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DESIGN OPTIMISATION OF RE ENTRY CAPSULE SHELL FOR HIGHER STRUCTURAL PERFORMANCE

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ABSTRACT : Reentry capsules were used for both manned and unmanned space missions. While entering to earth's atmosphere capsules experiencing very high pressure and temperatures leads to high aerodynamic heating and shear stress. to investigate the effect of changing the design parameters like spherical nose radius, shoulder radius and characteristic length on structural analysis of the capsule.Orthotropic material S glass epoxy composite material used as solver material for the analysis. Reentry capsule velocity is in between the range of 15 to 25 Mach number while entering to the earth's atmosphere at an altitude 100km above the sea level. Above the Karman line the air present in the atmosphere is too dense the capsule penetrates with high velocities and the capsules kinetic energy converts to heat energy. Dynamic pressure and temperature values at 100km altitude are taken as input values for structural analysis. Optimized designs are designed using solidworks2020 cad software. FEA analysis carried in ansys workbench. Static structural analysis performed on the optimized models and total deformation, maximum shear stress are plotted for different parameters and performance of the structures are evaluated based on the values.

Keyword; *Reentry capsule, blunt body, ballistic coefficient, orthotropic material, dynamic pressure*

INTRODUCTION

Atmospheric entry is the reentry of artificial objects passing through the Earth's atmosphere or the atmosphere of any other planet. It could be ballistic or non ballistic in nature. Early missions used ballistic reentry which is proven to be fatal. It's basically a capsule that returns to Earth following a space flight. It's aerodynamically stable which falls facing its blunt end. Soyuz, Apollo, Orion are certain space capsules used before lifting body with wings and control surfaces came into existence. The latter is comparatively safer than the former since the lifting force acts against the aerodynamic drag and thereby slowing down the descent speed. The modification carried out by adding the lifting technology is a remarkable revolution in reentry vehicles.

A blunt vehicle with light weight has lower BC and slows down much more quickly than a heavy, streamlined vehicle having a higher BC.

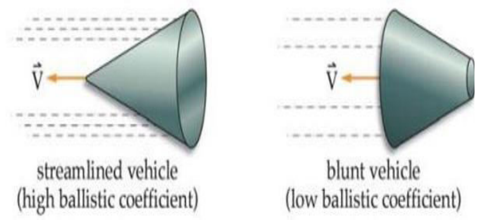

Fig 1.1 streamlined vehicle and blubt vehicle

Aerodynamic Heating:

When the vehicle begins to enter Earth's atmosphere, it has a large amount of kinetic energy due to its high velocity as it's now under the influence of gravitational pull of the planet.

This kinetic energy eventually gets converted to heat by skin friction on the surface of the vehicle. Also while reentry, near the outer edge of the atmosphere, the vehicle acquires a large amount of potential energy because of its high altitude. Ultimately, as the vehicle touches the surface of the earth, its velocity becomes comparatively small and its altitude becomeszero.

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ENTRY VEHICLE SHAPES

- The shape of this entry vehicle can be a complete sphere with an afterbody which is convergingand conical and hence sphere is the simplest axisymmetric shape.
- Newtonian impact theory can be used to determine the aerodynamics of a sphericalsection.
- Apuresspheredoesn'thaveanyliftbutiffl ownbyanangle ofattack,it hasconsiderableaerodynamic lift.
- These entry vehicles were used in the Vostok(Early Soviet), Soviet mars and venera descentvehicles.
- Soyuz,GeminiandMercuryaretheotherex amplesofsphericalsectiongeometryinman nedcapsules.

(II) NOMENCLATURE OF THE RE ENTRY CAPSULE

Shape of the reentry capsule is like a blunt body. Design parameters of a reentry capsule are

L - characteristic length or overall length of the capsule.

Rn- spherical nose radius

Rc- shoulder radius or corner radius

Fore body

Aft body

Semi apex angle

Heat shield or thermal protection system

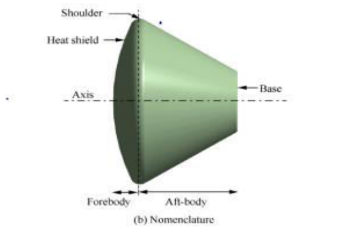

Fig. 1 Baseline re-entry vehicle geometry and nomenclature.

