Effect of Cylindricity on Buckling of Vented Interstage

Sinu C G
Assistant Professor
Department of Civil Engineering
Jyothi Engineering College Thrissur, Kerala

Nice Thomachan
Assistant Professor
Department of Civil Engineering
Vidhya academy of science and technology, Thrissur, Kerala

Abstract

Eigen value buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural eigen values for the given system loading and constraints. This is known as classical Euler buckling analysis. The indigenous version of IS 1/2V (Vented interstage of GSLV) is designed for an equivalent axial load of 5400KN. Isogrid structure acts like an isotropic material, with equal properties measured in any direction, and grid, referring to the sheet and stiffeners structure. The structure consisting of equilateral triangles offers superior strength with extraordinarily less weight due to its high strength to weight and stiffness to weight ratio characteristics.
Keywords: Aerospace structures, ISOGRID design, Monocoque Structure

I. INTRODUCTION

The vented interstage structure is a cylindrical structure that is situated between in the interstage middle structure at the fore end and the solid motor at the after end. This structure has a diameter of 2800mm and height of 1752 mm. In the earlier launch vehicles, the loading case considered was for compressive loading. Unlike the earlier launch vehicles, the thrust in the next generation launch vehicle is transferred at the fore end due to the attachment of the S200 strap on thrusters. This changes the loading criterion to tensile loading. This is the first attempt in designing isogrid structure for tensile loading case. It is configured as an independent structure to facilitate the easy assembly and testing of avionics. Isogrid is an integrally machined structure unlike the closely stiffened structure where the skin and the stringers were separate. The use of rivets and bolts is less thereby increasing the margin with a low weight the structure consisting of equilateral triangles offers superior strength with extraordinarily less weight due to its high strength to weight and stiffness to weight ratio characteristics. The repetitive pattern helps to reduce the manufacturing costs by allowing effective use of the equipment intensive manufacturing methods. Isogrid structures are effectively used in launch vehicles with the advantage of lower weight and higher structural efficiency. Isogrid is an integrally machined structure unlike the closely stiffened structure where the skin and the stringers were separate. The use of rivets and bolts is less thereby increasing the margin with a low weight. Material used for construction AA 2014. This is an alloy of aluminium. The main application of this alloy is for constructing interstage structures.

II. AEROSPACE STRUCTURES

Aerospace structures play a pivotal role in many aspects of launch vehicle design. Some of the major roles include:
- To provide an external shape as per aerodynamic considerations.
- To be able to withstand the ground and flight loads.
- To provide housing for the payload, propulsion, guidance and control systems.

The major constraints required for the design of aerospace structures are based on the structural integrity and low mass construction. Structural integrity means that the structure should not fails during its service life. Weight of an aircraft can have an adverse effect on the performance of the flight.

Launch vehicle structural systems can be classified into
- Primary load bearing structures.
- Auxiliary or secondary structures.

The primary load bearing structures contribute to the stiffness of the launch vehicle and thereby its performance. These are mainly stage motor cases or tankages (for liquid) interstages, Heat shield, payload adaptor, etc. The auxiliary structures are fue1 tanks for control systems, gas tanks for the pressurization of liquid stages, deck plates for EB etc. which do not carry the primary loads of the vehicle.

A. Structure Configurations:

1) Monocoque

Monocoque cylinder is the cylinder structure that does not have any longitudinal stiffeners called stringers or tranverse stiffeners like bulkheads. Materials with high stiffness to weight ratio are used. Usually used for light loaded structures of small diameter. Used for motor cases (solid propellants), propellant tanks (liquid) and interstage structures. In multistage rockets, the upper stages are usually of smaller diameter than the lower stages. Conical monocoque structures are employed to provide an interface to permit the transition of the diameter. The fig 1 represents a monocoque structure.

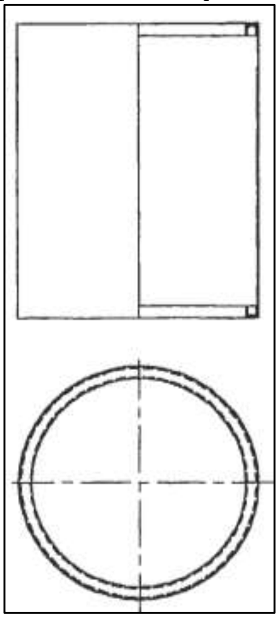

Fig. 1: monocoque structure

2) Semi Monocoque:

The substructure, which consists of bulkheads and/or formers of various sizes and stringers, reinforces the stressed skin by taking some of the bending stress from the fuselage. The semimonocoque is the most often used construction for modern, high-performance aircraft.Stringer structures are the structures that use only longitudinal stiffeners called stringers. This improves the strength and the stiffness of the structure.Closely stiffened structures employ both stringers and transverse stiffeners called bulkheads. The stringers should have sufficient enough strength and bulkhead should have enough stiffness.

