International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 06 | June 2019 www.irjet.net p-ISSN: 2395-0072

# Design of an Interstage Structure in Launch Vehicle: Isogrid Construction

**Athulya Sabu[1], Resmi SS[2], Anitta Jose[3]**

[1]*Mtech Student, Dept. of Civil Engineering, Amal Jyothi College of Engineering, Koovapally*
[2]*Scientist/Engineer SE, SED, VSSC, ISRO*
[3]*Assistant Professor, Dept. of Civil Engineering, Amal Jyothi College of Engineering, Koovapally*

---

**Abstract -** *Light alloy materials are used in launch vehicle structures due to its high specific strength and high specific stiffness. Availability, ease of fabrication, low cost makes aluminum alloys a major construction material in launch vehicle structures. There are primary and secondary structures in launch vehicles. Interstage structure is a primary structure in launch vehicles which is located in between the liquid and solid propellant tanks. The interstage is subjected to various forces imposed by launch vehicles, and must be designed to withstand these loads. Various types of construction such as monocoque, waffle, isogrid, closely stiffened and sandwich constructions are used for interstage structure. Isogrid is a lattice of ribs forming pockets of contiguous repetitive equilateral triangular pattern for integral stiffening of skin. The isogrid structure has the advantage to withstand both compressive and bending loads and also offers lower weight and high structural efficiency. Isogrid structure is the best choice for achieving the payload gain in launch vehicles. The main aim of the study is to design a cylindrical interstage structure using isogrid construction. The structure is designed for combination of axial force and bending moment. Stability of the structure is arrived through FE analysis and a comparison with design standards were utilized to arrive at an optimum design.*

***Key Words*: Isogrid, Interstage, Monocoque, Buckling, Cylindrical shell, Cutout**

## 1. INTRODUCTION

Launch vehicles are built as an assemblage of several stages, which may be solid, liquid, cryogenic etc depending on the propulsion systems, employed. Launch vehicle structures are classified as primary and secondary structures. Interstage structure is a primary structure in launch vehicle which is located in between the liquid and solid propellant tanks. Interstage structure is configured as a cylindrical structure with isogrid construction having a diameter of 4000mm and a height of 2750mm which has to accommodate the dome profile of the two propellant tanks with which it interfaces. It is connected to the tanks through bolted joints at the fore and aft end.

Different types of construction via. monocoque, closely stiffened, sandwich, waffle and isogrid structures are used for the realization of cylindrical strcutures. Monocoque is a structure consisting of skin without any reinforcement stiffeners. The monocoque structure has the lowest buckling strength compared to other techniques. The monocoque structure fails due to local or skin instability failure. In integrally stiffened construction, the skin and the stiffeners act as an integral unit without the provisions for any kind of connections. These modes of integral stiffening can be achieved by the use of an isogrid structure which consists of a skin stiffened integrally with repetitive arrangement of triangular stiffening ribs oriented in 60° pattern. Isogrid structure finds its applications mainly in aerospace structures due to its lower weight, lower construction cost and high efficiency in load carrying capacity.

## 2. ISOGRID STRUCTURES

Isogrid is a lattice of ribs forming pockets of contiguous repetitive equilateral triangular pattern for integral stiffening of skin. Isogrid behaves like an isotropic material with no directions of instability and poison's ratio of 1/3 has the advantage to resist both compressive and bending loads. Ribs can assume any geometric pattern. The rectangular or waffle pattern, originally developed was used occasionally. But rectangles are inefficient because only ribs in the loading direction gets more stress and the ribs in the perpendicular direction are idling. A triangular isogrid, in contrast, distributes the load among all ribs. With every member doing its share of the work, dead weight is virtually eliminated. The simplest isotropic stiffening pattern is the one with a network of 60° equilateral triangles and can carry combined loads. Isogrid lattice is a complete structure by itself ie, it can effectively resist tension, compression, shear and bending loads. The skin has the same capabilities as it is also stiffened by such a lattice. Therefore, either skin or lattice can be locally reinforced to handle local loads or discontinuities from cutouts.