Fig 1.18 base line re-entry vehicle geometry and nomenclature

Literature review

Mani kumara*, Parthasarathy Gareeb , Sundaram Sc [1] The Reentry capsule exhibits a vast amount of aerodynamic heating and shear stress acting on the structure while entering into the earth atmosphere. Earlier reentry vehicle structures are made up of Metal-matrix composites (MMCs) and ceramic-matrix composites (CMCs) and titanium alloys which are thermally stable and can withstand loads at high temperatures, in this paper we have taken up structural analysis of capsule by replacing Carbon fiber rein forced plastic (CFRP) composite materials. The vehicle enters the earth's atmosphere with a Mach number 15- 25 at an altitude of 100km from the sea level where the dense of air present, the capsule penetrate to the earth's atmosphere with a high velocity, the kinetic energy of the vehicles converts into Heat energy, it tends to melting the heat shield of capsule. In this paper we have calculated the Structural and aerodynamic behavior of reentry vehicle at Karman line above sea level and in the dense air. The methodology of this project followed is capsule designed in CATIA and did FEA Analysis.

METHODOLOGY AND MATERIALS

The Completed CAD models were successfully imported to ANSYS Workbench and then static structural module were used for analysis purpose. The material selected for analysis is present in ansys workbench under composite section in engineering materials library. Default material should be deleted before going for analysis and the material which we selected should be assigned to each capsule.

Properties of material

Epoxy resin s glass epoxy		
Property	**Value**	**Units**
Density	2000	Kg/m^3
Orthotropic elasticity		
Young’s modulus x-direction	50000	Mpa
Young’s	8000	Mpa

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modulus y-direction		
Young's modulus z-direction	8000	Mpa
Poisons ratio XY	0.3	
Poisons ratio YZ	0.4	
Poisons ratio XZ	0.3	

DESIGN OPTIMIZATION OF RE ENTRY CAPSULE (APOLLO)

Design optimization of the capsule has done by changing the geometrical parameters one by one by keeping other parameters as constant.

Reference capsule dimensions

Rn	D	Rc	L	□ semi apex angle
4.595m	3.95m	0.186m	3.522m	32.5 deg

4.5 Modified capsules

Case A: changing base diameter and corner radius by keeping length and semi apex angle as constants.

Rn	D	Rc	L	□ semi apex angle
4.595m	3.78m	0.15m	3.522m	32.5 deg
4.595m	3.95m	0.186m	3.522m	32.5 deg
4.595m	4.06m	0.25m	3.522m	32.5deg
4.595m	4.16m	0.3m	3.522m	32.5 deg
4.595m	4.26m	0.35m	3.522m	32.5deg
4.595m	4.36m	0.4m	3.522m	32.5 deg

Case B: changing nose radius by keeping other dimensions as constants.

Rn	D	Rc	L	□ semi apex angle
4.10mm	3.95m	0.186m	3.522m	32.5 deg
4.20mm	3.95m	0.186m	3.522m	32.5 deg
4.30mm	3.95m	0.186m	3.522m	32.5 deg
4.40mm	3.95m	0.186m	3.522m	32.5 deg
4.50mm	3.95m	0.186m	3.522m	32.5 deg
4.595	3.95m	0.186m	3.522m	32.5 deg
4.70	3.95m	0.186m	3.522m	32.5 deg
4.80	3.95m	0.186m	3.522m	32.5 deg
4.90	3.95m	0.186m	3.522m	32.5 deg
5.0	3.95m	0.186m	3.522m	32.5 deg

Case C: decreasing the length keeping all parameters as constants.

Rn	D	Rc	L	□ semi apex angle
4.595m	3.95m	0.186m	3.52m	32.5 deg

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4.595m	3.95m	0.186m	3.42m	32.5 deg
4.595m	3.95m	0.186m	3.32m	32.5 deg
4.595m	3.95m	0.186m	3.22m	32.5 deg
4.595m	3.95m	0.186m	3.12m	32.5 deg

4.6 MODELING

After altering the geometrical parameters optimized models were modeled using cad software solidworks2020. Commands used for modeling the capsules are revolved boss after making a constrained 2D sketch.