3) Integrally Stiffened:

In these structures, the skin and the skin stiffeners are produced as an integral unit.

Isogrid: The sheet of metal is integrated with the stiffeners in a triangular pattern. The triangular pattern is very efficient because triangular trusses are very efficient structures. This causes a high strength and stiffness structure. These structures are mainly employed in the lower stages of launch vehicles which have to support the full weight of the upper stages.

Waffle: It consists of a lattice of ribs forming an array of repetitive square or rectangular pattern.

4) Cored Face:

Sandwich structures: This structure constitutes of two thin load bearing face sheets bonded on either side on a thick light weight core. This prevents the face sheets from buckling. The core structure maybe of solid type (foam, balsa wood) or cellular type (aluminium). These structures have high strength to weight ratio. Laminated face sheets are more preferred over metallic face sheets due to their ease in machining into complex curved shapes. Due to its high strength characteristics, the use of stiffening elements can be reduced.

Honeycomb structure: These structures are used as core in sandwich structures. When these are sandwiched between carbon fibre layers, they exhibit good bending resistance.These exhibit the following advantages:

- Ease of Machining.
- High strength to weight and stiffness to weight ratio.
- Cost effective.
- Less weight.

III. DESIGN REQUIREMENT

A. Requirements

The structure shall have sufficient strength and stiffness to satisfy the following conditions:

1) The structure shall not fail at design/ultimate load.
2) The structure shall withstand proof load without global yielding.
3) Maximum deflection at any section of the structure shall not be so large so as to considerably redistribute the load during flight and handling.
4) The mechanical properties considered for the design shall be on the basis of 99% exceedance with 95% confidence level.

B. *Load Factors:*

The structure shall have sufficient strength and stiffness to satisfy the following load factors on the limit loads specified:
1) Design/ultimate load factor shall be 1.25
2) Proof load factor shall be 1.1
3) Fitting factor of 1.1 or greater shall be used for design of structural joints wherever necessary.

C. *Functional and Operational Requirements:*

Provision shall be made in the structure for reference marks and vehicle axis transfer. The axis marking on individual structure shall be by using 90 deg x 0.5 mm deep notch at Y+ location at forward and aft end of the structure.
1) All joints shall be rain/water proof
2) All defined cutouts shall be provided with suitable closures, which can be provided using a standard size fastener (M5 or bigger) and shall ensure water proofness.
3) Structure shall be configured to minimize the TPS application area and its mass.
4) All internal brackets and mountings are to be designed for the inertial loads acting on them considering both longitudinal and lateral loads acting simultaneously.
5) The natural frequency of the mountings shall be in excess of 70 Hz.
6) Ultimate load factor for the design of the brackets and mountings interfaces shall be 2.

IV. DESIGN DETAILS

Isogrid design is based on "The isogrid design handbook". Design iterations were performed over the different panels of the structure. Since, the structure experiences compressive loading, the iterations were performed to check the stability in the compressive case. Once these were satisfied these values were kept as the benchmark and then iterated for the tensile case and the different parameters were finalised.

A. *Isogrid Design:*

The hand calculations were performed based on the design handbook.Based on the hand calculations and the design iterations that were performed, the isogrid was successfully designed as per the design requirements. The detailed design procedures followed were explained below

Equivalent axial load (EAL) = 5400 KN

Force / unit length (N_x) $=5400000/2\pi R$

$= 613.88\ N/mm^2$

Where R is the radius of the interstage and which is equal to 1400 mm.
The depth of the rib calculated from the equation

$$\frac{d}{R} = \left[\frac{4.045\ kc}{\gamma^3}\frac{Nx^2}{ER}\right]1/5$$

Where γ = knock down factor =0.5
Assume K_C =2
Substituting the above values in the above equation we get
d = 26.27 and also β = 0.04824
We know that $\beta = \frac{b}{a}$
The circumference c = 2π R = 8794.8 mm
Take 35 pockets around the circumference

Then a = 8794.8/45

=195.44 mm

$H = \sqrt{\frac{3}{2}}\, a = 169.25\ mm$

$b = \beta a$

=0.04824x 195.44 = 9.428 mm

And finally the value of general instability is obtained from

$$Ncr(1) = \frac{0.706\ X\ 0.5\ X\ 73084.42\ X\ 0.04824\ X\ 26.27\ X\ 26.27}{1400}$$

=613.886 N/mm

After the design so many iteration are done for getting the finite element model.

