Feasibility of Cubesat Frames for Heat Dissipation
Multi-view Onboard Computational Imager (MOCI)

Nicholas Heavner[*1], Michael Ely[#1] , David L. Cotten[^1,2], Deepak Mishra[1,2]
[*]nah55525@uga.edu, [#]mje80254@uga.edu, [^]dcotte1@uga.edu,
[1]Small Satellite Research Laboratory, University of Georgia,
[2]Center for Geospatial Research, University of Georgia

UNIVERSITY OF GEORGIA

Overview

Flying a GPU on a 3U cubesat provides the benefit greater parallel computation in a small form factor, but presents the challenge of needing to dissipate the large amount of heat generated by this component. The research presented investigates the obstacles encounter by placing high heat generating component in 1U and 3U cube satellite designs; as well as the feasibility of using the Aluminum 6061-T6 (Al-6061-T6) structures to dissipate the aforementioned heat generated by these components. It will outline the constraints of this problem, as it pertains to the UGA Small Satellite Research Lab (SSRL) missions and cube satellites in general, and will present the results of thermal simulations ran on the full assemblies of the MOCI satellite and a 1U configuration. These results will be compared to baseline simulations of the high heat generating boards, the F'SATI S-Band Transceiver, F'SATI UHF Transceiver, and NVIDIA Jetson TX2, without heat mitigation techniques. Furthermore, it will detail the future work of this research which will include transient thermal simulations and thermal vacuum testing of the satellite.

Simulation Set Up and Baseline

Set Up

To limit the number of variables contributing to heat dissipation, each thermal simulation was ran with a similar set of parameters. The environmental parameters for each test were that the ambient and initial temperature of all components are set to 30 °C, and the only heat transfer boundary conditions applied were conductive or radiative. For each simulation, the emissivity of the radiation boundary conditions were defined as 0.96 and every outward facing surface was defined to be radiating to the environment. For enclosed surfaces, radiative boundaries were applied between surfaces of the enclosure and the same emissivity of 0.96 was applied. Material properties of each simulation were prescribed as followed: all PCB's were to be defined as FR4, all electronic chips were defined as silicon anisotropic, all PC 104/+ Headers were defined as Vectra E-130I, all heat straps were defined as copper, and all thermal transfer plates, RF shielding and structural components were defined as Al-6061-T6. The results collected from each simulation was the temperature and thermal error, and skewness of the mesh was checked to make sure the simulations were behaving properly. These results were then compared to the manufacturers' interface control documents (ICD's) recommended operating and storage temperature ranges for each component. A detailed table of these values can be seen in the

Manufacturer Operating and Storage Temperatures			
Component	S-Band Transmitter	UHF Transceiver	Jetson TX2 GPU
Max Operating Temp (degrees Celsius)	61.00	61.00	80.00
Max Storage Temp (degrees Celsius)	85.00	85.00	80.00

Baseline Results

To compare our thermal mitigation solutions to a baseline, we began by running steady-state thermal simulations on our four hottest boards, the F'SATI S-Band Transceiver, F'SATI UHF Transceiver, and NVIDIA Jetson TX2 .

Baseline Simulation Results			
Component	S-Band Transmitter	UHF Transceiver	Jetson TX2 GPU
Max Simulation Temp (degrees Celsius)	317.51	443.28	110.77
Max Simulation Temp [2-sigma Corrected] (degrees Celsius)	328.51	454.28	121.77

These results were obtained from running steady-state thermal simulations in ANSYS workbench on just the boards. Theboards were not incorporated in an avionics stack and were allowed to freely radiate to ambient. Heat loads applied to each board came from the SSRL's power budget as well as the manufacturers' ICD's for the components. The results that all of the components are outside of their operating range even without the correction for a 2-sigma confidence level. It is evident from these results that all boards require thermal mitigation of some form.

