Modular CubeSat Structure Enabling Rapid Payload Integration and Delivery

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Introduction

The CubeSat assembly, integration, and test (AIT) process is typically lengthy and serial in its execution. This introduces serious programmatic and schedule risks to many CubeSat missions. The modular structure presented here is aimed at mitigating these risks by providing a novel, "plug and play" approach where major system elements are compartmentalized and the critical path for avionics and payload is parallelized. This allows for a parallelized workflow throughout the AIT process, which can accelerate final integration. Breaking down the system into smaller, more manageable components also aides in the identification and isolation of any anomalies that arise during the assembly process.

A rigorous systems engineering approach was taken in the development of the modular structure. Formal requirements were written, and periodic design reviews were held with an emphasis on traceability and satisfying program objectives. The project would like to acknowledge the support of Michael W Miller.

Design

The structure design splits up a 6U CubeSat into three distinct modules (**Figure 1A**). Two modules are dedicated to housing necessary bus components, and one module is an open frame designed to accommodate a wide range of scientific payloads. The three modules can be assembled into multiple configurations, each of which makes up the form factor of a standard 6U CubeSat (**Figure 1**). Depending on the configuration used, different faces of the payload module are made available as apertures for externally facing payloads.

Data and power are transferred between the modules through a single panel mounted connector on each opposing face. These connectors are located such that the modules can be assembled in any orientation without the need for internal disassembly or rewiring.

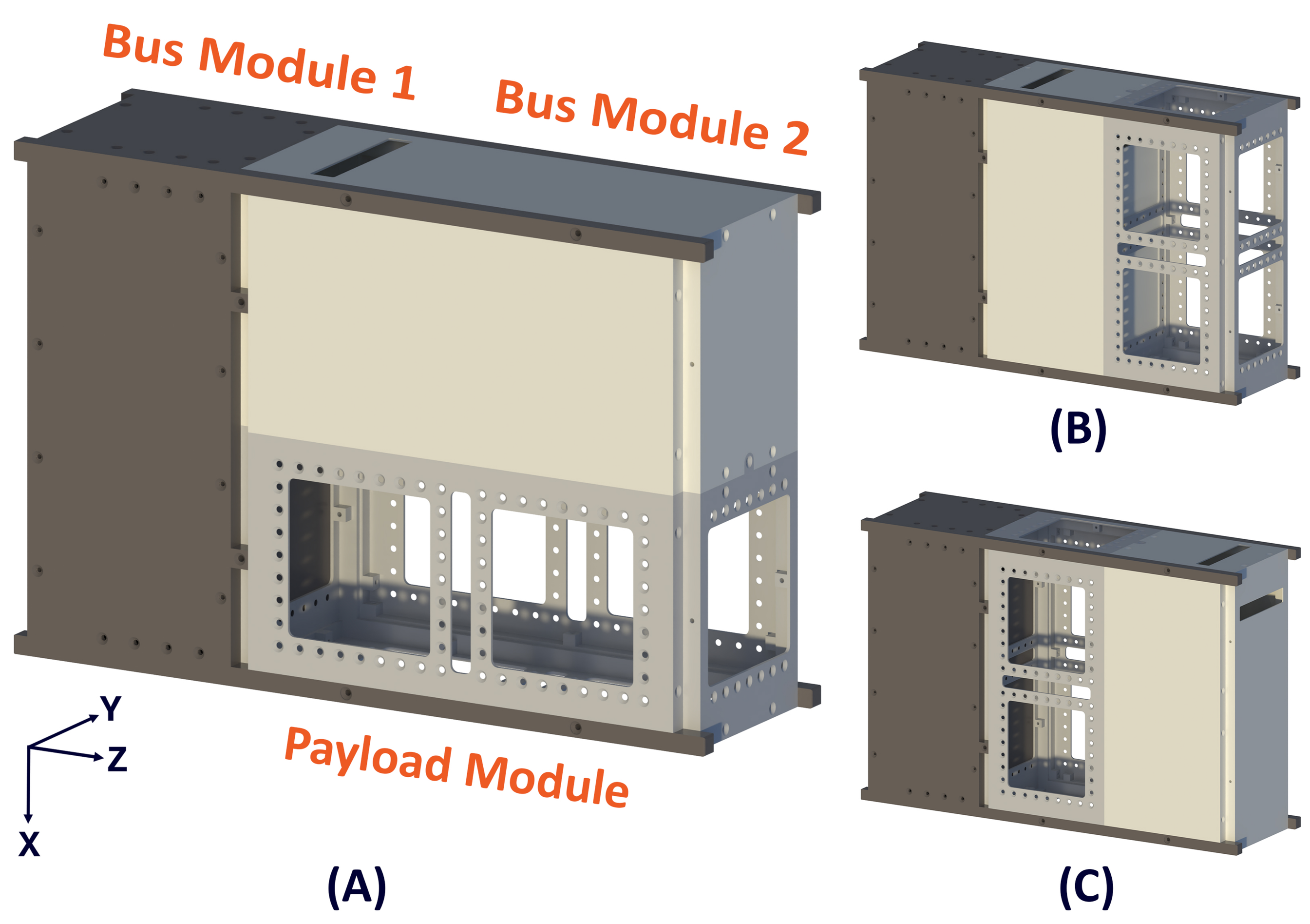

Figure 1: Modular 6U CubeSat Structure in Three Configurations

Analysis

The primary function of a satellite structure is constraining and protecting all bus and payload hardware from the harsh launch environment. A set of structural analyses were performed on the design in order to assess its behavior under the expected load conditions of launch before manufacturing a test unit. Siemens Simcenter 3D and NASTRAN were used for all finite element analysis.

