International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

Design and Analysis of Vented Interstage in a Typical Launch Vehicle

Yedhu U Krishnan
Mtech Student
TKM College Of Engineering
Kollam, India

Saidalavi P
Professor
TKM College of Engineering
Kollam, India

***Abstract*— In the space engineering launch vehicles are modified based on the new innovations. A typical launch vehicle is taken for the study. The launch vehicle is a multistage launch vehicle, between each stage there is an interstage. The lower portion of interstage lies between first and the second stage (1/2 L) is converted into vented. The main advantage of this system is that second stage starts firing even before the first stage blows off thus venting out the flue gases of combustion. Through the vented interstage structures are designed to take loads safely without failure. By making this as vented, the ullage rockets and retro rockets can be eliminated from the vehicle. The scope of this thesis is to Design of the vented inter stage, determine the buckling strength after considering a knockdown factor of 0.65 which proves that the structure is safe under the main mode of failure. Then find mass reduction between the vented interstage and the closely stiffened skin stinger construction.**

Keywords- Vented interstage, Ullage rockets, Isogrid cylinders, 1/2L interstage.

I. INTRODUCTION (HEADING 1)

In the aerospace engineering the launch vehicles have great importance so that various researches are being made on the launch vehicles. The typical launch vehicle under consideration is essentially a four stage launcher. A multistage rocket is a rocket that uses two or more stages, each of which contains its own engines and propellant. A serial stage is mounted on top of another stage; a parallel stage is attached alongside another stage. The result is effectively two or more rockets stacked on top of or attached next to each other

Between each main stages there is an interstage. The interstage is an inevitable portion in the launch vehicle and it interconnects two stages of the vehicle. The interstage that is provided between the first stage (solid rocket motor stage) and the second stage (Earth storable liquid stage) is being considered. The inter stage is again divided into three, Lower (1/2L), Middle (1/2M) and Upper (1/2U). Here the 1/2L is taken for study. Currently it is made as closely stiffened skin stinger construction. It has 2800mm diameter and 4100mm height. Over this height it houses many electronic components and other parts so only 1200mm height can be made as vented.

The vented interstage is constructed out of integrally stiffened isogrid structures. In launch vehicles, integrally stiffened sections have proved particularly effective as a lightweight, high strength construction. The isogrid structure is a lattice of ribs forming pockets of contiguous repetitive equilateral triangular pattern milled out of thick plate. The typical interstage structure is designed for the ultimate load conditions both tensile and compressive without any failure, which are found to be most critical. The main failure mode for these structures is buckling since predominant load is compressive in nature. The reduction of load carrying capacity due to imperfections is usually addressed by use of a knockdown factor. So it has been considered for finding the margin of safety.

Currently the 1/2 L configuration is closely stiffened skin stinger construction so it include many components such a retro rockets, ullage rockets, explosives etc. It increases the overall load of the launch vehicle. And also by making the part of inter stage as vented, the ullage rockets and retro rockets can be eliminated can be eliminated form this. The open iso grid structure allows ignition of upper stage prior to stage separation.

In this the structural analysis and buckling analysis of the structure under load conditions. The design is optimized in MATLAB software and the least mass configuration satisfying the required conditions is chosen. The project goes in detail with the modelling of the designed structure in a finite element analysis software and analyzing it to find out whether the designed model is safe under buckling load which is the main failure mode in the interstage structures. Then the finite element analysis results are validated with the mathematical calculations and the margin of safety is calculated to check whether the value is above the allowable limit. Also found out the mass reduction between the newly designed vented interstage and the closely stiffened skin stinger interstage. The vented intersatge is made of ALUMINIUM ALLOY AA2014 for the excellent mechanical properties and low weight.

CHARACTERISTICS OF ISOGRID STRUCTURES

- Considerably reduces the weight.
- Displays exceptional strength-to-weight and stiffness-to-weight characteristics.
- Minimizes manufacturing costs due to repetitive structure.
- Requires minimum tool change while machining.
- Needs no stabilizing frames.
- Minimal use of fasteners.
- Reduces costs while improving structural performance and reducing weight.

The open isogrid cylinder, consist of a grid work of ribs without skin, is loaded by resultant force, F, and resultant moment, M, at the ends of the cylinder. The initial axial load/inch, Nx, is given by

The maximum value of Nx occurs for $\Phi = 0$ degree,

Equivalent Axial Load (EAL) = Bending moment load + axial load

Axial load, F = 2580998 N

Axial load due to Bending moment load = 2M/R

Bending moment, M = 1242868 Nm

Section modulus, $Z = 2\pi R2t$ (for thin cylinder)

$$Area = 2\pi Rt$$

$$EAL = F + 2M/R$$

$$Nx = EAL/2\pi R$$

The method of optimization assumes that minimum weight occurs when general instability and Euler column bucking of the ribs within the cylindrical profile are equally likely. Buckling is a mathematical instability, leading to a failure mode. Buckling is characterized by a sudden sideways failure of a structural member subjected to high compressive stress, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding.

