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PARAMETRIC STUDY OF LATTICE CONICAL ADAPTOR

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Abstract— In aerospace and launch vehicle systems, grid stiffened composite play a vital role in the design of structures of high specific stiffness. Strength of light weight structures depends mainly on the stiffening methods employed in its design. Various stiffening methods being used for structural products are the T, Z, blade and hat. This provided the benefit of added load carrying capability with a marginal weight penalty. Due to lower weight and cost, composite grid/lattice structure concept is advantageous over stiffened and sandwich designs. Grid structures are characterized by a lattice of rigid, interconnected ribs. These are fabricated with or without skins depending upon the applications. The ribs that comprise the structure can be arranged in a variety of ways. Generally the ribs are arranged in axial, circumferential and helical directions. As per the literature, unidirectional arrangement of the ribs possesses good impact damage tolerance, resistance to delamination and crack propagation across the grid. The ribs comprising the grid structure are usually loaded in axial direction so that in composite grid structure fibers are usually oriented along the ribs axial direction to provide axial strength and stiffness. The main advantages of the grid structure are its stable configuration, higher structural efficiency and lower cost.

Index Terms— Isogrid, Composite, Grid stiffened structure, Compressive stress, Finite element analysis, , Laminates

1. Introduction

Composites are the most important materials to be adapted for aviation since the use of aluminum in the 1920s. While analyzing the literature, R.M.Jones [1] studied in detail the composite structure, its advantage as a structural design element. It includes different composites like sandwich; laminated, fibrous etc.this textbook has given a deep insight to the theoretical art behind composites. M. Kamruzzaman, A. Umar, S. Q. A. Naqvi and N. A. Siddiqui[2] in their present study, an effort has been made to identify better configuration of given composite to achieve higher buckling strength for laminated anti-symmetric cross and angle-ply simply supported rectangular orthotropic plates subjected to uniaxial compressive loads. He jingxuan , Ren mingfa , Sun shiyong , Huang qizhong , Sun xiannian [3]studied gridded structures . Axial compression test is performed on an advanced grid stiffened (AGS) composite cylinder and the progress of failure is recorded by strain sensors and LVDT sensors. Failure prediction on the AGS composite cylinder is accomplished by a cyclical symmetrical finite element (FE) model which can improve the efficiency structures of numerical simulation. Numerical results and experimental data are compared to verify the proposed model. Eyassu Wodesenbet, Samuel Kidane, Su-Seng Pang [4] developed an improved smeared method to model the buckling problem of an isogrid stiffened composite cylinder.

In this model the stiffness contributions of the stiffeners is computed by analyzing the force and moment effect of the stiffener on a unit cell. The equivalent stiffness of the stiffener/shell panel is computed by superimposing the stiffness contribution of the stiffeners and the shell. An improved smeared method is developed to model the buckling problem of an isogrid stiffened composite cylinder. In this model the stiffness contributions of the stiffeners is computed by analyzing the force and moment effect of the stiffener on a unit cell. G. Totaro, Z. Gürdal [5] studied an optimization method for composite lattice shell structures under axially compressive. The method implements and improves some previous results of the fully analytical approach which is currently adopted at the state-of-the-art. The fully analytical approach provides the minimum mass solution under buckling and strength constraints, irrespective of other possible design limitations, such as, shell stiffness constraints. The proposed method implements numerical minimization allowing the designer to easily handle suboptimal configurations which are located in the vicinity of the minimum mass solution.

E.V. Morozov , A.V. Lopatin , V.A. Nesterov[6] in their paper investigates the buckling behaviour of anisogrid composite lattice cylindrical shells under axial compression, transverse bending, pure bending, and torsion. The lattice shells are modelled as three-dimensional frame structures composed of curvilinear ribs subjected to the tension/compression, bending in two planes and torsion. The specialised finite-element model generation procedure (model generator/design modeller) is

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developed to control the orientation of the beam elements allowing the original twisted geometry of the curvilinear ribs to be closely approximated. Thomas D. Kim [7] describes the fabrication and axial compression testing of the composite isogrid sti€ened panel to identify various failure modes that are present in the structures such as rib crippling, skin(pocket) buckling, and general instability. The rib buckling was found to be the critical failure mode for the isogrid plate. Chiara Bisagni , Potito Cordisco [8] studied the buckling and post-buckling behavior of four unstiffened thin-walled CFRP cylindrical shells . The test equipment allows axial and torsion loading, applied separately and in combination, using a position control mode, and includes a laser scanning system for the measurement in situ of the geometric imperfection as well as of the progressive change in deformations.

