Investigating the Effects of Stiffeners on Structural Performance of Aircraft Pressure Bulkhead

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Abstract

Air vehicles flies at high altitude of about 35000 – 40000 feet from the earth's level. The air pressure at these level is very less when compared to earth's atmospheric pressure. Hence, it is required to maintain the earth's atmospheric pressure level inside the fuselage of an air vehicle (airplane). The frontend and rear end of the fuselage are enclosed by pressure bulkheads; it keeps the required air pressure inside the fuselage. Pressure bulkhead is one of the important structures and is used in every aircrafts to prevent the pressurized air leakage inside the fuselage. The present investigation focused on the effects of stiffeners on structural performance of fuselage pressure bulkhead of the sky-span dragon aero plane due to the pressurization from 6 psi to 9 psi. Modelling and finite element analysis is carried out to determine the effect of different types of stiffeners used in pressure bulkhead of air vehicles like riveted pressure bulkhead and integrated radial pressure bulkhead. The results reveal that, the stiffener does have a significant influence on the load carrying capability of pressure bulkhead. Further, the deflection and stress levels are considerably reduced in the case of pressure bulkhead with integrated radial stiffening grids. The safety pressure level inside the fuselage of an air vehicle is attributed to the stiffening grids used in pressure bulkhead.

Keywords : Stiffening grid, Pressure bulkhead, Fuselage, Air vehicle

1. Introduction

Transportation means moving one place to another place. Transportation takes place in three modes such as by road, by water and by air. Amongst these, air means is considered to be the fastest mode of transportation. Airplane or aircraft is a wonderful invention in the history of transportation. Aircrafts are designed in term of its wings structure, number of engines, type of fuselage construction and/or load carrying capacity. Major parts of the aircrafts are fuselage, wing, empennage, landing gear and power plant. Fuselage is the main part of the aircraft and it includes the cockpit and cabin where passengers and controlling crew will sit. The wings of an airplane are perpendicularly to the axis of the fuselage, and it carries all the major loads of the plane. Empennage is the tail part of the airplane which consists of horizontal and vertical tails as shown in the Figure 1. Air vehicles flies at high altitude of about 35000 – 40000 feet from the earth's level. The air pressure at these level is very less when compared to earth's atmospheric pressure. Hence, it is required to maintain the earth's atmospheric pressure level inside the fuselage of an air vehicle (aeroplane).

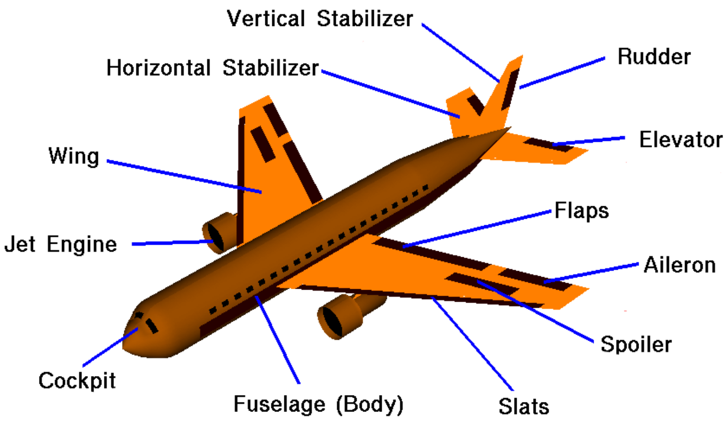


Figure 1 Civil Aircraft

Pressure bulkhead is one of the important structures and are used in every aircrafts. The pressure bulkhead is a part of aircraft having a circular shape that is fixed to front and rear ends of the fuselage structure. Pressure bulkhead consists of a skin, which is stiffened by stiffeners. These stiffeners are either riveted or welded to the skin, in some cases they are integrated to the skin material of pressure bulkhead during manufacturing. The frontend and rear-end of the fuselage are enclosed by pressure bulkheads; it keeps the required air pressure inside the fuselage. Figure 2 shows the rear pressure bulkhead and its position in the aircraft. Pressure bulkheads are classified into two types namely, dome pressure bulkhead and flat pressure bulkhead. The ends of the fuselage are air tightened with pressure bulkhead. The function of the pressure bulkhead is to prevent the pressurised air leakage. This is needed to maintain the required pressure level inside the fuselage of an aircraft.