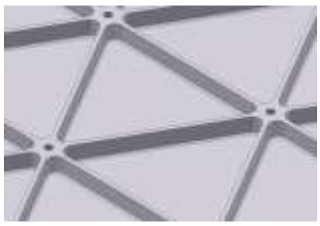

**Fig 1** Isogrid Panel

## 3. MATERIAL SELECTION

The selection of materials used for isogrid structures are based on weldability, machinability and chemical milling considerations required for each component of launch vehicle. These properties of materials are associated with the ability of the material to carry the mechanical forces and loads. The modulus of elasticity of materials chosen is an important parameter as it is directly related to buckling and deflection characteristics. Lighter and stiffer constructions are required for aircrafts. A structural engineer must choose a material with high specific stiffness and high specific strength along with other desirable characteristics. Also the fabrication process and types of heat treatment process on the material must be considered. Aluminum alloys are widely used materials in launch vehicles. Although the strength and stiffness of these alloys are not high compared to some other materials, they are more efficient. The aluminum alloys are inexpensive, easily formed and machined and are easily available. The 2xxx series aluminum alloys are commonly used in launch vehicle.

## 4. DESIGN OF ISOGRID STRUCTURE

Buckling is the primary mode of failure in cylindrical shell structures subjected to uniform axial compression. The isogrid design parameters are skin thickness (t), rib width (b), rib depth(d), triangle height(h) and leg of triangle(a).

### *4.1* Dimensional and Non Dimensional Parameters

These parameters ensure simultaneous failure of isogrid structure by local skin buckling, rib crippling and general instability. It ensures minimum weight to the structure. The other non-dimensional parameters used in Isogrid sizing are

$$\alpha = \frac{bd}{th}$$

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

$$\delta = \frac{d}{t}$$

An equivalent skin thickness and equivalent modulus is produced by combining the rib and skin elements so that the structure can be made as an equivalent monocoque structure.

Equivalent skin thickness $= \frac{t\beta}{(1+\alpha)}$

Equivalent modulus $= \frac{E(1+\alpha^2)}{\beta}$

Weight thickness which determines the structure weight is given by,

$$t_w = t\,(1+3\alpha)$$

For reducing the total mass and cost of the isogrid structure, the equivalent weight thickness should be kept minimum.

### 4.2 Failure modes of Isogrid

The isogrid parameters which ensure simultaneous failure of isogrid strcuture are:

**General Instability**

For a cylinder with L/R ratio ≤ 10 and subjected to combined bending and axial compression, the critical buckling load is given by

$$Ncr(1) = c_0E\,(t^2/R)\beta, \text{ where } c_0 = 0.397$$

On general instability Margin of safety,

$$MS_1 = \frac{Ncr1}{NX} - 1$$

Where, applied edge load,

$$Nx = \frac{P}{2\pi R} + \frac{M}{\pi R^2}$$

**Skin Buckling**

The critical stress for skin buckling is given by

$$Ncr(2) = c^1Et(1+\alpha)\,t^2/h^2, \text{ where } c_1 = 10.2$$

On skin buckling Margin of safety,

$$MS_2 = \frac{Ncr2}{NX} - 1$$

**Rib Crippling**

The critical stress for rib crippling is given by

$$Ncr(3) = c_2Et(1+\alpha)b^2/d^2, \text{ where } c_2 = 0.616$$

On rib crippling Margin of safety,

$$MS_3 = \frac{Ncr3}{NX} - 1$$

### 4.3 Loads Considered

**Table 1:** Loads Applied

| LOADS | FORE END |
|---|---|
| Axial force (kN) | -275 |
| Bending moment (kNm) | 2203 |
| Shear force (kN) | 148 |
| Equivalent axial load (kN) | -2478 |
| Ultimate load (kN) | 3100 |

### 4.4 Design Parameters

The various parameters used for design of an isogrid structure is shown in table 2

**Table 2.** Geometry Description

| ISOGRID PANEL GEOMETRY | DETAILS |
|---|---|
| Total thickness, d+t (mm) | 20 |
| Rib thickness, b (mm) | 1.5 |
| skin thickness, ts (mm) | 1.4 |
| Triangle side, a (mm) | 100 |
| Triangle height, h= 0.866 a (mm) | 86.6 |
| Radius,R (mm) | 2000 |
| Modulus of elasticity,E (N/mm$^2$) | 68670 |
| Poissons ratio | 0.33 |
| Equivalent thickness, t* (mm) | 15.77 |
| Equivalent modulus, E* (N/mm$^2$) | 7497.45 |
| t for mass (mm) | 2.36 |
| Ncr1 ( N/mm) | 370.28 |
| Ncr2 ( N/mm) | 315.25 |
| Ncr3 (N/mm) | 473.78 |
| MS on skin buckling | 0.88 |
| MS on global buckling | 0.6 |
| MS on rib buckling | 1.4 |

### 4.5 Cutout Reinforcement

Cutouts are provided in the structure to access and assemble mechanical modules, actuators and electronic components while assembly. The cutouts in the structure can cause localized stress concentrations and that can be reduced by providing various schemes of reinforcement. A cost effective method to eliminate the effect of cutout is to affix appropriate reinforcement around the cutout region. The cutout reinforcement is obtained as

