6.0 Structural Subsystem

The CubeSat Structural Subsystem is made of a lightweight material that provides adequate interfaces to each other subsystem to ensure safe passage through all phases of the mission. The ease of fabrication and assembly, light-weight, and free space for the payload sensors, circuitry, and batteries are the key features of the CubeSat structural subsystem design. The structural subsystem also has the ability to accommodate multiple payload sensors integrated in the subsystem in a simple manner.

This section begins with a discussion of the previous CanSat structural subsystem designs. Subsequent subsections will discuss the requirements and constraints for the new structural subsystem, followed by the options and evaluation of materials, and finally, the modifications to the current structural design. AutoCAD drawings of the structural components can be found in Appendix A.

6.1 Background

The previous CanSat (summer 2002) was a cylindrical-shaped structure, 12.3 centimeters tall and 6.6 centimeters in diameter, and weighed only 166 grams, as shown in Figure 28. The structure alone accounted for 50% of the total weight of the CanSat and was made from aluminum because of its light-weight and high tensile characteristics. The structure consisted of two sub-assemblies: a cover and a frame. When assembled with 3 mm stainless steel countersink bolts, the structure became a monocoque design that provided rigidity. The top plate had holes for parachute lines and an antenna. The parachute chords were attached directly to a bolt connected to the main frame. The circuit boards were mounted on the frame and the transceiver was placed between the walls of the frame. The frame of the structure provided extra protection for the expensive transceiver. The structural subsystem tests were conducted using various methods of vibration analyses, including static loading, and others. The final launch also proved that the CanSat design was able to withstand about 50 g's of load.

Figure 28: Previous Coke-Can size CanSat [Campbell and others, 2003].

The exterior of the CanSat design was strong; however, the interior setup lacked some planning. For example, incorrect temperature data was recorded because the temperature sensor was located next to an integrated microchip, see Figure 29. Furthermore, the location of the antenna (located on top of the CanSat, see Figure 30) created communication interruptions between the CanSat and the ground station. The communication interruptions occurred because the transceiver works on high frequencies that require line of sight communication. In addition, the off-center location of the center of gravity and improper setup of the parachute resulted in a continuous spin of the CanSat during the descent phase of the mission. The spinning of the CanSat also aggravated the communication interruptions. Next, since the structure was not properly sealed on all edges, an excessive amount of dust entered the CanSat when the parachute dragged the CanSat on the floor of the desert. The dust in return contaminated the circuit boards and the sensors. In addition, on the final project day, the parachute deployment rate was approximately 60%, according to the previous CanSat group; this resulted in a free fall of several CanSats, from different Universities, and caused their total destruction on the launch day. Furthermore, the CanSat did not have any external ports or peripherals; therefore, the previous group had to open the CanSat frequently to change the batteries and to upload and download data.

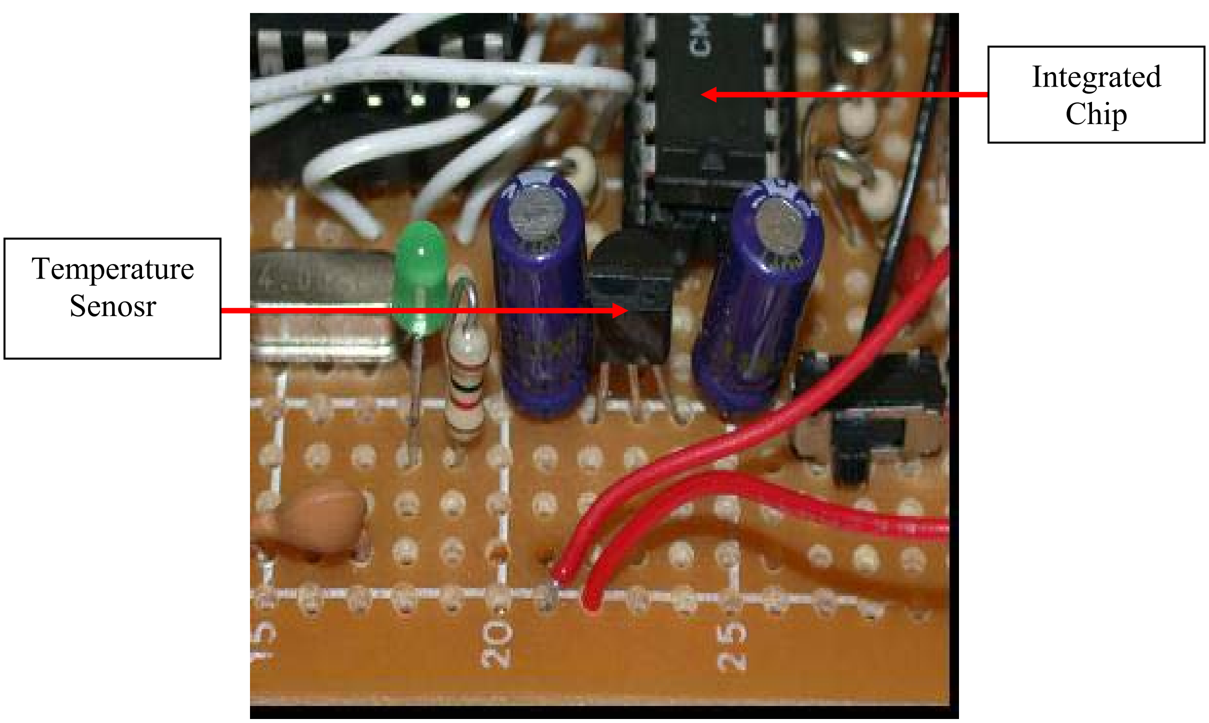


Figure 29: Location of Temperature Sensor Next to an Integrated Chip [Campbell and others, 2003].