Sustained acceleration simulations were performed using a load level of 17g referenced from the SpaceX Payload User's Guide [1]. The acceleration load was applied independently in each axis of the structure for all three configurations. The resulting maximum Von Mises stress values are shown to be well below the 276 MPa yield strength of aluminum 6061-T6 [2] (**Table 1**).

The resulting displacement represents the worst-case behavior without any secondary structure rigidizing the modules (**Figure 3**).

The free-free normal modes of the structure were also simulated for each configuration. This information is useful for determining the risk of coupling between the structure and launch vehicle during the vibration of launch. Most launch providers require that payloads have a first natural frequency greater than 40 Hz, with higher values being more desirable for reduced chance of excitation. The first six translational modes of the modular structure occur at frequencies less than 1.0E-03 Hz for every configuration, and the first significant natural frequency occurs at 98.15 Hz (**Table 2**).

Analysis Results

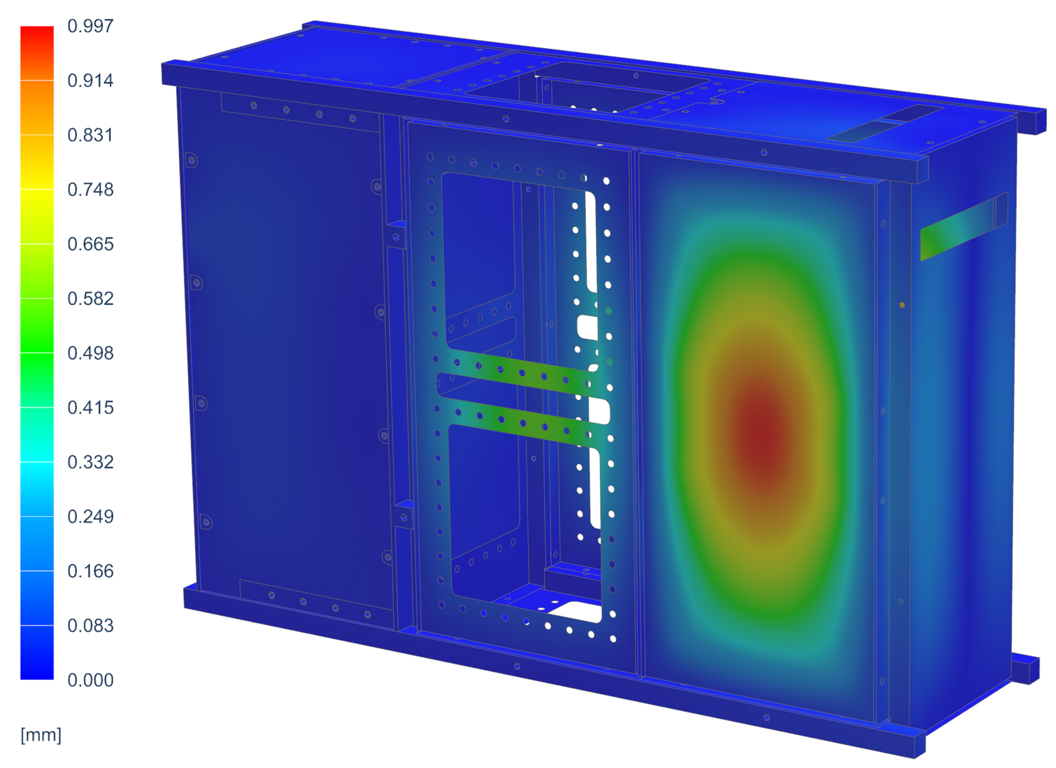

Figure 3: Configuration C Displacement 17g Y-Axis

Table 1: Maximum Von Mises Stress For 17g Load [MPa]

Load Axis	Configuration A	Configuration B	Configuration C
X	97.11	36.46	38.13
Y	153.76	143.12	157.14
Z	110.73	90.09	83.32

Table 2: Free-Free Normal Mode Frequencies [Hz]

Mode	Configuration A	Configuration B	Configuration C
1-6	< 5.48E-04	< 8.60E-04	< 6.00E-04
7	98.15	118.60	136.51
8	126.69	177.17	146.17
9	169.68	177.86	174.05
10	213.51	207.85	175.66
11	228.05	216.66	264.13
12	263.36	269.13	321.24

Conclusion and Next Steps

The modular structure design offers benefits that have the potential to radically reduce the time required for AIT compared to missions using traditional frame structures. The finite element analysis carried out on the structure indicates that it will perform well in harsh launch environments regardless of the selected module configuration. The next steps in the development of the structure will consist of manufacturing a test unit and performing a full shock, vibration, and environmental test campaign on it.

References

1. SpaceX, "Rideshare Payload User's Guide," Version 9, December 2023.
2. ASM, https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6