Too Hot to Handle: A Data Analysis on the Heat Transfer of the Ex-Alta 1 CubeSat During Re-Entry

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Background

- CubeSats are small (10cm³/unit), cheap satellites that make the space industry accessible to college students and researchers [1].

- The AlbertaSat student group launched its first satellite, the Experimental Alberta #1 (Ex-Alta 1), in May 2017 as a part of the international QB-50 mission [2].

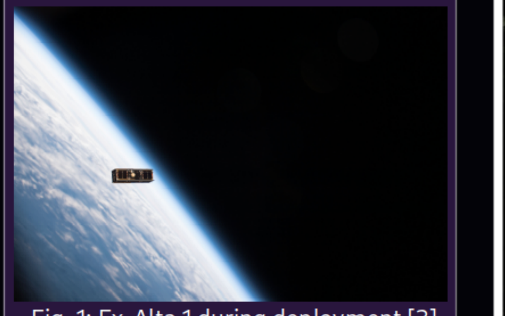


Fig. 1: Ex-Alta 1 during deployment [3].

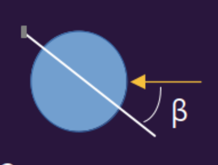
- In 18 months, the satellite orbited Earth 8301 times, using its position in the lower thermosphere (altitude of ~400km) to study space weather [2].
- There are many things that affect the temperature of a satellite located in low Earth orbit (LEO):

On Board Activity [4]

The payloads and electronics on the satellite use energy and emit heat while operating.

The Beta Angle [1]

- The angle between the orbital plane and the solar vector.
- Determines how long is spent in eclipse.
- The closer to 90°, the warmer the orbit.



The Sun [1]

Space [5]

Empty space has a cosmic microwave background giving it a uniform temperature of 2.7 Kelvin or -270°C.

Relative Position [4]

The eccentricity of Earth's orbit leads to varying distances from the sun and therefore varying the intensity of the radiation.

Earth's Radiation [1]

The earth emits its own infrared radiation that can warm the satellite.

- Analysis of the heat data from Ex-Alta 1's re-entry allows us to improve thermal models and simulations for future CubeSats and improve our understanding of the re-entry process.

Data

- Figure 4 depicts a nominal orbit. The temperature varies but remains in a range where the on-board components are operable. The rate of change prevents the satellite from assuming steady state.

- Figure 5 depicts the temperature change during re-entry. The data ends before the critical point is reached but an upward trend is clear. In the end of this period of time, an excessive drop in altitude also occurred.

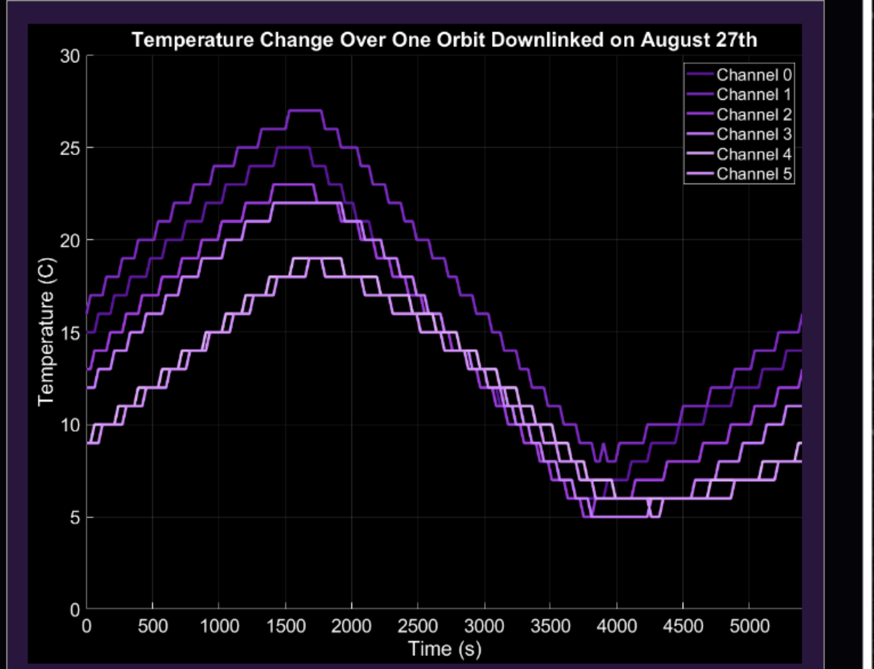


Fig. 4: Temperature graph over one orbit in August. Each channel represents one thermocouple on the satellite.

