International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 9, September- 2014

Analysis of Space Launch Vehicle

A Coupled Field Analysis

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***Abstract*— Space launch vehicles are manufactured by thin metallic or composite shells. Such shells are vulnerable and prone to buckling due to internal pressures produced because of the combustion process of the solid propellant. The first stage of GSLV – III solid booster stage is considered for the analysis. The cylinder will be modeled as an orthotropic cylinder and various thickness and orientations will be checked for the cylinder weather it can with stand those loads. Mathematical calculation will be used to calculate the appropriate thickness of each layer for orthotropic cylinder. Finite element analysis tool ANSYS 14.5 will be used to calculate the results for doing the static and buckling analysis.**

Keywords — Space launch vehicle ; Coupled field analysis; ANSYS; APDL.

I. INTRODUCTION

Cylindrical shells are structures which find uses in a large number of applications. In the aerospace field, they are used extensively as rocket bodies and aircraft fuselage. As designers look for methods of further reducing the weight of such shell structures, fibre reinforced composite materials are finding wider usage [1]. Because of the thinness of these structures, buckling is often the controlling failure mode. It is therefore essential that their buckling behaviour be properly understood so that suitable design methods can be established [2].

In India, the launch vehicles development program began in the early 1970s. The first experimental Satellite Launch Vehicle (SLV-3) was developed in 1980. An Augmented version of this, ASLV, was launched successfully in 1992. India has made tremendous strides in launch vehicle technology to achieve self-reliance in satellite launch vehicle program with the operationalization of Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV).

Figure 1. Launch vehicle family of INDIA

The primary objective of this paper is to do the optimum thickness calculations for the considered model of GSLV MK – III space launch vehicle and apply the thermal as well as structural loads and study the behavior of the cylindrical shell. It is of interest to examine the behavior of the proposed launch vehicle models under thermal loads and internal pressure loading. The outer cases of launch vehicle are considered as orthotropic (composite) cylindrical shells. They are the main structures of interest in the stability analyses. ANSYS Parametric Design Language (APDL) will be used to compare the results for different thicknesses and lay-ups.

II. OPTIMUM THICKNESS CALCULATIONS

The formula for calculating the optimum thickness based on the applied loading and radius is

$$t^3 = \frac{12PR^3\left(1 - v_{xy}v_{yz}\right)}{3E_y}$$

Where,
P – Applied pressure
R - Radius of the cylinder
$v_{xy}v_{yz}$ – Poisson's ratio in XY and YZ directions respectively
E_Y – Young's modulus in Y direction

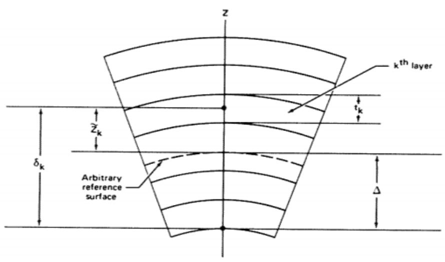

Figure 2. Multi-layered orthotropic cylindrical shell geometry

If we calculate the thicknesses for other ply-orientations with an applied pressure of 0.6 MPa [4], we are going to get the following values

Ply orientation	90 +10 -10 90	90 +45 -45 90	90 +85 -85 90
Modulus [E_y]	95753.26495	114752.4135	158831.1435
Thickness [t]	46.55955	43.83348	39.33218

Table-1 Thickness values for Different Ply-Orientations (P=0.6 MPa)

Similarly, if we calculate the thicknesses for other ply-orientations with an applied pressure of 6.2 MPa, we are going to get the following values

Ply orientation	90 +10 -10 90	90 +45 -45 90	90 +85 -85 90
Modulus [E_y]	95753.26495	114752.4135	158831.1435
Thickness [t]	101.41	95.47	85.67

Table-2Thickness values for Different Ply-Orientations (P=6.2 MPa)

III. METHODOLOGY

The re-usable large solid booster of GSLV MK-III is modeled as an orthotropic cylinder. The formula for calculating the optimum thickness is provided in the previous session. The material properties of these composites are shown in the table 1.

S. NO.	Parameter	Value
1	EX	120000
2	EY	9000
3	EZ	9000
4	PRXY	0.25
5	PRYZ	0.32
6	PRXZ	0.25
7	GXY	3580
8	GYZ	4500
9	GXZ	3580
10	KXX	7e-3
11	DENS	1.7e-6
12	ALPX	2e-6

Table-3: Material Properties of CFRP

IV. FINITE ELEMENT MODELLING AND ANALYSIS

A. Modeling

Outer radius	=	1600 mm
Inner radius	=	1249.36 mm
Length	=	22000 mm
No. of layers	=	4

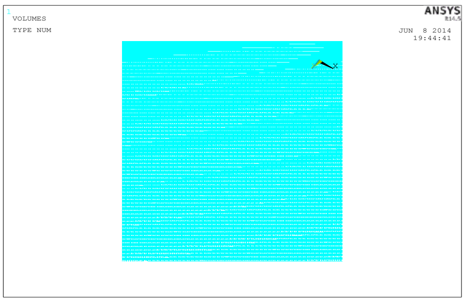

Figure-3. Geometry of cylinder

B. Analysis

The thermal and static analysis is done on the composite cylinder by applying composites. The thermal analysis is done by applying temperature of 1804 k on inner layers. The results obtained in the thermal analysis are applied for the space capsule in structural analysis and an internal pressures of 0.6 and 6.2 MPa are applied simultaneously.

