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The Design Optimization of a Cold Gas Propellant Tank Pressurized System for Nanosatellite

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Abstract

Nanosatellites have tight constraints on mass and volume and still require attitude control and orbital manoeuvring capabilities. The variation of propellant and pressurant storage and delivery systems amplifies this condition. This study focused on the effect of material selection on designing and optimizing a cold gas propellant tank pressurized system for a nanosatellite using SolidWorks software. The storage tank was designed using alternative material choices of Aluminium, Titanium and Nylon to achieve a high strength-to-density ratio while operating with thermofluid properties of the working fluid at satellite heights. The results showed that for the same amount of applied load, it is evident that Aluminium could withstand a higher stress level of 245.31 MPa than titanium (171.02 MPa), but titanium suffers lesser strain (0.001399) compared with Aluminium, which had a strain value of 0.002917. The membrane displacement was more tolerable for Titanium (0.03029 mm) than the 0.05589 mm witnessed in Aluminium. The mass of Aluminium (756.77684 g) was much higher than that of Titanium (409.413 g). All these made Titanium the material of choice.

Keywords: Nanosatellites, Propellant storage tank, Optimization, Finite element analysis, Solidworks.

1 | Introduction

Satellite systems play strategic socio-economic roles in a nation's development, especially in precision agriculture, security, water management, environmental and weather monitoring, and disaster management. Nanosatellites, defined as satellites with a net mass between 1-10 kg, are becoming increasingly popular for affordable access to space [1]. They allow institutes and organizations to conduct low-cost experiments and

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technology demonstrations in space [2]. Cold gas thrusters are common types of propulsion systems used on nanosatellites due to their simplicity, low cost, and relative safety [3].

A pressure-regulated gas storage tank, valves, nozzle, and a pressure regulator are the standard components of a cold gas propulsion system [4]. The pressurant gas, usually nitrogen or a Freon compound, expands through the nozzle to provide thrust [5]. Tank pressurization is required to provide sufficient propellant storage and flow for consistent thruster performance [6]. Most nanosatellites use a passive pressurization system consisting of an unregulated pressurant tank due to mass and volume constraints [7]. Active regulated systems provide consistent flow and tank pressure but at an increased system mass cost.

Material selection plays a significant role in optimizing the pressurization system design for nanosatellite cold gas propulsion. It is, therefore, an essential area of research to maximize thrusting performance and total impulse within the strict size and mass constraints [8]. This includes selecting and sizing tanks, regulators, tubing, and other components. Thermal modelling is critical as heat transfer affects tank pressure [9]. System-level models can determine optimal configurations based on objectives such as minimum mass or maximum total impulse [10]. Testing of pressurant flow characteristics and pressure regulation methods is also needed to anchor analytical models [11].

This study's primary concern is the selection of appropriate material in the design optimization of nanosatellite propellant tank pressurization system for cold gas, creating new, effective, and dependable Cold Gas systems that are suited to the unique requirements and limitations of nanosatellite missions in terms of mass and safety. Utilizing design and analysis software like SolidWorks helped to acquire numerical results quickly and efficiently while saving money and resources.

2 | Methods

The cold gas propellant tank pressurized system for a nanosatellite was modelled and simulated using SolidWorks tools. The results obtained were validated using a 3-D print model.

Nitrogen has been selected for the process design analysis due to its nonreactive tendency in the propellant fuel-air mixture. Its fractional representation of about 78% of air helps to improve the thrust as masses of Nitrogen with a molecular weight of 28 grams accelerate away from the propellant nozzle. In addition, nitrogen on its own is atmosphere-friendly and abundant, thus ensuring its continuous availability at nearly no cost.

2.1 | Design Baseline Parameters

The size and function of the satellite determined the propulsion features. The propulsion system is used for attitude control, station keeping, and deorbiting.

From the formula

$$\text{Mass flowrate} = \frac{\text{Force}}{\text{Exit Velocity}}. \tag{1}$$

The computed mass flow rate was determined to be 0.0015 kg/second.

The control volume is the main variable of the nitrogen tank's static pressure. *Table 1* describes the properties of nitrogen at 275 bar pressure and -60 degrees Celsius, which are the conditions that would exist inside the tank at an altitude of 30480 meters above the earth's surface [12].

Table 1. Properties of Nitrogen gas at 275 bar, -60 degrees C [12].

Property	Value	Unit
Medium	Nitrogen	
State of aggergation	Gas	
Pressure	275	[bar]
Temperature	-60	[Celsius]
Density	416.93	[kg/m^3]
Specific Enthalpy	145.31	[kj/kg]
Specific Entropy	4.5323	[kj/kgK]
Specific isobar heat capacity cp	1.652	[kj/kgK]
Specific isobar heat capacity cv	0.8339	[kj/kgK]
Isobar coefficient of thermal expansion	-496.4095	[10^{-3}(1/K)]
Heat conductance	-747.91	[10^{-3}(W/m*K)]
Dynamic viscosity	30.675	[10^{-6}(Pas)]
Kinematic viscosity	0.073607	[10^{-6} m^2/s]
Thermal diffusivity	-499.1256	[10^{-7} m^2/s]
Prandtl-Number	0.97844	
Coefficient of compressibility Z	1.0451	
Speed of sound	478.4	[m/s]

The propulsion system was intended to generate over 20 impulses of desirable thrust time, with a maximum of two minutes of continuous thrust and abrupt gas expulsion impulses lasting between 0.8 and 1 second. The mass of the gas is calculated as

$$\text{mass} = \text{mass flow rate} \times \text{desired thrust time} = 0.0015\frac{\text{kg}}{\text{m}^3} \times 120\ \text{s} = 0.18\ \text{kg of } \text{N}_2\ \text{gas}. \quad (2)$$

Using a known air density, this value was used as the tank's baseline from which volume was estimated. Thus, the volume V of the gas is needed.

$$\text{Aproximate volume} = \frac{\text{Designed Mass}}{\text{Density at Designed Conditions}} = \frac{0.18\ \text{kg}}{434.56\ \text{kg/m}^3} = 4.14\text{x}10 - 4\ \text{m}^3. \quad (3)$$

The calculated capacity of 4.14 x 10−4 cubic meters, or 0.41 litres, provided the baseline volume required for the propulsion system mission's appropriate amount of thrust duration. Developing the appropriate tank size for the mission depended heavily on this volume criterion.

2.2 | Tank Material and Geometric Parameters Derivation

The vertical tank is designed based on the ASME boiler and pressure vessel code (bpvc), Section II & VIII, Div1 Design Code (standard) to meet the minimal design standards. Material properties for Aluminium, Titanium and Nylon were simulated using the strength criteria provided in *Table 2* (SolidWorks 2020 Material Database).