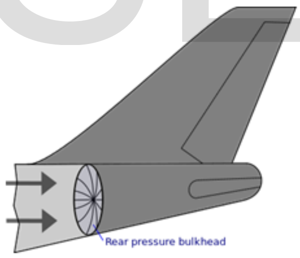


Figure 2. Pressure bulkhead

The variations in the pressure of air with respect to the height of flight of aircraft are measured by using barometer and radar respectively. To maintain the constant atmospheric pressure inside the fuselage of aircraft, pressurization technique is adopted. The Pressurization is a technique used in all the aircraft to maintain required pressure level (atmospheric pressure level) inside the fuselage of the aircraft. It involves the control of temperature, humidity, air circulation and cabin pressurization. **Nathan Medrek [1] (2010)** has carried out the work to investigate the sandwich pressure bulkhead. Two different types of sandwich pressure bulkheads are designed with different stiffening arrangements (i.e. radial and orthogonal stiffeners) between the two skins. Stress analysis is carried out for the pressure bulkhead, followed by its size optimization. Their results reveal that, both orthogonal and radial pressure bulkheads were capable of withstanding the maximum pressure. However, size optimization of orthogonally stiffened sandwich pressure bulkhead showed much reduction in weight when compared to radially stiffened sandwich pressure bulkhead. **Vigneshwaran [2] (2014)** in his work considered the pressure bulkhead of the BWB (blended wing body) fuselage. BWB fuselage satisfies the efficient fuselage design requirements. BWB suffers from wing bending loads and internal pressurization, the combine loading results in non-linear stress behaviour. The stress analysis of pressure bulkhead, was carried out on BWB fuselage. The pressure bulkhead of BWB fuselage was modelled by using the dimensions given by Boeing and NASA. ANSYS software tool is used to analyse the results. The results of their investigation reveal that, the deflection of pressure bulkhead of BWB fuselage as obtained from finite element analysis was found to be 8% larger than theoretical value. **Shreyas Krishnan [3] (2013)** worked on the pressure bulkhead of the fuselage. Stress analysis of pressure bulkhead was carried out considering the cabin pressure as a critical load conditions. NASTRAN and PATRAN software were used for preprocessing, post processing and for solving. They reported that, the thickness of pressure bulkhead significantly influences the stresses induced due to the cabin pressure.

Literature study reveals that, the thickness and stiffening elements does have a significant influence on overall performance of pressure bulkhead of aircraft fuselage. Hence in the present work, numerical investigations are carried out to determine the effect of different stiffening arrangements such as riveted type and integrated type on the structural performance of pressure bulkhead of sky-span dragon aircraft.

2. Modelling of Pressure Bulkhead

The 3D models of aircraft pressure bulkhead were designed by using CATIA V5 software and are detailed in the further sections.

2.1 Skin

Skin is a circular plate structure which needs to be fixed on both front and rear ends of the fuselage in order to maintain the atmospheric pressure level inside the fuselage cabin. Skin is provided with a wall flange having 20mm in width and 2mm in thickness. The purpose the wall flange is to fix the skin to the fuselage. This wall flange and inner side of the fuselage are cladded and fastened in order to prevent pressure leakage. The diameter of the pressure bulkhead is 1000 mm and is same as that of the fuselage inner diameter. The thickness of the skin of the pressure bulkhead is 2mm. Figure 3 shows the front and side views of the skin with dimensions.