The results identify the effects of laminate orientation, show that the buckling loads are essentially independent of load sequence and demonstrate that the shells are able to sustain load in the post-buckling field without any damage.P.E. John Higgins, Peter Wegner, Adrian Viisoreanu , Greg Sanford [9] studied a composite grid-stiffened structure concept was selected for the payload fairing of the Minotaur launch vehicle. Compared to sandwich structures, this concept has an advantage of smaller manufacturing costs and lighter weight. To reduce weight the skin pockets are allowed to buckle visibly up to about 0.5 cm peak displacement. Various failure modes were examined for the composite grid-stiffened structure.

2. CLASSICAL LAMINATE THEORY

All The formulation presented in this section, with some little modification, is based on Classical Lamination Theory, CLT [2]. To use this theory and derive expressions of buckling load for thin orthotropic antisymmetric cross-ply and angle-ply laminated plates, following assumptions have been made:

- The plate thickness is very small compared to its length (a) and width (b).
- The plate is made up of perfectly bonded laminae.
- The bonds are infinitesimally thin and no lamina can slip relative to the other. This implies that the displacements are continuous across the lamina boundaries. As a result, the laminate behaves like a lamina with special properties.
- No body force exists.
- Stresses acting in the xy plane (the plane of the plate) dominate the plate behavior. The stresses σ_z; ζ_{xz} and ζ_{yz} are assumed to be zero such that an approximate state of plane stress is said to exist.
- Displacements u, v, and w in X, Y , and Z {directions are small compared to the plate thickness.
- Strains ε_x; ε_y;and γ_{xy} are small compared to unity.
- Rotary inertia terms are negligible.

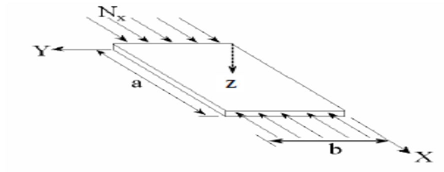

Fig 1. Simply Supported Laminated Rectangular Plate under In-Plane Uniaxial Compression.

2.1 Governing Equation for Buckling Load

Classical Laminate Theory, CLT has been used to derive the governing buckling equations for a plate subjected to in plane load. To derive the governing equations we have considered first the equilibrium of force and then the equilibrium of moment in a way as discussed below:

$$\frac{\partial N_X}{\partial x} + \frac{\partial N_{XY}}{\partial y} = 0$$

$$\frac{\partial N_{XY}}{\partial x} + \frac{\partial N_Y}{\partial y} = 0$$

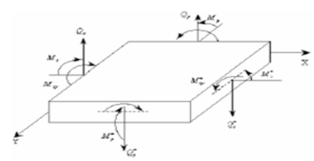

Fig 2 In Plane Forces On Laminate

where N_x; N_y; and N_{xy} are the internal forces in normal and tangential direction. Again, the equilibrium equation in terms of the moments where, N_x;N_y;N_{xy} are the forces applied at the edges.The Figure 2 shows the resultant forces N_x; N_y and N_{xy} and moments M_x;M_y and M_{xy} acting on a laminate are obtained by integration of the stress in each layer or lamina through the laminate thickness.

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = [T]^{-1} [Q] [T] \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix}$$

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} \overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}} \\ \overline{Q_{12}} & \overline{Q_{22}} & \overline{Q_{26}} \\ \overline{Q_{16}} & \overline{Q_{26}} & \overline{Q_{66}} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix}$$

Synthesis of stiffness matrix

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^o \\ \varepsilon_y^o \\ \gamma_{xy}^o \end{bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix}$$

$$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^o \\ \varepsilon_y^o \\ \gamma_{xy}^o \end{bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix}_k \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix}$$

$$\begin{bmatrix} N \\ M \end{bmatrix} = \begin{bmatrix} A & | & B \\ B & & D \end{bmatrix} \begin{bmatrix} \varepsilon^o \\ k \end{bmatrix}$$

A, B, D are called extensional stiffness matrix, coupling stiffness matrix, and bending stiffness matrix, respectively.