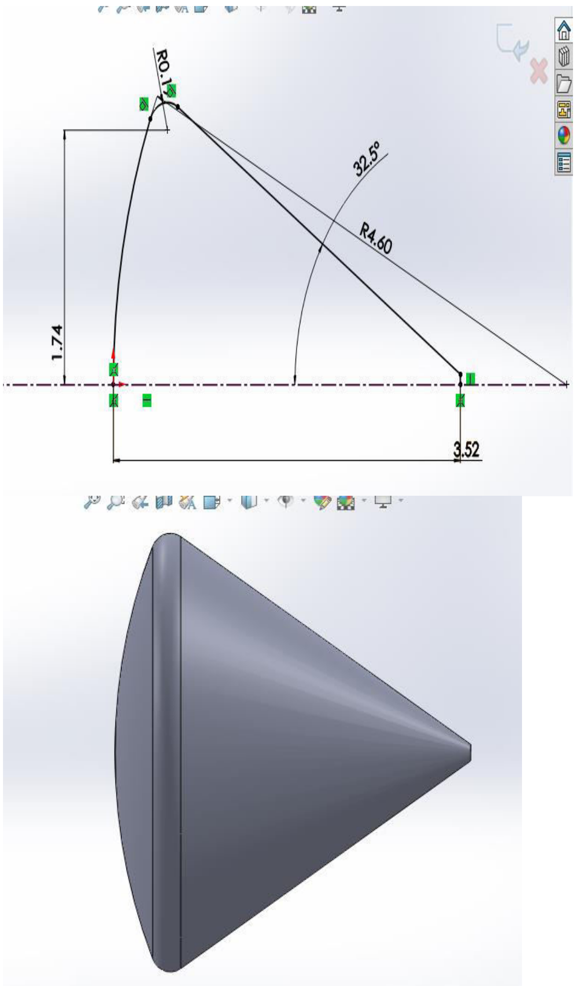

Fig 1.1 Reference model

4.7 Optimized models

Case A: changing base diameter and corner radius by keeping length and semi apex angle as constants.

Discretization or meshing

Coarsen mesh results in high error percentage meanwhile which takes less time to compute the results. In order to getting higher accuracy, fine mesh size 0.01m with smooth transition and skewness are used. Mesh details are shown in below table

Mesh details	
Physical preference	Ansys mechanical
Element size	0.01m
Mesh metric	Skewness
Inflation	Smooth transition
Mesh statistics	
Number of Nodes	1104682
Number of elements	651279

Above mentioned mesh details are for reference capsule for optimised models mesh statistics changes because the surface area and length changes. The number of nodes is in the range of 10 lakhs to 15 lakhs and the number of elements is in the range of 6 lakhs to 9 lakhs.

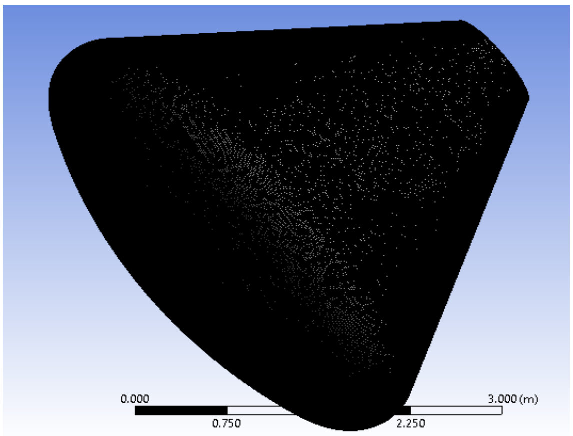

Fig 5.2.1 meshed model

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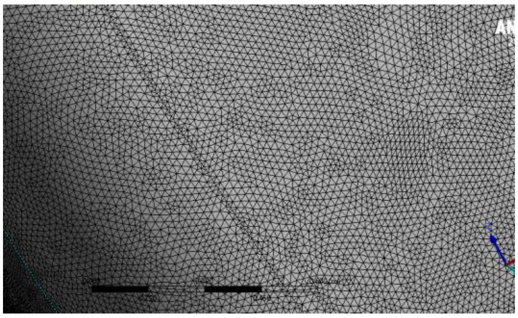

Fig 5.2.1 Close view mesh

The pressure applied on the capsule is dynamic pressure, which is calculated by the formula given below,

Dynamic pressure, $q = \frac{1*ƒ*v^2}{2}$

Where, ƒ is the density of air = 1.22g Kg/m3

V is the velocity of the capsule = 6600m/s (i.e., avg. capsule Mach 20)

It is clear that that the pressure is purely depends on the velocity of the capsule, the pressure value increases with square of velocity.