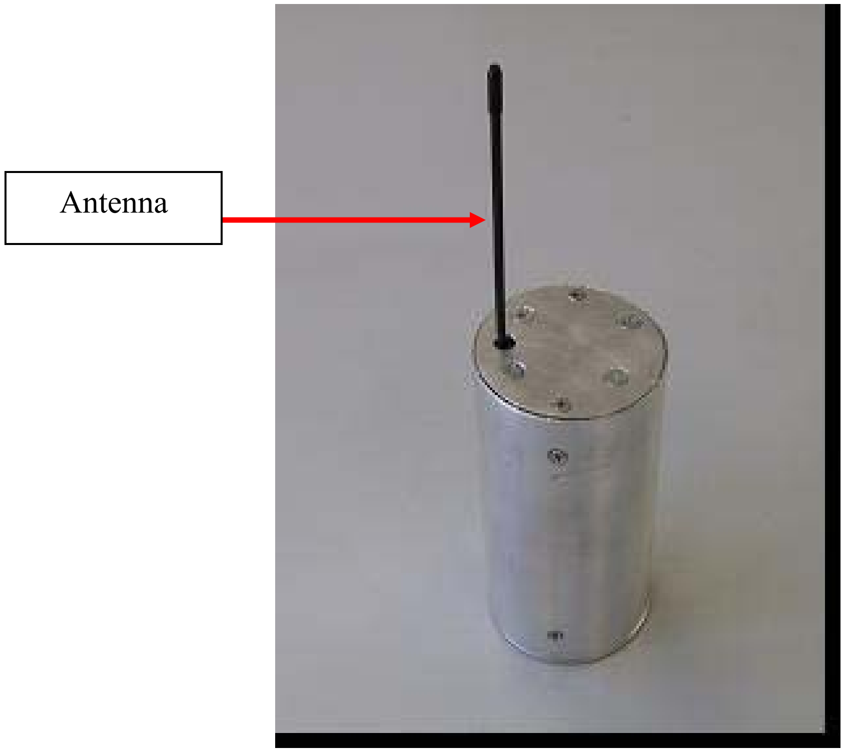


Figure 30: Location of Antenna on Previous CanSat [Campbell and others, 2003].

6.2 Requirements and Constraints

The objective of the structural subsystem for the CubeSat project is to provide a simple, sturdy structure that will survive launch loads, while providing an easily accessible data and power bus for debugging and assembly of components. Because of the size constraints of the CubeSat and small expense budget, this must be done with the philosophy of maximizing usable interior space, while minimizing the complexity and cost of the design. The design of the CubeSat conforms to the structural and launcher requirements set by the Stanford/Calpoly CubeSat program. The shape of CubeSat is essentially a cube, with outer dimensions of 10 x 10 x 10 cm, with 3.0 mm clearance above each face of the cube for mounting exterior components such as antenna, data link and power charger inlet port. The satellite must have four launch rails along four edges of the cube, allowing for easy ejection from the P-POD (Poly Picosatellite Orbital Deployer) launch tube, shown in Figure 31. To maintain spacing and prevent sticking with other CubeSats, standoff contacts or feet must exist at the ends of these rails; therefore the four rails are extruded by 5 mm on all ends. The center of mass of the CubeSat must be within ±2 cm of the geometric center. The maximum allowable mass of CubeSat is 1 kg, and it is desired that the structure be no more than approximately 30% of the total CubeSat mass, and should be able to withstand a minimum of 50 g's load [Wells, Stras, and Jeans, 2003]. The structural subsystem shall have an external power-off switch, such that when pressed should lie flush with the surface. The structure should be assembled with flat head metal screws and all sides should be sealed properly. The structure should also be able to pass harmonic and random vibration tests. There must be two holes, one on each diagonally opposite guide rail to connect the parachute chord. A hole will be carved on the lower surface to place the flexible antenna.

The suggested material for the main satellite structure is Aluminum 7075 or 6061, Stainless Steel, Titanium, Composites, and Honey Comb. If other materials are used they must have the equal or more value for thermal expansion and yield strength as the aluminum.

