

Modeling And Analysis Of Rocket Outer Shell

Sheikh Naunehal Ahamed, Jadav Vijay Kumar, Mohammed Mushraffuddin, Parimi Shrawini

Abstract: The research aims at modeling a rocket case to accomplish mission requirements. The various reasons that may cause case failures are improper design and analysis, lack of non-destructive tests during critical phases of fabrication, negligence in service conditions, improper material selection. Hence it's very essential to model rocket with perfect designing and analysis. This journal entails the designing of rocket case using Catia V5, meshing with Hypermesh and Analysis with Ansys, where different materials like Aluminium and Epoxy-carbon are selected. The results focus on the deformation produced under same loading condition in two different materials and studying the results.

Index Terms: Multistaging, Finite Element Method, Catia, Hypermesh, Ansys, Epoxy-carbon

1 INTRODUCTION

The important aspects the case design must satisfy are presented and the detail procedure for designing the rocket shell using CATIA v5 tools is also presented. The model is then imported into hyper mesh software in order to mesh the model properly and then exported into the ANSYS software to conduct the analysis. The analysis on the rocket shell model designed and meshed is conducted using ANSYS10.0 tools representing that the model designed when an advanced material such as Carbon-EPOXY is considered in spite of aluminium is suitable for mission requirements and proved to be effective.

1.1 Rocket Structural System

The structural system of a rocket includes all of the parts which make up the frame of the rocket; the cylindrical body, the fairings, and any control fins. The function of the structural system is to transmit the loads from the forces generated during the flight and to provide low aerodynamic drag for flight through the atmosphere. Rocket structures must be strong but light weight. The performance of the rocket depends directly on the weight of the structure. A variety of mass ratios are used to characterize the structural weight of a rocket. The distribution of the structural weight also affects the center of gravity of the rocket which, in turn, affects the stability and control of the rocket. During the flight of a rocket to orbit, some parts of the structure are discarded in a process called staging.

1.2 Basic Structural Design Requirements

1. Rocket structures must be strong but light weight. The performance of the rocket depends directly on the weight of the structure.
2. The casing must be able to sustain the mechanical loads acting on the structure.
3. It should able to sustain the weight of the engine, propellant, and the payload.
4. The body is profiled to avoid drag that is encountered when travelling at super- and hypersonic speeds in the atmosphere.

1.3 Rocket Staging

Most modern, high performance rockets, particularly those used in space applications, are multistage rockets. The Saturn V moon rocket is a perfect example of a multi stage vehicle; this rocket uses three distinct stages in order to send its payload of astronauts and equipment towards the moon. The Saturn 1C first stage lifts the rocket to 200,00feet with 7-1/2 million pounds thrust. The first stage then separates and the S-II second stage ignites to accelerate the rocket to 15,300

mph and lift it to 1000 miles altitude. At that point the third stage takes over to complete earth orbital injection (17,500 mph), and later to accelerate the rocket to the 25,000 mph velocity necessarily to escape the pull of earth's gravity. Staging in the rocket means combination of stages. In other words, it's the stacking of rockets. The first stage is the launching rocket or the booster. The booster is shed when it has consumed all fuel. It takes place within two minutes. After this, engine of the second stage starts. When it uses up all its fuel, it too is released and the third engine fires up and so on.

1.4 Why Multistaging?

Why do rocket designers complicate their task with several engine sizes, many separate fuel tanks and complicated separation mechanisms, instead of designing one huge rocket, containing all the fuel that will be doing the whole job at once? There are two fundamental reasons for staging:

1. To improve the performance by eliminating dead weight during powered flight
2. To maintain acceleration within the reasonable limits by reducing thrust in mid-flight.

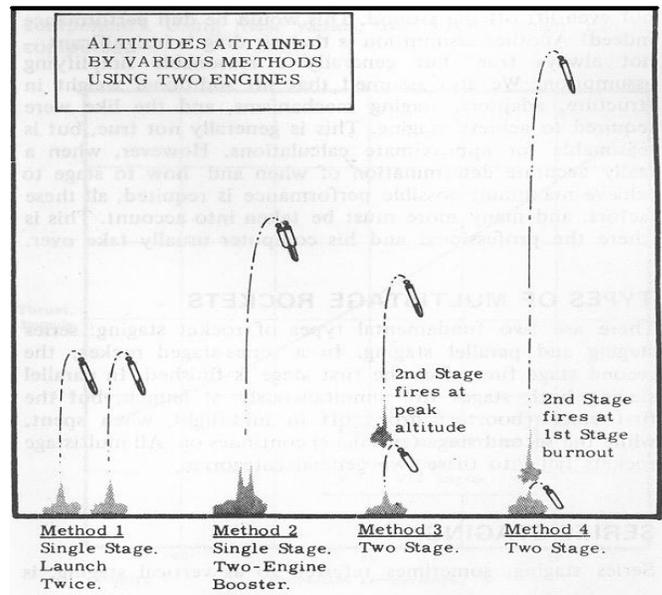


Fig 1: Altitudes attained by various methods using two engines.

2 DESIGNS

2.1 Design Consideration

The outer shell configuration is selected as the optimum or best envelope to maximize performance and minimize cost. The final shell configuration can be determined on the basis of payload, inter-stage connecting structures, handling equipments, launch facilities, use of specified propellant configuration or auxiliary equipment. Some commonly used configurations are below:

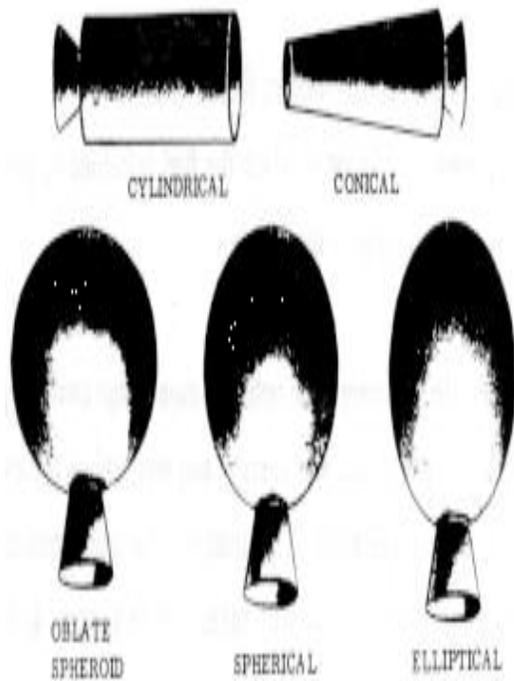


Fig 2: Some commonly used rocket shell configurations.