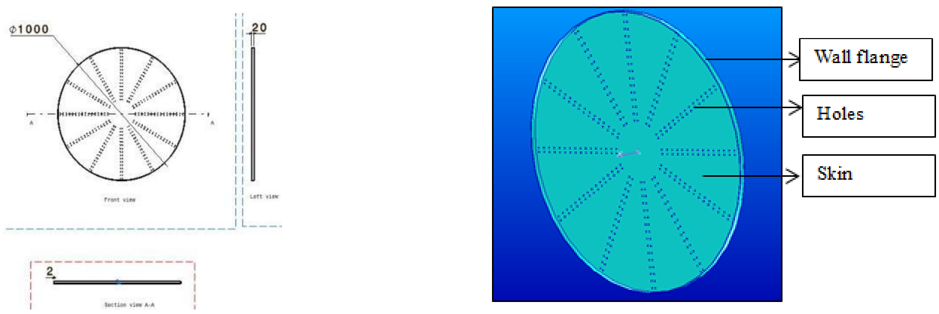


Figure 3 Skin of pressure bulkhead

2.2 Stiffeners

The thickness of the skin is 2mm which is very thin, hence it must be stiffened to withstand the load conditions. Figure 4 shows the I-section stiffener used in the riveted pressure bulkhead having radial stiffeners. Dimensions of the I section beam is as shown in Table 1. Twelve stiffeners are used radially to stiffen the skin, these are fixed to hub using shear clips. Hub is a hollow cylindrical construction which has 90mm diameter and 80mm height.

Table 1. Dimensions of I-Section Beam

#	Front I-Section (mm)	End I-Section (mm)
Top flang	20	20
Bottom flang	30	30
Web	37	80
Thickness	2	2

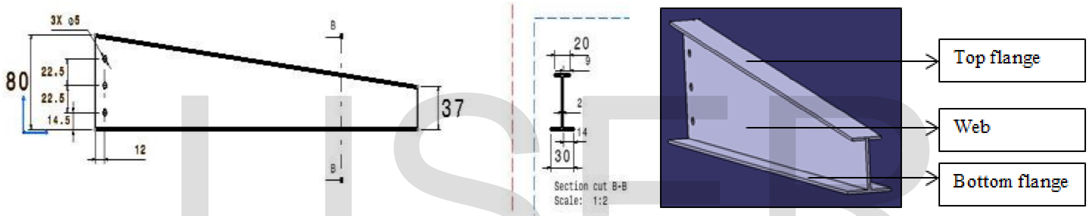


Figure 4. Stiffeners having tapered I-section

2.3 Hub and Shear clips

Shear clips are the L shaped joining components used to connect stiffener to the hub. Shear clips shown in Figure 5 are used to connect stiffeners to the hub structure. Stiffeners are then riveted to skin of the pressure bulkhead as shown in Figure 6.