For rib, $A_{req} = A_0\,(1+0.5\xi^2+1.5\xi^4)$

For skin, $t_{req} = t_0\,(1+0.5\xi^2+1.5\xi^4)$

where $\xi = a/r$

The reinforcement provided around the cutout region is shown in Table 3

**Table 3.** Reinforcement Provided near Cutout

| Location | Skin thickness | Rib thickness |
|---|---|---|
| 1st pocket reinforcement | 4.88 | 12 |
| 2nd pocket reinforcement | 3.19 | 6.98 |
| 3rd pocket reinforcement | 2.92 | 4.87 |

Isogrid with nine cutouts were assessed to access and assemble mechanical systems. Different iterations were carried out to optimize the skin and rib thickness and cutout reinforcement. The cutout region showing the reinforcement is shown in Fig 1.

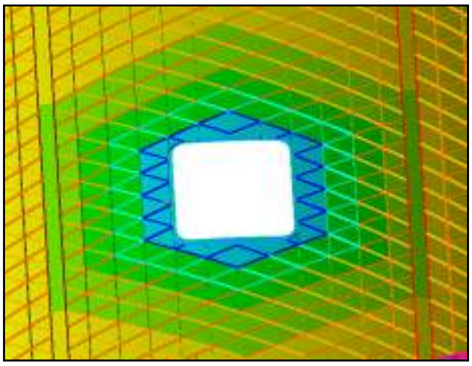

**Fig 2.** Cutout Reinforcement

## 5. FE MODEL DESCRIPTION

In this study, the isogrid and monocoque structures were idealized as a shell structure in which much iteration were carried out to optimize the skin and rib thickness. Static and buckling analysis was done for each of the structure and is modeled and analyzed using FEAST. The corresponding displacements, stresses and buckling load factors are analyzed and compared for monocoque, isogrid and isogrid with cutout structures.

### 5.1 Monocoque Structure

Equivalent monocoque structure is idealized as shell element having equivalent thickness of 15.77 mm and equivalent modulus of 7497.45 N/mm$^2$ for compression load of 3100. Material property is assumed to be isotropic and the boundary condition assumed to be fixed. The structure is analyzed for static and buckling.

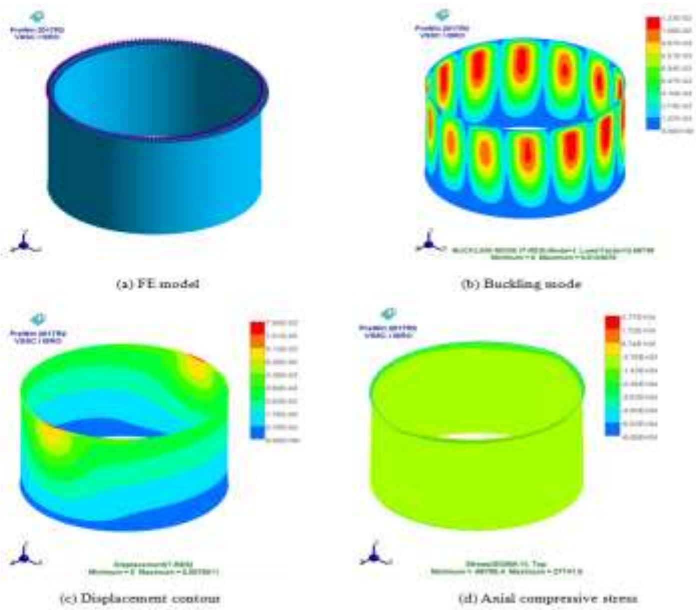


**Fig 3.** Monocoque Strcuture

### 5.2 Isogrid Structure

In this study, isogrid cylindrical structure is idealized as shell element having skin thickness of 1.4mm, rib thickness of 1.5mm and elastic modulus as 68670 N/mm² for compression load of 3100 kN. Material property is assumed to be isotropic and boundary condition is assumed to be fixed. The structure is analyzed for static and buckling.