2.2 Grid Stiffened Structure

Isogrid consists of a lattice of intersecting ribs forming an array of equilateral triangles integral with the face sheet. This pattern takes advantage of the simple fact that triangular trusses are very efficient structure. Isogrid behaves like an isotropic material with no directions of instability or weakness and Poisson's ratio as 1/3. It is found to be most efficient in resisting compression and bending loads. It gives lower weight, less structural depth, standard pattern for attachments at nodes and better resistance to impact damage. It is also a cost effective structure. Isogrid structures shown in Figure 3 are effectively used in many aerospace applications such as Delta vehicle, Skylab and Space Shuttle to name a few [3].

Fig 3. Gridded conical adaptor

2.2.1 Isogrid-Design Aspects

Isogrid structures are effectively used in such applications with the advantage of lower weight and higher structural efficiency. An Isogrid structure is characterized by face-sheet thickness (*t*), rib thickness (*b*), rib depth (*d*) and height of triangle (*h*). These parameters ensure simultaneous failure of Isogrid structure by local skin buckling, rib crippling and general instability. Therefore, it is necessary to evolve a systematic iterative procedure to obtain a feasible and optimum design. It is proposed to use Finite Element Method (FEM) based software (PATRAN)[4]. The Isogrid design parameters are *t* (skin thickness), *b* (rib width), *d* (rib depth), *h* (triangle height) and *a* (leg of triangle). The other non-dimensional parameters used in Isogrid sizing are

$$\partial = \frac{d}{t}, \alpha = \frac{bd}{th}$$

$$\beta = \left[3\alpha(1+\delta)^2 + (1+\alpha)(1+\alpha\delta^2)\right]^{1/2}$$

A node of an Isogrid structure is a point where all six ribs intersect. In the manufacture of Isogrid, extra material is left at the node because the milling cutters cannot cut to the center of the intersection without cutting in to the ribs.

3. SUBSCALE STUDY

3.1 Modeling the Geometry

An Isogrid cylindrical structure is modeled in using the modeling software CATIA V5 for easiness in the geometric creation. Here surface modeling techniques are implemented for design. Material used: CARBON FIBRE T800.

Table 1 Material Properties of Carbon Fibre T800

Young'smodulus in longitudinal direction,E_1	145 GPa
Young's modulus in transverse direction,E_2	6 GPa
Poisons ratio (υ_{12})	0.32
Stress,σ_{1T}	190 MPa
σ_{12}	70 MPa
G_{12}	2.3 GPa
σ_{1C}	110 MPa

3.2 Cylindrical Model

This cylindrical structure is modeled to assess all the designing parameters like thickness of ribs, width of the ribs, angle of ribs etc. Parametric study and analysis of this structure is conducted in finite element softwares Dimensions of the cylindrical structure are shown in the Table 2 below.

Table 2 Dimensions Of Cylindrical Model

Diameter of cylinder	300 mm
Height of cylinder	200 mm
Helical angle	30º
width of ribs ,b	4mm
height of ribs, h	10mm
h/b	2.5

The structures are given compressive load on the top portion by fixing the base part. . Analysis is carried out by varying the applied load on the structure in order to find the maximum stresses occurring on the structure. The load applied is 15000kgf.

- Y component

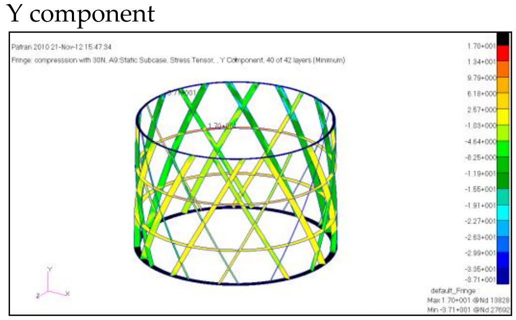

Fig 4. Stress Acting In Y Direction 15000kgf Load

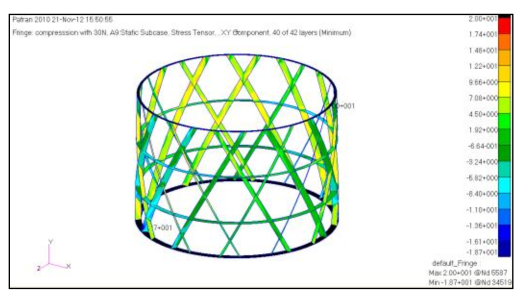

Fig 5. Stress Acting In XY Direction 15000kgf Load

4. THEORETICAL ANALYSIS

It includes theoretical calculation of transverse Young's Modulus with the given data and geometrical parameters.

