Bolted Satellite Structure Analysis in ANSYS Mechanical

Satellite requirements: Higher Performance and Lighter Weight

Fixed Parameters:

- Acceleration – 10g, Radius of beam element, Deformable beam

Modified Parameters: (Source: https://www.nap.edu/read/2351/chapter/7#45)

- Material for structure
  1. Aluminum Alloy (Reference)
  2. Alloy 2090 (Al-Li alloy) – Lower density, Higher strength than Aluminum alloy
  3. Titanium Alloy – High strength, relatively light, resistant to heat and cold
  4. Carbon Fiber – High dimensional stability against temperature variation.

- Material for bolts (Source: https://www.thomasnet.com/articles/hardware/aerospace-fastener-types/)
  1. Titanium Alloy (Reference)
  2. Inconel 718 – Retains high tensile strength even in higher temperatures

Model Description:

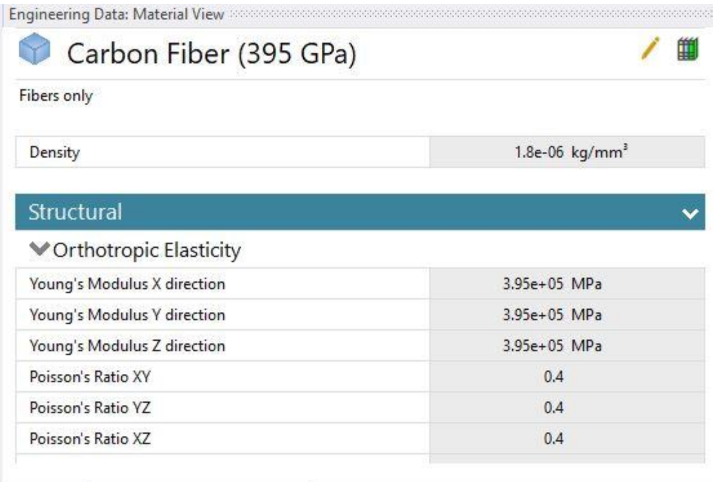
In this report, four types of materials ('One' reference and 'three' new) are tested and compared in the satellite structure via simulations. The idea is to find the best material for the structure based on their Margin of Safety (MoS) (Source: https://content.sciendo.com/view/journals/arsa/53/1/article-p29.xml?language=en). Based on the best structure material, then bolt materials are tested and compared to find the best out of them.

$$\mathrm{MoS} = \frac{\sigma_{\mathrm{allowable}}}{1.25 \times \sigma_{\mathrm{max}}} - 1$$

Table 1: Mechanical Properties of materials used

Material	Al- Alloy	Ti -Alloy	Alloy 2090	Carbon Fiber	Inconel 718
Satellite Mass (Kg)	**3.1528**	**5.2585**	**2.948**	**2.0488**	**-**
	Physical Properties				
Density (Kg/m3)	2770	4620	2590	1800	8220
	Mechanical Properties				
Ultimate Strength (Mpa)	310	1070	550	600	1035
Yield Strength (Mpa)	280	930	520		648
Young's Modulus (Gpa)	71	96	76	395	165
Poisson's Ratio	0.33	0.36	0.34	0.4	0.3

Note: Alloy 2090 is made as a custom material in Ansys and Carbon fiber (395 Gpa) is modified to not display direction-specific behavior



