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Finite Element Analysis of Interface ring of a Rocket Launcher

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Abstract: This paper aims at performing linear static analysis of laminated composite interface ring of rocket launcher and to investigate the effect of ply orientation of laminates on deformation and stress pattern. The interface ring is a part of conical shell, having a top radius of 367mm and bottom radius of 472mm. The shell is made of laminated carbon fibre plastic composites with distribution of total of 20 layers forming a total thickness of 2mm. The load of 200kN from the components above the ring acts as distributed compressive load on the top of the ring, the bottom of which is fixed. The analysis carried out on structure lead to best suited laminate and optimum ply orientation. The minimum deformation for laminated conical shells having angle plies is obtained with a ply orientation of 10 degree.

Keywords: Interface ring; CFRP; ply orientation; deformation contour; stress contour

I. INTRODUCTION

Design of structures for space missions is a formidable challenge to design community due to contradictory requirements of low margin, low mass and cheaper but high reliability. These requirements are presently met by design and construction concepts of externally stiffened construction and integrally stiffened construction, such as, closely stiffened structures, ring stiffened structures, waffle, isogrid structures, sandwich, composite structures etc. The innovations in design and structures have parallely led to advancements in materials and manufacturing technologies and have substantially contributed to satisfy the specified requirements of the present space mission applications. The use of advanced composite materials has become essential in spacecraft structures for achieving low mass while satisfying structural and functional requirements related to stiffness, strength, dimensional stability and agility. Reduction of structural mass is important in many ways – it helps to increase payload fraction in a spacecraft, improves agility and also reduces the launch cost. These properties of composites would result in large weight savings thus replacing the conventional metallic designs.

A satellite launch vehicle is a complex transportation system which is tailored and engineered to function as a flying machine. This vehicle is made capable of transcending the harsh atmospheric regime and beyond near earth space and deliver the encapsulated satellite in the orbit; thus fulfilling the mission. Launch vehicles are built as an assemblage of several stages which may be solid, liquid, cryo/semi cryo, etc depending on the propulsion systems employed. In multi– stage launch vehicles, the inert stages, which have performed their function, are jettisoned sequentially as flight progresses. Fig.1 shows the different stages & structures in a launch vehicle. This is enabled by staging/separation systems which are essentially pyro/explosive based systems. Launch vehicle structures which have the primary role to provide/maintain necessary external aerodynamic shapes while withstanding the flight loads and environments may be broadly classified under two headings such as primary structures and secondary structures. Use of advanced composite materials has been the most contributing factor. Till nowadays the base structure, especially the interface ring remained metallic due to a number of practical considerations. Such metallic base structures are normally integrally machined parts and contribute to a significant part of the spacecraft structure mass. The upper interface of such structures made of aluminum alloy often poses serious problems of dimensional accuracy and stability when such requirements are mandatory. These base structures are used mainly for compatibility between the launch vehicle payload adaptor, clamp band release mechanism and other requirements. Recently there have been attempts on the use of light weight materials like composites for the construction of spacecraft structural systems. These are specially designed for meeting the stringent requirements of stiffness, dimensional stability, impact resistance and fatigue. The structure under study is a composite base structure of 600 kg class spacecraft. It is a conical shell type structure. Fig.1 shows exploded view of spacecraft structure showing base / interface ring. The spacecraft bus elements are attached to it through horizontal decks and radial panels. In addition, a heavy alignment sensitive payload is also attached at one end. All spacecraft loads are transferred to the launch vehicle adaptor during launch through this part. This interface structure is made of carbon fiber reinforced plastic (CFRP) [2].