Height of the rib, b=10mm
Diameter of the rib, d=300mm
Width of the rib, t=4mm
Length of the rib, h=200mm

Alpha, α = $\frac{b.d}{t.h} = \frac{10 \times 300}{4 \times 200} = 3.75$

Delta, δ = $\frac{d}{t} = \frac{300}{4} = 75$

$$\beta = \sqrt{3\alpha(1+\partial)^2 + (1+\alpha)(1+\alpha.\partial^2)}$$

$$= \sqrt{3 \times 3.75(1+75)^2 + (1+3.75)(1+3.75 \times 75^2)} = 406.42$$

Longitudinal Young's modulus, E_L=145000 MPa
Transverse Young's modulus

$$E_T = E_L \frac{(1+\alpha)^2}{\beta}$$

$$= 145000 \frac{(1+3.75)^2}{406.42} = \underline{\underline{8GPa}}$$

The theoretical transverse young's modulus (8GPa) we got is almost close to the actual transverse young's modulus of the material (6 GPa) used. From this we can fix the parameters height of the rib (b) and width of the rib (t).

4.1 Comparison of experimental results

Compression test is done with Universal Testing Machine (UTM) [8] and the results are analyzed. Maximum load applied in the experiment is 86000 kg because of UTM limitations.

Fig 6. Fabricated Gridded Cylindrical Lattice Structure

a) Y component

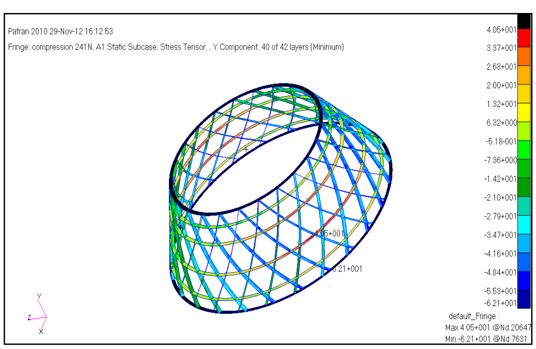

Fig 7. Stress Acting In Y Direction 313kN Load

b) XY component

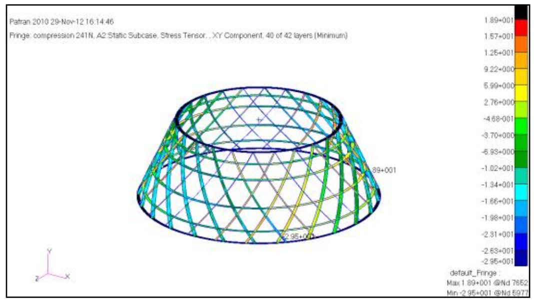

Fig 8. Stress Acting in XY Direction 313kN Load

4.2 Buckling analysis 313 kN on new model(24 helical ribs,4 inner circular ribs)

Buckling analysis is also performed on the same conical structure; first, second and third mode is extracted as shown in the figure 9, figure 10, figure 11.The buckling factor is analyzed and found that it is greater than one and hence safe design.

a) first mode

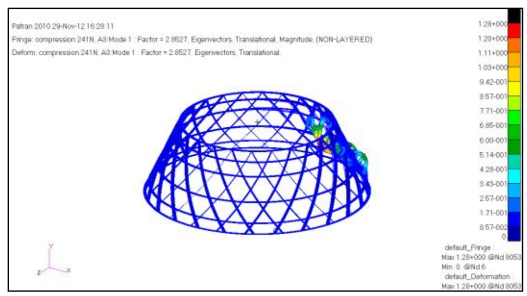

Fig 9. Buckling First Mode with 313kN Load

b) Second mode

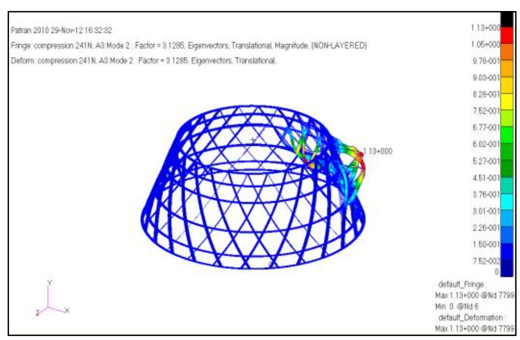

Fig 10. Buckling Second Mode with 313kN Load

c) third mode

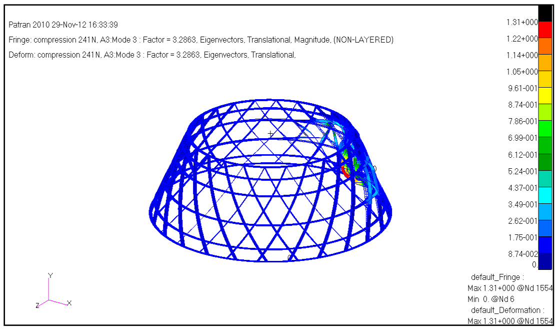

Fig 11. Buckling Third Mode with 313kN Load

Both theoretically calculated stress along y direction (57.05N/mm2) and numerically calculated value of stress (62.1N/mm2) we got are almost same. Here both stresses as well as buckling factor are safe for the design so loading is increased to 400 kN.