Here we considered a multi-staged rocket with multi-sectioned cylindrical casing which is considered from a previous rocket model i.e., Saturn V. The dimensions for the design and other requirements are taken based on the specifications of Saturn V shown in the figure below

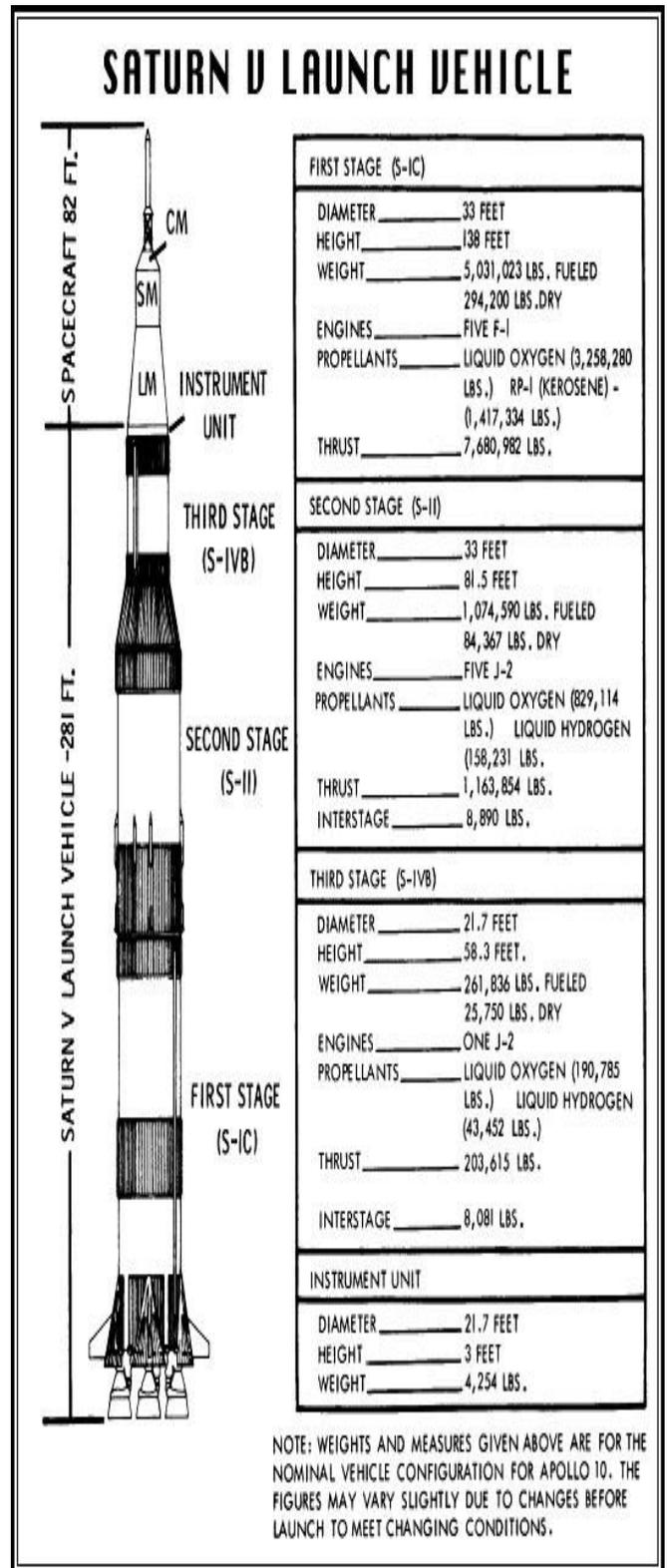


Fig 3: Saturn V launch vehicle specifications & dimensions.

2.2 Rocket Outer Shell Design

Open CATIA v5 software

Start> programs> CATIA> CATIA v5r20

STEP 1: start> mechanical design> wireframe and surface

design> select an axis> insert> sketcher

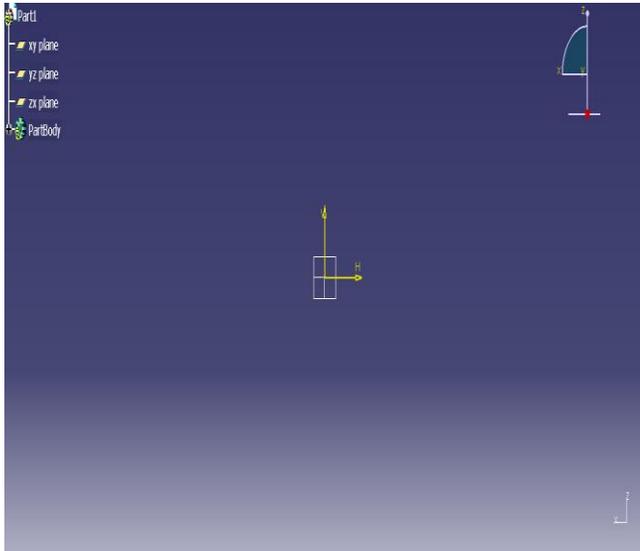


Fig 4: sketcher.

Draw the 2D profile of the rocket outer shell using the sketcher tools like line/profile.

>constrain the geometry to the dimensions considered.

>if there is any over constrains or geometrical problems. Follow the below steps to rectify them.

Tools> sketch analysis> diagnostic/geometry.

The figure below shows the 2D profile of the rocket outer shell using sketcher tools:

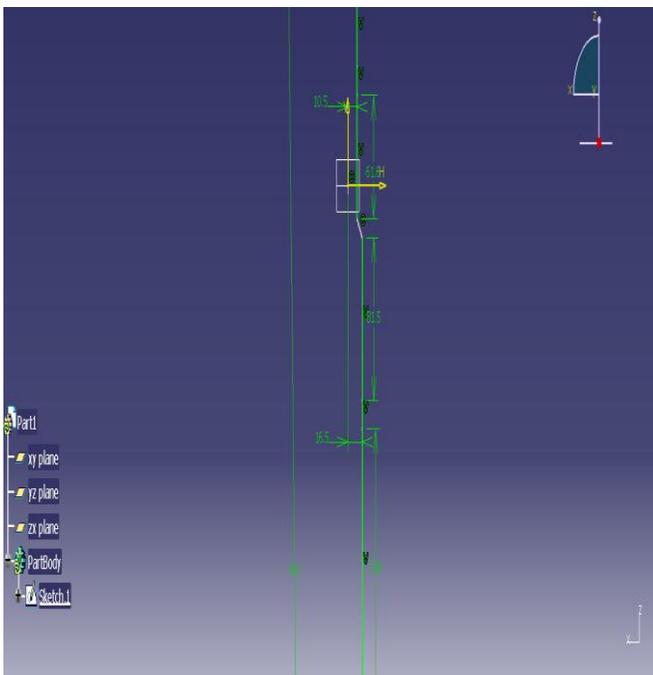


Fig 5: 2D profile of rocket shell in sketcher.

