Thermal and Structural Simulations of Small Satellite Systems

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Overview

To aid in the development of the University of Georgia's satellites, SPOC (Spectral Ocean Color) and MOCI (Multiview Onboard Computational Imager), behavioral models of various environments had to be created, using engineering modeling software. Primary concerns are the high-stress environment of launch, and thermally dynamic environment of low Earth orbit. Launch stresses can disintegrate the satellite due to mechanical failure. Overheating can cause fatal damage to the components causing the system to be shut down. Progressively more detailed models were created in MATLAB/Thermal Desktop for thermal analysis, and ANSYS for structural.

Methods and Model Development

Thermal and structural analyses of highly detailed models can be time consuming and difficult to post-process. Extremely exact thermal and structural models do not offer sufficiently more information for the additional processing time required to run the models.

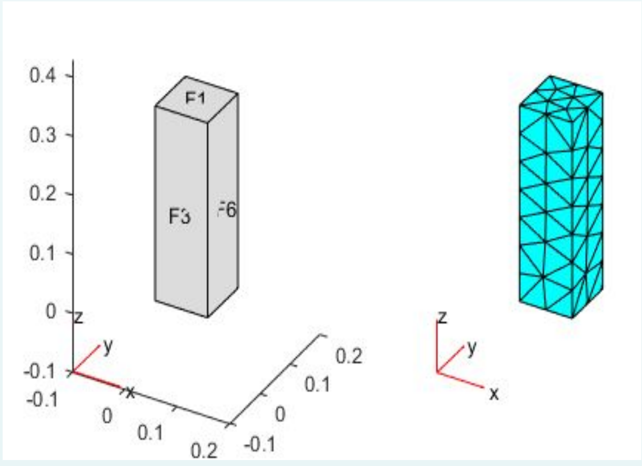

Figure 1

Initially, for the thermal simulations, extremely simplified models were created to show progressive convergence as they become more complex (Figure 1, 3). As MATLAB does not lend itself well to performing structural simulations (modal, response spectrum, random vibration and inertial), these were immediately run in ANSYS. Figure 2 shows the ANSYS geometry.

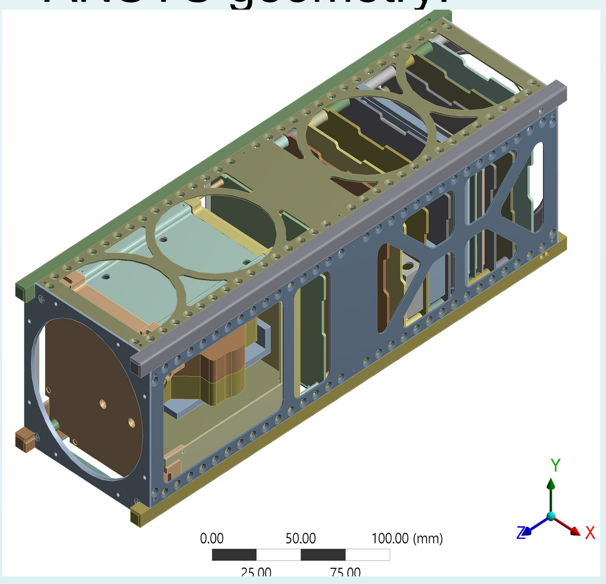

Figure 2

The design constraints in thermal analyses come from the operating temperatures of the electronics on board. To prevent shutdown of any processes, overheating should be avoided. The thermal simulations aim to find problem areas where excessive heat generation might require additional thermal mitigation systems. On MOCI, the GPU is a predicted problem area, as well as the UHF/UHF and S-Band transceivers on both SPOC and MOCI.

NASA requires the first mode of the structural design to be above 100Hz, as well as a minimum factor of safety of two. At this stage, the structural analysis will primarily help determine the placement of structural ribs, but will also be integrated with the structural analysis to model the effects of thermal expansions and its influence on the optical characteristics of the camera systems.