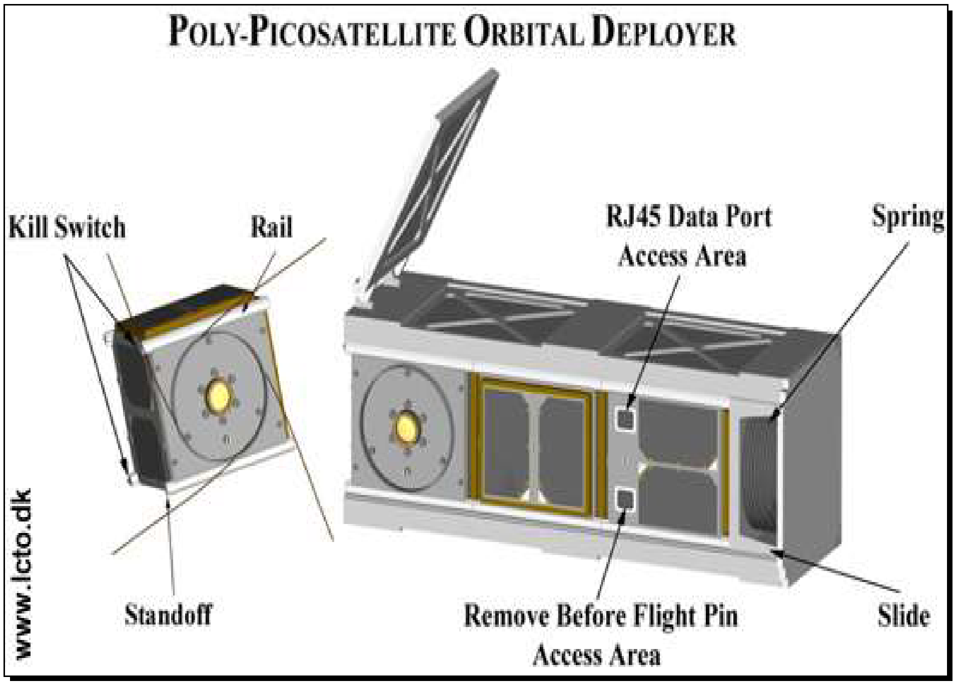


Figure 31: Poly-PicoSatellite Orbital Deployer [“About AAU CubeSat,” 2003].

6.3 Material Options and Evaluation

As suggested in the previous subsection, several materials were considered before selecting the final material. The criteria for selection were based on characteristics listed below:

- Strength
- Weight
- Machinability
- Cost

Table 15 lists several materials along with their strength, density, and cost for a 12 x 12 inch sheet. Some of the cost data is not available for 12 x 12 inch sheets, but the common knowledge available to an engineer relates that these materials would not meet the needs of our system.

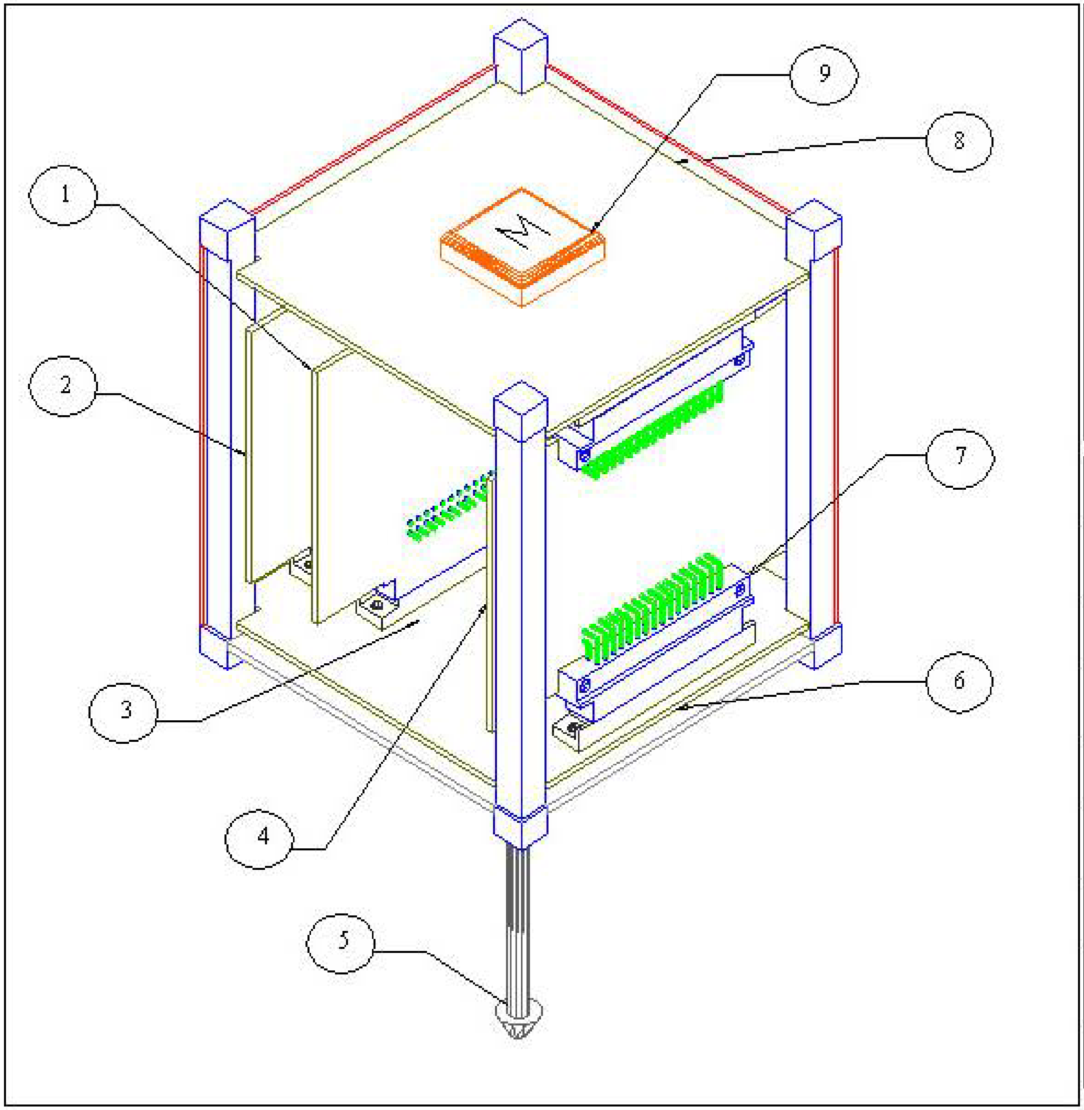
Table 15: Selected Material properties and cost data.