Table 2. Mechanical properties of selected material for the Nitrogen propellant tank.

Material	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Modulus of Elasticity (GPa)
Aluminium (7075-T6)	570	505	72
Titanium (Grade 2)	485	345	105
Nylon 6/10	142.559	139.043	8.3

With a height-to-diameter ratio of 3, the volume of the tank is

$$\text{Volume} = \pi\ \frac{3\text{D}^3}{4}. \quad (4)$$

The required thickness was obtained from

$$\text{Volume} = \pi\ \frac{3\text{D}^3}{4}, \quad (5)$$

where P is the designed pressure, R is the inner radius of the propellant tank, S is the allowable stress, E is the Weld effect, and C is the corrosion allowance.

The maximum in-cylinder pressure is given as

$$(P_s)_{max} = \frac{S\,E\,\sigma_s}{R + 0.6\,\sigma_s}, \quad (6)$$

where d = internal diameter, e = coefficient of connection of welding = 0.7 for non-radiated tests, P = designing pressure, P_s = maximum pressure, r = internal radius, S = maximum allowable stress and τ_s = shell thickness, circumferential stress.

The circumferential and longitudinal stress τs were determined from

$$\sigma_c = \frac{Pd}{2t}, \sigma_L = \frac{Pd}{4t}. \quad (7)$$

The corresponding strains are given as

$$\varepsilon_C = \frac{\sigma_c}{E}, \varepsilon_L = \frac{\sigma_L}{E}, \quad (8)$$

where t = the wall thickness, E = Modulus of elasticity, σ = stress, and ε = strain.

The lateral changes diameter was obtained from circumferential strain as

$$\delta d = \varepsilon_C\, d, \quad (9)$$

where d = internal diameter of the shell, δd = change in diameter and ε_C = circumferential strain.

Similarly, longitudinal changes are defined as

$$\delta l = \varepsilon_L\, L, \quad (10)$$

where L = length, δl = change in length.

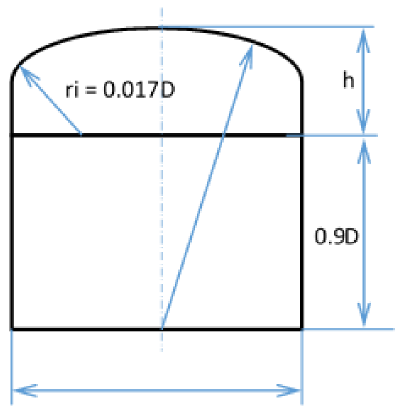

Fig. 1. Tank head.

The base diameter to the height

$$D/h = 4/1. \quad (11)$$

The radius of the neck

$$r_i = 0.17D. \quad (12)$$

$$\text{Head height} = h = \frac{D}{4}. \quad (13)$$

After the evaluation of the above equations using the *Table 3* summarizes the geometries and basic properties of three considered tank materials.

Table 3. Tank design parameters characteristic summary.

Parameter	Aluminium (7075-T6)	Titanium (Grade 2)	Nylon 6/10
Overall length (mm)	168	168	168
Inner diameter (mm)	56	56	56
Wall thickness (mm)	5.2	5.6	13.3
Volume of tank (L)	0.41	0.41	0.41
Height of the tank head (mm)	14	14	14
Corrosion allowance (mm)	3	3	3

2.3 | Tank Modelling

The tank is modelled with the geometric parameters in *Table 3* as input parameters using the SolidWorks interface, having various modifiable fields with intrinsic features. *Fig. 2* presents the concept model of the tank, which uses simple hemispherical forms for the top and bottom. This configuration supports significant weight compared to sharp corners and small stress concentrators. This idea offers a sizable volume for storing the gas under high pressure.

Fig. 2. Concept models of the propellant storage tanks.

2.4 | Model Simulation

This modelling was implemented in SolidWorks Premium 2020 SP1.0 to run simulations using the SolidWorks Simulation Interface. The simulations analyzed the transient behaviour of the pressurized system under various components and system operating conditions. The model helps to provide insights into system dynamics and interactions through pre- and post-analyses. The shell structure is discretized using the finite volume method with the built-in meshing generator. *Fig. 3* shows a high mesh quality for the simulation.

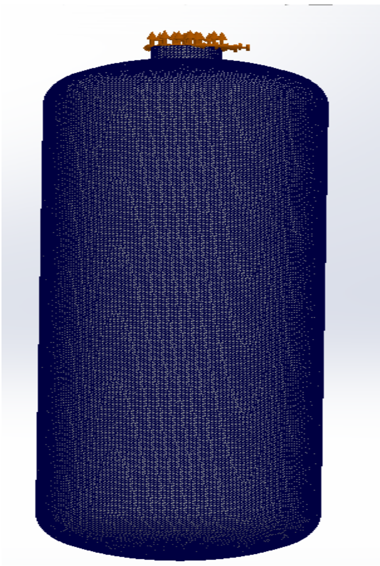

Fig. 3. Pressurized tank mesh.

The material property definition and the numerical experiment served as the foundation for the boundary setup. The material property is chosen from the database of materials within the SolidWorks Simulation. The standard mesh was used in this simulation with an element size of 1 mm and tolerance of 0.05 mm. The Aluminium tank mesh had a total node of 1869071 and a total element of 1279484. The titanium tank mesh had a total node of 20122434 and a total element of 1386771. The nylon tank mesh had a total node of 5100214 and a total element of 3683337.

2.5 | Optimization Parameter

The modelled tank design was optimized in SolidWorks using the SolidWorks Simulation Interface. The optimization developed data ranges for the pressurization system under various operating conditions and parameters, which provided important insights into overall system interactions. The design optimization study was set up with the following parameters:

Table 4. Design variables.

Name	Type	Value	Units
Shell Thickness	Range with step	Min: Max: Step:	Mm

Table 5. Constraints.

Sensor Name	Condition	Bounds	Units	Study Name
Minimum factor of safety	is greater than	Min:2.000000		-
Stress	Monitor only	-	-	-
Strain	Monitor only	-	-	-
Displacement	Monitor only	-	-	-

Table 6. Goals.

Name	Goal	Properties	Weight	Study Name
Mass	Minimize	Mass	10	-

3 | Results and Discussion

The numerical results of the structural analysis are presented and discussed based on the assumptions and the calculations made with the boundary conditions listed in Section 2.2 (tank geometric parameters). The comparative analysis of thermodynamic parameters is also highlighted in this section, which includes detailed results from the tank design, analysis, and optimization effort. The analytical method facilitated the development of an optimal tank configuration and propulsion system architecture.