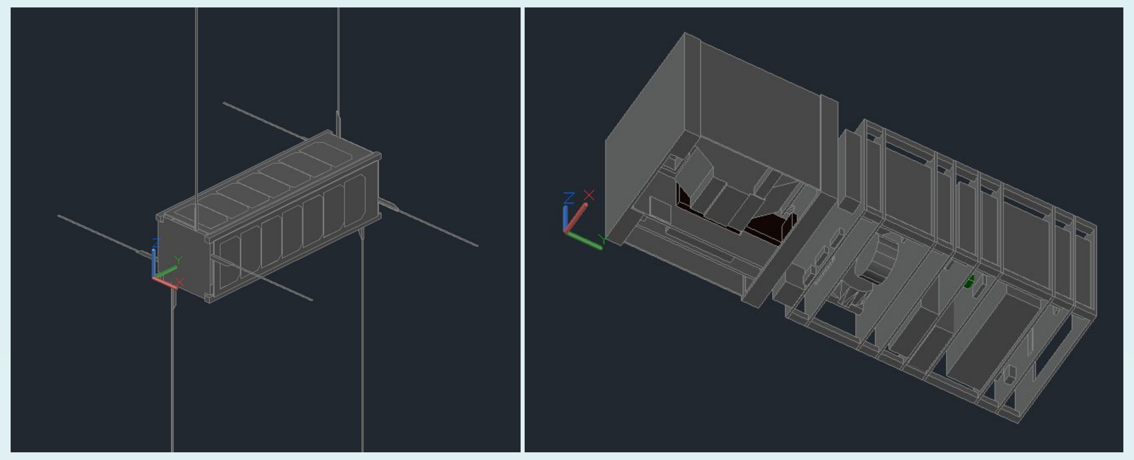

Figure 3

Simulation and Results

The thermal simulations were run as "cold case" (summer) and "hot case" (winter), as incident thermal radiation changes over seasons. Due to the parameters of the expected orbit, the mission was also simulated at varying beta angles, which change exposure times to sunlight. Lastly, results were obtained for different orientations of the satellite:

1. 1U to velocity, 3U Nadir (Figure 4)
2. 3U to velocity, 3U Nadir
3. 3U to velocity, 1U Nadir

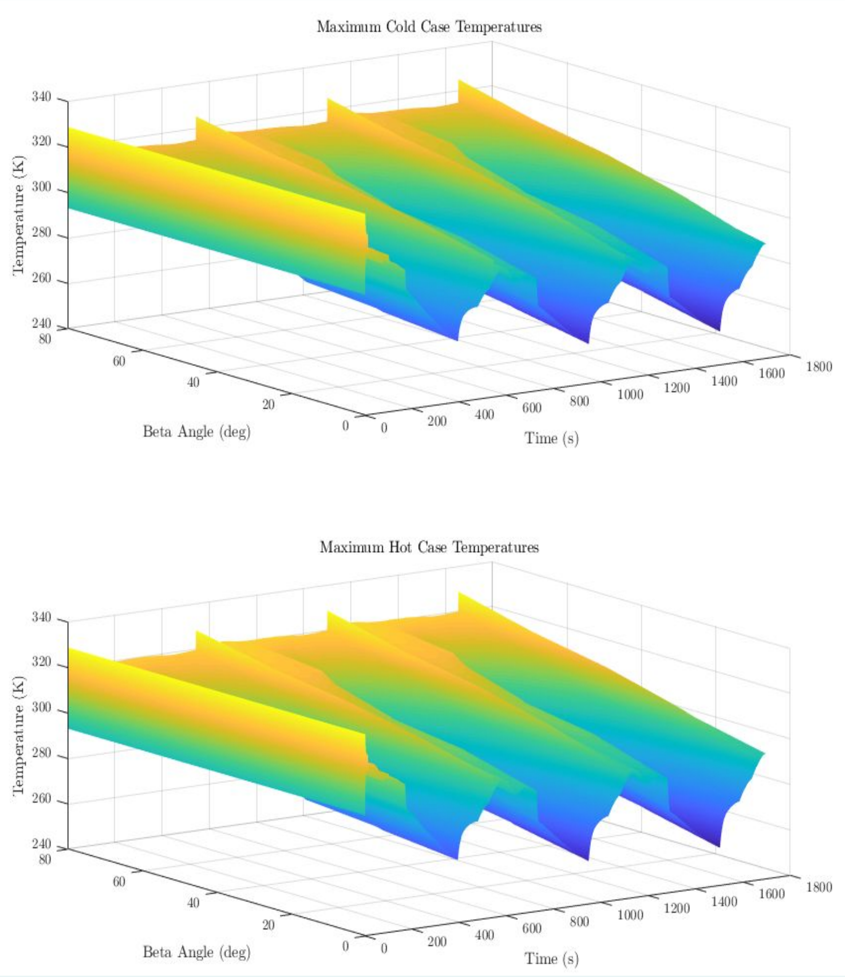

Figure 4

All of these cases are accounted for to understand how changing some physical parameters can change the behavior of the same model. The primary interest is the highest temperature reached in the satellite to prevent aforementioned overheating. The 3D plots in Figure 4 show the temperature results obtained from the simulation as run in Thermal Desktop for SPOC.

