# Design and Analysis of Aluminum-6061 Structures for Low Earth Orbit Cubesatellite Missions

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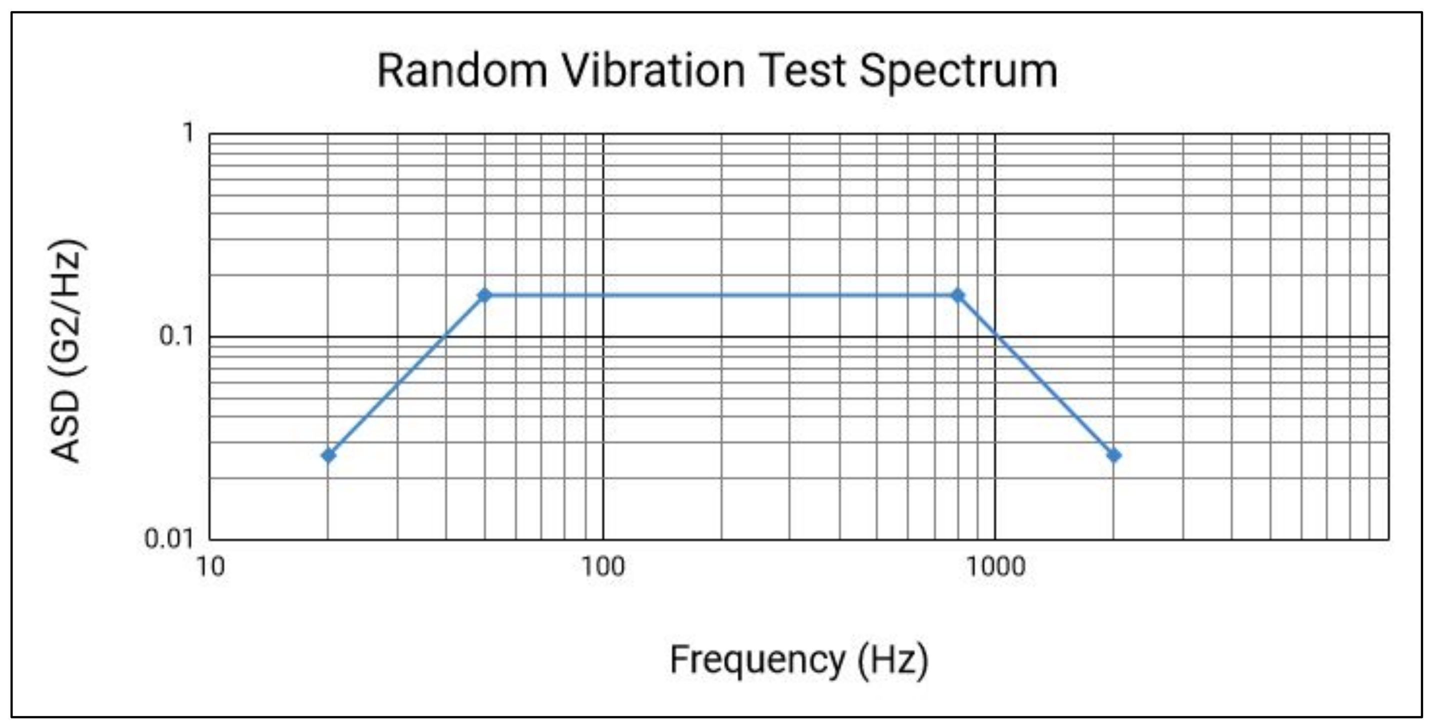
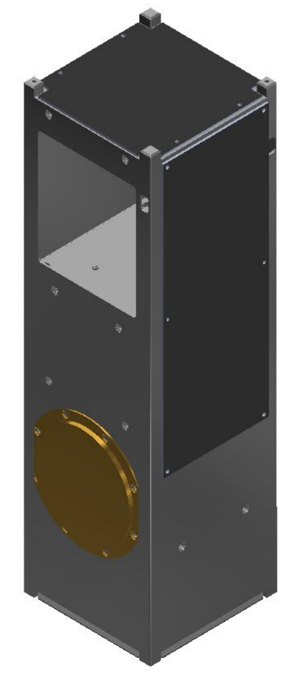
## RESEARCH OVERVIEW

The goal of this research was to design and analyze a frame that was capable of protecting mission critical subsystems of the Multi-view On-Board Computational Imager (MOCI) cubesat. To achieve this goal, various design criteria was set by the Small Satellite Research Lab (SSRL) and the University Nanosat Program sponsored by the Air Force Research Lab. The design requirements for the the frame were as followed: the frame was to weigh less than one kilogram and be of a 3U form factor (10.00 cm x 10.00 cm x 34.05 cm), be machined from Aluminum 6061, 6063, or 7075, act a a heatsink for the GPU and other electronic components, withstand a minimum inertial loading of 30 g's with a yield factor of safety greater than 2.0 and an ultimate factor of safety greater than 2.6, have its first mode be higher than 100 Hz, and be capable of surviving the random vibration test spectrum as outlined in the UNP user manual section 7.3.2.6. The frame was then designed around the avionics stack and payload. To verify that the criteria was met various vibrational, structural and thermal simulations were run on the frame and full system using ANSYS finite element analysis software.