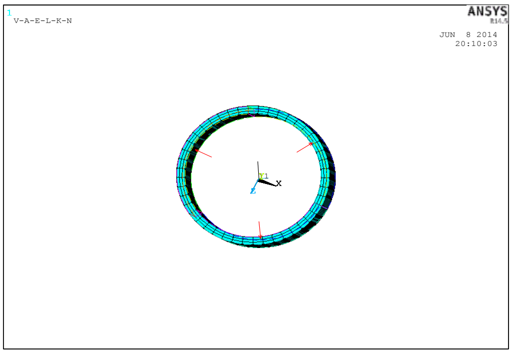

Figure-4: Applied Boundary Conditions

V. RESULTS AND DISCUSSION

The below figure shows the results of the nodal solution for the displacement vector sum and von-mises stress.

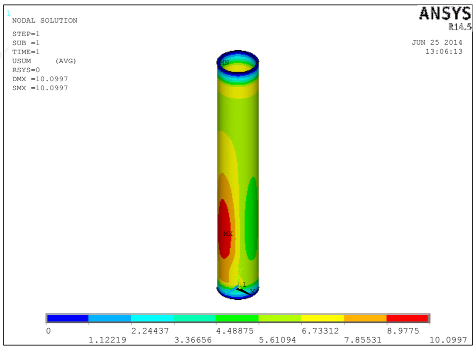

Figure-5: Displacement Vector sum for P = 0.6 MPa

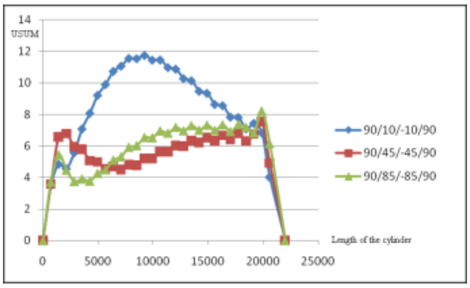

Figure-6 Displacement vector sum vs. length of the cylinder graph

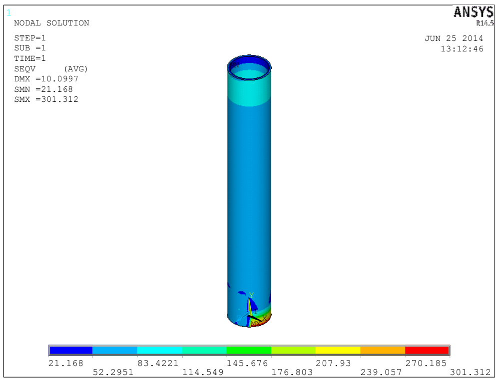

Figure-7 Von-mises stress for P=0.6 MPa

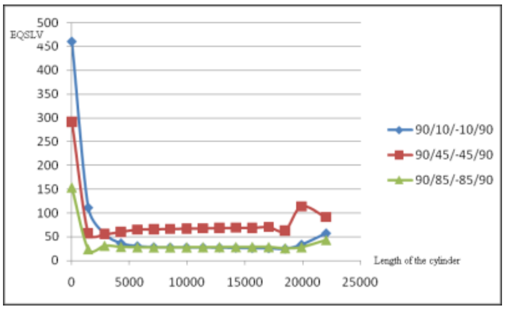

Figure-8 Vonmises stress Vs. length of the cylinder

The above results shows the displacement vector sum and von-mises stresses result. Figures 6 & 8 are showing the comparison for different lay-ups for the same applied load. The coupled field analysis results are tabulated in the below tables.

Applied pressure (MPa)	0.6		
Thickness (mm)	**46.55** **(90/10/-10/90)**	**43.83** **(90/45/-45/90)**	**39.33** **(90/85/-85/90)**
Maximum Displacement (mm)	11.5406	10.0997	10.7876
Maximum Vonmises stress (MPa)	474.211	301.312	188.24

Table-4 Comparison of results between different orientations for P=0.6 MPa

Applied pressure (MPa)	6.2		
Thickness (mm)	**101.41** **(90/10/-10/90)**	**95.47** **(90/45/-45/90)**	**85.67** **(90/85/-85/90)**
Maximum Displacement (mm)	11.0958	9.9479	12.316
Maximum Equivalent stress (MPa)	640.812	489.059	340.288

Table-5 Comparison of results between different orientations for P=6.2MPa

From the results we can say that, as per the stiffness criterion the 90/45/-45/90 lay-up is best suitable. But as per the strength criterion, the 90/85/-85/90 lay-up is suitable. On the over-all consideration the 90/45/-45/90 lay-up is best suited for all kind of loading conditions.

VI. CONCLUSION

Based on the results that we got from the analysis the following conclusions have been drawn:

- The Composite cylinder designed is meeting the stipulated internal pressure. The procedure followed has worked out to be efficient in accurately predicting the structural response of composite components.
- It meets all the desired functional requirements.

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