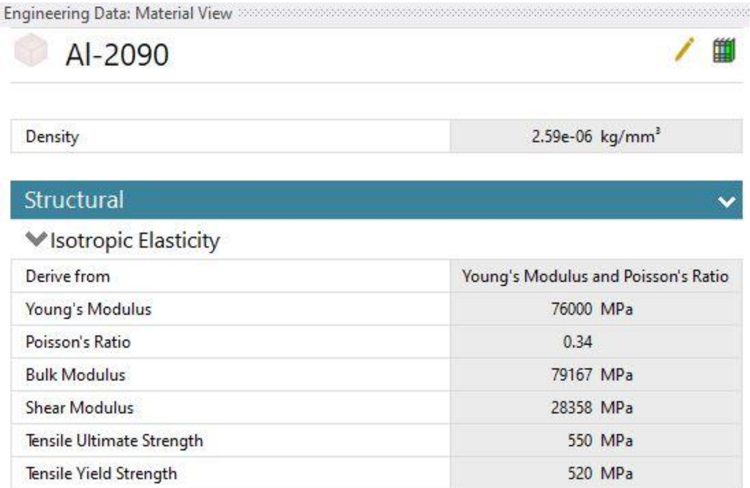
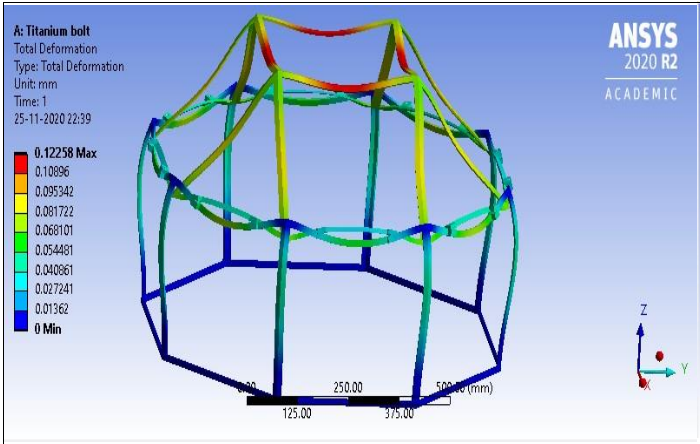
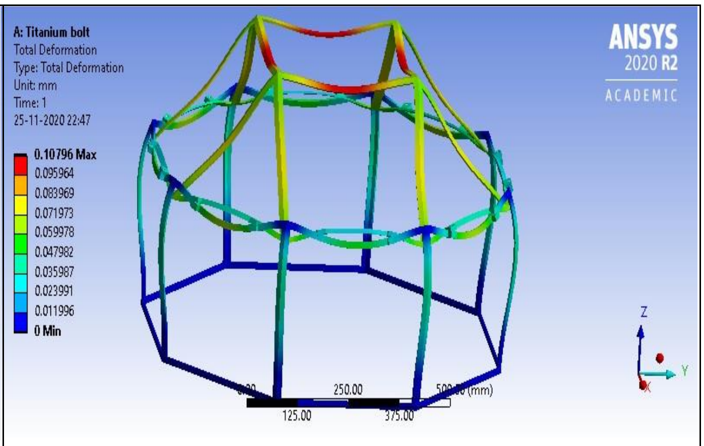
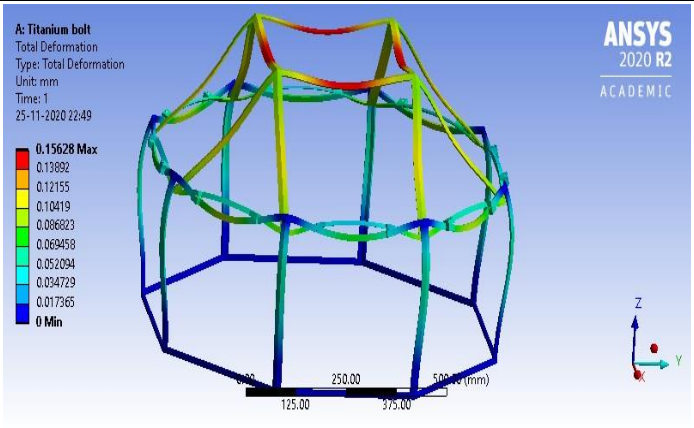
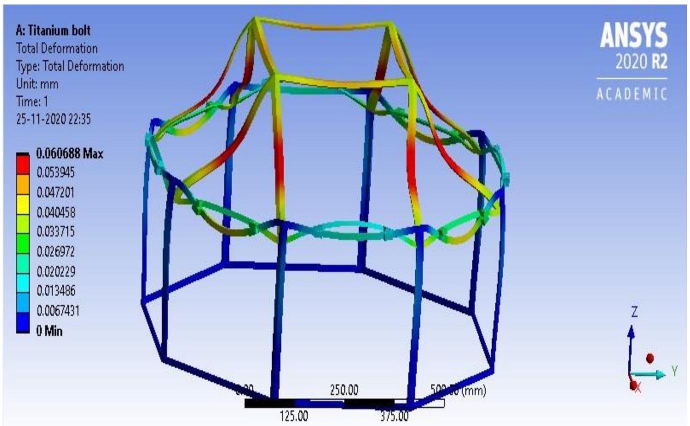