3.1 | Theoretical Analysis

Table 7. Theoretical data calculations.

	Aluminium (7075-T6)	Titanium (Grade 2)	Nylon 6/10
Shell thickness t_s (mm)	5.2	5.6	13.3
Maximum pressure P_s (N/mm2)	66.7		
Circumferential stress σ_c (N/mm2)	161.5	149.7	63.3
Longitudinal stress σ_L (N/mm2)	80.7	74.9	31.7
Circumferential strain ε_C	0.0022	0.0014	0.00076
Longitudinal strain ε_L	0.0011	0.0007	0.00038
Diameter change $\boldsymbol{\delta d}$ (mm)	0.1257	0.0799	0.4275
Length change $\boldsymbol{\delta l}$ (mm)	0.1885	0.1199	0.6412

Table 7 was developed using the equations from Section 2.2. The nozzle is intended to have a 1N thrust. As a result, the intended thrust level served as the foundation for all calculations and assumptions. Microsoft Excel was used in the analytical modelling to calculate the values—each chosen material's tensile strength and elastic modulus cause variations in the tank specifications.

Table 7 also presents an analytical model that demonstrates that for the selected materials, Aluminium, despite its low shell thickness of 5.2 mm, can withstand a higher maximum pressure of 66.7 N/mm2 than Titanium with a shell thickness of 5.6 mm, maximum pressure of 60.7 N/mm2 and Nylon 3-D filament with a shell thickness of 13.3 mm and maximum pressure of 36.8 N/mm2. This explanation is easily summed up in the *Fig. 3*. These observations can explain why Aluminium is used in most literature [13].

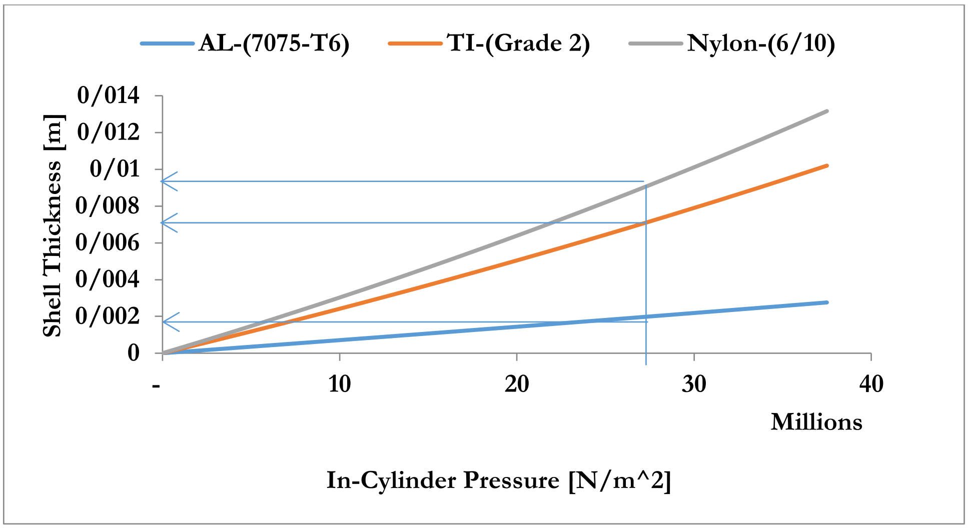

Fig. 3. Optimization behaviour of tank materials.

3.2 | Static Analysis

3.2.1 | Stress analysis

Detailed 3D Finite Element Analysis (FEA) modelling using shell or solid elements enables mapping the multi-axial stress distribution under expected loading conditions. Applying the design propellant tank pressure as an internal surface traction load to solve the discretization matrices visualizes normalized von Mises stresses.

As the propellant tank experiences static pressure loads, quantifying the stress state in the vessel walls is critical to ensuring structural integrity. The results obtained from the simulation are given in *Figs. 4-6*.

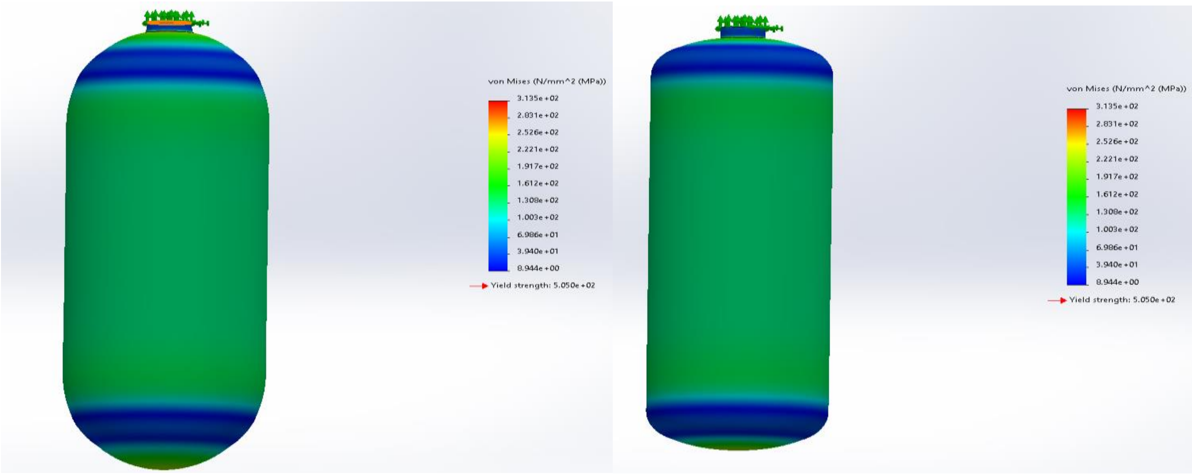

Fig. 4. Aluminium stress distribution with and without scale.