STEP 2: Start> mechanical design> wireframe and surface design

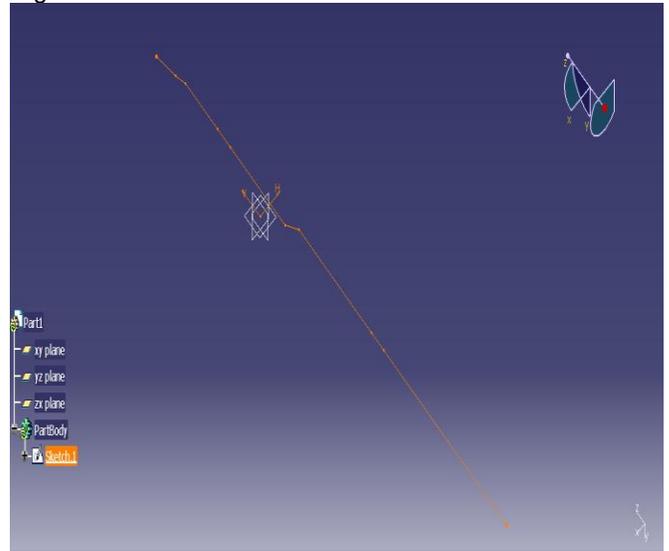


Fig 6: wireframe and surface design.

STEP 3: insert> surfaces> revolve> select the profile> select the revolution axis> angular limits-angle1 360deg, angle2 0deg> ok

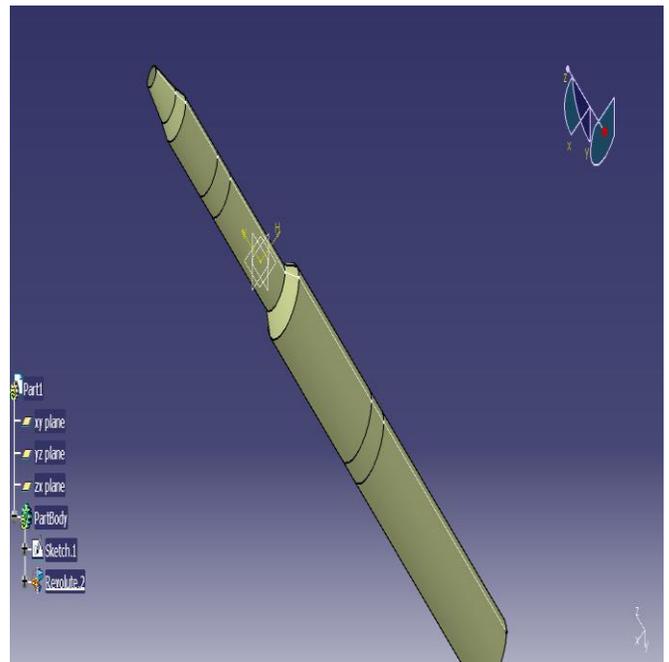


Fig 7: revolve the rocket shell profile

STEP 4: Insert > surfaces> fill> select the curve> select support> continuity-tangent>preview> ok

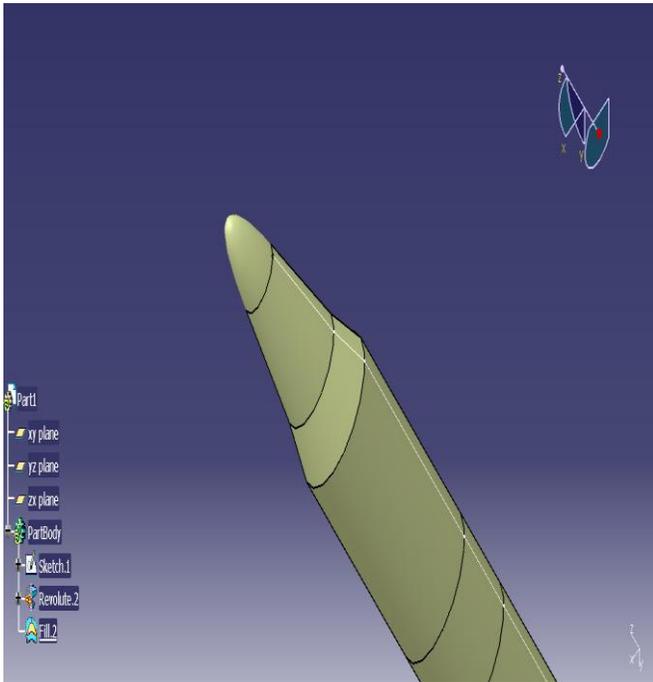


Fig 8: fill the surface.

STEP 5: Insert> operations> join> select the elements to join> ok

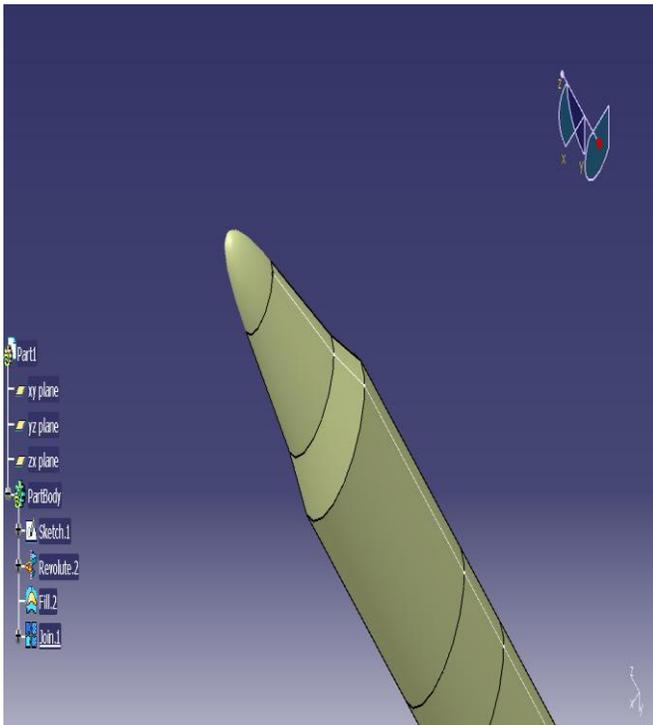


Fig 9: Joining of all the elements.

STEP 6: Start> mechanical design> part design>

Insert> surface-based features> thick surface> select the object> reverse direction> preview> ok

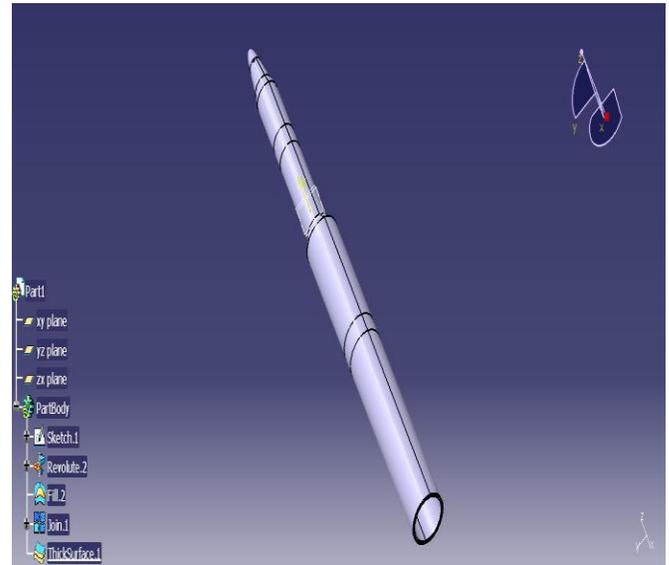


Fig 10: Assign thickness to the rocket shell.