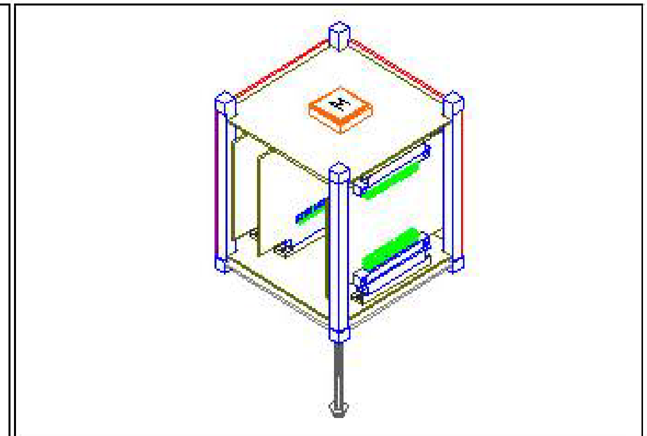
Material	Yield Strength	Density	Machinability	Cost/ft^2
Stainless Steel	790 MPa	7760 kg/m^3	Easy	$6.52
Titanium	900 MPa	4429 kg/m^3	Hard	NA
AL-6061-T6	320 MPa	2850 kg/m^3	Easy	$3.80
AL-7075-T6	340 MPa	2796 kg/m^3	Easy	NA
Composites	640 MPa	~1000 kg/m^3	Hard	NA
Inconel	848 MPa	8321 kg/m^3	Hard	$96.25

The above table clearly indicates that AL-6061-T6 meets the required criteria of high strength, light-weight, easy machinability, and cost; therefore, Aluminum 6061 was chosen as the structural material for the CubeSat.

6.4 Structure Bus Design: Exterior, Interior, and Assembly

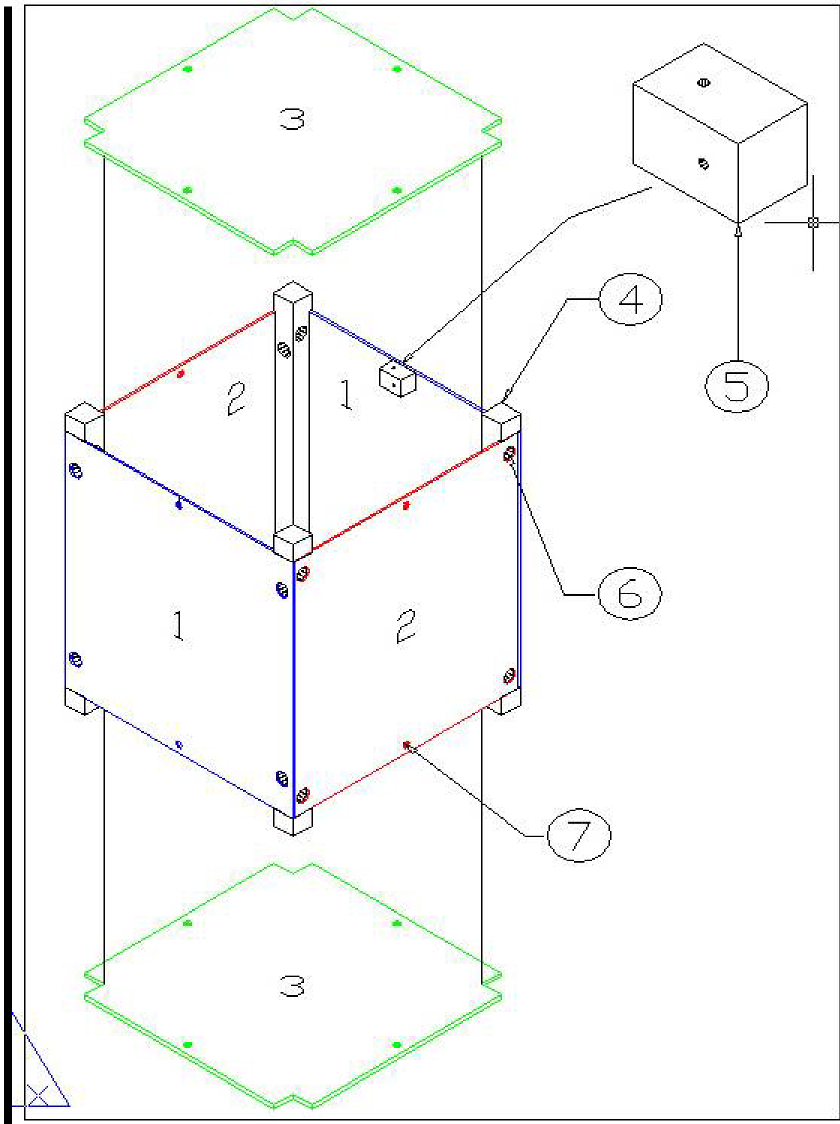
Access to the electrical components is an important design consideration. During the development and testing phase of the CubeSat, the circuit boards and the transceiver will be removed and replaced with great frequency. Easy access to these components will save a significant amount of time over the entire development and launch phase. In short, it is necessary to have a structure that is light, strong, versatile, and easy to disassemble [Campbell and others, 2002].

