A Study into the Structural and Thermal Integrity of 6U Cube Satellite Subsystems and Components

Michael Ely*[1], David L. Cotten#[1]

*mje80254@uga.edu, #dcotte1@uga.edu, [1]Small Satellite Research Laboratory, University of Georgia

RESEARCH OVERVIEW

The objective of this research was to study different techniques of cube satellite frame design for the stress mitigation of sensitive components. During the launch process of an orbital mission, satellites are subjected to large forces of acceleration and vibration which can have adverse effects on the performance of a system. The main sensitive components of a cube satellite are the optical system lenses and electronic pcbs. This research focuses on structural support for the electrical components. This research was performed as a part of the UGA SSRL (Small Satellite Research Lab) on the MOCI (Multi-view Onboard Computational Imager) satellite. The MOCI satellite uses a 6U frame (roughly 100 mm x 200 mm x 300 mm) made of Aluminum 6061. Design requirements were set by the Air Force Research Lab. The first requirement is that the satellite frame as an individual subsystem must maintain structural integrity for the duration of a mission. Other requirements include sustaining a factor of safety of 2.0 for the yield strength and 2.6 for the ultimate strength when subjected to a force of 35 Gs (343.232 m/s^2). The satellite must possess natural frequencies above 100 Hz. Simulations were performed in ANSYS Workbench, an industry standard for finite element analysis.