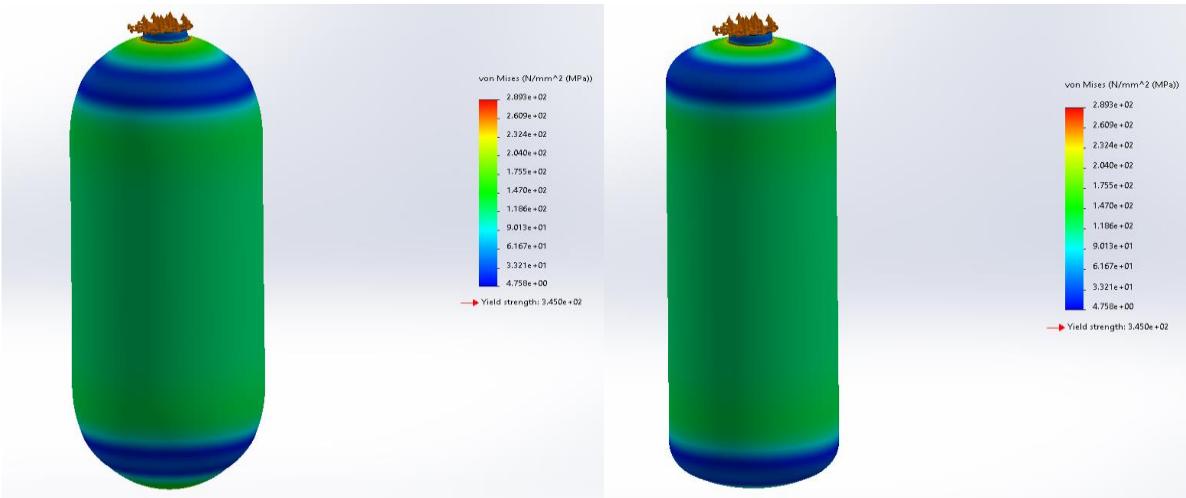

Fig. 5. Titanium stress distribution with and without scale.

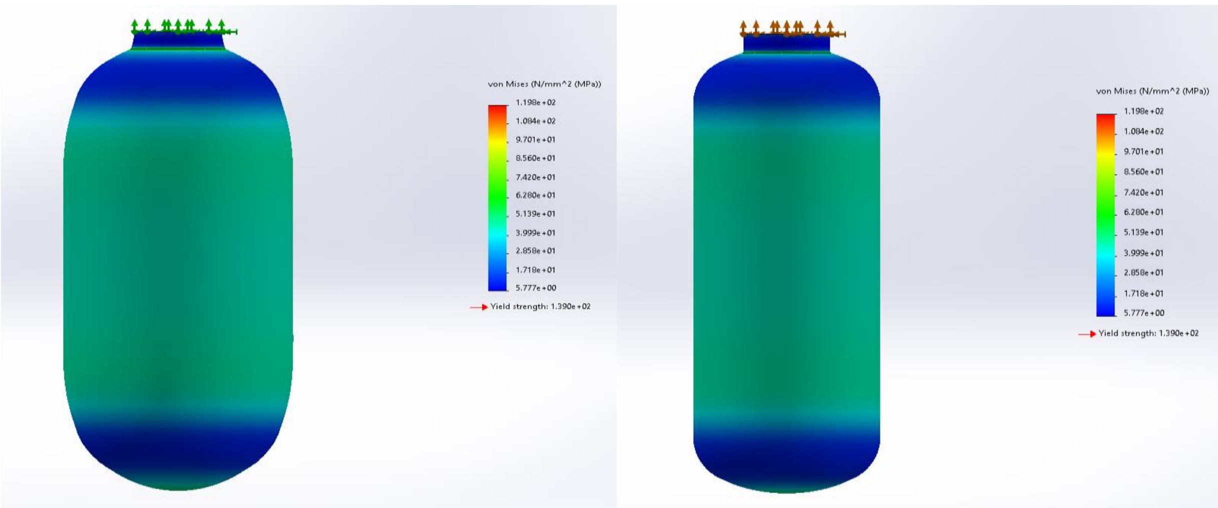

Fig. 6. Nylon stress distribution with and without scale.

From *Figs. 4-6*, the colour gradient indicates the stress distribution across the structure, with their corresponding stress level indicated as values in the legend to the right of each Figure. Though the three structures showed similar patterns in their stress distribution, differences in the concentration values are observed. The Aluminium pressure vessel with an optimized thickness of 5.2 mm thickness yielded the maximum Von-Mises Stress for the vessel design at 303.5 MPa, while the minimum Von-Mises stress for the vessel design is observed to be 8.944 MPa with a yield strength of 505 MPa.

The Titanium pressure vessel, which had an optimized 5.6 mm thickness, was observed to have a maximum Von-Mises Stress for the vessel design of 289.3 MPa with a minimum Von-Mises stress for the vessel design of 4.758 MPa at a yield strength of 345 MPa. After optimal analysis, the Nylon pressure vessel with 13.3 mm thickness showed a maximum and minimum Von-Mises Stress for the vessel design of 119.8 MPa and 5.777 MPa, respectively, with a yield strength of 139 MPa. The majority of the cylinder is coloured green, indicating moderate stress levels within the cylindrical region and less stress concentration at the ellipsoidal head region. The red areas at the top ellipsoidal head joint indicate higher stress concentrations. Comparing maximum FEA predicted stresses to material yield limits validates that the design withstands loading.

3.2.2 | Strain analysis

In conjunction with modelling stress distributions, FEA also enables mapping full-field strain contours over the tank geometry under various loading scenarios. Combining stress and strain FEA contour visualizations ensures tank integrity while guiding structural optimization to balance mass efficiency against load capacity limits.

Tracking mechanical strains proves vital in pressure vessels. The propellant pressure loads the structure and causes deformation gradients, resulting in a mix of tension, compression, bending, and shear strain components at each element, depending on the element's position within the tank. Contour plots visualize the strain energy density fields, as shown in *Figs. 7-9*.

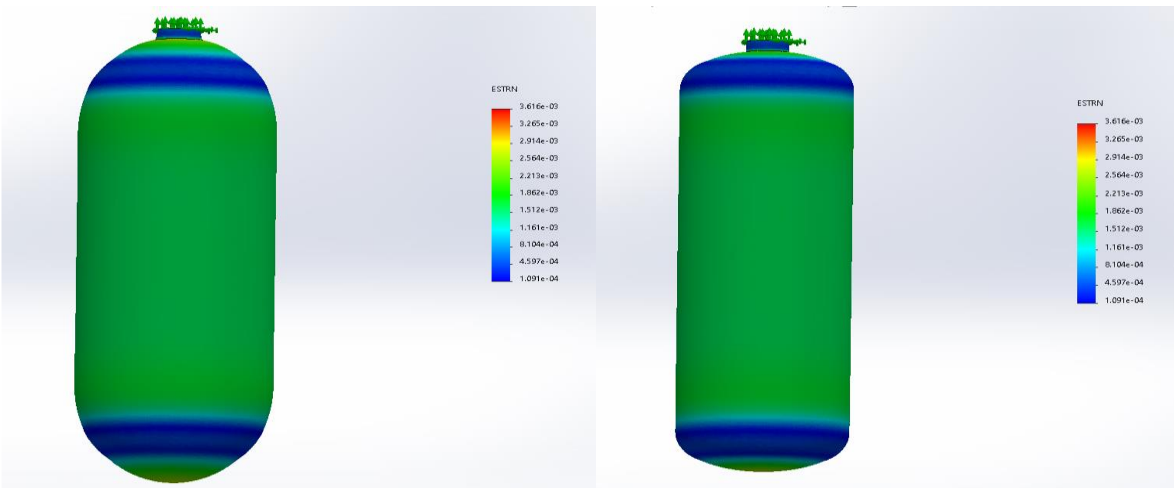

Fig. 7. Aluminium strain distribution with and without scale.