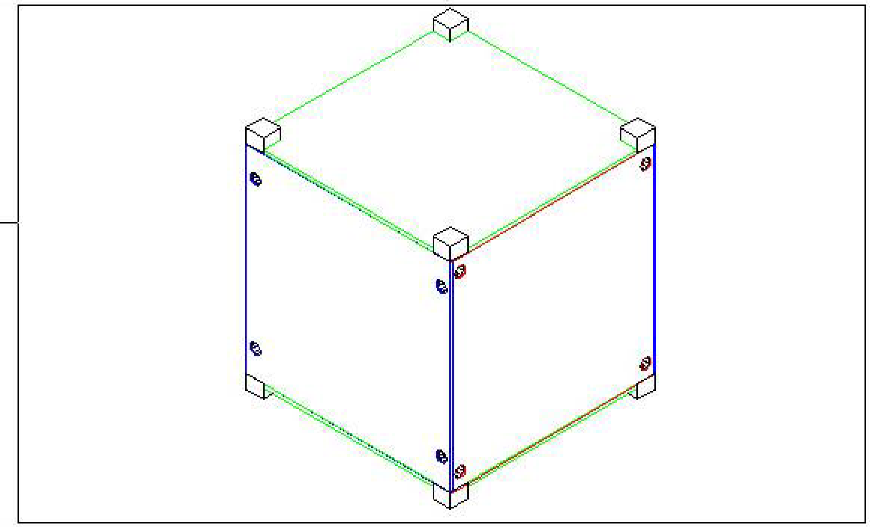




1	Additional Payload Board
2	Sensor Payload Circuit Board
3	Space for Batteries
4	GPS and Communication Subsystem Board
5	Communication Antenna
6	Power Subsystem Board
7	DIN Connector
8	Command & Data Handling Subsystem
9	GPS Antenna

Figure 32: Layout of CubeSat: Internal and External.





1	2 SIDE PANELS - 100 x 96 x 1 mm
2	2 SIDE PANELS - 98 x 96 x 1 mm
3	2 TOP & BOTTOM PANELS - 100 x 100 x 2 mm
4	4 GUIDE RAILS - 8.5 x 8.5 x 110 mm
5	8 DELRIN BOSS - 9.5 x 6.4 x 6.4 mm
6	16 X 2-56 THREADED THRU HOLES
7	16 X Ø 0.84" THRU HOLES

Figure 33: External Layout of CubeSat.

6.4.1 Exterior Structure

The CubeSat structure was designed using AutoCAD Power Pack software to ensure that all components fit together without interference, and to aid in the finite element analysis. The detail drawing of CubeSat's component made in AutoCAD can be seen in Appendix A.

The exterior structure of CubeSat consists of six aluminum (AL-6061-T6) walls connected together using stainless aluminum screws and 8 Delrin bosses. The orientation of the body axes is such that the Z axis is perpendicular to the top and bottom panel (panel 3 in Figure 33) of the CubeSat and the other two sides (panels 1 and 2 in Figure 33) are perpendicular to the X and Y axis, respectively. From this reference frame, the structural walls are named the ±1, ±2, ±3, accordingly. The ±3 aluminum walls have 2 mm thickness, while all other walls are 1 mm thick. The launch rails are incorporated in between the ±1 and ±2 walls, and are oriented parallel to the Z-axis. Attached to ±3 structural walls are circuit boards and solar panels. Panels number ±3 and + 2 will require rectangular cutouts to accommodate the GPS antenna (top panel), electronic data port (side panel) and a battery charger port (bottom). One circular cut out is required on the -3 wall for the communication antenna.

A finite element analysis of the bottom panel was done to ensure that the CubeSat will not experience unacceptable stresses or displacements during the launch which could create up to 50 g's load. The results given by the AutoCAD Power Pack FEM package are shown in (Figure 34). Figure 34 below clearly indicates that the maximum stress is at the point where the Delrin Boss and the base panel are connected and is 8.89 psi (less then yield strength of AL 6061-T6 (see Table 15). In addition Figure

35, which shows the results of the finite element analysis run on the bottom panel, indicates the maximum deflection that results because of the applied load (also shown in Figure 35) is 0.00016 in. at the periphery and 0.001245 in. at the center (also not a major deflection). Therefore, the preliminary run of the Finite Element Analysis method indicates that the designed CubeSat can withstand the 50 g's load. A more complete finite element analysis should be performed over the entire structure, but it requires a lot of computer memory.