Final design of the rocket outer shell modeled in CATIA v5 following the above steps is shown in the figure below:

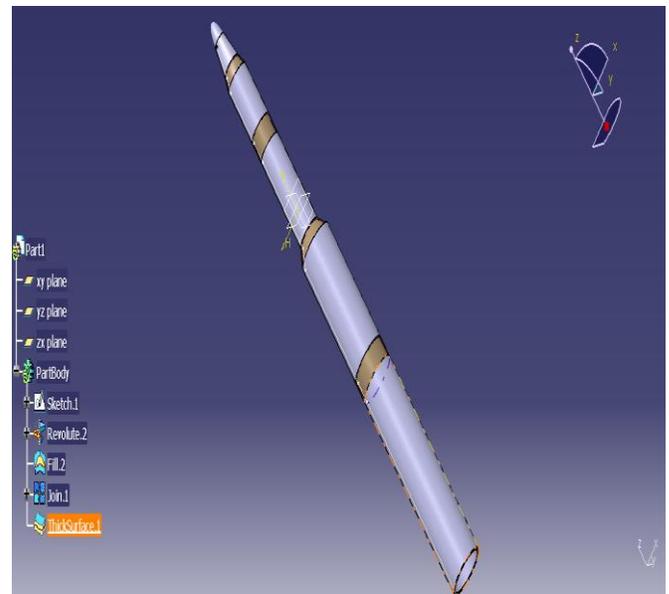


Fig 11: Final design of rocket shell.

2.3 Interactive Drafting

STEPS INVOLVED IN INTERACTIVE DRAFTING:

1. Start> mechanical design> drafting> new document creation> select front, top and left view> modify> ok.
2. Sheet> properties> sheet name: Saturn v> scale-1:2> landscape> first angle standard> ok.
3. Insert> views> projection> auxiliary view> cut a section> double click> click to locate the draft.
4. Insert> dimensioning> dimensions> length/distance/diameter dimensions> select the entity.
5. Edit> sheet background> frame and title box> drawing title block sample 1> apply> ok.

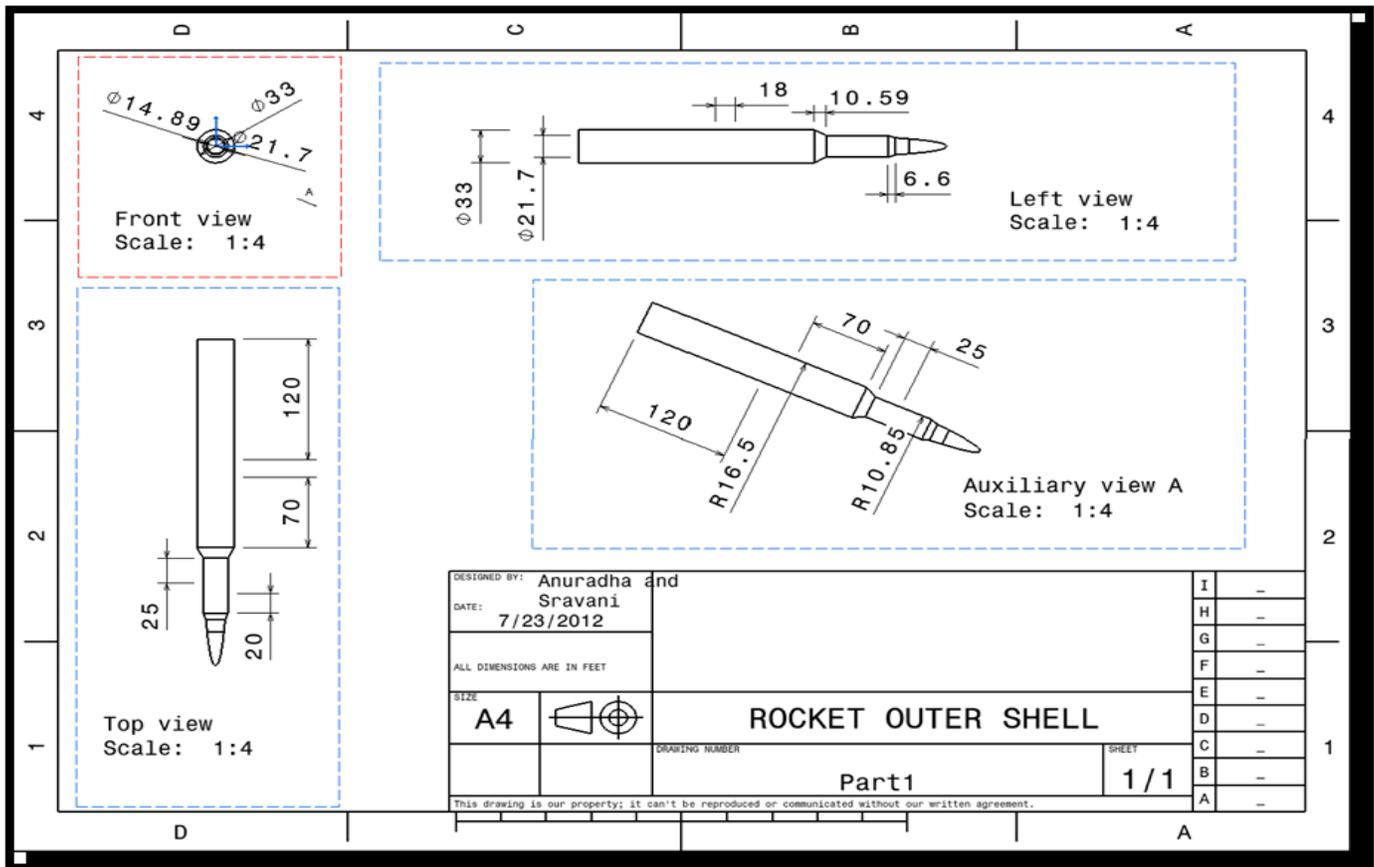


Fig12: Draft produced for the final design of rocket shell obtained.

3 MESHING

3.1 Hypermesh Introduction

Hypermesh, software by Altair Engineering, is used as a pre- and post processor for Finite Element Analysis and CFD.

3.2 Advantages of using Hypermesh

Hypermesh is a high performance pre-processor and post-processor that provides highly interactive and visual environment to analyze the product's design performance. Hypermesh is user friendly software.

1 GEOMETRIC CLEANUP: when the design model is imported from CAD to CAE software, we get the data loses (*unwanted geometrical errors*) within the geometry. We cannot proceed further with these data loses. Hypermesh helps to remove these errors completely by using geometric clean up options or geometric editing features.

5 MESHING: Fine meshing is done in hypermesh maintaining element to element connectivity.

6 QUALITY: Check and improve the quality of mesh by using different quality of mesh & by using different quality parameters in hypermesh.