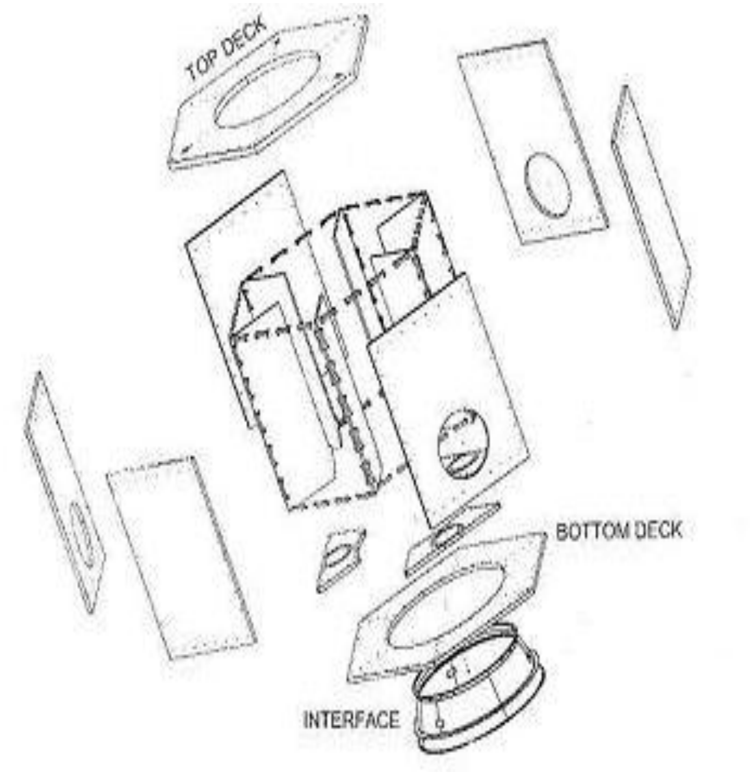


Fig.1. Exploded view of spacecraft structure showing base / interface ring

II. METHODOLOGY

Interface ring of the rocket launcher was modelled and analysed using ANSYS software as CFRP material. ANSYS is a finite element analysis (FEA) software package. It uses a preprocessor software engine to create geometry. Then it uses a solution routine to apply loads to the meshed geometry. Finally it outputs desired results in post-processing. ANSYS includes a large number of different structural elements which are developed for specific applications. ANSYS is an FEA package which supports layered elements like SHELL99 for the analysis of shell structures and BEAM189 for the analysis of beam elements. The selection of an element for an application should be based on its capabilities, its cost (stiffness matrix generation, decomposition, stress calculation etc.) and the desired accuracy in the results.

A. Composite Modeling in ANSYS

Composite materials can be modeled in ANSYS using specialized elements called layered elements. After building the model using these elements, any structural analysis like static, nonlinear static, Eigen buckling, nonlinear buckling, modal analysis, dynamic analysis etc. can be performed. SHELL 99 is a linear Layered Structural Shell Element is an 8-node, 3-D shell element with six degrees of freedom at each node. It is designed to model thin to moderately thick plate and shell structures with a side-to-thickness ratio of roughly 10 or greater. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes.

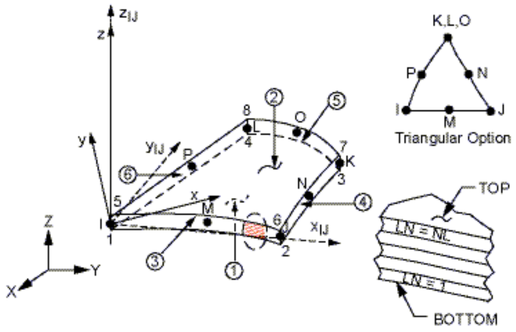


Fig.2. SHELL 99 -Geometry

Fig.2 shows the geometry of the layered shell element where, LN = Layer number and NL = Total Number of Layers. The element is defined by eight nodes, average or corner layer thicknesses, layer material direction angles, and orthotropic material properties. Mid side nodes may not be removed from this element. A triangular-shaped element may be formed by defining the same node number for nodes K, L and O. BEAM189 is an element suitable for analyzing slender to moderately stubby/thick beam structures. This element is based on Timoshenko beam theory. Shear deformation effects are included. BEAM189 is a quadratic (3-node) beam element in 3-D. BEAM189 has six or seven degrees of freedom at each node, with the number of degrees of freedom depending on the value of KEYOPT(1). When KEYOPT(1) = 0 (the default), six degrees of freedom occur at each node. These include translations in the x, y, and z directions and rotations about the x, y, and z directions. When KEYOPT(1) = 1, a seventh degree of freedom (warping magnitude) is also considered. This element is well-suited for linear, large rotation, and/or large strain nonlinear applications.