Under these assumptions, equivalent weight thickness, *t*, the plate thickness d, and the ratio of rib width, grid spacing, are determined. The magnitude of the rib width, b, and the grid spacing ‘ a ’ are determined to satisfy β, make the triangle size an integral multiple of the circumference to make the rib depth , d > b, the rib width so that local Euler column buckling of the ribs in the radial direction of the cylinder will not occur.

General Instability

Instability due to bending may be written in form,

$$Ncr(1) = 1/(\sqrt{(3(1-\nu^2))})\ (E t^2)/R$$

General instability is independent of the cylinder length.

For Rectangular Stiffeners

$$Ncr(1) = 2\nu/(\sqrt{(1-\nu^2)})\ E/R \sqrt{(AI)}$$

$$= 2.12\gamma E/R \sqrt{(AI)}$$

Where γ is “correction factor” In above equation A and I are “transformed” area and moment of inertia.

If A0 and I0 are the actual rib area and moment of inertia, then since A and I are linearly proportional to the width,

$$A= Ao/h ,\ I = Io/h$$

Giving

$$Ncr(1) = 2.12\gamma E/Rh \sqrt{(AoIo)}$$

$$Ao = db \text{ and } Io = (bd)^3/12$$

$$Ncr(1) = 0.612\gamma E(bd)^2/RH$$

Margin of safety,

$$MS(1) = (Ncr(1))/Nx - 1$$

Euler Column Buckling of Ribs

Assume one rib in ϕ direction,

$$\sigma = 2h/3bd\ Nx = P/bd$$

$$P = 2hNx/3 = aNx/(\sqrt{3})$$

By Euler Formula,

$$P = (Kc\pi^2 EI)/a^2 = Kc\pi^2\ (Ebd^3)/(12a^2)$$

where Kc is the column fixity.

Thus,

$$Nx = (\sqrt{3})/a\ (Kc\pi^2 Ebd^3)/(12a^2)$$

$$= 1.422\ (KcEbd^3)/a^3$$

Therefore,

$$Ncr(2) = 1.422KcEd\beta^3$$

On rib crippling , Margin of Safety,

$$MS(2) = (Ncr(2))/Nx - 1$$

II. OPTIMAL MASS DESIGN

Minimizing the mass of the interstage structure be achieved by reducing the dimensions of the isogrid elements. However, the reduction in the dimension of the isogrid reduces its load carrying capability as well as resist the stresses induced during flight. Hence, an optimal point needs to be reached where the mass of the interstage structure as well as its strength is not compromised. In this project, the optimal design condition is obtained by coding a program in MATLAB software. The material for the interstage structure is chosen as Aluminium AA2014-T6 due to high strength to weight ratio and high stiffness to weight ratio.

From the data available, the diameter of the interstage D was found to be 2800 mm and the total axial load on the interstage, F = 4356500 N. The value of Height(H) on calculation was found to be 1200 mm. The objective of the MATLAB program is to find the dimensions b, d and a of the isogrid rib.