4.3 COMPRESSIVE AND BUCKLING ANALYSIS 400 kN (24 helical ribs,4 inner circular ribs)

Compressive load 400 kN on new model (24 helical ribs,4 inner circular ribs). Here the conical structure, the load is increased to 400kN; the stress obtained is 80.4 MPa in Y direction and 37.7 MPa in XY direction as shown in the Figure 12 and Figure 13. It is coming in the safe range as given in the Table 1.

a) Y component

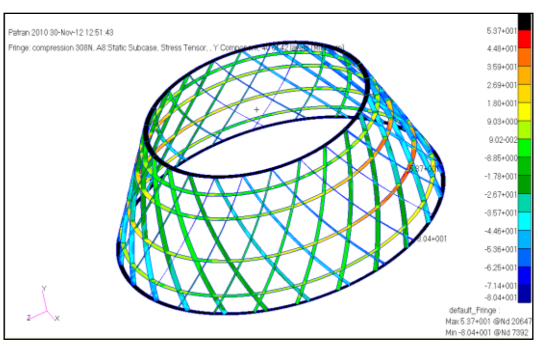

Fig 12. Stress Acting In Y Direction 400kN Load

b) XY component

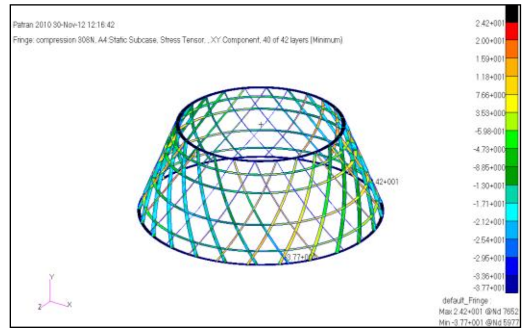

Fig13. Stress Acting In XY Direction 400kN Load

Buckling analysis 400 kN on new model(24 helical ribs,4 inner circular ribs)

Buckling analysis is also performed on the same conical structure; first, second and third mode is extracted as shown in the figure 14, figure 15, figure 16. The buckling factor is analyzed and found that it is greater than one and hence safe design.