III. LINEAR STATIC ANALYSIS OF INTERFACE RING

As per the Research and Development Programs conducted at ISRO recently, the problem may be identified as an interface ring possessing the following conditions regarding dimensions of interface ring modeled as conical shell with top radius = 367 mm, bottom radius = 472mm, height = 290mm, thickness = 2mm, no. of layers = 20, thickness of each laminae = 0.0001mm [2].

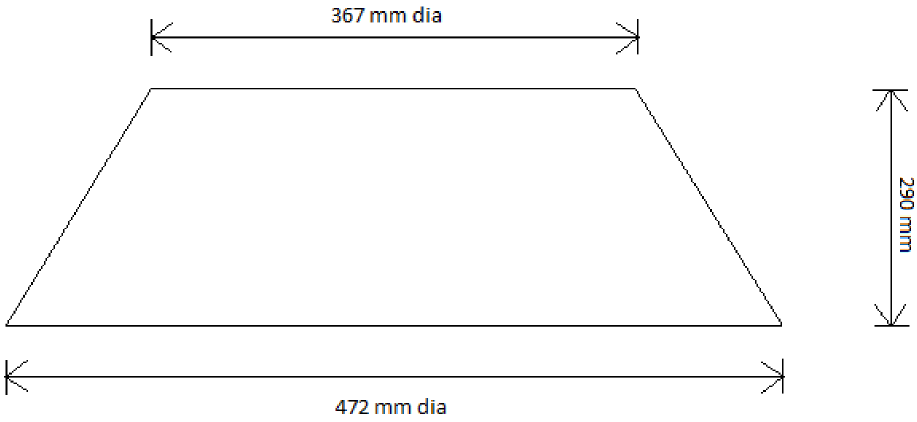


Fig.3. Interface ring

Elements used are SHELL 99 for conical shell and BEAM 189 for stiffeners. Boundary condition of the ring is fixed at bottom using fixtures. Loading along longitudinal direction of intensity 200 kN as distributed compressive load on the top of the ring. Fig.4 shows the loading diagram of conical shell in ANSYS window. The properties of the CFRP composite used for the analysis are given in Table 1 below. It is evident that CFRP possess improved properties in comparison with other conventionally used materials.

TABLE 1.
PROPERTIES OF CFRP COMPOSITE

Property	Value
Young's Modulus – Longitudinal	270.0 G Pa
Young's Modulus –Transverse	5.535 G Pa
In plane shear Modulus	3.870 G Pa
Major Poisson's Ratio	0.365
Mass Density	1760 Kg/m^3
Tensile Strength – Longitudinal – Transverse	1.80 G Pa 0.022 G Pa
Compressive strength	0.600 G Pa
In plane shear strength	0.092 G Pa