3.3 Meshing the rocket outer shell

To import the geometry modeled in CATIA v5 software, we should first save the catia file with the extension ".igs"

Open hypermesh software: Start> programs> Altair Hyperworks10.0>hypermesh

Preferences> user profiles> select ANSYS> ok.

STEP 1: file> import> file type: iges> open file> browse the file> select> import.

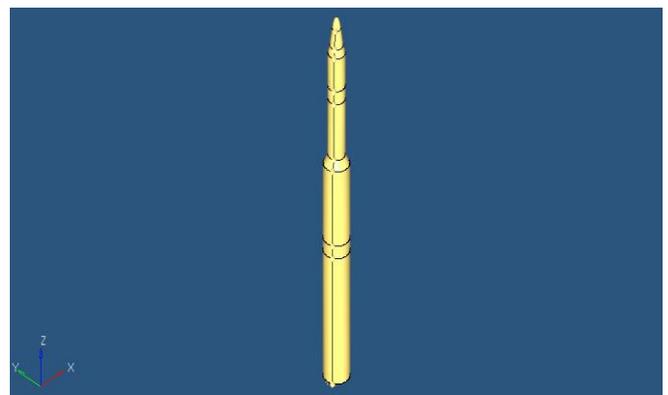


Fig 13: Import geometry.

STEP 2: GEOMETRY CLEANUP-set auto to 'by topo' (immediately the color changes to grey). If there are any geometric data loses or errors, it will represent them with red color.

Geom.> auto cleanup>

The auto clean up panel is automatic geometry that cleans up

preparing for meshing. It includes the equivalence of "red" free edges, fixing of small surfaces (*relative to the element size*), and detection of features such as beads. It also performs specified surface editing/disfeaturing operations like removal of pinholes (*less than specified size*), removal of edge fillets, and the addition of a layer of washer elements around holes.

STEP 3: AUTOMESH: 2D>automesh> surfs> all> element size=1.000> mesh type: quads> mesh.

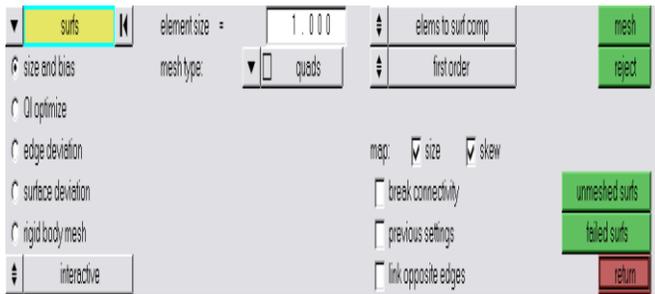


Fig 14: Auto mesh panel.

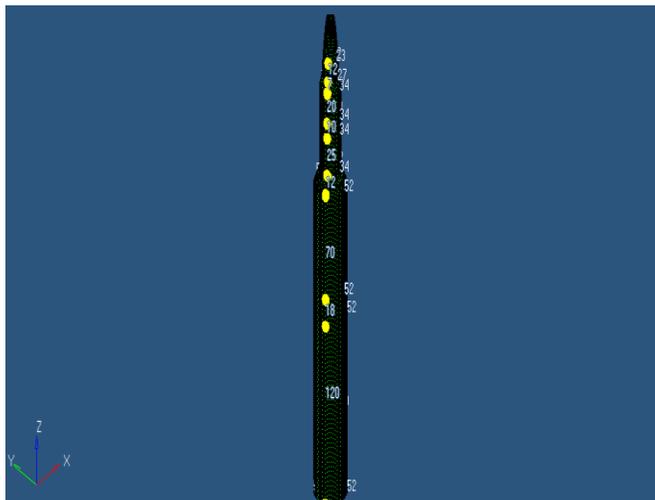


Fig 15: Mesh generated on the design.

STEP 4: See that nodes on either side of the mesh are maintained in same number to obtain neat mesh.

Nodes edit: increase or decrease the nodes on one end to exactly match with the nodes on the other side. The figure below shows the nodes adjustment or mesh edit.

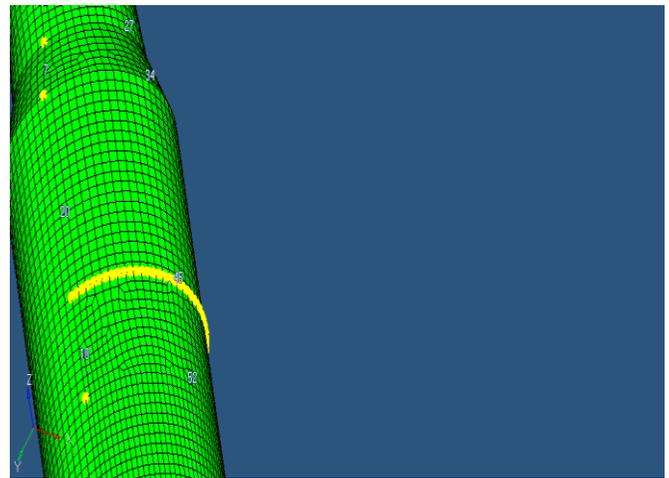


Fig 16: Increasing or decreasing the nodes to maintain same number of nodes on both the sides.

Nodes on the either sides of the mesh of each component or division are set to be equal in number to obtain a perfect mesh on the object.

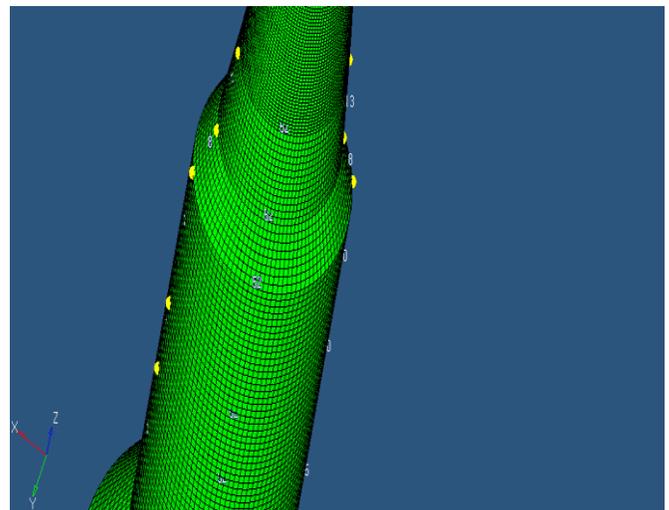


Fig 17: After adjusting the nodes all over the design.