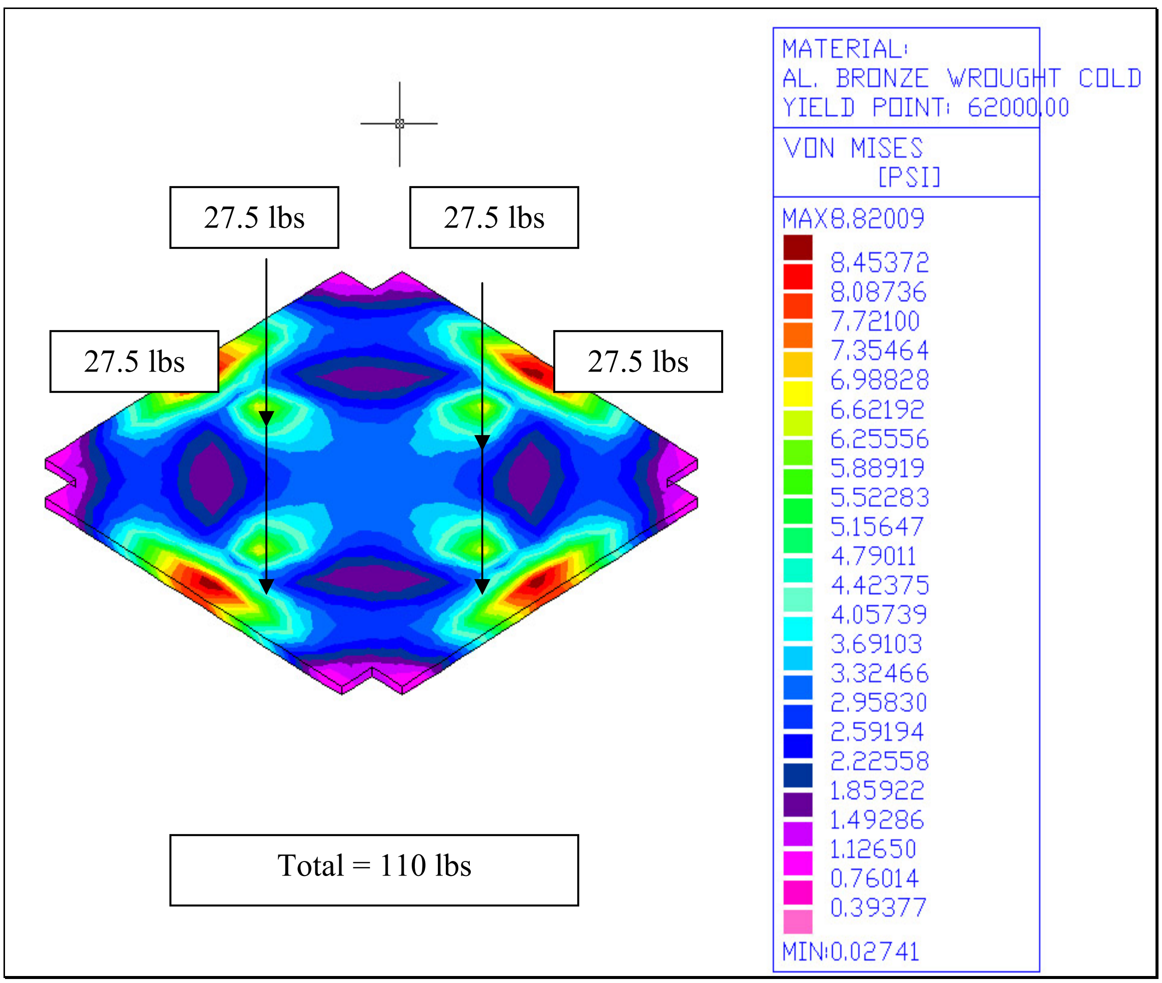


Figure34: Finite Element Analysis on the CubeSat's Bottom Panel for stress Analysis (AutoCAD Power Pack Software).