V. Finite element analysis

A. *Introduction:*

Finite element analysis of the structure is carried out using finite element software ANSYS 14.5 for the expected flight loads to obtain stresses and displacements.Buckling strength of the structure was analysed using buckling analysis

B. *Details of FE Modelling:*

FE analyses are carried out for ultimate loads.Full model is considered for analysis. The FE model is shown in fig 1

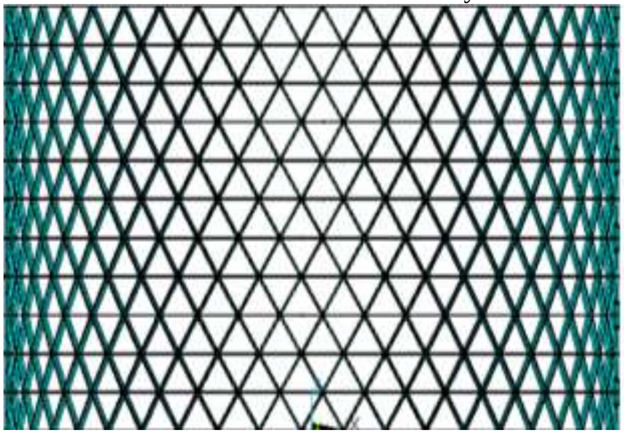

Fig. 1: Finite element model of the Vented Interstage

The finite element model of vented interstage was modelled using beam element (2node 188).The circumferential beams are modelled using beam section of size 26.27x8.42 mm. The inclined beams are modelled using beam sections of size 26.27x9.42 mm. The vented cylindrical structure having a total height of 1861.86 mm (11 x 169.26). The total numbers of elements are 2070 mm.

C. *Loads:*

During the first stage when the strapons burning, theinterstage structure is under tension and later, after the separation of strapons, the same structure is subjected to compression.The calculated loads are applied on the z- axis.

D. *Boundary Conditions:*

Boundary Conditions (BC) are different for different load cases. BCs are applied in cylindrical co-ordinate system. The boundary conditions applied for the structure is shown in fig 9.2. For the top nodes of the model U_x= U_y =0 restraints are applied and for bottom nodes of the model having U_x=U_y=U_z=0 are applied.

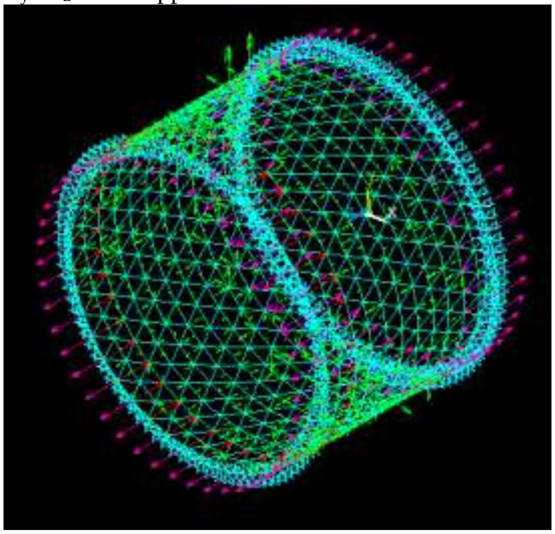

Fig. 3: Loading and boundary condition

VI. BUCKLING ANALYSIS

Eigenvalue buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural eigenvalues for the given system loading and constraints. This is known as classical Euler buckling analysis. Buckling loads for several configurations are readily available from tabulated solutions. However, in real-life, structural imperfections and nonlinearities prevent most real-world structures from reaching their eigenvalue predicted buckling strength; ie. it over-predicts the expected buckling loads. This method is not recommended for accurate, real-world buckling prediction analysis. Buckling analysis carried out for ultimate compressive load to determine the buckling strength. The theoretical buckling load factor is found from eigen value buckling analysis is 2.4. The result obtained from buckling analysis is shown in the following Table 1. Buckling analysis was done after the static analysis was completed.

Table – 1
LIST OF EIGEN VALUES

SET	*EIGEN VALUE*
1	*2.449*
2	*2.449*
3	*2.3168*
4	*2.3679*
5	*2.3679*
6	*2.4069*
7	*2.4315*

VII. CONCLUSION

The indigenous version of IS 1/2V is designed for an equivalent axial load of 5400 KN .The research carried out helps to contribute to applying and checking the feasibility of this technology for future design. The results help to conclude the advantages of open Isogrid over skin stringer configuration. It is very lighter than the other configurations. The primary objective was to design an open Isogrid structure to for the given requirements. This was achieved. The static analysis and buckling analysis was successfully achieved. The structure has an axial displacement of 10.8 mm and radial displacement of 3mm under the load. The maximum compressive stress obtained after the analysis is 316 Mpa. And the maximum tensile stress is 160 Mpa. The eigen value obtained after the buckling analysis is 2.4.The total mass of the structure is 199 Kg.

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