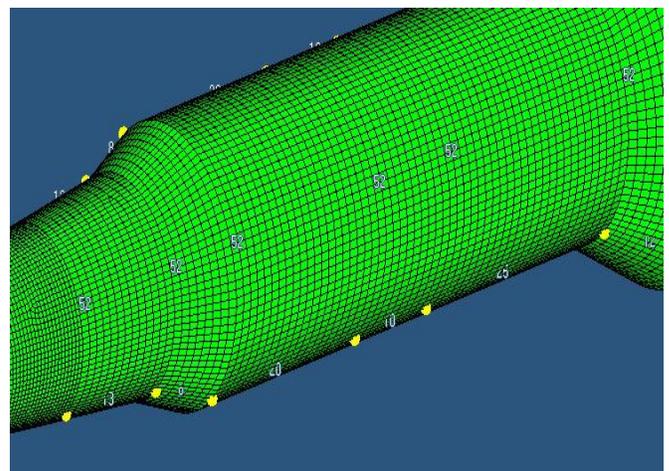


Fig 18: Mesh obtained after editing.

STEP 5: checking for the connectivity. The following steps are involved

Tool> delete> geometry or press f2

Geom.> temp nodes> all> clear all or press shift+f2

Equivalence for nodes: press f3

Equivalence for elements: press shift+f3

STEP 6: Quality parameters: tool> check elems>

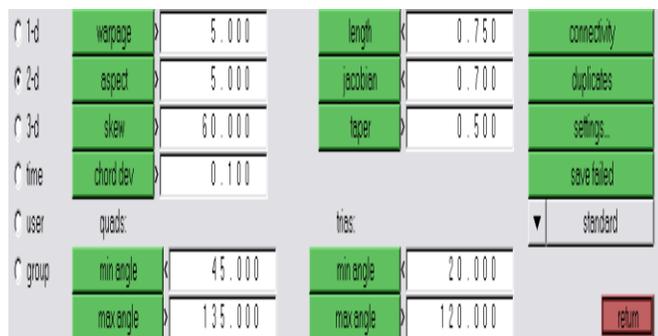


Fig 19: Quality parameters panel.

The quality parameters for the mesh obtained are as follows:

1. Warpage: 0 of 37416 (0%) failed. The maximum warpage is 0.0363.
2. Aspect ratio: 0 of 37416 (0%) failed. The maximum aspect ratio is 2.21.
3. Skew angle: 0 of 37416 (0%) failed. The maximum skew angle is 44.42.
4. Chord deviation: 0 of 37416 (0%) failed. The maximum deviation is 0.03.

5. Length: 14848 of 37416 (40%) failed. The minimum length is 0.210728.
6. Jacobean: 47 of 37416 (0%) failed. The minimum Jacobean is 0.55.
7. Taper: 1 of 37416 (0%) failed. The maximum taper is 0.50.
8. Quads:

Minimum interior angle: 0 of 37414 (0%) failed. The minimum interior angle is 45.58.

Maximum interior angle: 0 of 37414 (0%) failed. The maximum interior angle is 132.89.

Trias:

Minimum interior angle: 0 of 2 (0%) failed. The minimum interior angle is 47.26.

Maximum interior angle: 0 of 2 (0%) failed. The maximum interior angle is 82.71.

From the above information obtain, there 7 parameters which are satisfying the mesh. Hence the mesh generated may be said to a perfect mesh and it can be exported to solver software like ANSYS, NASTRAN etc.

4 MATERIAL SELECTIONS

4.1 Flight structure materials

Some of the materials commonly used in flight structures are aluminium, steel, titanium, high-temperature nickel alloys, composites etc. In this paper we are considering the aluminum and the composite material carbon epoxy for the comparison.

Table 1: Atomic properties of aluminium.

Atomic number	13	
Atomic radius-goldschmidtv (nm)	0.143	
Atomic weight (amu)	26.9815	
Crystal structure	Face centred cubic	
Electric structure	Ne 3s ² 3p ¹	
Ionization potential	No	e
	1	5
	2	1
	3	2
	4	1
	5	1
	6	1

Table 2: Mechanical properties of aluminium.

Material condition	Soft	hard	polycrystalline
Youngs modulus (GPa)	75.2		
Hardness-vickers	21	35-48	
Poison's ratio	0.345		
Tensile modulus (GPa)	70.6		
Tensile strength (MPa)	50-90	130-195	
Yield strength (MPa)	10-35	110-170	

Table 3: Physical properties of aluminium.

Boiling point (C)	2467
Density@20 C (g cm ⁻²)	2.70
Melting point (C)	660.4

energy of UV photons is high enough to dissociate the bonds in polymers and subsequent absorption of moisture becomes easy through the cracks. This leads to thermo-physical, mechanical and chemical changes and deterioration of material properties. Moisture absorption on the other hand depends on a variety of factors such as temperature, strength of the interfacial bonds between the fibers and the matrix, and flaws such as voids and fiber orientation during processing. Hence, the objective is to study the effect of nanoclay on the mechanical and thermal properties of carbon/epoxy nano composites subjected to UV radiation and condensation.

The Epoxy-carbon composite properties table is shown below:

4.2 Carbon Epoxy

Carbon fibre reinforced polymer composite (CFRC) are widely used as engineering materials due to:

- High stiffness to weight ratio
- Versatile advanced material systems
- Cost effective, light weight
- Ease of fabrication of complex shapes and forms
- Enhanced material properties
- Major concerns
 - Polymeric composites are viscoelastic in nature
 - Exposure to harsh environmental conditions
 - Presence of UV radiation in polymeric composites could lead to changes in chemical structures which ultimately deteriorates their properties

Mechanical and Thermal Properties of Carbon/Epoxy Nanoclay Composites Exposed to Synergistic Effect UV Radiation and Condensation

The use of Fiber Reinforced Polymer Composites (FRPC) has gained a lot of traction due to the high stiffness, corrosion resistance, light weight and high fatigue performance they offer compared to some metals, and metal alloys. However, polymeric materials responses to harsh environmental conditions have been one of the major concerns during its usage in engineering applications, because of their viscoelastic nature. Addition of small amounts of nanoclay has shown to improve most of the properties of these polymeric composites. These polymeric composites once exposed to UV radiation absorb the UV rays which in turn initiate photo-oxidation reaction in the matrix leading to formation of radical chemical groups. Degradation mechanisms have shown that

Table 4: properties of carbon Epoxy.

Property	Value
Material	High precision tubes
Thermal expansion coefficient (longitudinal)	$0.1 \times 10^{-6} \text{ k}^{-1}$
Volume fraction of fibres	55-60 %
Young's modulus longitudinal	110-120 GPa

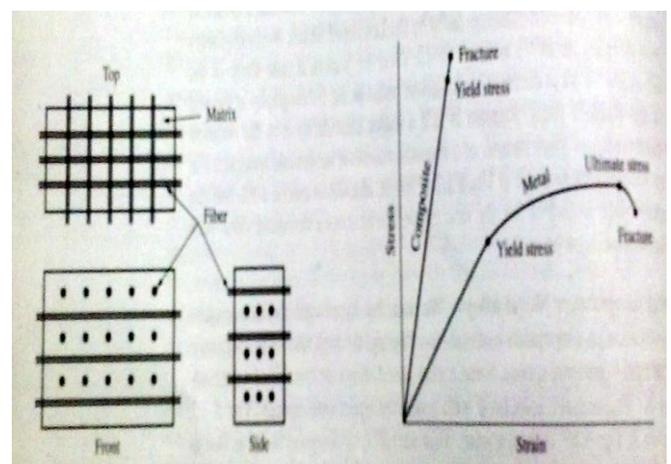


Fig 19: structure of composites and stress-strain curve for the composite material

5 PROJECT ANALYSES

5.1 Introduction to ANSYS

ANSYS is software based on Finite Element Method to solve different mechanical problems. It helps us analyze the structure in different conditions using finite element method to solve complex equations.