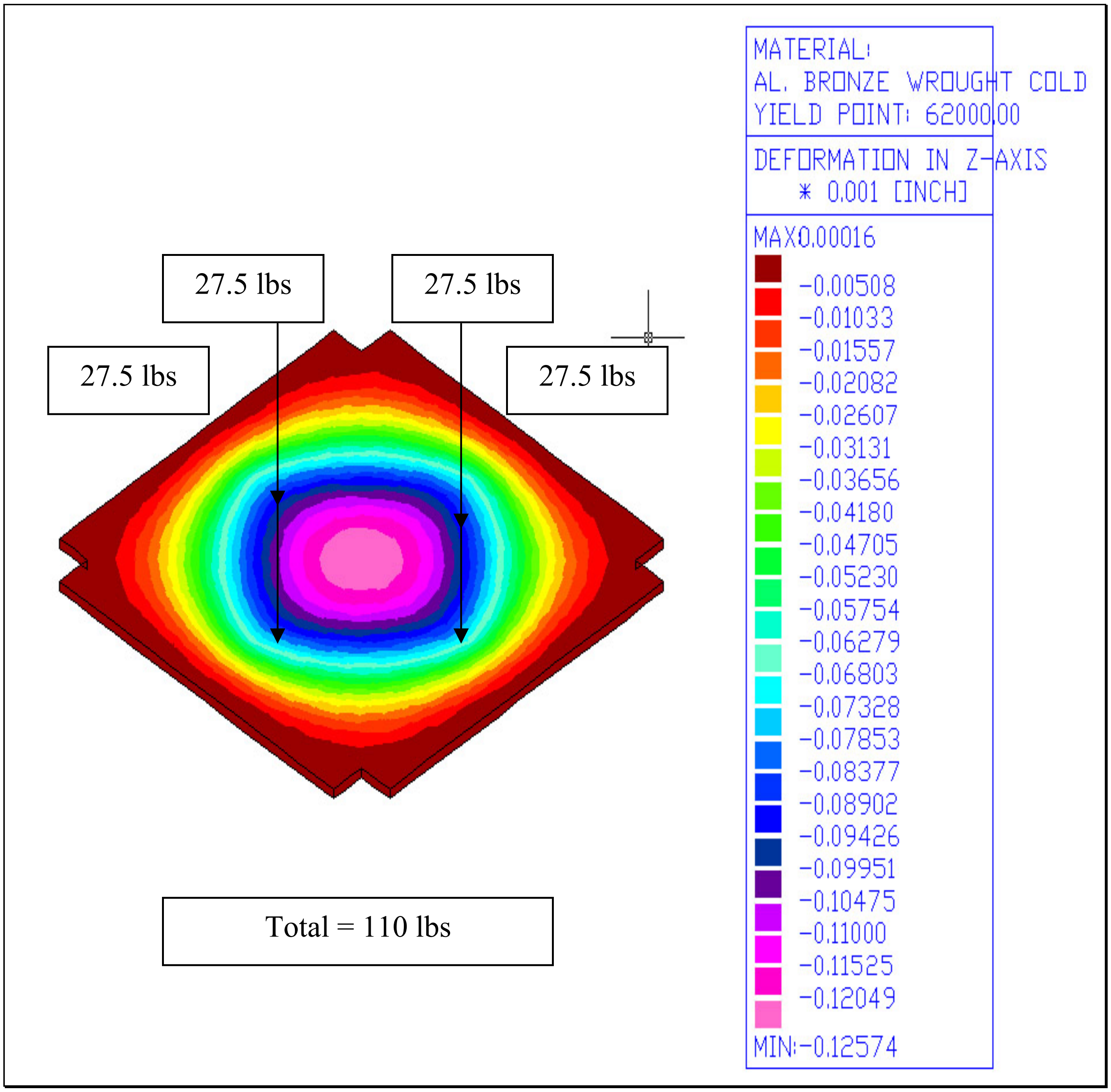


Figure 35: Finite Element Analysis on the CubeSat's Bottom Panel for Deformation Analysis (AutoCAD Power Pack Software).

6.4.2 Interior Structure

The interior structure of the CubeSat will consist of five circuit boards. Since the CD&H and the power subsystems are shared by all other subsystems, they are allocated Circuit Boards 8 and 6, respectively, as can be seen in Figure 32. The communication subsystem and GPS module are allotted Circuit Board 2, while Circuit Board 4 is reserved for payload sensors subsystem. The empty space represented as 3 in Figure 32 is allocated for batteries. The boards are spaced such that components do not interfere with each other, while the CubeSat mass center remains within its constrained range. The boards will be held in place using four columns of nylon spacers, see Figure 36. These columns will also act as structural supports along the Z-axis. The dimensions of the circuit boards can be found in Appendix A. The total mass of the interior and exterior structure is estimated to be 950 grams or 95 % plus 5 % for any unexpected weight during construction. Therefore, the total weight of the CubeSat is less then 1 kg, see Figure 37. In addition, Table 16 indicates the approximate space allotted to various subsystems [Wells, Stras, and Jeans, 2003].