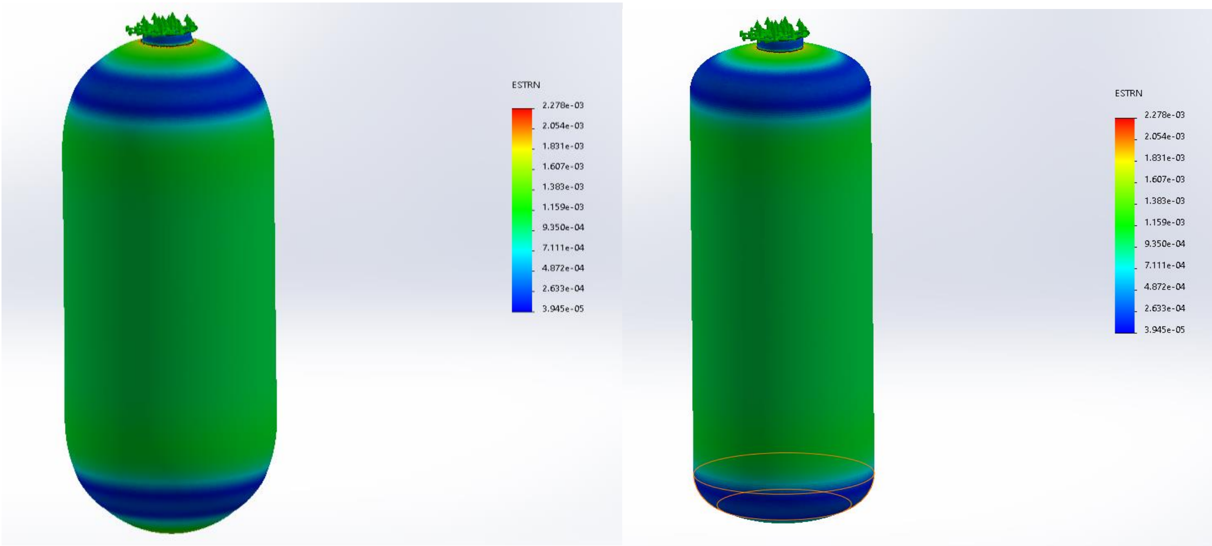

Fig. 8. Titanium strain distribution with and without scale.

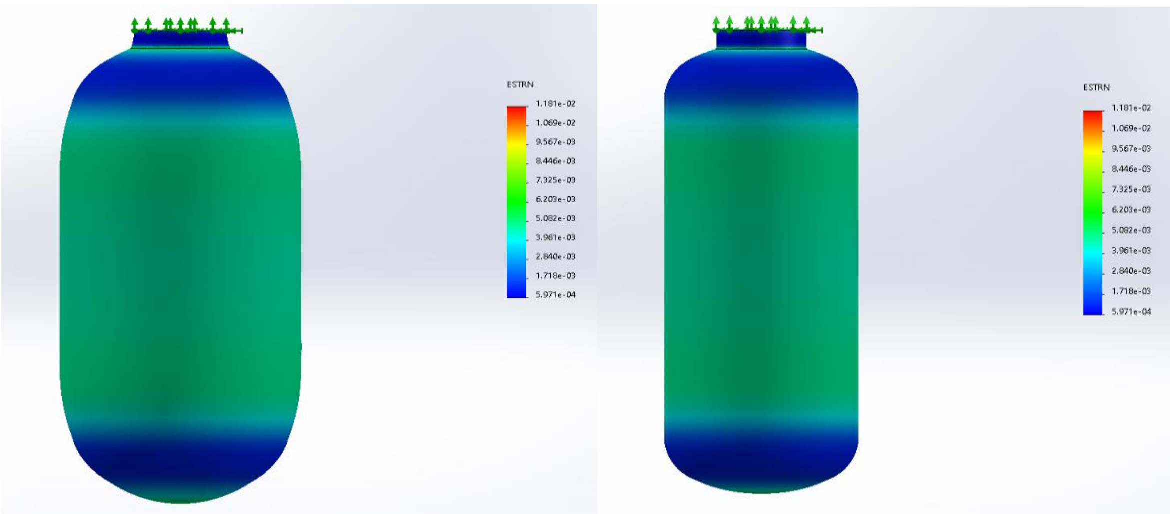

Fig. 9. Nylon strain distribution with and without scale.

From *Figs. 7-9*, the colour gradient indicates the deformation across the structure. The three structures show similar patterns in their strain distribution with differences in the concentration value. The Aluminium tank with the optimized thickness of 5.2 mm presented a maximum strain for the designed tank at a value of 0.003616, and the minimum strain that could occur in the tank was 0.0001091. The Titanium pressure vessel with an optimized thickness value of 5.6 mm presented minimum and maximum strain records of 0.002278 and 0.00003945, respectively. The tank was designed with nylon with an optimized thickness of 13.3 mm and had simulated maximum and minimum strain values of 0.01181 and 0.0005971. Much of the cylinder is coloured green, indicating moderate strain levels within the cylindrical region and less strain concentration at the ellipsoidal head region. The Red areas at the top ellipsoidal head joint indicate higher strain concentrations.

3.2.3 | Displacement analysis

In addition to quantifying strain and stress states, structural finite element analyses also enable mapping expected wall deflections and general deformations under pressure loads. The same 3D mesh modelling the tank for stress analysis readily handles solving for deformations. Applying expected pressure differentials induces slight wall bulging effects that can be contoured. These are shown in *Figs. 10-12*.