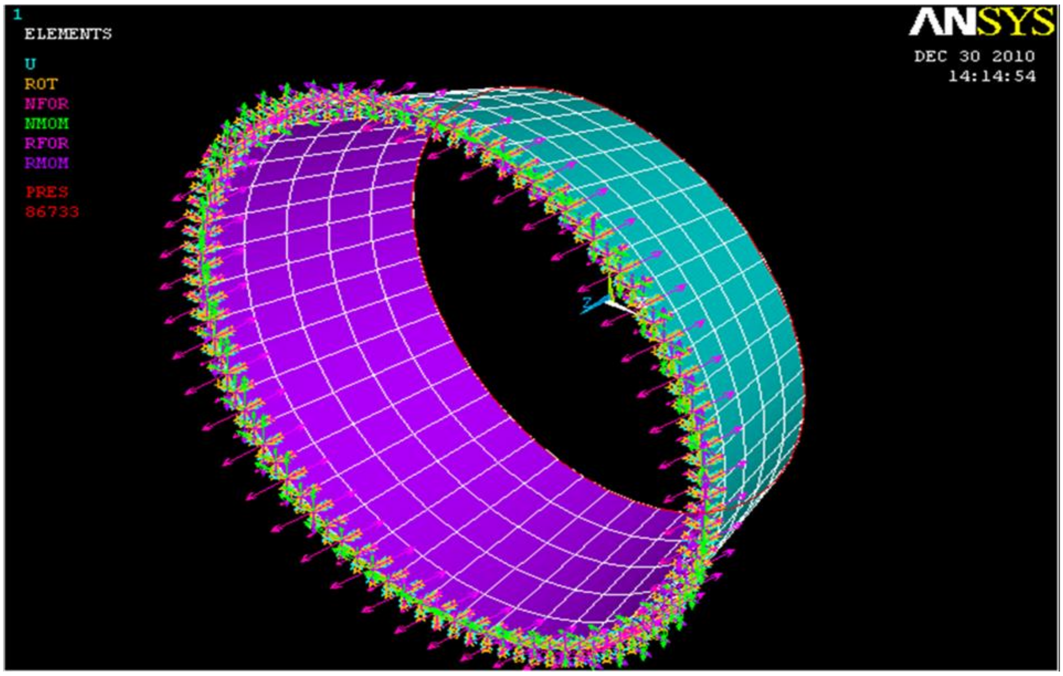


Fig.4. Loading diagram of conical shell in ANSYS window

IV. RESULTS OF LINEAR STATIC ANALYSIS

A. *Mesh Convergence*

The accuracy of the finite element solution depends on the discretisation which is characterized by the finite element mesh and the choice of elements. Various mesh sizes are selected arbitrarily so that the entire area of the shell is divided proportionally. The one that gave minimum value of deformation for the given conditions was selected as the optimum mesh size and the same was taken for analysis of optimum ply orientation and study of laminate behaviour [7]. Various mesh sizes were randomly selected and design loads were tried upon the model and deformation values for respective mesh sizes were tabulated as shown in Table 2.

TABLE 2.

MESH CONVERGENCE

Mesh size	Axial deformation(mm)
48 x 5	0.0858
60 x 7	0.0819
76 x 8	0.0800
96 x 10	**0.0790**
118 x 13	0.0790

On comparing the deformations shown by the interface ring with progressively increasing mesh sizes, the mesh convergence was obtained at a mesh size 96 x10. Hence for further analysis optimum mesh 96 x10 was selected.

B. Types of Laminates and their Behaviour

The behaviour of different laminates under the design loads was studied with respect to deformation observed on the shell. The comparison on deformation shown by cross ply and angle ply laminates were done for both symmetric and anti symmetric arrangement. Fig .5 shows the layer stacking sequence of cross ply and angle ply laminates. For cross ply laminates, 0^0 ply and 90^0 ply are placed alternately. For angle ply laminates, plies are oriented in a random fashion.

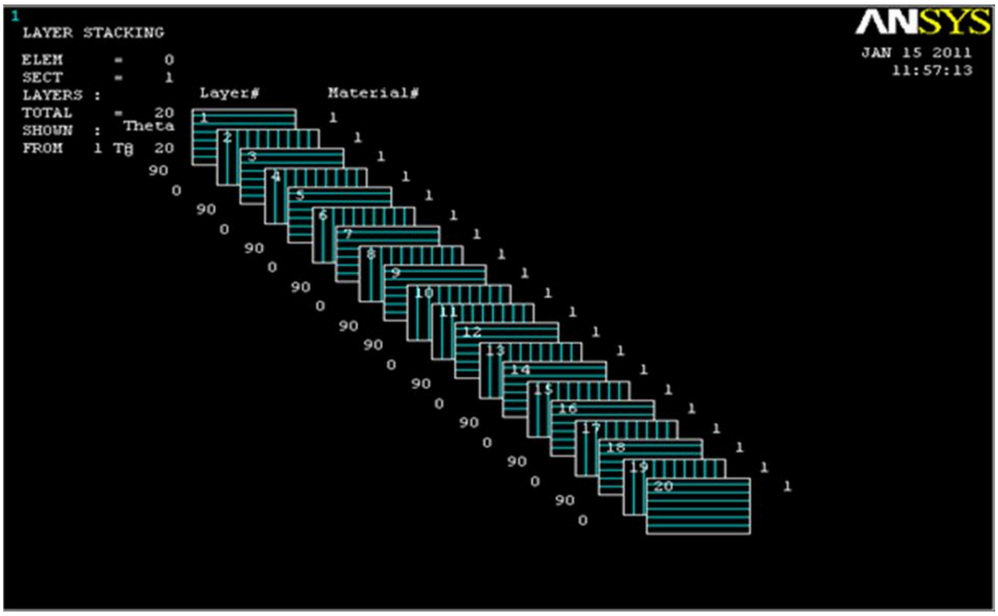


Fig.5. Layer stacking sequence of cross ply laminates showing laminate configuration $[0_2/90_2/0/90_2/0_2]_s$