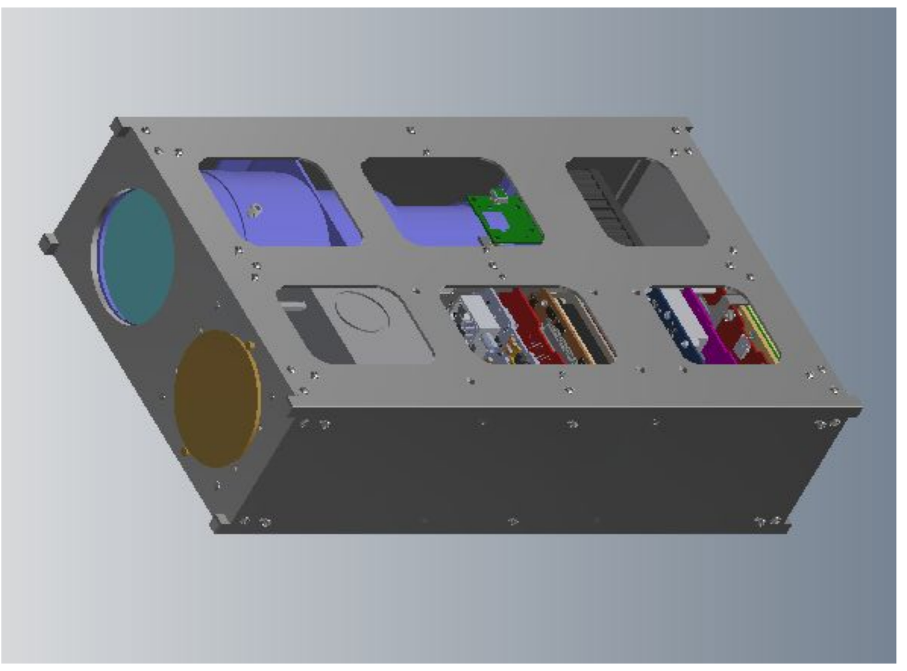


Figure 1: MOCI full system satellite modeled in Autodesk Inventor

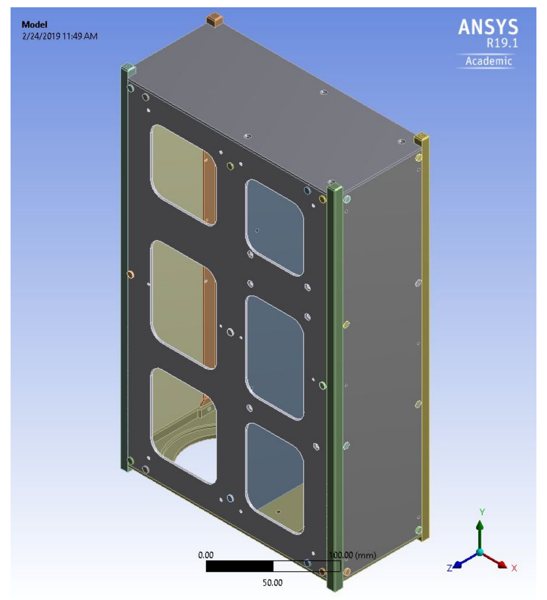


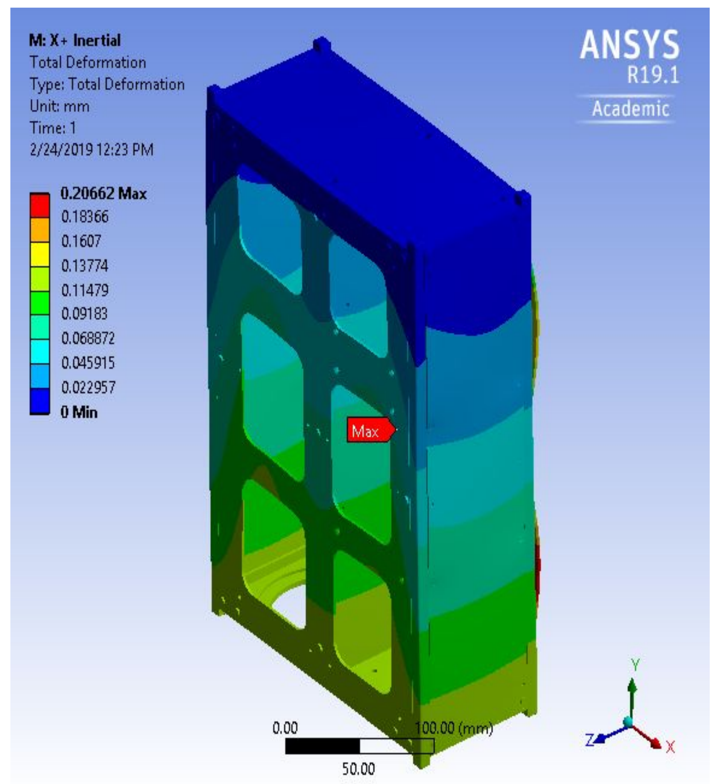
Figure 2: MOCI 6U frame modeled in ANSYS Workbench (no internal subsystems)

FRAME STRUCTURAL SIMULATION RESULTS

The satellite frame was modeled in Autodesk Inventor and exported to ANSYS Workbench. The system was meshed so that the satellite frame would have a quality skewness between 0.1-0.5 for 90% of the elements. Simulated bolts were used inplace of threaded screws to lower the number of elements needed for meshing. The frame was assigned Aluminum 6061 and bolts were assigned A2 Stainless Steel. A mass of 12 kg was assumed for the satellite.

The results showed that natural modes started at 327.2 Hz. This is well above the required 100 Hz threshold. The first six modes are shown below. The factors of safety are in a safe range for the 35 G load applied to the MOCI satellite frame. The load was tested in the X, Y, and Z orientations. Aluminum yield and ultimate strength are 276 MPa and 310 MPa respectively. Maximum stress occurs on one of the frame rails with a value of 104.55 MPa, producing a 2.64 yield factor of safety and a 2.97 ultimate factor of safety. All factors of safety can be seen below.

Figure 3: Deformation results from inertial loading in the X+ direction



Mode	1	2	3	4	5	6
Frequency (Hz)	327.3	362.02	565.78	570.78	594.79	682.85

Table 1: First six natural modes of the frame

Launch Orientation	X-Axis	Y-Axis	Z-Axis
Maximum Stress (MPa)	104.55	58.036	30.17
Factor of Safety (Yield)	2.64	4.76	9.15
Factor of Safety (Ultimate)	2.97	5.34	10.28

Table 2: Results from a 35 G load in different launch orientations

FRAME AND AVIONICS SIMULATION RESULTS

Launch Orientation	X-Axis
Maximum Stress (MPa)	54.802
Factor of Safety (Yield)	4.78
Factor of Safety (Ultimate)	6.30