**Figure 1:** a) Graph of the Random Vibration Test Requirement set by the AFRL b) Image of the MOCI satellite Full System CAD



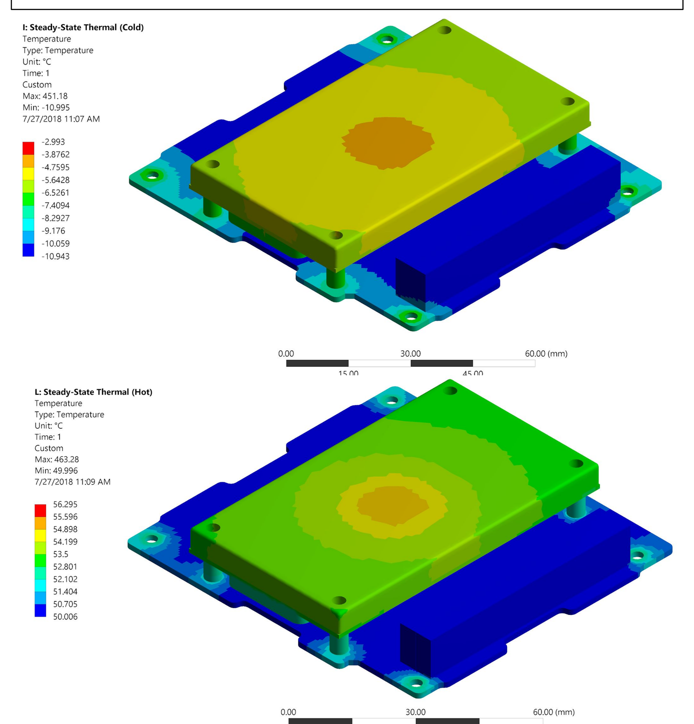



## THERMAL SIMULATION PROCEDURES AND RESULTS

For thermal simulations, the geometry of the full system was exported into ANSYS, since an important feature of the frame is its ability to dissipate the heat of the GPU and various avionic stack components into its structure. The material properties were added to this model and cross referenced with manufacturer material data to make sure the properties were correct. Surface contacts were added between components, and the geometry was meshed. The final mesh had 2,319,780 nodes and about 642,908 elements with an average skew of 0.26604. Heat loads were applied to various components of the avionics stack and a radiation condition with an emissivity of 0.9 was applied to all surfaces of the cubesat. With these parameters set, a steady state thermal analysis was ran on the full system for a cold case of -11 °C and a hot case of 50 °C.

The results of these simulations were compared to the operating temperatures of the avionics stacks. To obtain a confidence interval of at least 2-sigma, 11 °C was added to the maximum temp on the hot case simulation of each component and subtracted from the minimum temp on each cold case simulation. The hottest component was the RF chip on the UHF transceiver at +474.3 °C; this result is highly unlikely and reasons why will be discussed in more details in the conclusions and future improvements section below.

**Figure 2:** a) cold case simulation results for the Jetson Tx2 and b) hots case simulation results for the Jetson TX2 GPU



| Component | Jetson TX2 | OBC | UHF Transceiver | S-Band Transmitter |
|---|---|---|---|---|
| Operating Temperature | -25.0 °C to +80.0 °C | -40.0 °C to +80.0 °C | -25.0 °C to +61.0 °C | -25.0 °C to +61.0 °C |
| Simulation Temperature Range | -10.9 °C to +56.3 °C | -10.7 °C to +74.7 °C | -11.0 °C to +463.3 °C | -11.0 °C to +278.0 °C |
| Corrected Temperature Range | -21.9 °C to +67.3 °C | -21.7 °C to +85.7 °C | -22.0 °C to +474.3 °C | -22.0 °C to +289.0 °C |

**Table 1:** The temperature results for the simulations of the most susceptible components compared to their operating ranges

## STRUCTURAL SIMULATION PROCEDURES AND RESULTS

The same material properties for the thermal simulations were used in the structural simulations. However, the contacts for structural sims were defined differently. For structural simulations, the contacts were defined as the edge of screw holes, defining the holes as this provided the most conservative results. The mesh for the structural simulations consisted of 2,337,106 nodes and 651,219 elements with an average skewness of 0.26541.

The full system was then subjected to a loading of 294.20 $m/s^2$ along each axis, and the factor of safety on the frame was calculated per the distortion energy theorem. The design constraints for factors of safety were easily surpassed with the lowest factors of safety coming from a Z-plus launch orientation. This launch orientation incurred a yield factor of safety of 11.855 and a ultimate factor of safety of 13.315.