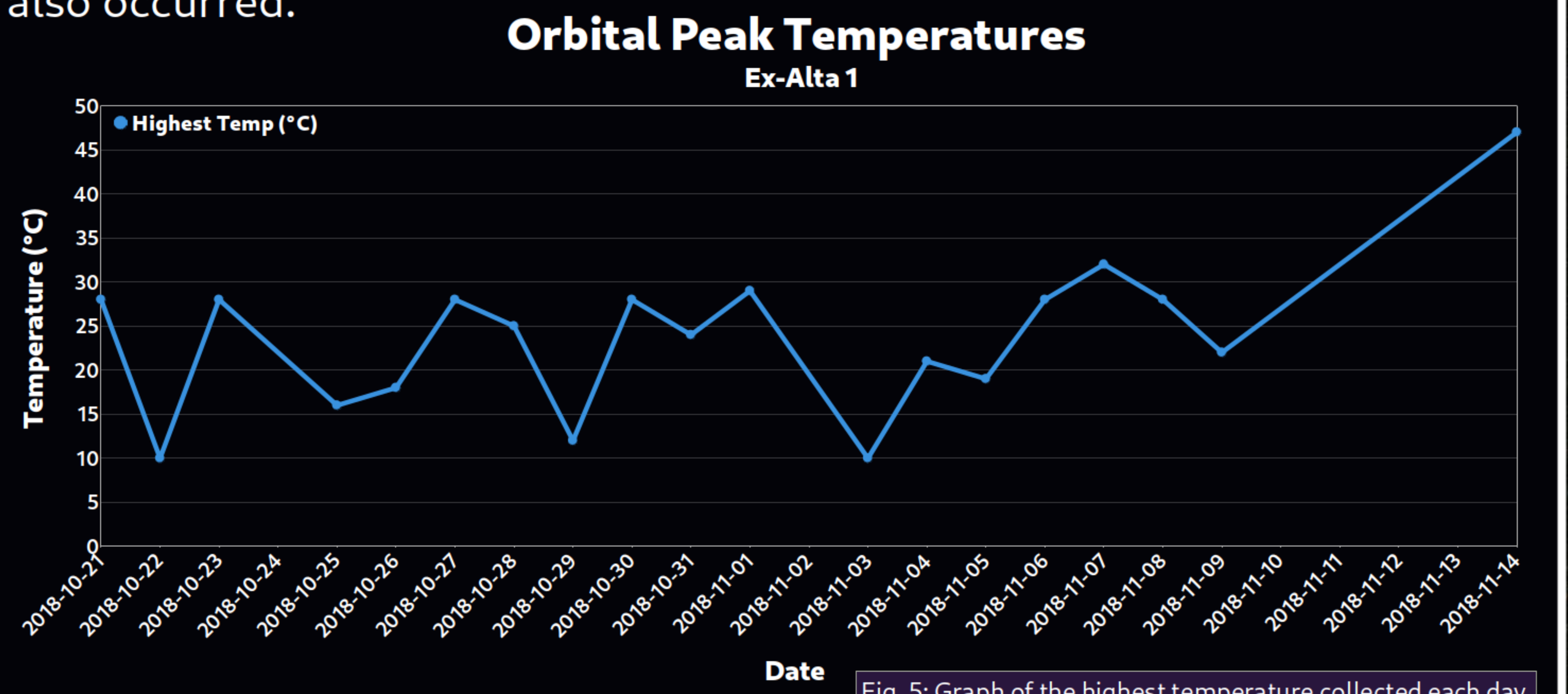


Fig. 5: Graph of the highest temperature collected each day.

Expanded View

- The re-entry process is complex, but understanding these mechanisms is extremely useful.
- As space becomes increasingly accessible, LEO also becomes more populated with new technologies and satellites constantly being launched [11].
- After satellites are retired, they form orbital debris that encompass Earth.
- This poses a growing hazard, due to the fact that as the debris build-up increases, the chances of high-velocity collisions occurring and rendering satellites useless while also creating more orbital debris [12].

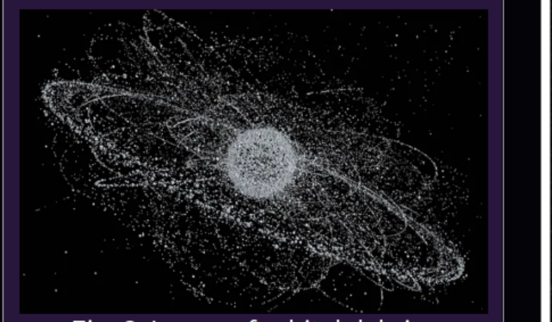


Fig. 8: Image of orbital debris surrounding Earth, debris size scaled up to be visualized [13].

- Orbital debris can be mitigated by purposely re-entering satellites at their end of life, even those that orbit at altitudes beyond LEO.
- This re-entry has to be done in a way that ensures the entire satellite is consumed, and proper data analysis can assist in building the knowledge required to make this practice successful [14].