1U Configuration and Results

To simulate a full heat load on a 1U frame, a hypothetical 1U mission was designed, as the SSRL does not currently have a 1U mission. This hypothetical mission consists of many of the same components as the SSRL MOCI mission, but due to spatial constraints a few boards needed to be removed. To justify a comparison between the satellites, the 1U had contains an avionics stack that can reach the computation based mission requirements of the MOCI mission. Primary differences between the 1U and 3U mission however are the number of boards that make up their respective avionics stacks. For heat producing boards, the 1U mission contains an F'SATI UHF Transceiver and an NVIDIA Jetson TX2. This avionics excludes an F'SATI S-Band Transceiver. The Jetson TX2 dissipates its heat to the frame face through an aluminum mass. The UHF Transceiver use a copper heat strap connected between the power amplifier and a side face of the frame.

1U Frame Results			
Component	S-Band Transmitter	UHF Transceiver	Jetson TX2 GPU
Max Simulation Temp (degrees Celsius)	N/A	52.08	45.25
Max Simulation Temp [2-sigma Corrected] (degrees Celsius)	N/A	63.08	56.25

Results of these simulations showed that the UHF Transceiver max temperature dropped to 20% of the baseline. With the inclusion of a frame, the temperature dropped to a safe storage temperature, but still remained over the operational temperature. The Jetson TX2 dropped to 70% of the baseline, resulting in values that are within both the safe storage and operating limits.

3U Configuration and Results

To simulate a 3U satellite, analysis from the MOCI and SPOC missions were used, in future work a 3U frame design that represents a generic 3U cubesat will be used. Thermal analysis was performed on the MOCI satellite and results were verified using previously compiled data from the SPOC satellite. In this configurations all boards that generate the largest amount of heat were present. Similar to the 1U case, the Jetson TX2 dissipates its heat through an aluminum mass which creates a conductance path between it and the frame. The UHF Transceiver and S-Band Transmitter utilize copper heat straps connected between the power amplifier chips and a 3U face of the frame.

3U Frame Results			
Component	S-Band Transmitter	UHF Transceiver	Jetson TX2 GPU
Max Simulation Temp (degrees Celsius)	67.26	62.35	56.30
Max Simulation Temp [2-sigma Corrected] (degrees Celsius)	78.26	73.35	67.30

Results showed that the UHF Transceiver max temperature dropped roughly 9 degrees from 1U to 3U case. With a larger frame the UHF was within a 1.4 degrees of being at a safe operating temperature. The Jetson TX2 max temperature also lowered by close to 9 degrees. As seen with the 1U frame, max temperatures for this board are within maximum storage and operating temperatures. The S-Band Transmitter dropped to about 20% of its baseline temp. The temperature for it was below in the storage temp but still remain above the operating temperature. Further research and testing will investigate the functionality of the communication system at maximum temperatures outside safe operating bounds.