Thermal desktop allows for modeling periodic heat generation, which was incorporated assuming 0% component efficiency to generate conservative results. With this included, this thermal model predicts the peak temperature range to be about -20 to 60°C in all cases. Although, as is to be expected, the specific profiles differ for each case.

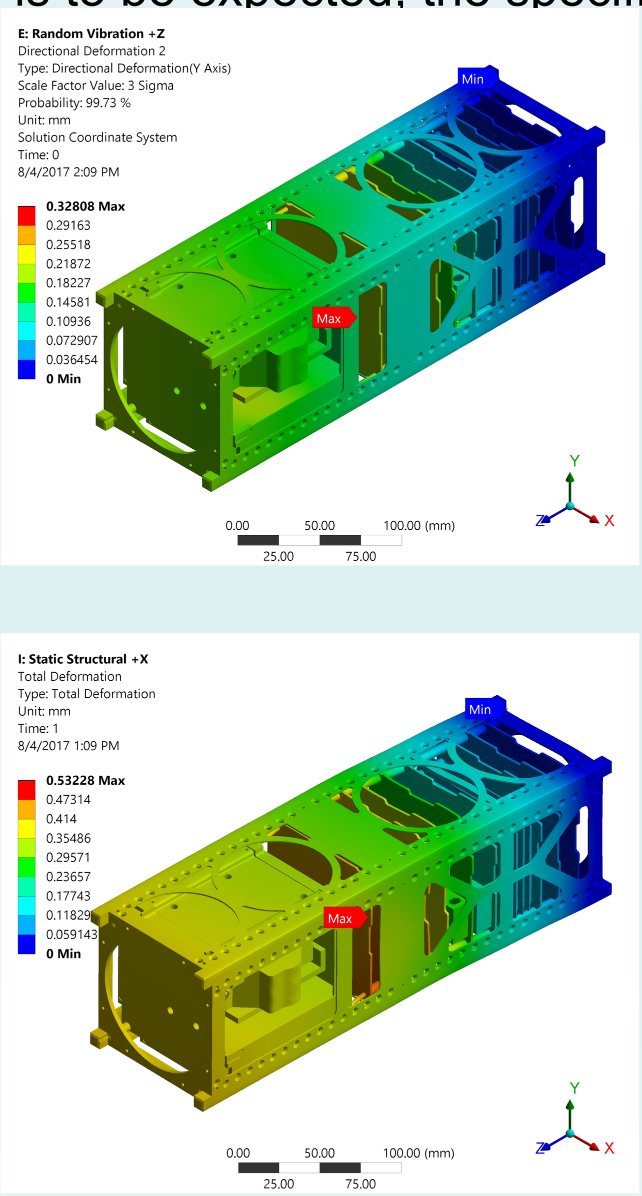

Figure 5

As with the thermal analysis, the structural analysis runs through several cases that apply to the different types of analyses. The cases modeled in structural, are the attachment points (top, bottom or both), as well as launch orientation (+X, +Y, +Z) for inertial models.

The purpose of the structural models is to determine the mechanical stress and deformation in the structure. The total strain on the structure will be a superposition of all the analyses, although it is not as simple as just summing the deflections, as they are highly situational, hence they are run in different simulations.

As a prerequisite for response spectrum and random vibration analysis, the first six modes of the structure are found, the first of which lies in a 180 to 200Hz range, depending on attachment points. The deflection found by the response spectrum analysis is generally in the order of 200mm, whereas random vibration rarely exceeds 1mm, as does the inertial loading analysis. The largest deflections generally occur around the most massive part of the satellite: the reaction wheels. This suggests that placing a structural rib around the reaction wheel could improve the satellite's performance in simulations.