Dynamic pressure, q = 0.5 x 1.225 x (6600)2

= 2.6x107 Pa

The pressure value will be applied on the TPS and the fixed constraint was at the docking side of the capsule, the analysis completely program controlled.

5.2.3 Boundary conditions

Structural analysis carried out by fixing one side of the capsule i.e., docking side of the capsule and the dynamic pressure 2.6*10^7 pa is applied on the capsule and the re-entry temperature 2000 deg centigrade applied on the capsule. Before going for analysis body should be constrained fully (locking the degree of freedom of body). Constraining the body achieved by using fixed support and displacement conditions

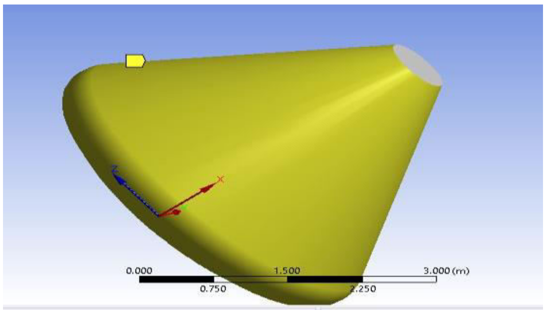

Fig 5.2.3 boundary conditions

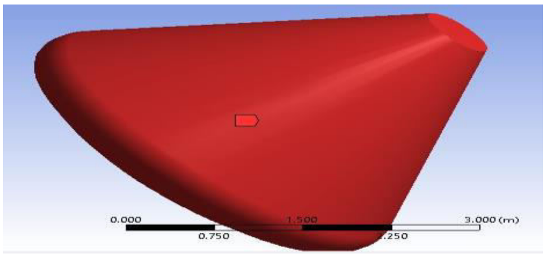

Fig 5.2.4 pressure applied

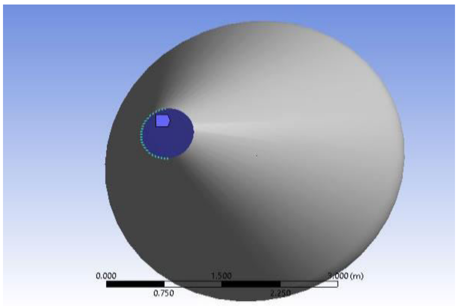

Fig 5.2.5fixed support

Analysis

Static structural analysis carried out using ansys workbench 2020R1. All optimized models are imported to ansys workbench and meshing, bounadary conditions applied then required results are defined to the solver. For this analysis total deformations, shear stress (YZ) and maximum shear stress are defined to solver and did solution. Results are tabulated to generate the plots and deformation and stress contours are captured for visualization.

CASE A

A1

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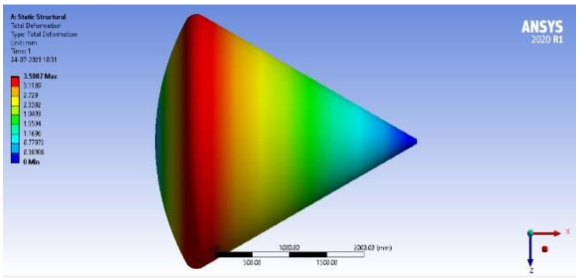