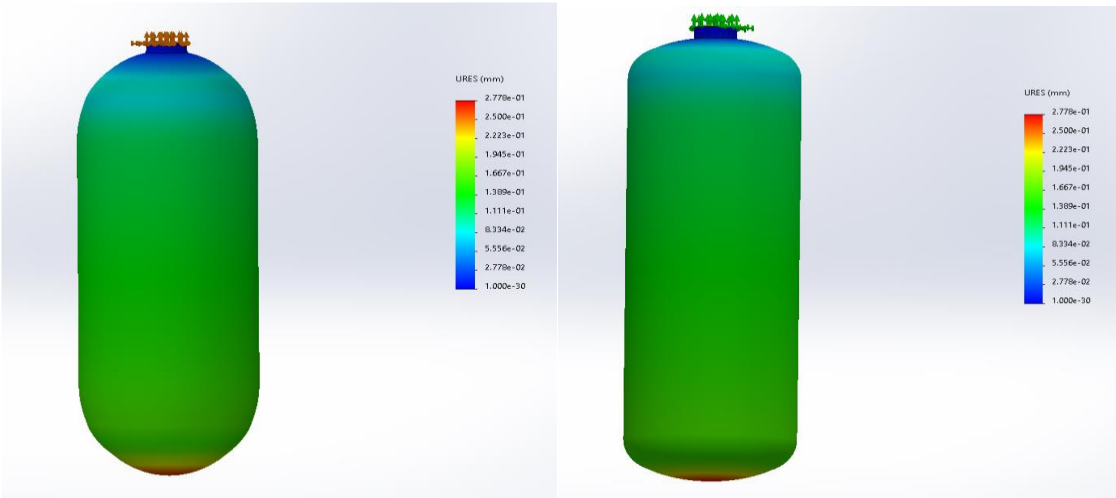

Fig. 10. Aluminium displacement distribution with and without scale.

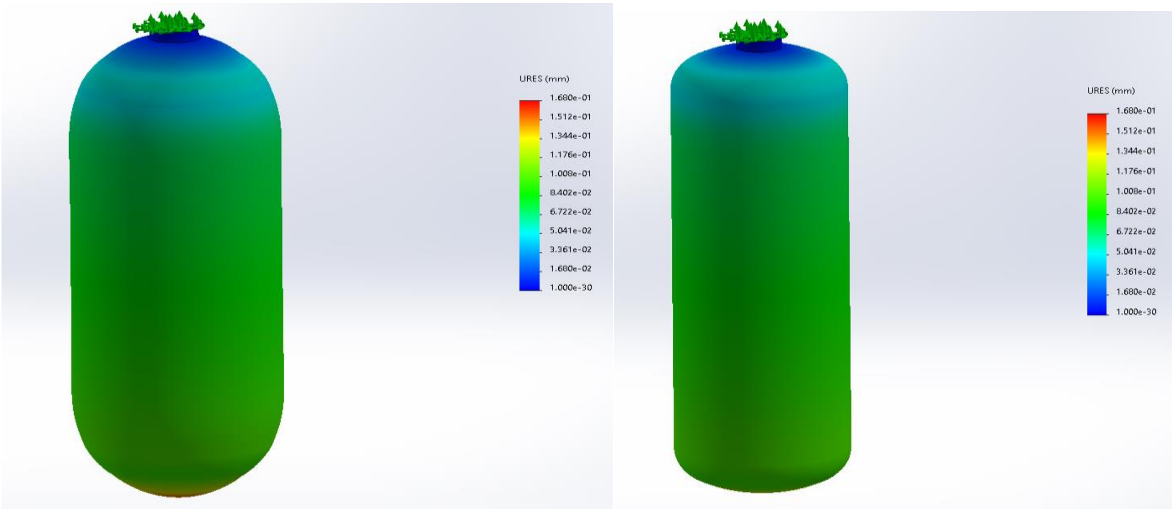

Fig. 11. Titanium displacement distribution with and without scale.

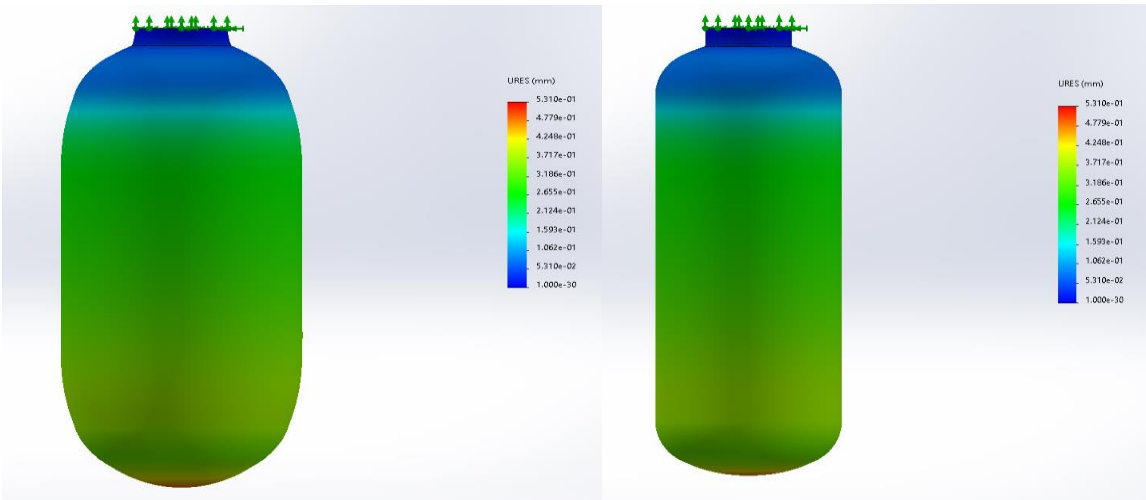

Fig. 12. Nylon displacement distribution with and without scale.

From *Figs. 10-12*, the colour gradient indicates the displacement across the structure. The three structures show similar displacement distribution patterns with differences in the concentration value. The displacement increases downward from the top of the tank to the base ellipsoidal head. The Aluminium pressure vessel with 5.2 mm thickness was seen to have a maximum displacement for the vessel design of 0.2778 mm and a minimum displacement for the vessel design of 1e-30 mm. The titanium pressure vessel with 5.6 mm thickness would distend maximally at 0.1680 mm, presenting a minimum displacement of 1e-30 mm. The Nylon pressure vessel with 13.3 mm thickness would yield a maximum displacement of 0.5310 mm and minimum displacement of 1e-30 mm. The minimum displacement for the three tank materials appears to be the same because the value reported is the minimum the computer could record. Although the Aluminium material presented a relatively higher distension than the titanium, the performance of the Aluminium tank is superior in other areas than titanium. The blue areas at the top ellipsoidal head joint indicate lower displacement concentrations, and the red areas at the bottom ellipsoidal head indicate higher displacement concentrations.

3.2.4 | Factor of safety

When dealing with a pressurized tank, safety is a crucial consideration in design to ensure the structural integrity and safety of the tank under varying operating conditions. The Factor of Safety (FoS) distribution across the tank is given in *Fig. 13*.