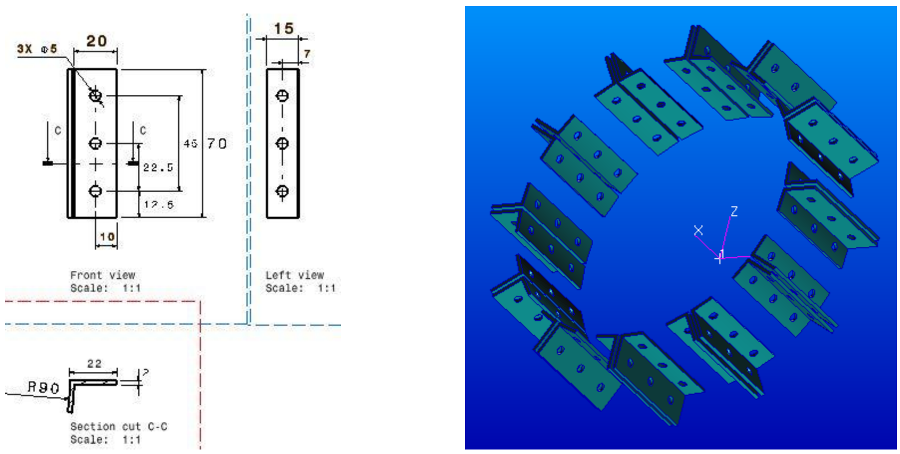


Figure 5 Shear clip

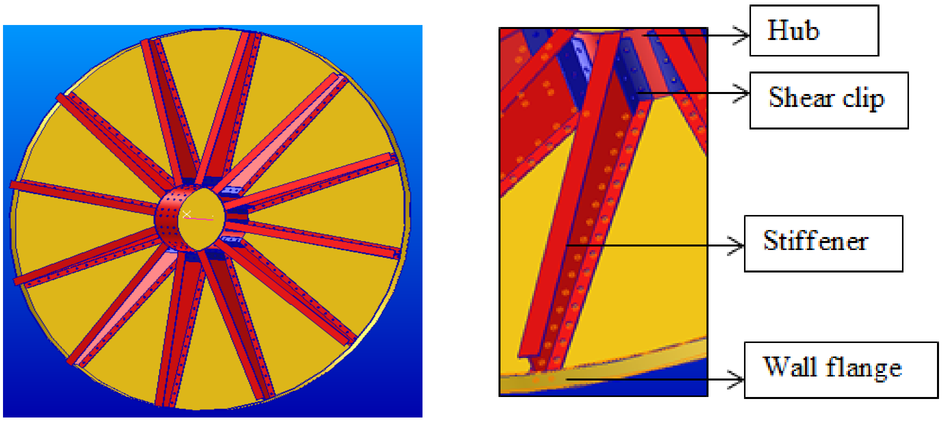


Figure 6. Aircraft pressure bulkhead

3. Finite Element Analysis

Quadrilateral element shown in Figure 7 are used to discretize the pressure bulkhead assembly. Quadrilateral element has four nodes and each node has six degrees of freedom. Finite element model of the pressure bulkhead is having 75144 elements and 78062 nodes and are detailed in Table 2. Continuity is maintained between the elements and nodes to get accurate results. Finite element models of pressure bulkhead parts are shown in the Figure 8.

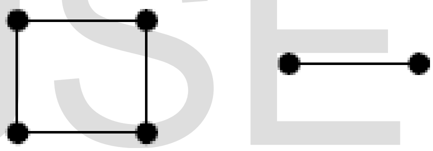


Figure 7. Four nodded quadrilateral element and 2 nodded bar element

3.1 Material Specification

Aluminum alloys are widely used in modern aircraft construction. Aluminum alloys are valuable because they have high strength-to-weight ratio. Aluminum alloys are corrosion resistant and comparatively easy to fabricate. The outstanding characteristic of aluminum is its lightweight. Selection of aircraft materials depends on the cost and its structural performance. The key material properties which are essential to maintain structural performance are: Density, Young's modulus, Ultimate and Yield strengths, Fatigue strength, Damage tolerance (fracture toughness and crack growth) and Corrosion, etc. Aluminium 2024-T3 is used for pressure bulkhead components and rivet. Table 3 describes material properties of Aluminium 2024-T3 used for the pressure bulkhead of sky-span dragon aircraft.

Table 3. Material Properties of Aluminium 2024 – T3

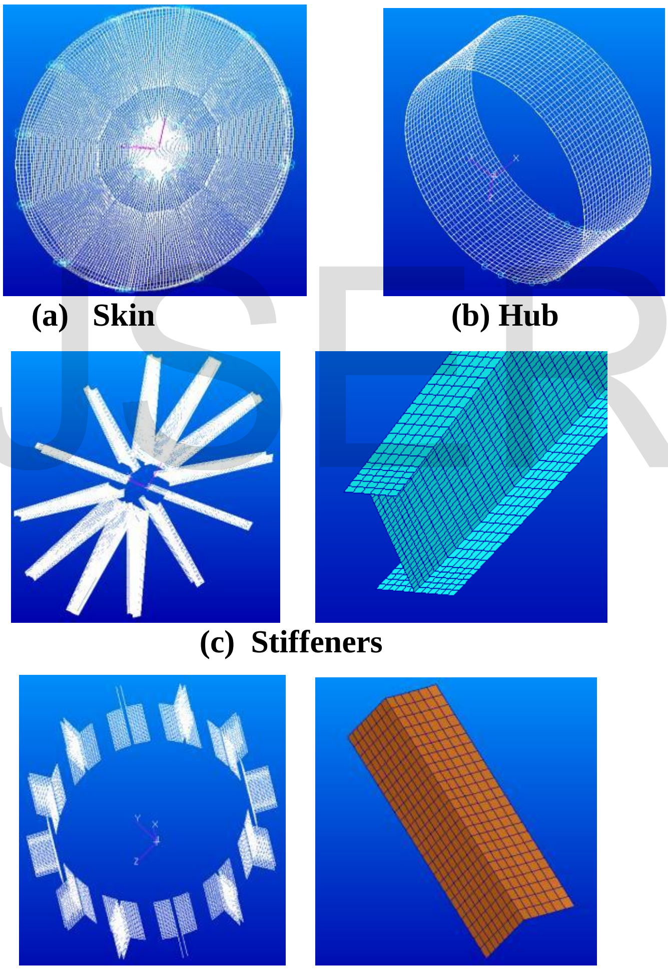
Property	**Aluminium**
Density	2.77 g/cc
Ultimate Tensile Strength	483 MPa
Tensile Yield Strength	362 MPa
Young's Modulus of Elasticity	70 GPa
Poisson's Ratio	0.33