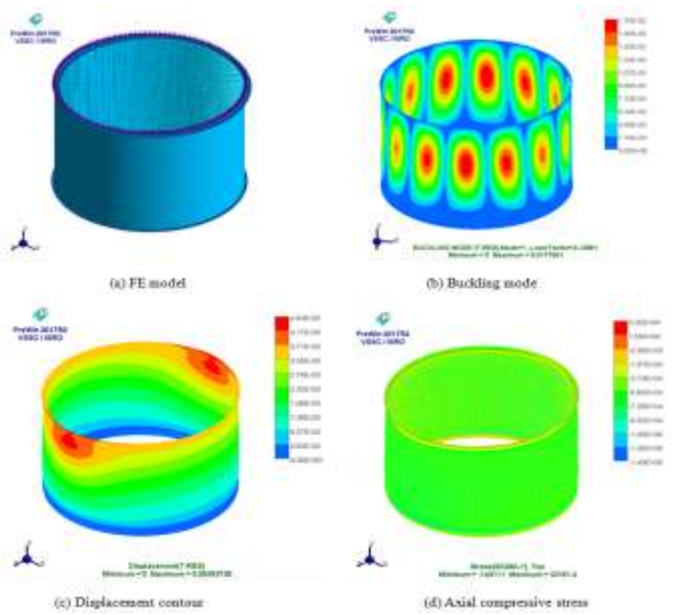


**Fig 4.** Isogrid Structure

### 5.3 Isogrid Structure with Cutout

Isogrid cylindrical structure with cutouts is idealized as shell element having skin thickness of 2.8mm, rib thickness of 4mm and elastic modulus as 68670 N/mm² for compression load of 3100 kN. Also edge thickness is assumed as 16mm and splicing thickness as 12mm. Cutout reinforcement is provided as shown in Table 3. Material property is assumed to be isotropic and boundary condition is assumed to be fixed. The structure is analyzed for static and buckling.

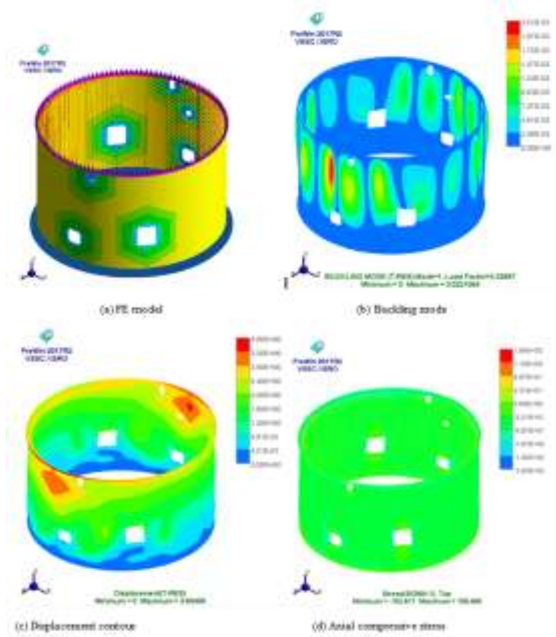


**Fig 5.** Isogrid with Cutout

## 6. RESULTS

Buckling load factor is shown in Fig 6 and mass comparison is shown in Fig 7. Comparison of monocoque, isogrid and isogrid with cutout are tabulated in Table 4.