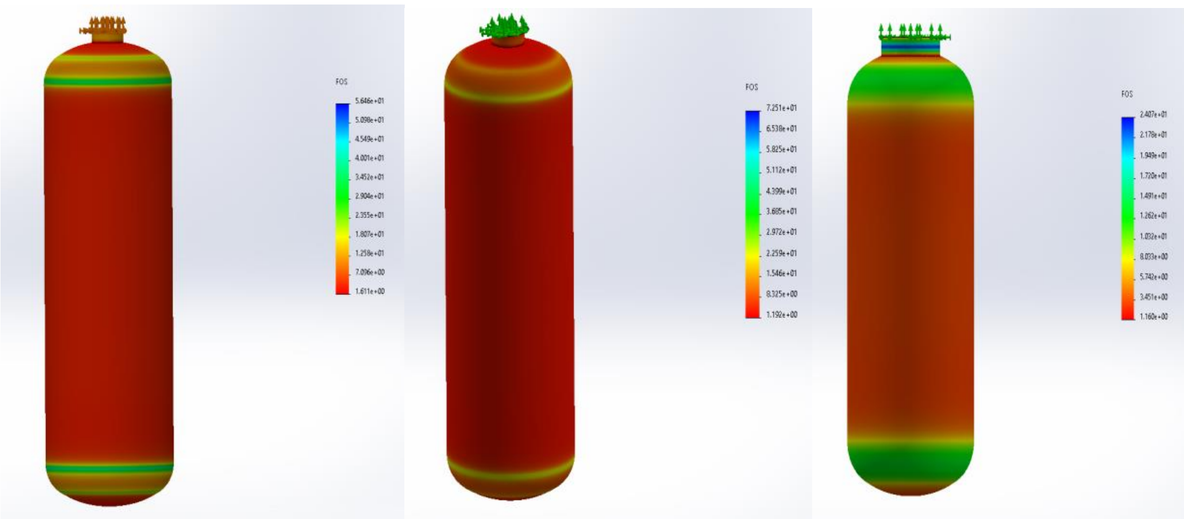

Fig. 13. FoS distribution for Aluminium, Titanium and Nylon.

From *Fig. 13*, the colour gradient indicates the safety factor across the structure. The simulation shows that a minimum safety factor of 1.6 is required for the tank designed with Aluminium as opposed to the value of 1.2, which is required for both titanium and nylon. A FoS of 1 means that the structure or component is designed to handle precisely the expected load or stress without any margin for error. It is common practice in engineering design to design structures with a safety factor greater than 1 to provide a safety margin. A FoS greater than 1 ensures that the structure can withstand unexpected loads, variations in material properties, and other uncertainties without failing. Therefore, the design is relatively safe. Although the simulation carried out in this work has given a range of 1.2 to 1.6 for the tank design (depending on the tank material of choice), the NASA-STD-5007 Standard for Pressurized Gas Pressure Vessels establishes a minimum safety factor of 2.6 for cold gas propellant tanks made of 6A1-4V Titanium. The code also allows down to 2.0 for short-duration flight loads. Similarly, the AIAA S-080A-2019 Standards allow new expendable launch vehicle pressure vessels to be designed for ultimate safety between 2.0 and 2.25, based on the mission risk category. Therefore, the consideration for a FoS of 2.0 used in this study is adequate, considering the goal of minimizing the overall weight of the satellite.

3.3 | Final Optimized Design

Adjusting tank wall thickness parameters in the FEA and re-solving stress distributions facilitates optimization to balance mass against strength requirements. By thoroughly mapping multi-axial steady stress states using high-fidelity simulation, the structural integrity of the pressure vessel design is ensured with margin against material capabilities. This mitigates the risk of overloading failures.

Leveraging validated analyses and test data, multi-objective optimization balancing performance and reliability metrics converged on an optimized pressure vessel configuration and integrated propulsion system architecture.

3.3.1 | Optimized aluminium tank

The study results to determine the optimal shell thickness with less mass and a minimum of 2 safety factors for the design after 10 iterations are given in *Table 8*, presented in segments.

Table 8. Aluminium optimization.

Component Name	Shell Thickness	Minimum FoS	Stress	Strain	Displacement	Mass
Units	mm		N/mm^2		mm	g
Initial	5.2	1.610769	313.51	0.003616	0.0658	599.819
Optimal	6.4	2.058655	245.31	0.002917	0.05569	756.777
Scenario 1	5.2	1.610769	313.51	0.003616	0.0658	599.819
Scenario 2	5.8	1.755394	287.68	0.00328	0.06006	677.421
Scenario 3	6.4	2.058655	245.31	0.002917	0.05569	756.777
Scenario 4	7	2.26254	223.2	0.002601	0.05171	837.892
Scenario 5	7.6	2.463992	204.95	0.002383	0.04875	920.771
Scenario 6	8.2	2.814344	179.44	0.002176	0.04587	1005.4
Scenario 7	8.8	2.965528	170.29	0.001994	0.0434	1091.8
Scenario 8	9.4	3.183878	158.61	0.001894	0.04142	1180.1
Scenario 9	10	-	-	-	-	-
Scenario 10	10.2	-	-	-	-	-

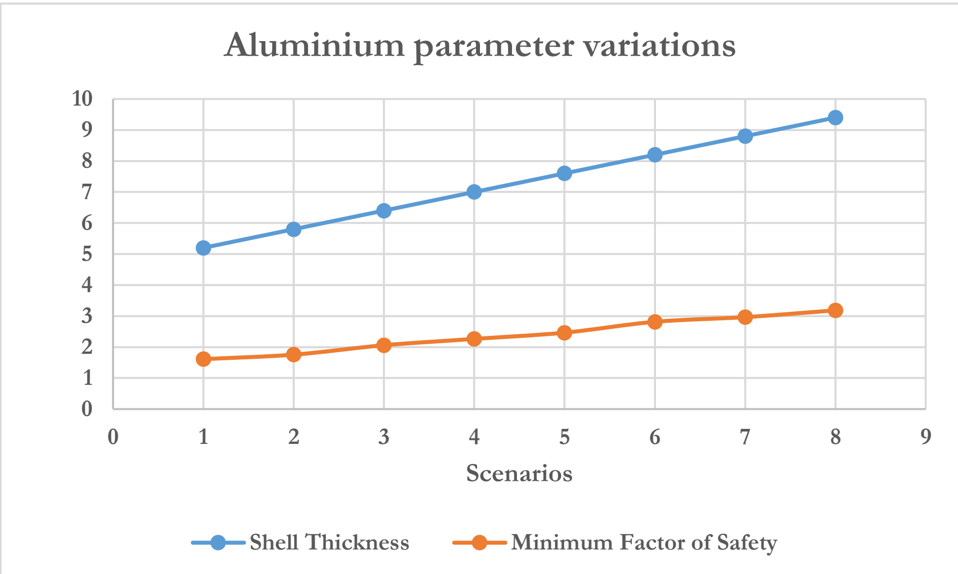

Fig. 14. Aluminium parameter variations.