For Main rib,b=16mm, d=19mm and h= 170

For Sub rib,b=11mm, d=19mm and h= 85

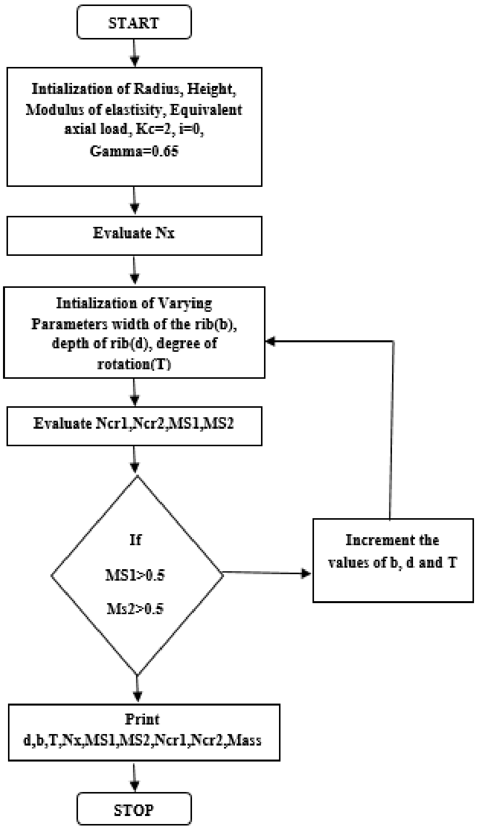

Fig.1. MAT LAB flow chart

III. FINITE ELEMENT ANALYSIS

A. FINITE ELEMENT MODELLING

The part of a typical interstage overall dimension is

Height = 1200mm

Diameter = 2800mm

Radius = 1400mm

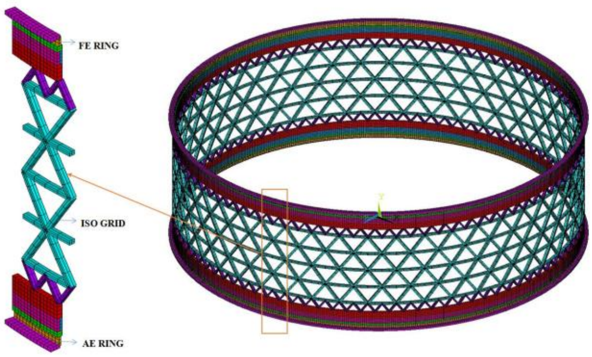

Fig.2. Model

B. BOUNDARY CONDITIONS

- Top face UX and UZ are Constrained
- The bottom face UX, UY and UZ constrained
- At the top face load is applied in UY direction

Force Per Node = Force / number of nodes

= - 4356500/2520

= -1728.77N per node (-ve sign denotes the force acted downwards)

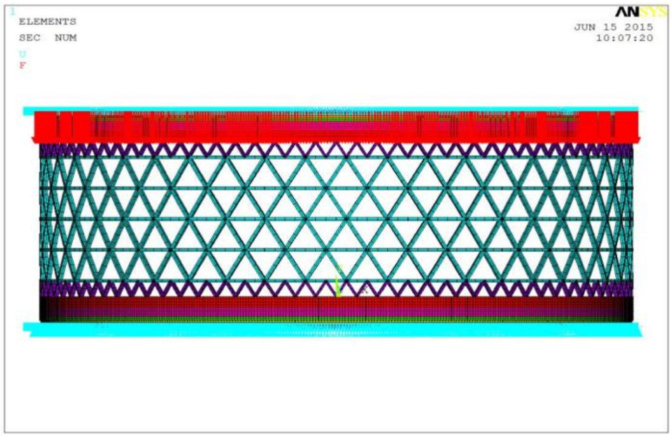

Fig.3. Boundary conditions

C. *FINITE ELEMENT ANALIYSIS*

1. STATIC ANALYSIS

Static analysis of vented interstage model with b = 16 mm and d = 19 mm is carried out for the load described, to obtain displacement and stresses and also to understand the structural behavior of the isogrid cylinder. The axial deformation of the structure is given in figure and the maximum axial deformation obtained is 6.87 mm.

The stress distribution on the structure is shown in the figure, the maximum stress occurring in the structure in 782.92 N/mm2. In the figure the maximum stress occurring is 782.92 N/mm2 and is occurring at the ring section from where the flange is projected out. This is due to the local bending moment caused due to the eccentricity at which the load acts. Due to sufficient preload with adjacent structures thus bending stress reduces.

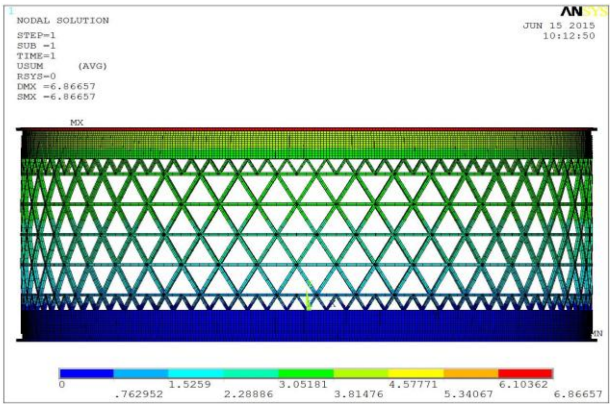

Fig.4. Axial displacement

Identify applicable sponsor/s here. If no sponsors, delete this text box. (sponsors)

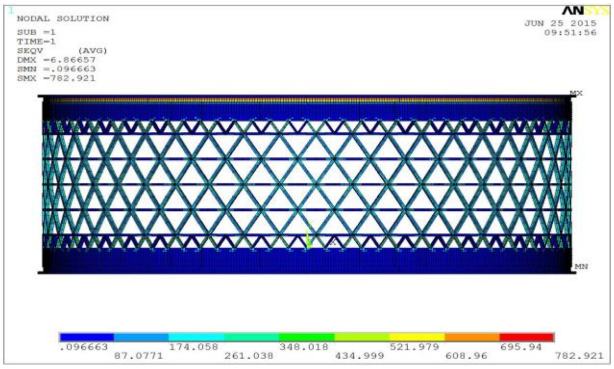

Fig.5. Stress distribution

2. BUCKLING ANALYSIS

Buckling analysis is a technique used to determine buckling loads-critical loads at which a structure becomes unstable-and buckled mode shapes-the characteristic shape associated with a structure's buckled response. The buckling analysis has also been carried out and the first ten buckling load factors after considering a knock down factor of 0.65, buckling margin of safety is 0.48 against buckling.

