Atmospheric Drag on Low Earth Orbit Satellite Swarms

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Abstract

Space weather and Coronal Mass Ejections (CMEs) can have drastic impacts on the Earth's atmosphere, specifically the thermosphere. During geomagnetic storms the thermosphere expands, causing increases in density at satellite altitudes. This can cause tracking stations to lose sight of the satellites and makes space traffic management difficult.

Introduction

- These CubeSats exist in mega-constellation swarms. The CubeSat swarms usually travel through Low Earth Orbit (LEO), and experience a normal amount of atmospheric drag. This is accounted for in their design and orbit
- The Sun goes through cycles where it is active, and sometimes it releases Coronal Mass Ejections(CMEs). When these CMEs hit Earth, they have big impacts on the atmosphere and its properties. The increased amount of particles and energy affect the whole atmosphere. The CMEs generates stormy conditions and causes the Thermosphere to increase in density(2).
- As the density and other properties of the Thermosphere change, the drag acceleration increases on the CubeSats(1). Their orbits begin to decay, they start to lose elevation, and their position becomes unpredictable.

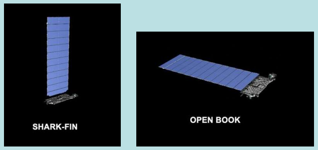

Figure 1. and Figure 2. showing the CubeSat and its configurations

Acknowledgements

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Methods

- Several pieces of data were put into a function for calculating drag. During the 2003 storm, a Whole Atmosphere Model (WAM) snapshot was created to simulate the storm conditions virtually. The WAM had information about density, temperature, and other factors (shown in figure 3).
- TLE data concerning orbit information is extracted as well. All the conditions serve as inputs for the dragging function, which outputs a drag acceleration vector in Erath Centered Earth Focused (ECEF) coordinates.

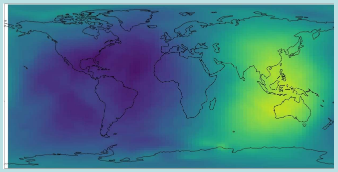

Figure 3. Density across atmosphere

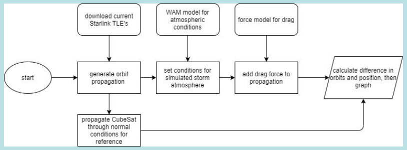

Figure 4. Flowchart for calculating drag

Results

- Over the course of the 24 hour simulation, several notable trends were found. The first is that not only does the orbit does decay, but it begins to change very rapidly as time goes on. Seen in figure 5, the drop in elevation begins to fluctuate between .5 km to almost 1 km, changing directions in very short intervals
- When we look at the difference in all the axes in ECEF coordinate, we see an even bigger change. Shown in figure 6, the difference between normal conditions and those during a storm could be as large as 150km in any direction after 24 hours.
- These rapid changes would make it extremely difficult to track and communicate with.

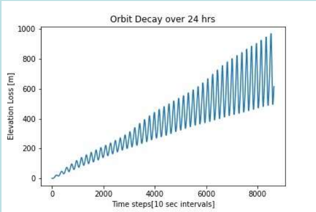

Figure 5. showing elevation drop and orbit decay

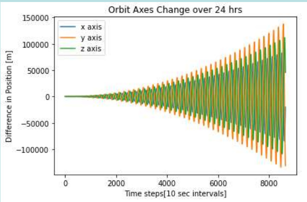

Figure 6. difference in axes (ECEF)

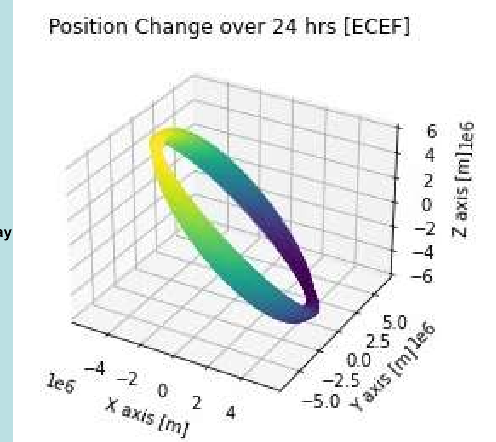

Figure 7. 3D visualization of change in Orbit

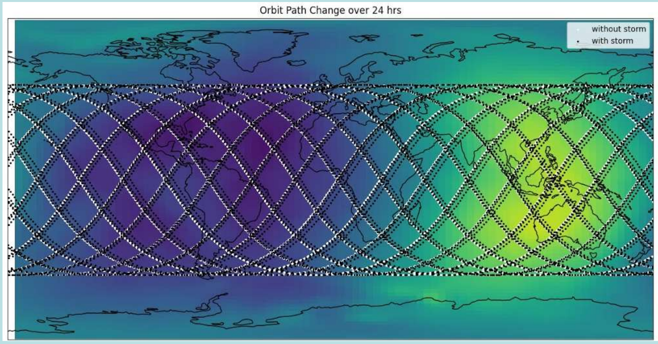

Figure 8. This is an exaggerated graph of what happens to the orbit during storm conditions

Conclusions

- Atmospheric drag from geomagnetic storms has serious impact on mega-constellations in orbit
- This research shows the importance of incorporating physics-based atmospheric density into orbital propagation models
- If we do incorporate it, we could reduce (or eliminate) the number of satellites lost during large geomagnetic storms.

Future Work

- Use WAM to forecast and simulate a 4D model with time variability
- Run multiple simulations at a time
- Create a more dynamic model for greater accuracy

References

Reference (1): Sutton, E. K. *et al.* Toward accurate physics-based specifications of neutral density using gnss-enabled small satellites. *AGU Journals* (2021). Available at: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021SW002736.

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Reference (2): Sutton, E. K. A new method of physics-based data assimilation for the quiet and disturbed thermosphere. *AGU Journals* (2018). Available at: https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2017SW001785.

(Accessed: 6th August 2021)