Fig. 14 shows a graph pattern denoting increased shell thickness with an increasing safety factor. Considering the optimization parameter, the Aluminium material most optimized design data was obtained at iteration three (3) with a shell thickness of 6.4mm, FoS of 2.058655, stress of 245.31 MPa, strain of 0.002917, displacement of 0.05569mm and mass of 756.77684g.

3.3.2 | Optimized titanium tank

The study results to determine the optimal shell thickness with less mass and a minimum of 2 factors of safety for the design after 10 iterations are given below;

Table 9. Titanium optimization.

Component Name	Shell Thickness	Minimum FoS	Stress	Strain	Displacement	Mass
Units	mm		N/mm^2		mm	G
Initial	5.6	1.19245	289.32	0.002278	0.04235	231.8
Optimal	8.6	2.017338	171.02	0.001399	0.03029	378.235
Scenario 1	5.6	1.19245	289.32	0.002278	0.04235	231.8
Scenario 2	6.2	1.363659	253	0.002034	0.039	259.833
Scenario 3	6.8	1.51742	227.36	0.001804	0.03624	288.49
Scenario 4	7.4	1.658771	207.99	0.001687	0.03393	317.775
Scenario 5	8	1.855382	185.95	0.001505	0.03196	347.69
Scenario 6	8.6	2.017338	171.02	0.001399	0.03029	378.235
Scenario 7	9.2	2.123785	162.45	0.001315	0.02892	409.413
Scenario 8	9.8	-	-	-	-	-
Scenario 9	10.4	-	-	-	-	-
Scenario 10	10.6	-	-	-	-	-

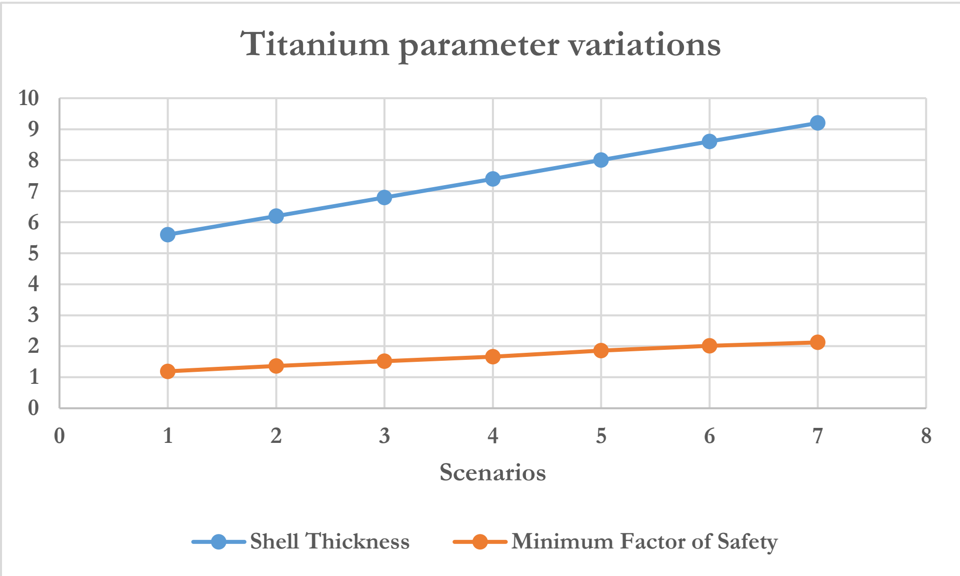

Fig. 15. Titanium parameter variations.

Fig. 15 shows a graph pattern denoting increased shell thickness with an increasing safety factor. Considering the optimization parameter, the titanium material's most optimized design data was obtained at iteration six (6) with a shell thickness of 8.6mm, FoS of 2.017338, stress of 171.02 MPa, strain of 0.001399, displacement of 0.03029 mm and mass of 378.235g.

3.3.3 | Optimized nylon tank

The study results to determine the optimal shell thickness with less mass and a minimum of 2 safety factors for the design after 10 iterations are given in *Table 10*.

Table 10. Nylon optimization.

Component Name	Shell Thickness	Minimum FoS	Stress	Strain	Displacement	Mass
Units	mm		N/mm^2 (MPa)		mm	g
Current	13.3	1.16011	119.85	0.01181	0.28337	648.712
Initial	13.3	1.16011	119.85	0.01181	0.28337	648.712
Optimal	-	-	-	-	-	-
Scenario 1-10	-	-	-	-	-	-

The optimization simulation failed for the 10 iterations with higher shell thickness above 13.3 mm. This is largely due to material properties and design variables, which set a safety factor 2. This material, therefore, can withstand the design pressure but would not meet the standard FoS considering the operating conditions.

4 | Conclusion

The cold gas propellant tank structure design was done using standard equations that considered three (3) materials, Aluminium, titanium, and nylon, to fit into a 2U CubeSat. 3D CAD modelling, simulation and optimization are done on SolidWorks Premium 2020 SP1.0. Simulation is done to get maximum deformation value, maximum Von-Misses stress, and factor of structure safety. The optimization results obtained after 10 iterations are summarized in *Table 11*.

Table 11. Summarized optimized design data.

	Aluminium	Titanium	Nylon
Old shell thickness	5.2 mm	5.6 mm	13.3mm
Shell thickness	6.4 mm	8.6mm	-
Minimum FoS	2.058655	2.017338	-
Stress	245.31 MPa	171.02 MPa	-
Strain	0.002917	0.001399	-
Displacement	0.05589	0.03029	-
Mass	756.77684 g	409.413 g	-

Based on the optimized data, it is safe to state that titanium would be the preferred material for the manufacture of the cold gas propellant tank pressurized system for the reasons summarized: that Aluminium could withstand a higher stress level of 245.31 MPa than titanium (171.02 MPa), but titanium suffers lesser strain (0.001399) compared with Aluminium which had a strain value of 0.002917. The membrane displacement was more tolerable for Titanium (0.03029 mm) than the 0.05589 mm witnessed in Aluminium. The mass of Aluminium (756.77684 g) was much higher than that of titanium (409.413 g). This has a negative effect on fuel consumption and propulsion efficiency. Nylon 6/10 failed to meet the requirements in almost all the assessed criteria. All these made Titanium the material of choice.

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Conflict of Interest

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Author Contributions

I. B. U and Sh. M. contributed equally to this work. N. M. L and E. O. O conducted the experiments and analyzed the data. I. B. U designed the study and provided supervision. All authors contributed to manuscript preparation and approved the final version.

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