MODE	BUCKLING LOAD FACTOR (BLF)
1	2.2752
2	2.2752
3	2.2768
4	2.2768
5	2.3254
6	2.3254
7	2.3293
8	2.3293
9	2.3504
10	2.3504

Table.1. Buckling Analysis

As the Eigen values indicate, the first four modes give the same deformed shape and the next four modes give the same deformed shape and so on. Also there is only a slight variation happening in the Eigen values (Load Multipliers) and as a result the buckling mode shapes will be almost similar. Thus we take the first mode shape for studies.

Buckling load factor (BLF) = 2.2752

Buckling load = BLF x APPLIED LOAD

= 2.2752 x 4356500

= 9911908.8 N

The reduction of load caring capacity due to imperfections is usually addressed by knock down factor. Knock down factor (KDF) for isogrid = 0.65

MARGIN OF SAFETY = (BLF x KDF) – 1

= (2.2752 x 0.65) – 1

= 1.48 – 1

= 0.48

IV. MASS ESTIMATION

1. VENTED INTERSTAGE MASS

Mass of the structure can be estimated by using the macro in the ANSYS software. Total mass of the vented interstage is 277.60 kg

2. CLOSELY STIFFENED SKIN STRINGER MASS

It includes many components such as seven skin panel sub assembly ullage rockets, retro rockets and other components. Except ullage and retro rockets all the other parts are made of AA2014T6 material (density 2.8 x 10-6Kg/mm3) each of skin panel assembly it include stiffeners, stiffener channel back up plate hard point, splice plate bulkhead segment and other components. Total mass of closely stiffened structure over a height of 1200mm= 1075.13 Kg

3. MASS REDUCTION

Total mass reduction = Mass of closely stiffened skin stinger construction – Mass of vented interstage

=1075.13 - 277.60

= 797.53 Kg

V. CONCLUSION

A 1200 mm long 1/2 Vented system was designed in order to replace a part of the existing 1/2L of a typical launch vehicle. The design parameters were optimized using MATLab software to get the least mass configuration satisfying the given load bearing. The Structure was modelled and analyzed using ANSYS 14.5. Necessary load conditions and movements arrested according to the needs .The designed model were analyzed the static and Buckling Analysis to find out the deflections and study buckling modes and find out the mass reduction.

From the analysis, closely stiffened skin stringer construction and isogrid structure, the isogrid structure is more compact to the typical launch vehicle. The buckling load is greater than the applied load and by considering the knock down factor the margin of safety is 0.48 therefore the structure is safe.

By this creating the stage as vented, four ullage rockets and eight retro rockets can be eliminated from the inter stage. The isogrid structure has less mass as comparing with the closely stiffened skin stringer construction is of about 797.53 kg. The cause of failure due to ullage rockets and retro rockets can also be eliminated.

REFERENCES

[1] Krishna Prasanth K &Muruganantham P, “Design And Analysis Of A Typical Inter-Tank Structure Of A LaunchVehicle Using Integrally Stiffened Construction”, International Journal of Research inEngineering & Technology (IJRET)Vol. 1, Issue 1, June 2013, 21-34

[2] S EzhilSelvan, “Design Of Isogrid Structures For AerospaceApplications”, Vikram Sarabhai Space Centre, Thiruvananthapurarn, India, MS 1961, june 1990

[3] McDonnell Douglas Astronautics Company, " Isogrid Design Handbook", NASA CR-124075, February 1973.

[4] C.Bhaskaran, K.Raghavan, S.S.Ahmed and B.P.Shastry, “Design and analysis of PSLV – Interstage 1/2L”, structural design and analysis division, VSSC, Thiruvanathapuram, February 1990.

[5] Task Team," Proposal for Vented Interstage Separation for PSLV/GSLV" , June 1990

[6] LVDG , "Comparison Between Vented Interstage and Non Vented Interstage for GSLV", VSSC Trivandrum,

[7] Paul Slysh, J.E Dyer, J.H Furman, J.E Key, "Isogrid Structural Tests and Stability Analyses", Journal of Aircraft, Vol 13, No. 10, pp 778-785.

[8] Robert D Cook,David S Malkus, Michael E Plesha, Robert J Whitt,” Concepts and Applications of finite Element Analysis”, john Wiley and Sons ,Inc , p639-651.

[9] John W. Hutchinson, “Knockdown factors for buckling of cylindrical and spherical shells subjectto reduced biaxial membrane stress”, International Journal of Solids and Structures, Harvard University, Cambridge, MA 02138, USA, 18 February 2010.