a) first mode

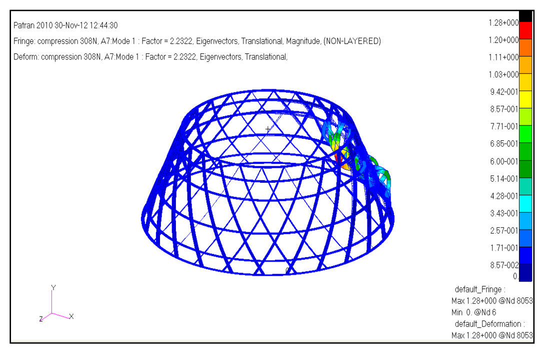

Fig 14. Buckling First Mode with 400kN Load

b) Second mode

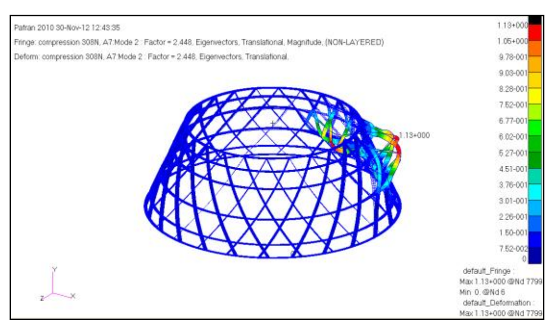

Fig 15. Buckling Second mode with 400kN load

c) third mode

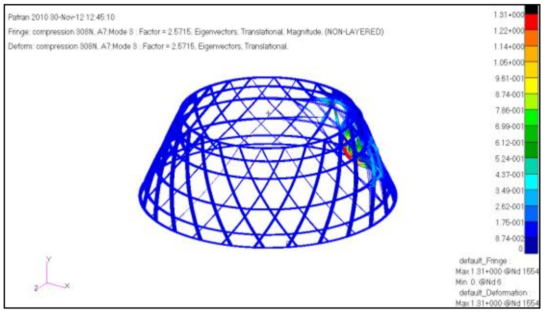

Fig 16. Buckling Third Mode with 400kN Load

While increasing the load to 450 kN, it is found that Buckling factor is less than 1. The structure fails due to buckling and compression test also. Hence from this analysis, it can be concluded that the maximum axial compressive load the gridded structure can withstand is 400kN. It is found that structures with width to thickness ratio 20:8(2.5) and helix angle of 30º are able to withstand a load up to 400kN.

5. CONCLUSION

The development of lightweight and highly efficient structural component is desirable for next generation of aerospace systems. Reducing the structural weight and improving the load carrying capabilities of these systems will allow designers to add additional capabilities while reducing life cycle costs. Grid stiffened composite play a vital role in applications where strength to weight ratio is the designing factor. My aim was to investigate the strength of composite gridded lattice structures and to achieve the most weight efficient design with the highest compressive load efficiency. Also analyzed the structure with parametric studies conducted on it using finite element software MSC Patran. For the same, cylindrical gridded model and conical gridded model of different loading conditions are considered. It is found that structures with width to thickness ratio 2.5 and helix angle of 30º are able to withstand a load up to 400kN. The results are matching with the experimental data. Its load carrying capacity is very high compared to other structures. It is providing high strength to weight ratio and advantages in cost too.Also as the structure is manufactured by using filament winding technique it has the added advantages of high reliability and repeatability.

6. REFERENCES

1. R.M.Jones, "Mechanics of composite materials", 2nd edition, Taylor and Francis, Philadelphia, 1999.

2. M. Kamruzzaman, A. Umar, S. Q. A. Naqvi and N. A. Siddiqui, "Effect of composite type and its configuration on buckling strength of thin laminated composite plates", Latin American Journal of Solids and Structures 3 ,279-299,2006.

3. Jingxuan , Ren Mingfa , Sun Shiyong , Huang Qizhong , Sun Xiannian "Failure prediction on advanced grid stiffened composite cylinder under axial compression" College of Astronautics, Northwestern Polytechnical University, Xi'an 710072, China. Composite Structures 93 (2011) 1939–1946.

4. Eyassu Wodesenbet, Samuel Kidane, Su-Seng Pang "Optimization for buckling loads of grid stiffened composite panels" Department of Mechanical Engineering, Louisiana State University, Baton Rouge, LA 70803, USA.

5. G. Totaro , Z. Gürdal, "Optimal design of composite lattice shell structures for aerospace applications" CIRA – Italian Aerospace Research Center, Via Maiorise snc, 81043, Capua (CE), Italy. Aerospace Science and Technology 13(2009) 157-164.

6. E.V. Morozov , A.V. Lopatin , V.A. Nesterov " Finite-element modeling and buckling analysis of anisogrid composite lattice cylindrical shells" School of Engineering and Information Technology, University of New South Wales at the Australian Defence Force Academy, Canberra, Australia. Composite Structures 93(2011) 308-323.

7. Thomas D. Kim, "Fabrication and testing of thin composite isogrid stiffened panel" Asian office of Aerospace Research and Development, 7-23-17 Roppongi, Minato-ku, Tokyo 106, Japan. Composite Structure 49(2000) 21-25.

8. Chiara Bisagni , Potito Cordisco " An experimental investigation into the buckling and post-buckling of CFRP shells under combined axial and torsion loading".Dipartimento di Ingegneria Aerospaziale, Politecnico di Milano, Via La Masa 34, 20156 Milano, Italy. Composites Structures 60(2003) 391-402.

9. P.E. John Higgins , Peter Wegner , Adrian Viisoreanu , Greg Sanford "Design and testing of the Minotaur advanced grid-stiffened fairing" Air Force Research Laboratory, Space Vehicles Directorate, 3550, Aberdeen Avenue, SE, Kirtland AFB, NM 87117-5776, USA. Composite Structures 66(2004) 339-349.

10. E.V. Morozov , A.V. Lopatin , V.A. Nesterov "Buckling analysis and design of anisogrid composite lattice conical shells" School of Engineering and Information Technology, University of New South Wales at the Australian Defence Force Academy, Canberra, Australia. Composite Structures 93(2011) 3150-3162.