Table 3: PCB results from a 35 G load in the X-Axis launch orientation

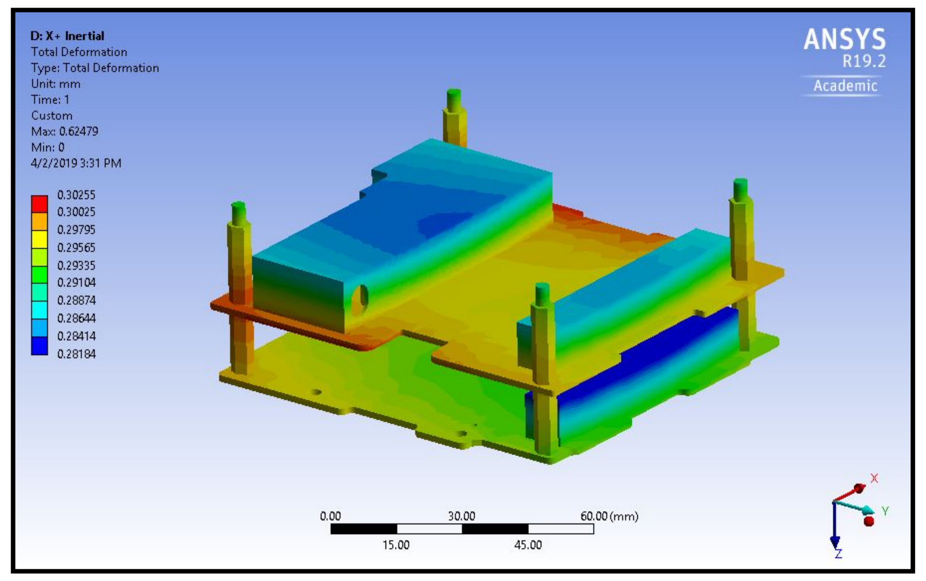


Figure 4: PCB deformation results from inertial loading in the X+ direction

For testing the structural integrity of the electronics boards, other satellite components (Optical payload and ADCS) were included to ensure accurate stress distributions. PCBs were assigned FR-4 as the material. Previous simulation work found that applying a 35 G load in the X direction provided the worst case scenario for stress and deformation on the the electronics boards.The results from these tests are shown to the left.

With the inclusion of more systems in the simulation and subsequently more mass, the frame previously tested reached a critical point by which minimum factors of safety were no longer reached on the rail system of the frame. To remedy this problem, changes have been made to the frame. One advancement was to integrate the rail protrusions into the -Z face instead having them connect independently to this face through fasteners. Another change was the inclusion of fillets on the -Z face to relieve stress on the right angle corners. These solutions have partially fixed the low factors of safety on the frame, but none have fully corrected the problem.

CONCLUSION AND FUTURE DEVELOPMENTS

Simulations have shown that the electronic systems will maintain structural integrity under a 35 G load. The stress and deformation for the PCB components settled in a safe range where damages will not occur. Simulations determined that thermal deformation did not have a major effect on the PCBs. The standalone 6U MOCI frame was able to withstand the 35 G load, but when combined with the extra mass from additional subsystems, the frame fell below required factors of safety.

Research is continuing to develop methods of remedying this problem. Some proposed solutions include expanding the width the edge rails or increasing the thickness of the -Z face. Another solution is to add more structural ribs surrounding the avionics stack, but this could lead to more problems with the additional mass. It has been considered that a complete redesign of the structural frame might be necessary with recommendations from members of the space hardware industry. Development of the MOCI satellite will continue. This satellite is set to launch in spring of 2020. Expected timelines set satellite system designs to finish in August 2019.

This research was developed in Autodesk Inventor and ANSYS Workbench. Satellite frame designs were created by Michael Ely and Alexander Watson Jones. Simulation data was developed by Michael Ely and Grayson Bellamy. Research was performed in the UGA Small Satellite Research Lab. Requirements were designed by the Air Force Research Lab.

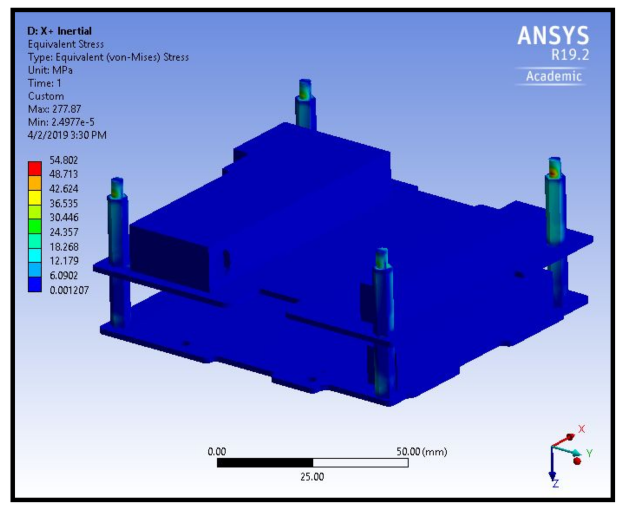


Figure 5: Stress distribution on PCBs

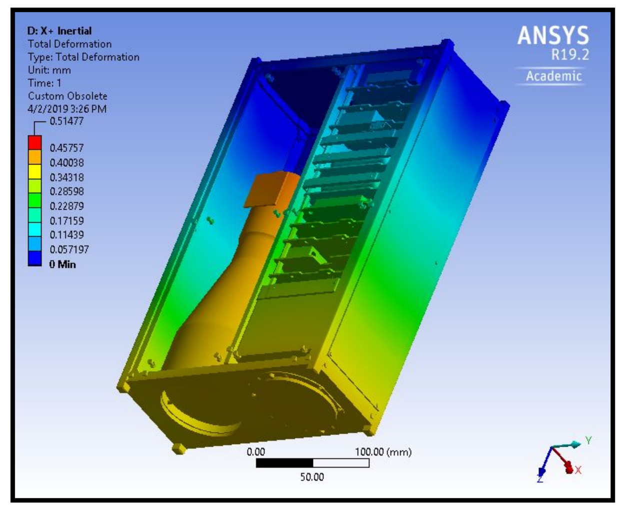


Figure 6: Deformation of the MOCI full system

Small Satellite Research Laboratory
Franklin College of Arts and Sciences
UNIVERSITY OF GEORGIA www.smallsat.uga.edu

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