3.2 Loads and Boundary Conditions

The pressure bulkheads are fixed to both front and read ends of the fuselage to maintain constant atmospheric pressure inside the fuselage. The skin flange of the pressure bulkhead is fixed to the fuselage either by riveting or welding, and this can be simulated by constraining the outer surface of the flage. This can be done by constraining the nodes at the circumference of the flang of the skin. Further, the cabin pressure, which is the critical load acting on the surface of the pressure bulkhead skin. Pressure is varied from 6psi to 9psi. 9psi is the maximum pressure considered in the pressent work.

3.3 Riveted Radial Pressure Bulkhead

The finite element models of different components of riveted pressure bulkhead is shown in Figure 8.



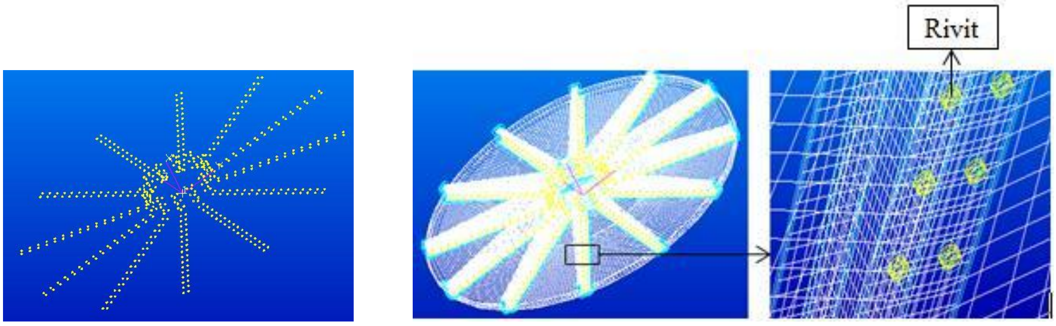
(a) Skin **(b) Hub**

(c) Stiffeners

(d) Shear clips

Figure 8. Finite Element Model of Riveted Radial Pressure Bulkhead Components

The rivets are the connecting elements which are used to connect the two stiffeners to the skin of the pressure bulkhead. Rivets are created by using 1D bar element. Rivits having circular cross-section with 2.5 mm radius are used for this purpose. Finite element model of the rivets are shown in the Figure 9(a). The finite element model of the pressure bulkhead with rivet connections are shown in the Figure 9(b).



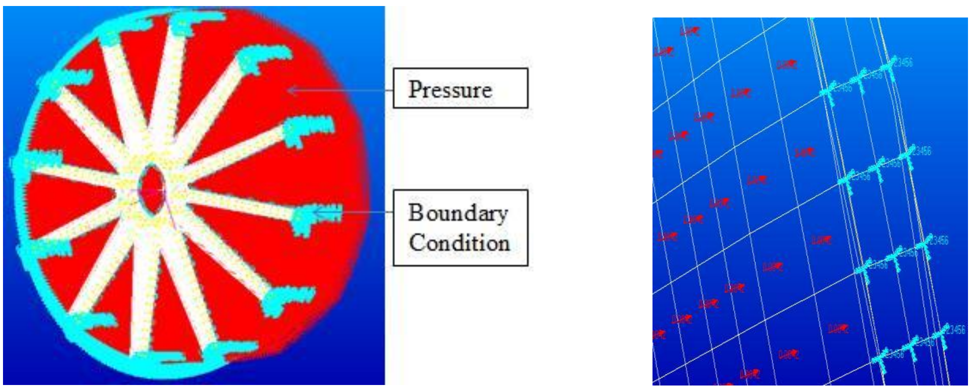
(a) Rivets **(b) Stiffeners riveted to the skin**