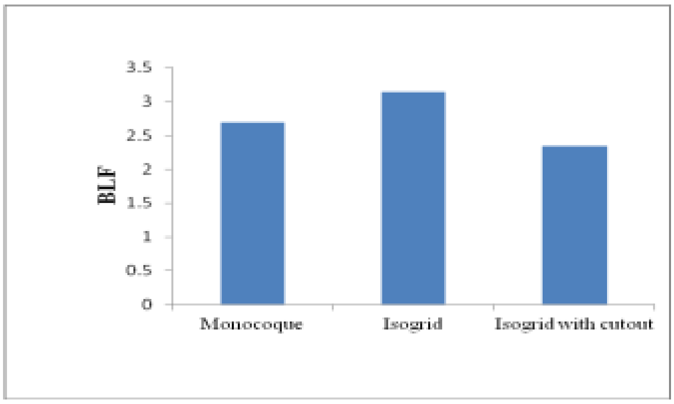


**Fig 6.** Comparison of Buckling load factor for monocoque, isogrid and isogrid structure with cutout

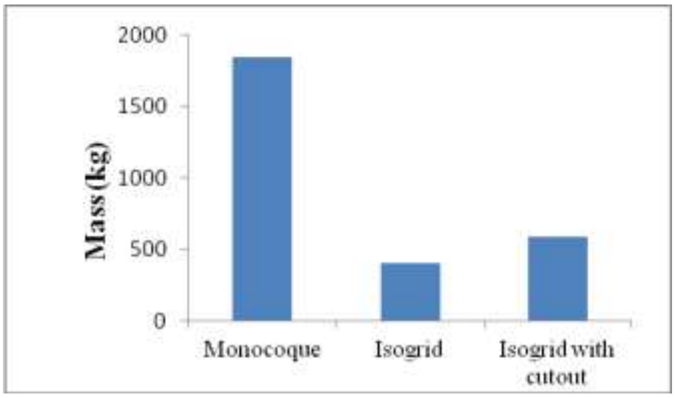


**Fig 7.** Comparison of mass of structure for monocoque, isogrid and isogrid structure with cutout

**Table 4:** Results of Comparison

| Parameter | **Monocoque** | **Isogrid** | **Isogrid with cutout** |
|---|---|---|---|
| Axial displacement (mm) | Min - -4.9<br>Max – 0 | Min - -3.8<br>Max – 0 | Min - -3.07<br>Max – 0 |
| Radial displacement (mm) | Min – -1.4<br>Max - 1.4 | Min – -1.1<br>Max - 1.1 | Min – -1.45<br>Max - 1.45 |
| Axial stress (N/mm$^2$) | Min - -66.7<br>Max – 27.7 | Min - -143.1<br>Max - 33.16 | Min - -182.6<br>Max – 155.9 |
| Circumferential stress (N/mm$^2$) | Min - -17.5<br>Max - 8.73 | Min - -28.8<br>Max - 41.7 | Min - -61.8<br>Max - 105.4 |
| BLF | 2.69 | 3.13 | 2.34 |
| MS | 0.75 | 1.5 | 0.87 |
| Mass of structure (kg) | 1844.7 | 406.1 | 585.3 |

## 7. CONCLUSION

- This paper highlights the effect of isogrid structure on static as well as on buckling compared to monocoque.
- Design of isogrid structure as well as cutout reinforcement on it was arrived.
- Static as well as buckling analyses were carried out in FEAST.
- Based on the studies carried out on comparing equivalent monocoque and isogrid structure, BLF is more for isogrid for same configuration.
- The mass of the structure is minimum for isogrid structure compared with equivalent monocoque

## REFERENCES

[1] Romy Mathew, N. Murali, and Jenny John Mattam (2015), "Design Studies of Conical Shells in Launch Vehicles", International Journal of Innovative Research in Advanced Engineering, Vol.22, Issue 3, April 2015, pp.66-72.

[2] Rizwan Sabir, Abid Ali Khan, Hassan Junaid, Qasim Zeeshan and Yousaf (2015), "A Survey of Recent Developments in Optimization of Isogrid structure", Journal of Space Technology, Vol.5, No.1, July 2015, pp.103-115

[3] Joseph Clint, Santosh Kumar, and Nazumuddin Shaik (2014), "Buckling Analysis on Aircraft Fuselage Structure Skin", International Journal of Engineering Development and Research, Vol. 2, Issue 4, 2014.

[4] Steven Huybrechts and Stephen W. Tsai (1996), "Analysis and Behaviour of Grid Structures", Journal of Composite Science and Technology, Vol.56, pp.1001-1015.

[5] Krishna Prasanth K and Muruganantham P (2013), "Design and Analysis of a Typical Inter-Tank Structure of a Launch Vehicle using Integrally Stiffened Construction", International Journal of Research in Engineering and Technology, Vol. 1, Issue 1, June 2013, pp. 21-34

[6] R.R Meyer (1973), "Isogrid - A Simple, Efficient, Stiffening Concept", AIAA/ASME/SAE 14th Structures, Structural Dynamics and Materials Conference, AIAA Paper No. 73-365

[7] Paul Slysh (1976), "Isogrid Structural Application", Thirty fifth annual conference of the society of the allied weight Engineers, Inc-SAWE 1096, 1976

[8] W.Akl, A. El-Sabbagh, and A.Baz (2008) "Optimization of the Static and Dynamic Characteristics of Plates with Isogrid Stiffeners", Journal of Finite Elements in Analysis and Design, Vol. 44, January 2008, pp. 513-523

[9] A. Guemes, E. del Olmo, M.Dorte, and A. Fernandez-Lopez (2012), "Structural Testing and Simulation of Composite Isogrid Structures for Aerospace Applications", ECCM-15th European Conference On Composite Materials, Venice, Italy, 24th -28th June 2012.

[10] Resmi SS and Anu Antony(2017)"Effect of RIB Orientation in Isogrid Structures: Aerospace Applications",International Journal of Research in Engineering and Technology, Vol. 1, Issue 1, Pg No. 21-34

[11] Mc Donnell Douglas Astronautics Company, Isogrid Design Handbook of NASA, February 1973.

[12] E.F Bruhn, Analysis and Design of Flight Structures