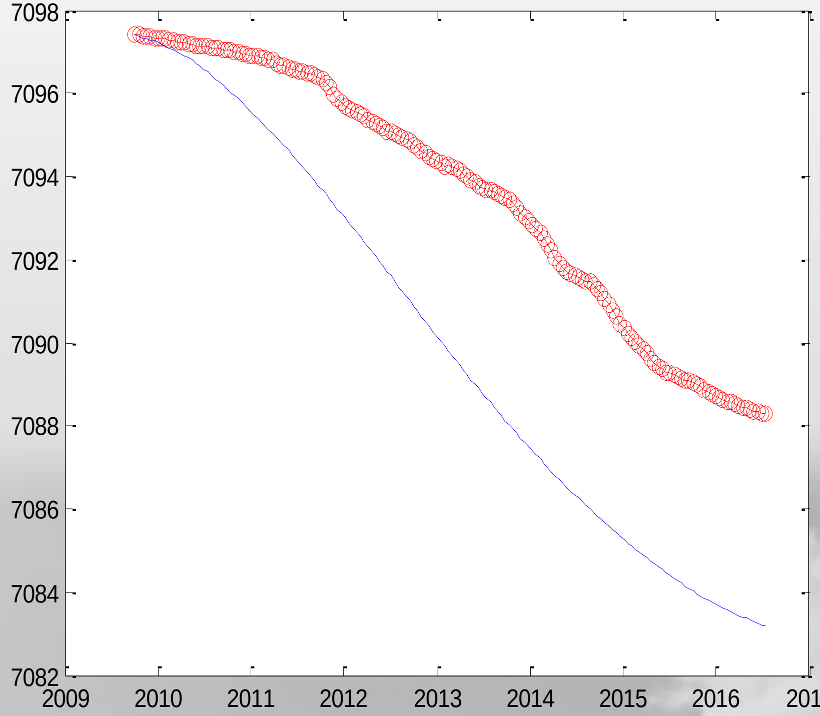
Investigation of Results

- The analysis is done for all 1U CubeSats covered in this study.

Satellite	Analysis Duration (year)	Ballistic Cofficient	Initial Altitude (km)	Normalized Cost
UWE3	2.61	92.59259	648.90	0.76
ZACUBE-1	2.65	96.15385	641.09	0.83
HINCUBE	2.61	83.33333	640.63	0.94
FUNcube-1	2.57	81.30081	640.60	0.95
ESTcube-1	3.19	119.0476	667.21	1.33
iCUBE-1	2.59	86.2069	617.12	1.43
PUCPSat-1	2.61	81.96721	616.95	1.49
UWE-2	6.80	181.8182	719.39	1.54
Libertad1	9.27	140.8451	722.33	1.66
ITUpSAT1	6.80	163.9344	721.35	1.73
HumSat-D	2.62	66.22517	616.96	1.90
Duchifat-1	2.09	69.44444	615.27	1.95
SwissCube-1	7.30	147.0588	721.34	1.99
CSTB1	9.28	117.6471	712.00	2.41
BEESAT-2	3.22	78.125	569.86	8.17
BEESAT-3	3.21	75.18797	637.09	8.61
SOMP	3.26	67.11409	569.96	9.90
MEAN:102				

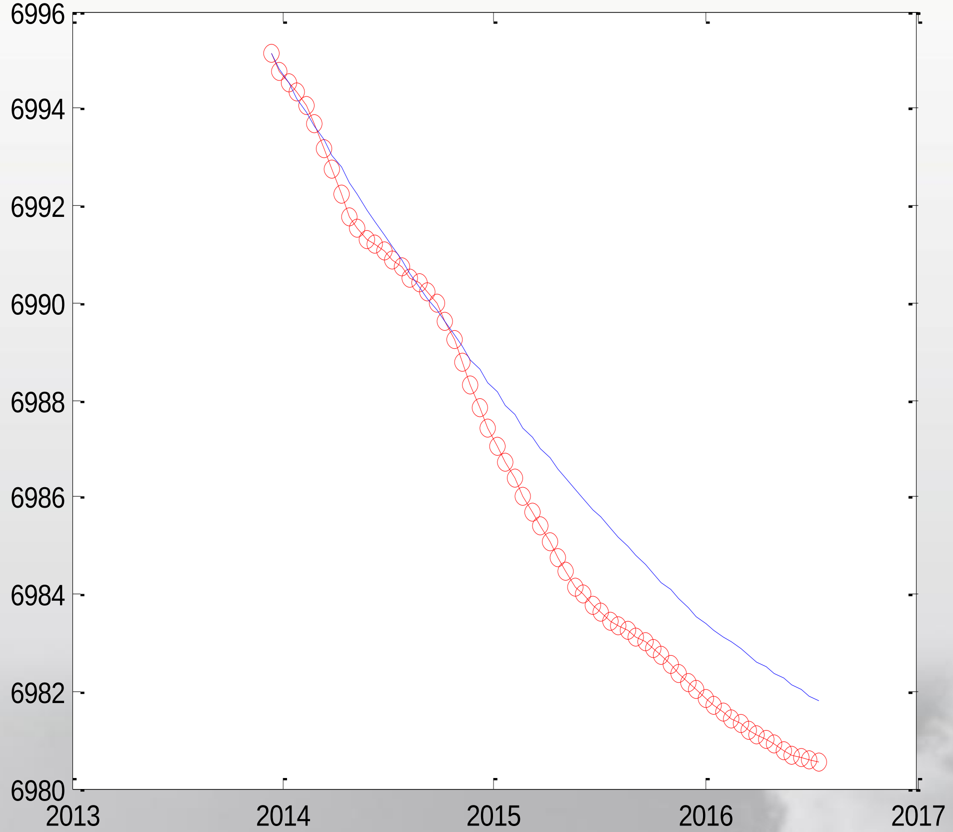
Investigation of Results (Worst-Case)

- The calculated mean value of ballistic coefficients is 102.
- All analyses for satellites are performed again with the mean value and the best and worst cases were investigated.



- The worst case occured for UWE-2 satellite and the semi-major axis difference at the end of 7 years analysis is smaller than 6 kilometers.

Investigation of Results (Best-Case)

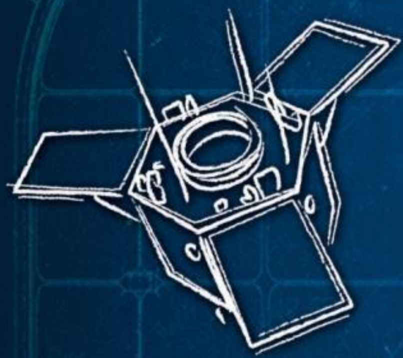


- The best case occured for iCUBE-1 satellite and the semi-major axis difference at the end of 2.5 years analysis is smaller than 1 kilometers.

CONCLUSION

- A quick assumption can be made for CubeSat ballistic coefficient B taking $C_d = 2.5, A = 0.1x0.1 = 0.01\ m^2, \mathrm{m} = 1.33\ \mathrm{kg}$.
- This leads to a value $B_{standart} = 53.2$ which is different than the found mean value in this paper.
- This paper investigated the ballistic coefficient using real satellite data for 1U CubeSats.
- Finally, it can be proposed that usage of modified mean ballistic coefficient $B_{mean} = 102$ with the proposed modified solar activity approximation.

TAI



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