Table 2:Deformation comparison between Structural materials (Bolt – Titanium)

 Aluminium Alloy	 Alloy 2090
 Titanium Alloy	 Carbon Fiber

Results:

The simulations are carried out in Ansys program. The combinations of structure and bolt materials were –

- Aluminum alloy structure, Titanium alloy bolt (**Al-Ti**) (Reference)
- Alloy 2090 structure, Titanium alloy bolt (**Al2090-Ti**)
- Titanium alloy structure, Titanium alloy bolt (**Ti-Ti**)
- Carbon Fiber structure, Titanium alloy bolt (**CF-Ti**)
- Carbon Fiber structure, Inconel 718 bolt (**CF-Inconel**)

The following table shows the values of stress, deformation, etc. calculated by the program. Based on that, **MoS** is calculated by hand for each combination according to the given formula

Table 3 Margin of safety calculations for different combination of materials

	Al-Ti	Al2090 -Ti	Ti-Ti	CF-Ti	CF-Inconel
Structure					
Maximum Deformation (mm)	0.12254	0.10792	0.15622	0.0606	0.058
Maximum Stress (Mpa)	9.4056	8.6037	14.248	6.5123	7.5744
Margin of Safety	22.81	47.35	51.21	72.7	62.37
Bolt					
Axial Force (N)	9.308	8.7245	15.371	5.3867	5.6648
Torque (N.mm)	33.956	29.695	41.244	20.747	34.681
Shear Force (N)	2.1988	2.0213	3.4649	1.9457	2.9436

Discussions:

According to the calculated results the best structure and bolt combination for the satellite should be **CF-Ti**, as it has the best margin of safety, followed by **CF-Inconel**. Also, as we can see in the figure: Carbon Fiber above, the deformation is least for this. Especially, in the lower half of the structure the deformation is almost negligible. The forces experienced by the bolt is also least compared to other models.

But, based on this assumption that Carbon fiber basically have same Yield strength and Ultimate strength and very high Young's modulus. So, it can be deduced that the structure will be extremely stiff and will break instantly in case of a failure without yielding. So, a designer must be careful while choosing the material based on his/her operating conditions.

Ti-Ti may have the best Margin of safety outside of Carbon-Fiber. But it also induces maximum stresses in the system. The bolts experience maximum axial force, torque and shear forces in this combination. Hence, a designer must be careful on the operating conditions.

In my opinion, **Al2090-Ti** should be most acceptable material for the satellite. Since, it is the 2nd lightest after Carbon Fiber and is a significant improvement on conventional Aluminum alloy (Reference).

Also, as a footnote, the 'Fixed Support' for the lower structure is modified from Face support to outer 'Edge Support' for the **CF-Ti** model and results are similar as shown in the table below –

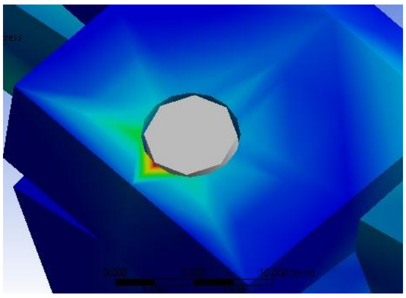
CF-Ti		
	Face Support	**Edge Support**
Maximum Deformation (mm)	0.06060	0.06068
Maximum Stress (Mpa)	6.5123	6.5059
Margin of Safety	72.7	72.77

Conclusion:

- The Margin of safety shows that the Carbon Fiber structure along with Titanium alloy bolts are the best suited for satellite launch. It is stiffer; hence, it will resist the loads of launch more.
- But the mechanical properties of Carbon Fiber are modified based on assumptions from varied sources. Therefore, the next best choice for satellite material will be Alloy 2090 whose mechanical properties are included based on actual data.

Drawbacks:

- The simulation is performed on a very coarse mesh due to the limitation of Ansys version. Therefore, the Maximum stresses in the system which occur around the bolts could not be displayed properly.



- Other materials for satellite structure (for ex – Metal matrix composites, etc) and bolts (for ex – Monel, H-11, Waspaloy, etc) are not investigated due to the fact that, their use is very operational specific and research on them is much larger for the scope of this report.
- The results shown in this report should be interpreted as indicative rather than accurate.