Fig 5.2.5 total deformation

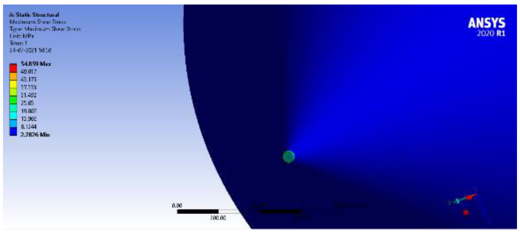


Fig 5.2.6 maximum shear stress

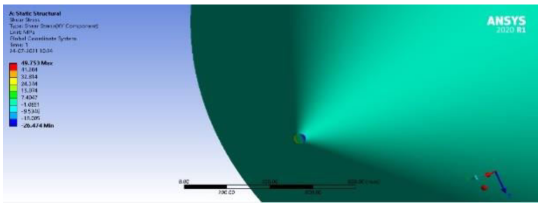
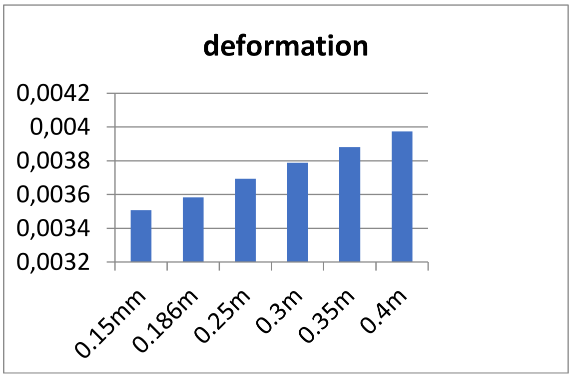


Fig 5.2.7 shear stress YZ component

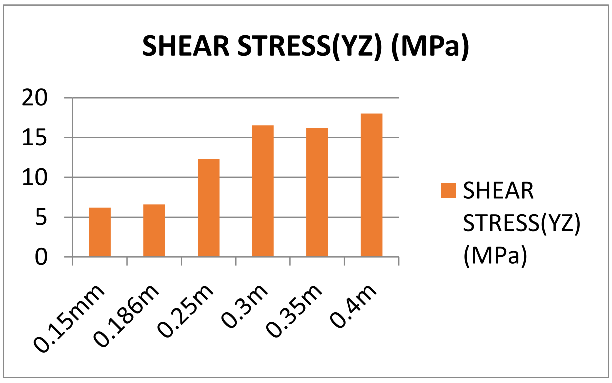
RESULTS AND PLOTS

Table 6.1 Results for case A:

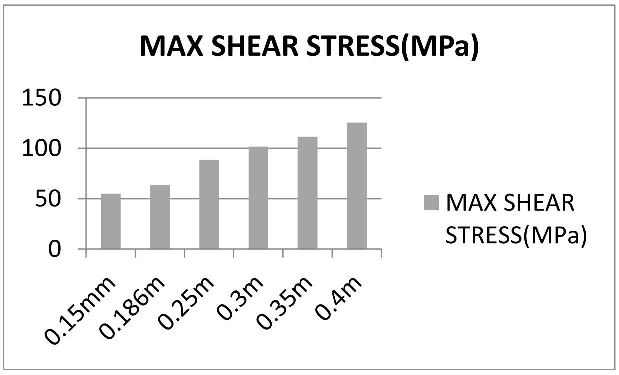
MATERIAL (S GLASS EPOXY)			
Rc	DEFORMATION(M)	SHEAR STRESS(YZ) (MPa)	MAX SHEAR STRESS(MPa)
0.15 mm	0.0035087	6.2137	54.859
0.186 m	0.0035829	6.5973	63.531
0.25 m	0.0036943	12.311	88.624
0.3m	0.0037874	16.548	101.8
0.35 m	0.0038808	16.167	111.6
0.4m	0.0039744	18.014	125.44



Plot 6.1 deformation plot



Plot 6.2 shear stress (yz)