The deformation observed on different configuration of laminates for symmetric and anti symmetric arrangements were tabulated as in table 3 and explained in Fig. 6

TABLE 3: DEFORMATION OBSERVED IN DIFFERENT TYPES OF LAMINATES

Type	Geometric peculiarity	Axial deformation(mm)
Cross ply	Symmetric	0.0942
	Anti symmetric	**0.0916**
Angle ply	Symmetric	0.177
	Anti symmetric	0.174

On comparing cross ply and angle ply laminates, cross ply anti symmetric laminates has found to give better result. Using the criteria for selection and taking into account, the advantages of cross ply laminate over other configuration, an improved configuration that employs the best suited orientation is adopted. Herein, for further analysis, the improved configuration of laminates is designated as $[0_2/90_2/\pm\theta/90_2/0_2]_s$.

C. Determination of optimum Ply Orientation

Anti-symmetric cross ply laminates were found to have minimum deformation on comparison with other types. Hence optimum ply orientation was tried upon varying the values of θ in the orientation configuration stated as $[0_2/90_2/\pm\theta/90_2/0_2]_s$. The axial deformation was obtained for different ply orientations on analysis under design loads and was tabulated as in Table 3. A graph was plotted between deformation and ply orientation and a smooth continuous curve was obtained. In Fig. 6, the curve initially sags down up to 10^0 and then rises upwards.

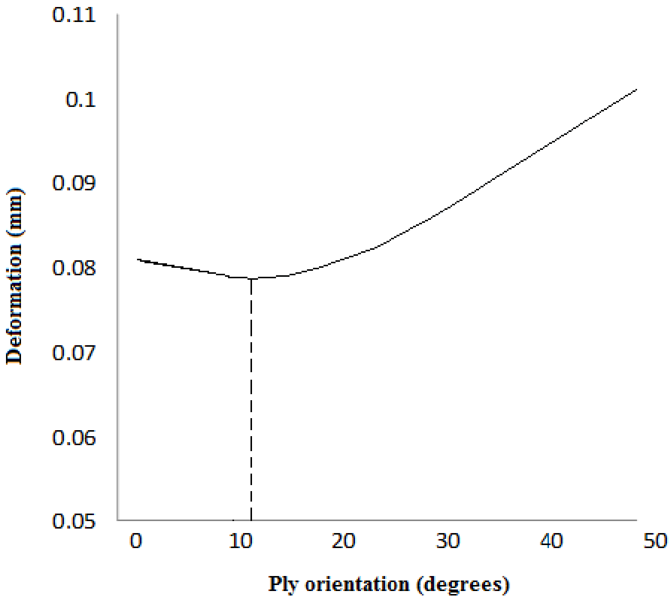
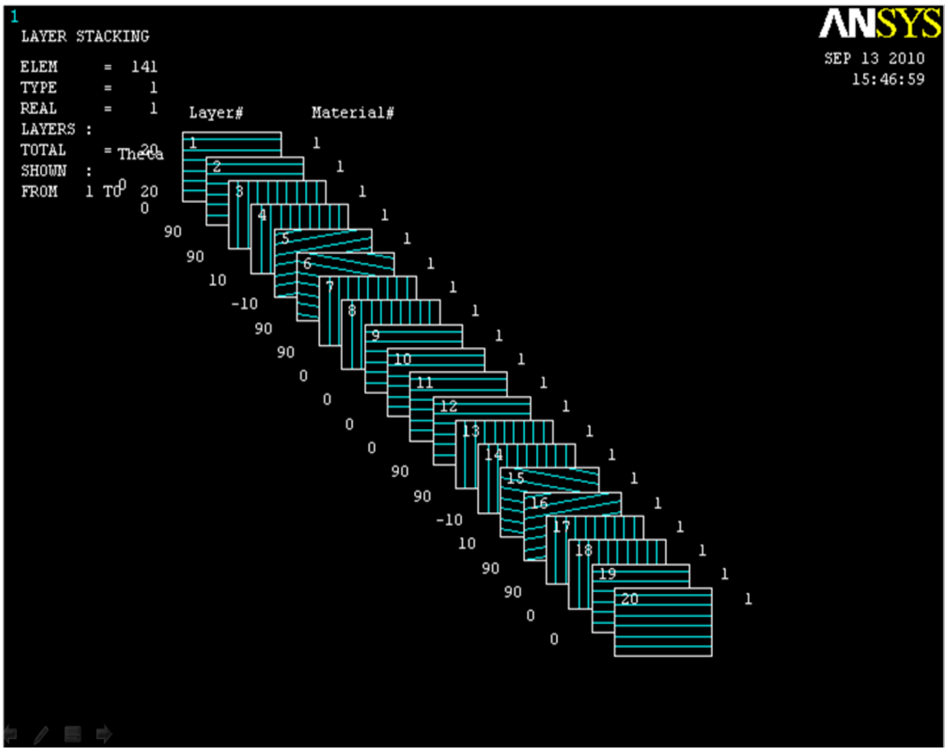