THE FEM PROCESS

The finite element process is generally divided into three distinct phases

1. PREPROCESSING - Build the FEM model.
2. SOLVING - Solve the equations.
3. POSTPROCESSING - Display and evaluate the results.

5.2 Steps to conduct static analysis

STEP 1: Start> all programs> ANSYS 10.0> ANSYS.

STEP 2: save the design project file with the extension as ".igs".

File> import>iges... > ok> browse for the file> ok

STEP 3: preferences> structural> h-method> ok

STEP 4: pre-processor> element type> add/edit/delete> add...> shell 99, linear layer 99> ok> close

STEP 5: real constants> add/edit/delete> add> ok> real constant set no. 1> ok> number of layers= 1> MAT=1, THETA=0, TK=1> ok > close

STEP 6: Material props> material models> structural> linear> elastic> isotropic>enter EX and PRXY value> ok

STEP 7: meshing>mesh tool> global set number of element divisions=20> mesh> pick all> ok

STEP 8: loads> define loads> apply> structural> displacement> on lines> select the free edges of the shell (*lines*)> apply> all DOF> ok

STEP 9: loads> define loads> apply> structural> force/moments> on nodes> use box to select all the nodes at the stages> apply> FZ> constant value> -10000> ok

STEP 10: solution> solve. Wait for the software intimation, software is trying to solve the problem till the solution is done window appears on the screen> ok

STEP 11: General postproc> plot results> displacement>deform+undeform> ok

Contour plot> DOF solution> z-component> ok.

5.3 Displacement and contour results

The analysis is conducted by applying the loads on each of the stages of the rocket outer shell model comparing using two materials as already mentioned aluminium and carbon epoxy. The material offering lesser deformation for the applied load is considered to be the effective one for the rocket casing to achieve the mission effectively. The comparison is made by applying same value of loads, boundary conditions and constraints on the model for both the materials considered separately. The results exhibited below are obtained when load is applied on the first stage of the rocket outer shell model comparing the displacement and contour results for the aluminium and the carbon epoxy materials respectively.

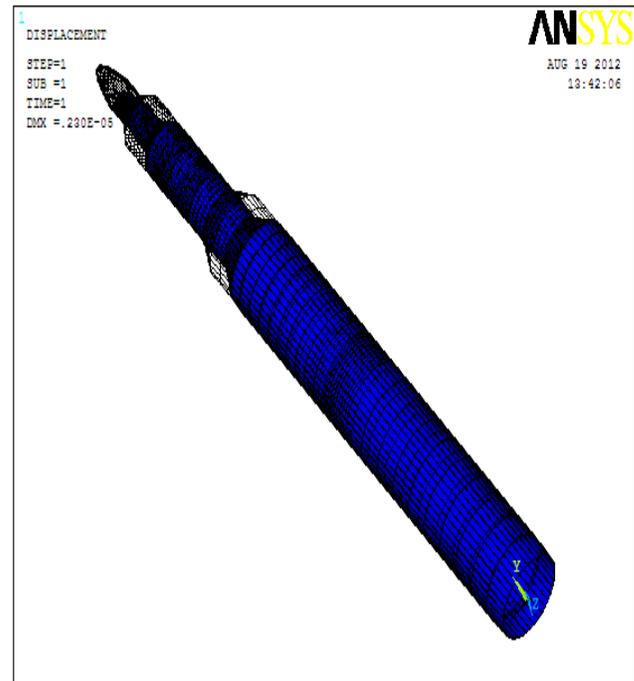


Fig 20: Deformation in the rocket outer shell when aluminium is considered (1).



Fig 21: Deformation in the rocket outer shell when carbon-epoxy is considered (1).

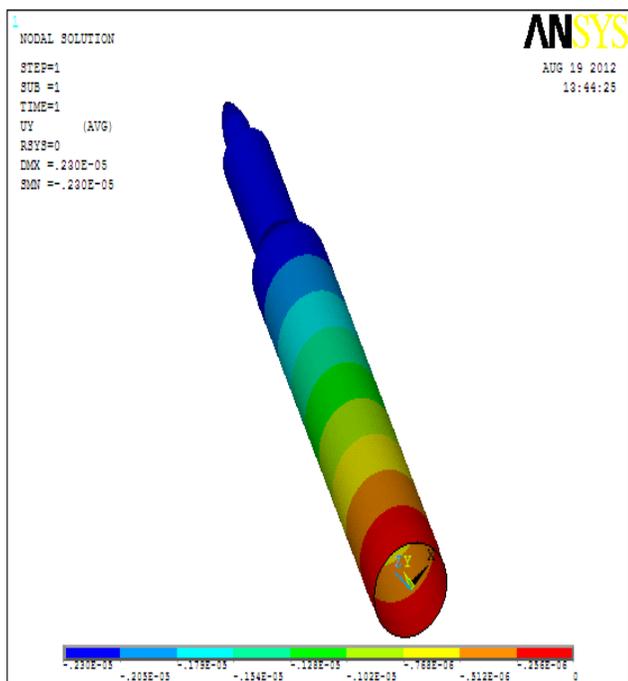


Fig 22: Nodal solution for the rocket shell model when aluminium is considered (1).

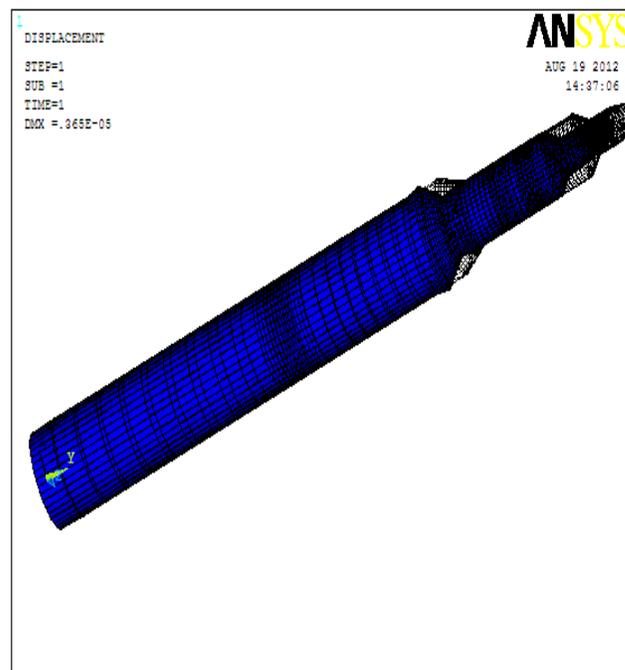


Fig 24: Deformation in the rocket outer shell when aluminium is considered (2).