Conclusion

Heat transfer in Earth's orbit is complicated. There are a variety of things that influence the temperature of satellites, resulting in a significant rate of change over just one orbit. The temperatures grow to an extreme during re-entry, and data analysis allows us to build a comprehensive understanding of what actually occurs. This knowledge can be applied in finding solutions to the increasingly relevant problem of space debris.

Methods

- At its end of life, Ex-Alta 1 still downlinked the data it was collecting.
- Raw data in binary can be processed with scripts from the Ex-Alta 1 archives to be turned into WOD (whole of data) files in the form of spreadsheets.

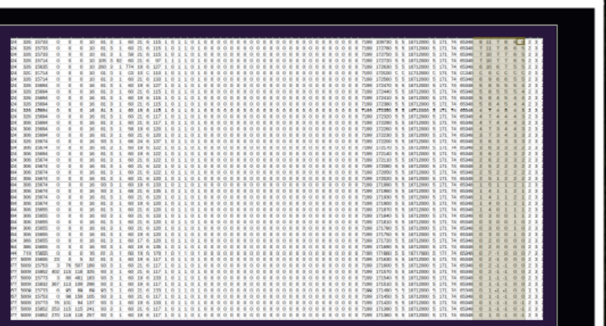


Fig. 2: Sample of a WOD spreadsheet, highlighted columns are used.

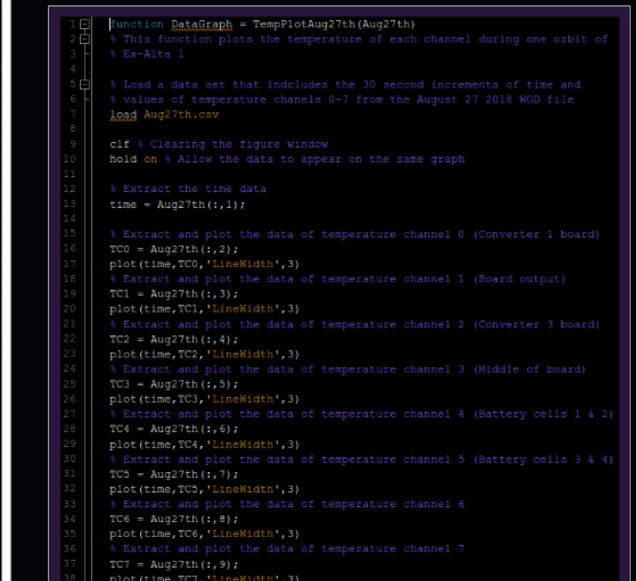


Fig. 3: Sample of MATLAB code to graph data.

- These files are composed of numerous sets of useful data, but I collected the information that correlates with thermocouples (type of electric thermometer) that were placed around the satellite.

- I developed MATLAB code from a past project [6] to extract relevant data and plot it in a meaningful way.

Cause

- The trend in figure 5 can be explained by the concept of pre-heating.

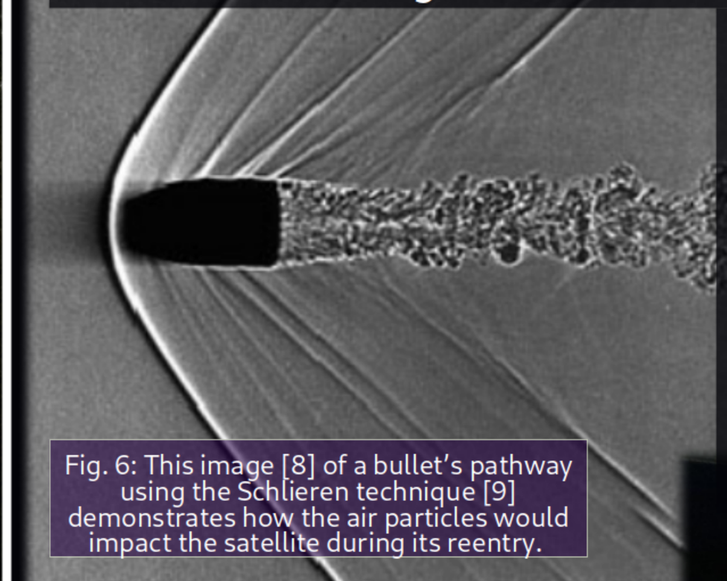


Fig. 6: This image [8] of a bullet's pathway using the Schlieren technique [9] demonstrates how the air particles would impact the satellite during its reentry.

- Pre-heating occurs when the friction between Ex-Alta 1 and the atmosphere becomes significant.
- In this phenomenon, particles in the air collided with the surface of Ex-Alta 1, causing the temperature to increase [7].
- This occurred at a rate proportional to the increasing ambient air density [7] which also correlates with the decreasing altitude.

- This process eventually escalates into ablation heating.
- Here, instead of simply melting, the satellite experienced spallation (fragmentation) and vaporization until there was nothing left but small particles scattered in the atmosphere [7].

Fig. 7: Re-entry illustration of Apollo capsule [10].

Citations

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