Fig. 6 Graph showing variation of deflection with ply orientation



```
1
LAYER STACKING
ELEM    =  141
TYPE    =    1
REAL    =    1
LAYERS :
TOTAL   =   20
SHOWN  :
FROM   1 TO  20
```

Fig.7 Layer stacking sequence of laminate having configuration $[0_2/90_2/\pm10/90_2/0_2]_s$

The minimum deformation under axial loading was obtained for $\theta = 10^\circ$.The corresponding laminate configuration is designated as $[0_2/90_2/\pm10/90_2/0_2]_s$.

V. CONCLUSION

Stiffened composite laminated conical shells are integral part of spacecrafts and launch vehicle structures. The best suited laminate for interface ring was obtained as cross plies comparing with angle plies. The optimum ply orientation for laminated conical shells having angle plies was obtained with a ply orientation of 10 degree.

REFERENCES

[1] March, S.," *Influence of Predetermined Delaminations on Buckling and Postbuckling Behavior of Composite Sandwich Beams"*, Composite Structures, Vol. 17, pp. 295-329, 1991.

[2] Cheng, S. and Ho, B.P.C., "*Stability of Heterogeneous Aeolotropic Cylindrical Shells Under Combined Loading"*, AIAA Journal, Vol. 1, pp. 892-898,
1963,

[3] Jones, R. M., and Morgan, H. S., "*Buckling and Vibration of Cross-ply Laminated Circular Cylindrical Shells"*, AIAA Journal, Vol. 5(8), pp. 1463, 1967.

[4] Reissner, E.," *On The Theory of Bending of Elastic Plates"*, Journal of Mathematics and Physics, Vol. 23, pp. 184-191, 1944,

[5] Yang, P., Norris, C. H. and Stavsky, Y., "*Elastic Wave Propagation in Heterogeneous Plates"*, International Journal of Solids and Structures, Vol. 2, 1966, pp. 665-684, 1966.

[6] Librescu, L., Khdeir, A., and Frederick, D.," *A Shear Deformable Theory of Laminated Composite Shallow Shell-Type Panels and Their Response Analysis"*, I: Free Vibration and Buckling, Acta Mechanica, Vol. 76, pp. 1-33, 1989.

[7] Van der Neut, A.," *The General Instability of Stiffened Cylindrical Shells under Axial Compression"*, National Aeronautical Research Institute (Amsterdam), Report Series 314, 1947.

[8] Baruch, M., and Singer, J., "*Effect of Eccentricity of Stiffeners on the General Instability of Stiffened Cylindrical Shells Under Hydrostatic Pressure*," Journal of Mechanical Engineering Sciences, Vol. 5, pp. 23-27, 1963,

[9] Hedgepth, J. M., and Hall, D. B.," *Stability of Stiffened Cylinder"*, AIAA Journal, Vol. 3, pp. 2275-2286, 1965,

[10] Venkatesh, A., and Rao, K. P., "*Analysis of Laminated Shells with Laminated Stiffeners Using Rectangular Finite Elements"*, Computers Methods in Applied Mechanics and Engineering, Vol. 38, pp. 255-272, 1983.

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