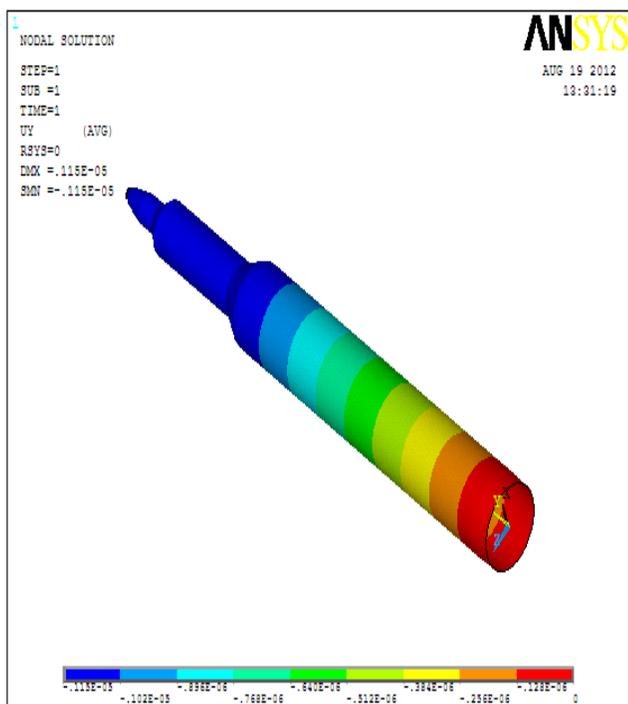


Fig 23: nodal solution for the rocket shell model when carbon-epoxy is considered (1).

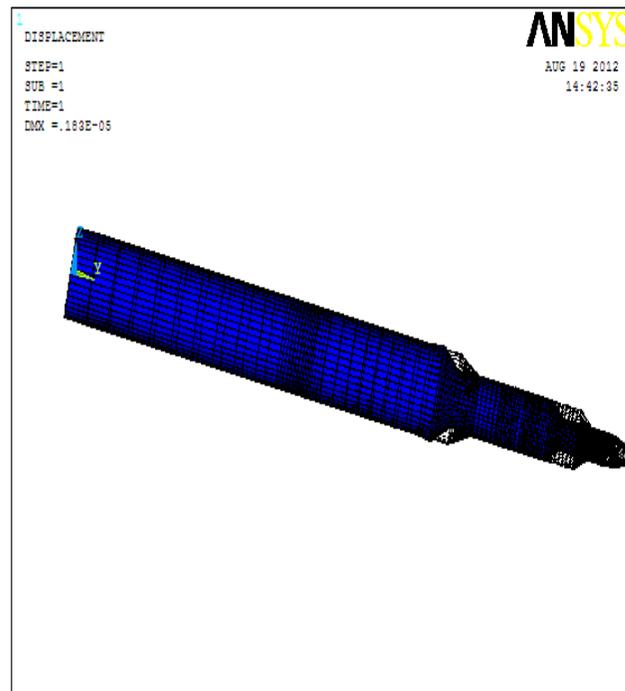


Fig 25: Deformation in the rocket outer shell when carbon-epoxy is considered (2).

The results exhibited below are obtained when load is applied on the second stage of the rocket outer shell model comparing the displacement and contour results for the aluminium and the carbon epoxy materials respectively.

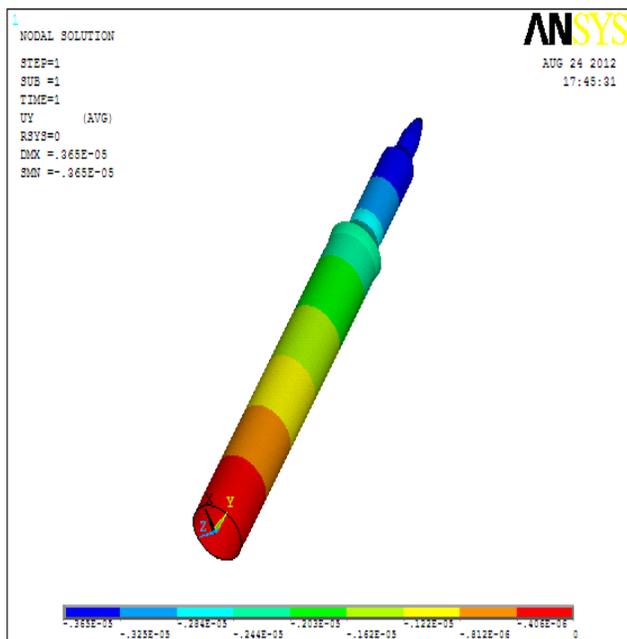


Fig 26: Nodal solution for the rocket shell model when aluminium is considered (2).

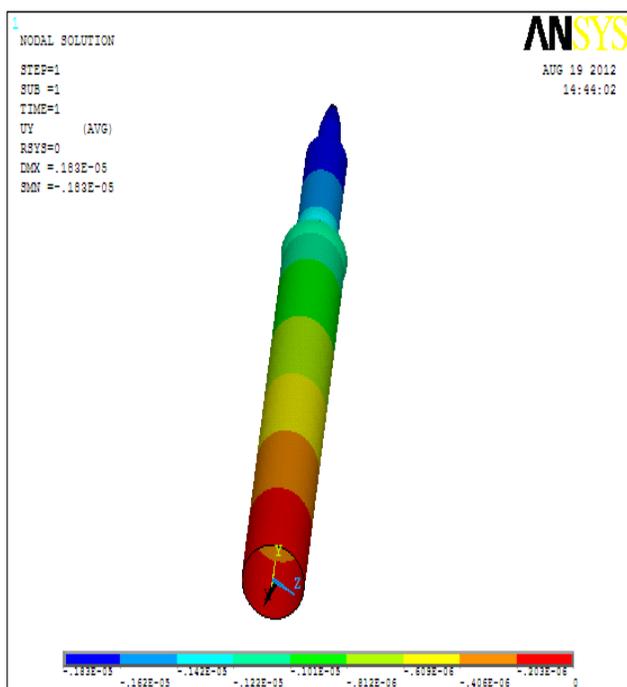


Fig 27: Nodal solution for the rocket shell model when carbon epoxy is considered (2)

CONCLUSION

This project was undertaken to model and to conduct analysis on the rocket outer shell while comparing with two different materials such as aluminium and carbon epoxy to provide with a best option for the rocket structure that it can perform effectively in its flight. The results of this study shows that Carbon epoxy can be able to perform better over that of aluminium as noted from the results of analysis, the

deformation occurred is less for the carbon epoxy compared to aluminium when applied same loading. It is recommended that further research be undertaken in developing the composite materials (eg: *Carbon Epoxy*) for the rocket casing as they consists of high strength and they are reusable.

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