Plot 6.3 maximum shear stress

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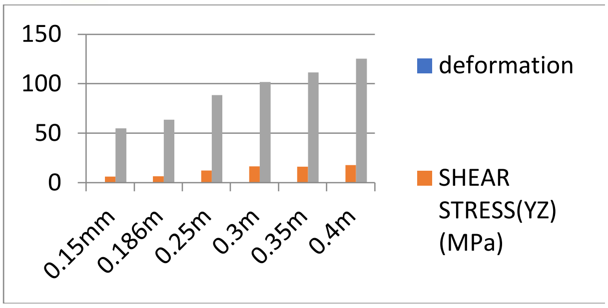
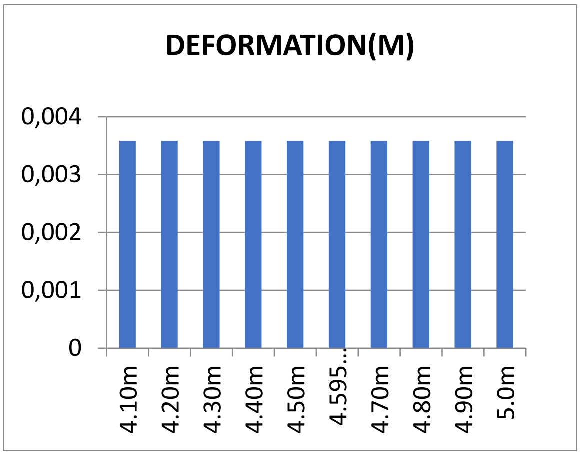


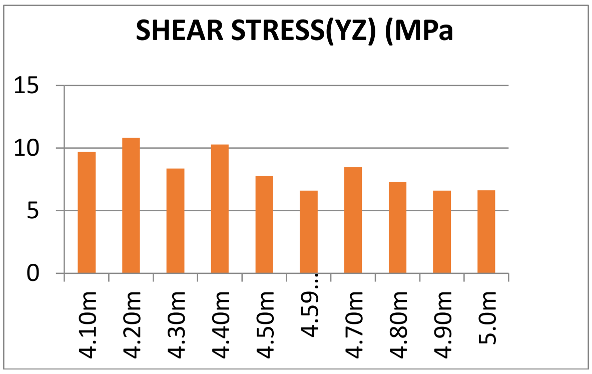
Plot 6.4 comparison plot

Table 6.2 Results for Case B

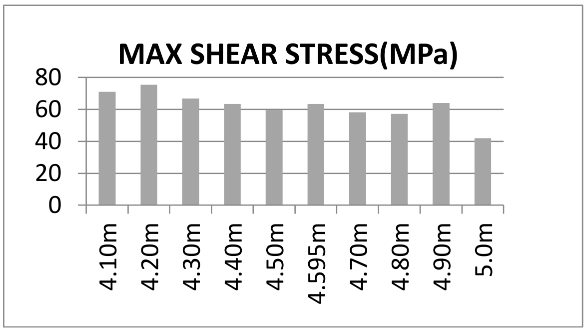
MATERIAL (S GLASS EPOXY)			
Rn	DEFORMATION(M)	SHEAR STRESS(YZ) (MPa	MAX SHEAR STRESS(MPa)
4.10 mm	0.0035829	9.6911	71.054
4.20 mm	0.0035829	10.814	75.416
4.30 mm	0.0035829	8.3747	66.905
4.40 mm	0.0035829	10.296	63.514
4.50 mm	0.0035829	7.7684	59.677
4.595 m	0.0035829	6.5973	63.531
4.70 m	0.0035829	8.4755	58.185
4.80 m	0.0035829	7.3007	57.307
4.90 m	0.0035829	6.5954	64.1
5.0m	0.0035829	6.6126	41.902



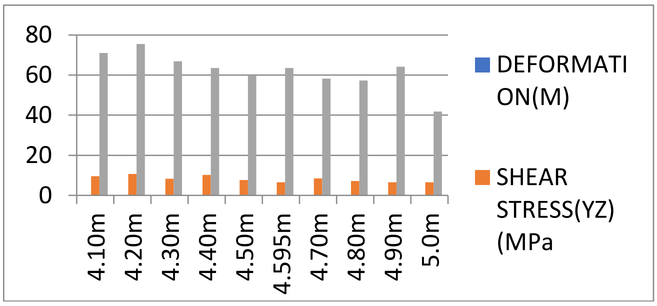
Plot 6.5 deformation plot



Plot 6.6 shear stress (yz)