Future Work

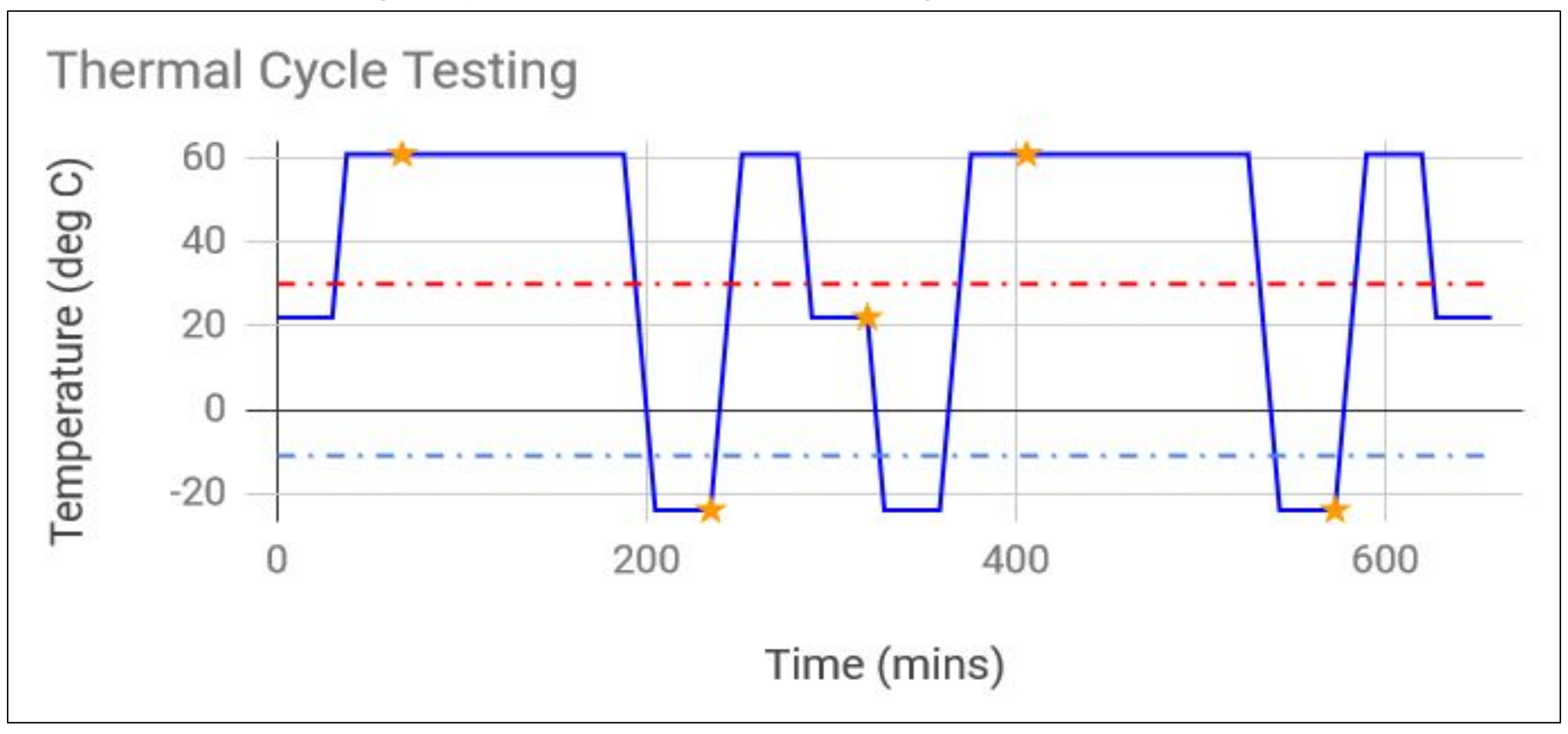
Due to the promising nature of the initial results future iterations of the steady state simulations will better define the material properties and the mesh as well as work on better defining the the radiative boundary conditions, i.e. enclosure bounds and emissivity values.Other factors not taken in to account are the emissivity of the radiation protection that line the inside of most cubesats. In addition to these minor adjustments to steady state the following simulations and test will also be performed.

Transient Simulations

Currently the only thermal simulations ran were steady-state thermal, for many of the RF components this does not accurately represent their operation. To account for this a transient thermal simulation will be run on the full system in Thermal Desktop. Thermal Desktop allows for greater control over a transient simulation by allowing the user to program orbit data and component on/off time. This great control provides a more realistic simulation to what will be experienced in orbit. The parameters for these transient simulations will be a 400 kilometer ISS orbit, but these parameters can be varied. An expanded research scope could include farther orbits and different beta angles. The data from these simulations will be used to compare to the steady state simulations, but it will also be used to set temperature parameters for thermal vacuum testing.

Thermal Vacuum Testing

The final verification of the using a frame a heat dissipator will be thermal vacuum testing. This testing will replicate the environment the cubesat will see while in orbit. Currently, the SSRL has a thermal vacuum chamber that has the ability to test up to 3U cubesats achieving a temperature range of -100 to 150 °C and the ability to create a vacuum of 10^{-6} Torr. Test in the vacuum chamber will consist of two hot functionality test and two cold functionality test. The hot test are ran at 61 °C and the cold test are ran at -24 °C, these values are chosen to ensure a high level of confidence that the satellite design will survive the harsh thermal environment. More details about the testing temperature can be seen in the figure below.



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