Discussion and Future Work

Because of the extensive simplification in the thermal models, there are some effects that are not adequately captured in the existing analyses, that *do* show up in component-level analyses. Namely, the UHF/UHF and S-Band transceivers do not show to have any issues in this analysis, but the component-level analysis clearly indicates overheating issues in steady-state. Future models will take care to more accurately model the geometry of predicted problem areas to create more accurate models. This will be especially useful in further development of the MOCI thermal model, where the GPU is a substantial thermal concern.

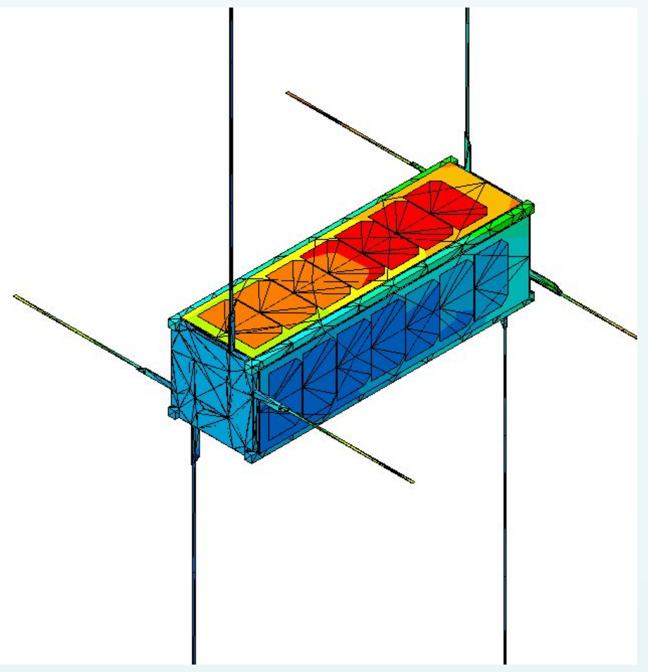

Figure 6

The response spectrum analysis takes in results from the prerequisite modal analysis, and produces the maximum, steady-state, modal deflection. As such, response spectrum results are expected to show large deflections. However, their concerns are mitigated by the realization that, as long as the first mode is above the required 100Hz, these deflections will not become reality.

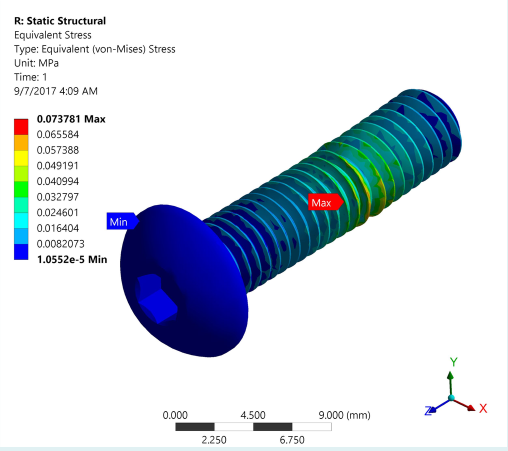

Figure 7

In the structural model, all touching surfaces are considered connected. For screwed connections, this is an adequate approximation, but this does warrant a discussion about fastener stress. Figure 7 shows a preliminary study of fasteners, but this will need to be further developed.

A last point of future research, both missions will require a Structural Thermal Optical Performance, or STOP analysis performed, so the structural effects of thermal expansion on optical performance can be gauged, and the payload calibrated accordingly.

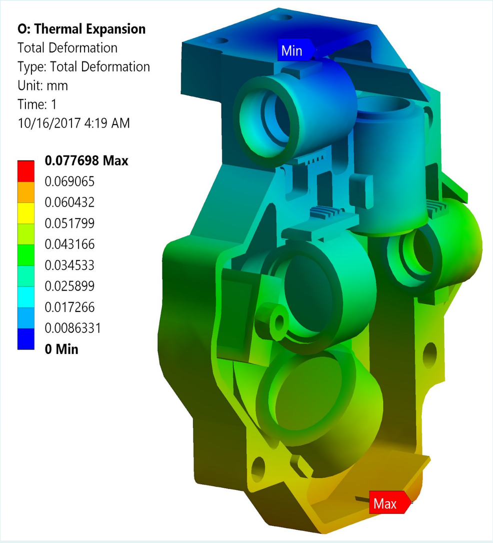

Figure 8

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