A simulation was then ran that subjected the frame to a modal analysis and random vibration along each axis. For the modal simulation, the frame was fixed at its Y-minus plane; this simulation resulted in a first mode of 167.02 Hz. The random vibration simulation yielded deformations averaging about two-tenths of a millimeter in each direction with a maximum deformation of 0.488 mm occurring along the Y direction during a Y-plus launch orientation.

| Mode | Frequency (Hz) |
|---|---|
| 1 | 167.02 |
| 2 | 352.99 |
| 3 | 396.70 |
| 4 | 418.43 |
| 5 | 457.08 |
| 6 | 458.65 |

Table 2: Results from the modal analysis of the full system

| Launch Orientation | Along X-Axis | Along Y-Axis | Along Z-Axis |
|---|---|---|---|
| Maximum von-Mises Stress (MPa) | 17.039 | 5.586 | 23.282 |
| Factor of Safety (Yield) | 16.198 | 49.407 | 11.855 |
| Factor of Safety (Ultimate) | 18.194 | 55.493 | 13.315 |

**Table 3:** Results from the Static Structural simulations representing each possible launch orientation

## CONCLUSION AND FUTURE IMPROVEMENTS

From these results much of the design criterias are met, but two important criteria that cannot yet be confirmed, from the current progress of this research, are the weight of the frame and thermal survivability of the satellite. The weight can only be guessed at with models, but cannot be verified until the frame is manufactured and we are able to weigh it in our lab. Thermal survivability is especially important to verify due to a single component failure on the satellite, especially something such as the communication systems, can be the difference between mission success or failure. The high heat seen on the comm system components, in simulations, could be the result from improper meshing or lack of thermal solutions, such as heat straps, in the simulation model. Thermal simulations will need to be verified in our thermal vacuum chamber before it can be stated with confidence whether components will not overheat.

In future iterations of this research heat straps will be added to the comm system components to allow heat to flow from the components to the frame. However, these components are not being designed by our lab and their design was not completed as of the CURO 2018 Summer Research Forum. The structural simulations will also need to be ran with updated models of the optical payload and ADCS, as these systems were not fully designed at time of submission, and any effect the addition of these components would have on the simulations would be speculation. Future iterations will also seek to better simulate the heat generation of RF components as well as include updated geometries and material properties of the optical payload and ADCS. Radiation constraints will be adjusted to better fit the real world case instead of just the worst case scenario of 0.9 emissivity. In addition to adjusting the emissivity constraint, a real world ambient temperature determined from STK simulations will be used instead of just using the temperatures of -11 °C and 50 °C for the cold and hot cases, respectively.

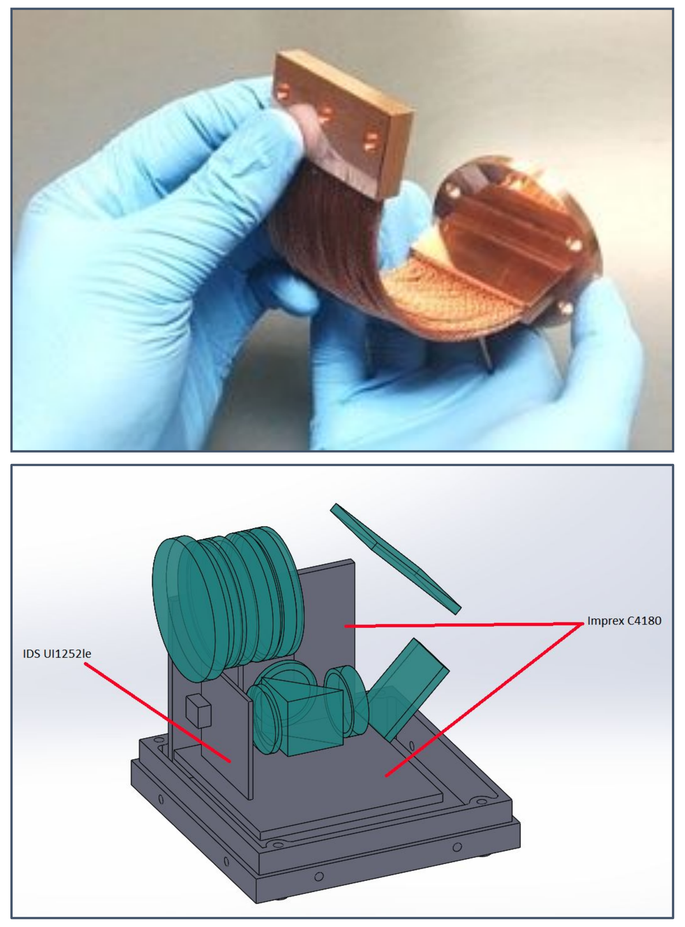


**Figure 3:** a) image of a thermal strap source: www.techapps.com b) Image of the current design for the optical payload

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2019 UGA CURO Symposium
Athens, GA April 8

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