Plot 6.7 maximum shear stress



Plot 6.8 comparison plot

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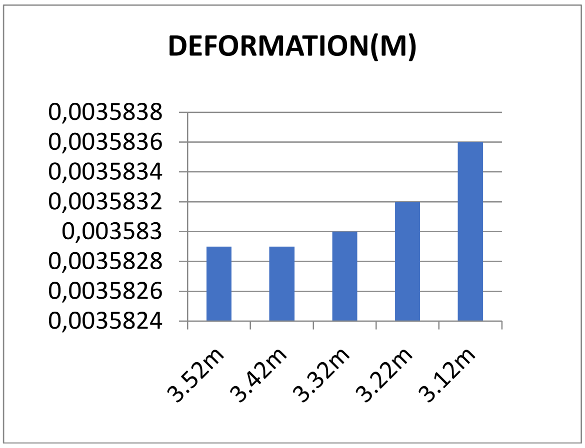
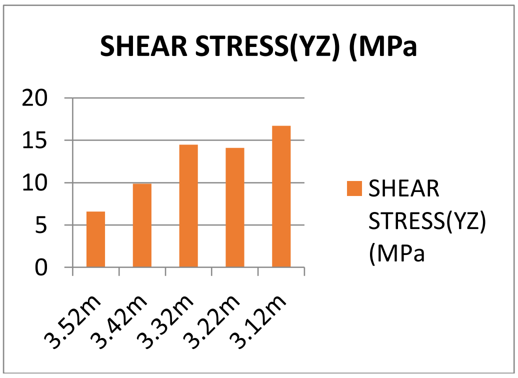
Table 6. 3 Results for Case C

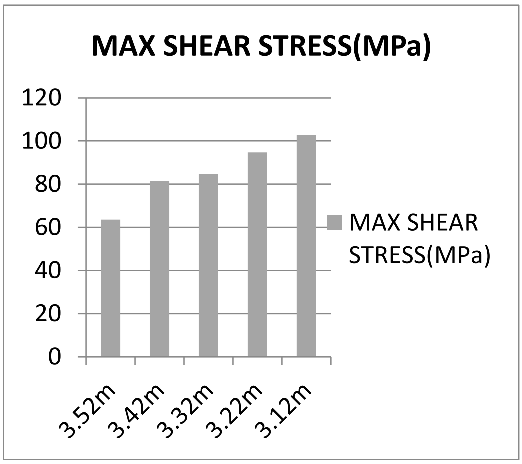
MATERIAL (S GLASS EPOXY)			
L	DEFORMATION(M)	SHEAR STRESS(YZ) (MPa	MAX SHEAR STRESS(MPa)
3.52 m	0.0035829	6.5973	63.531
3.42 m	0.0035829	9.8548	81.456
3.32 m	0.003583	14.485	84.605
3.22 m	0.0035832	14.093	94.716
3.12 m	0.0035836	16.714	102.71



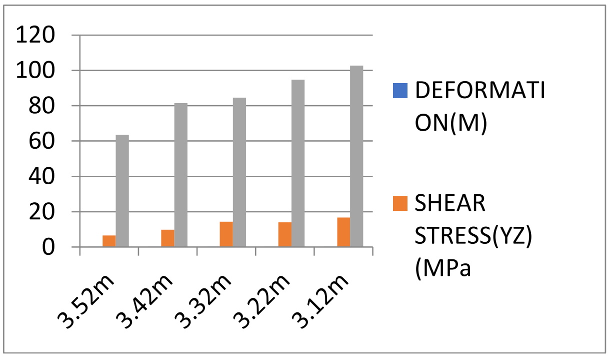
Plot 6.9 deformation plot



Plot 6.10 shear stress (yz)



Plot 6.11 maximum shear stress



Plot 6.13 comparison plot

CONCLUSION

From the results tables and charts it is observed that the maximum shear stress and total deformations of re entry shell capsules are got affected by geometrical parameters and the effect caused by changes made to capsules are as follows.

Maximum shear stress and total deformation of capsules increases with increasing shoulder radius of the capsule and decreases with decreasing shoulder radius of the capsule. Maximum shear stress value observed at shoulder radius 0.4m and its value is 125.44 Mpa.

Maximum shear stress decreases with increasing spherical nose radius of the capsule but the total deformation is constant and its value is 0.0035829m. Maximum shear stress value observed at spherical nose radius 4.20mm and its value is 75.416 Mpa.

Maximum shear stress and total deformations are increased with decreasing of length of the capsule and the maximum shear stress value observed at 3.12m length and the value is 102.71 Mpa.

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