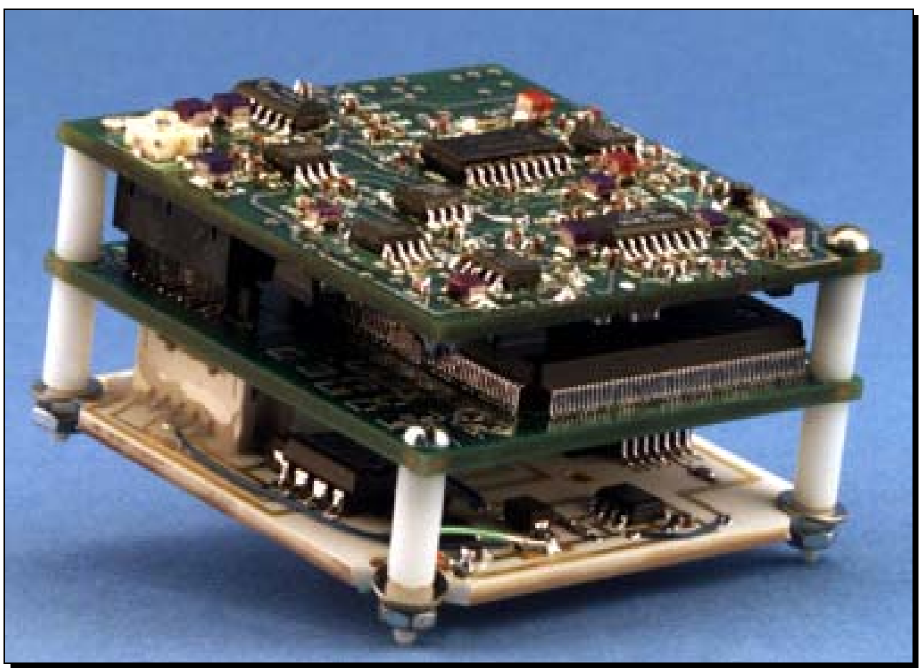


Figure 36: A sample of circuit boards connected with Plastic Spacers (the size is about 4 x 4 inches for each board; five boards will be connected in a similar manner) ["Tactical Systems," 2003].

6.4.3 Assembly

From the structural design, the satellite will be built from the inside out. This means that the interior electronics will be populated and assembled first using rubber washers and nylon spacers. The rubber washers will dampen the noise and vibrations during all phases of the CubeSat flight. All of the internal components will be fastened to the structure as a single package using rubber washers and fasteners. Next the +3 aluminum wall will be attached, followed by the ±1 walls, columns, and the -3 wall. Attaching the ±2 walls will complete the assembly. For debugging, the interior circuit boards can be removed easily by removing the screws on –3 and removing the +3 aluminum wall.

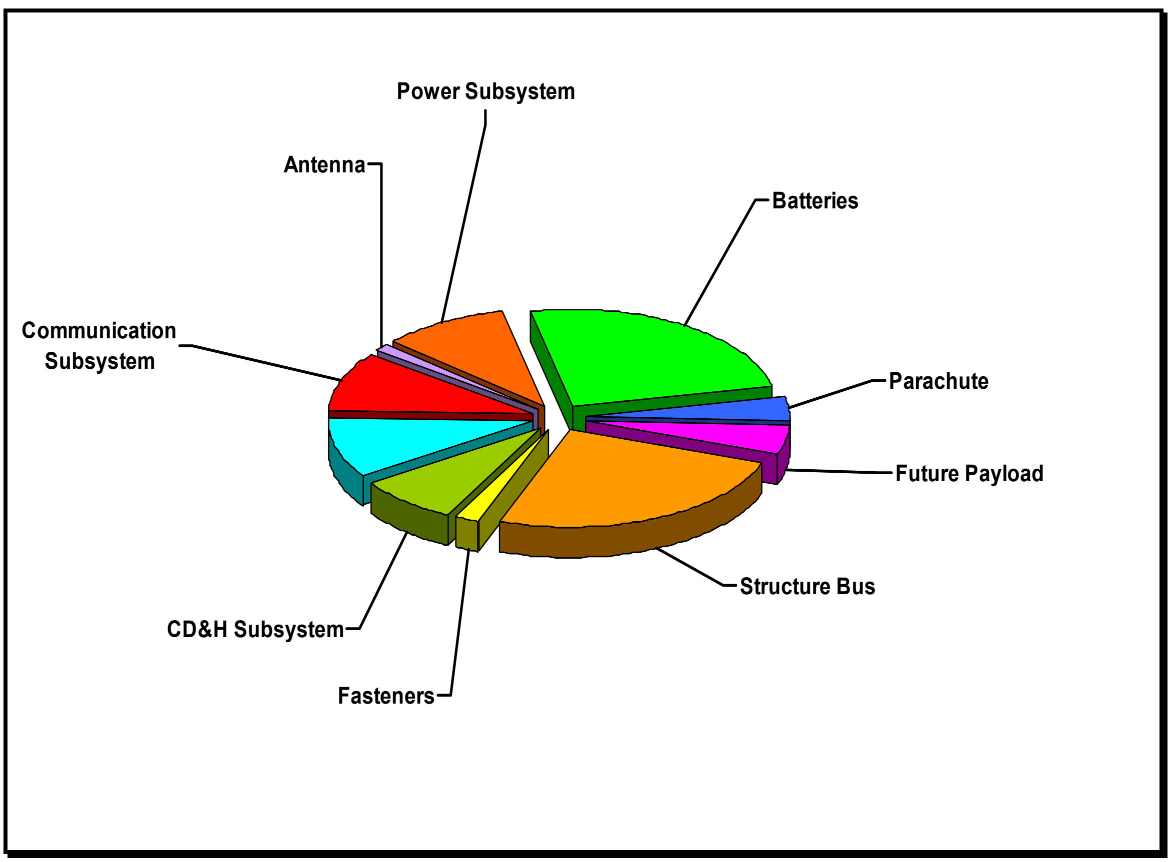


Figure 37: Estimated Weight Distribution for CubeSat (Total weight = 1 kg).

Table 16: Approximate Space Allotment for various components of the CubeSat.

Components and Subsystems	Space Allotted, Width (mm)
Command and Data Handling Subsystem	17.0
Payload Sensors	18.0
Communication Subsystem	5.0
Power Subsystem	17.0
Batteries	35.0
GPS Module	5.0
Margin	3.0
Total	100.0