Figure 9. Finite element model of Pressure bulkhead assembly

Table 2. Elements and Nodes in the Riveted Pressure Bulkhead

Parts of the Pressure bulkhead	Type of Element	Number of Elements	Number of Nodes	Aspect Ratio
Stiffener hub	Quadrilateral Element	2640	2760	5
Shear clip	Quadrilateral Element	8064	9000	5
Skin	Quadrilateral Element	13536	13669	5
Stiffeners	Quadrilateral Element	50904	52633	5
Rivet	Bar	529	-	-

Figure 10 shows the boundary conditions and pressure acting on to the surface of pressure bulkhead.



(a) Pressure bulkhead **(b) Enlarged view**

Figure 10. Loads and boundary conditions applied to riveted pressure bulkhead

3.4 Integrated Radial Pressure Bulkhead

In riveted pressure bulkhead, parts like hub, stiffeners and skin are designed separately and then with the use of rivets and shear clips, all these parts are joined to form whole pressure bulkhead. Unlike rivited pressure bulkhead, in integrated pressure bulkhead stiffeners are integrated to skin. This eliminates the use of rivets and shear clips in fixing the stiffeners to the skin of the pressure bulkhead. Figure 11 shows the integrated pressure bulkhead with I section stiffener stiffened to the skin.

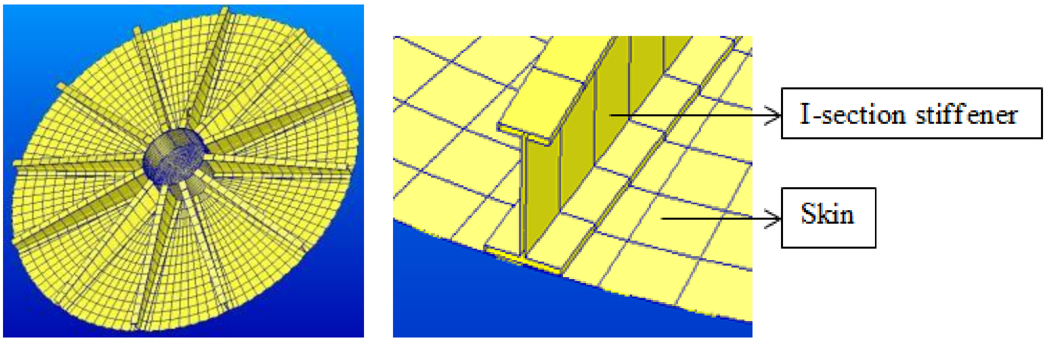
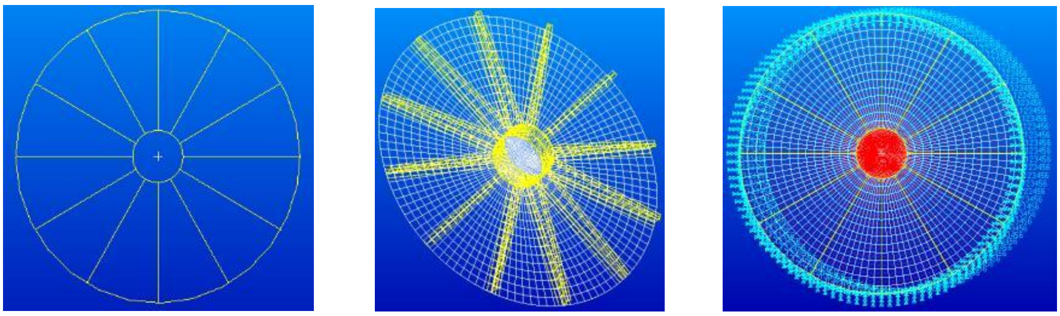


Figure 11. Integrated radial pressure bulkhead with I section stiffener

3.4.1 Integrated Radial stiffeners having I-Section

Pressure bulkhead with radial stiffener having I-section is modelled Using MSC PATRAN tool. The geometry of the integrated pressure bulkhead having I section stiffener is shown in the Figure 12 (a). Here to stiffen the skin, tappered I-section beams are radially integrated to the skin of the pressure bulkhead.



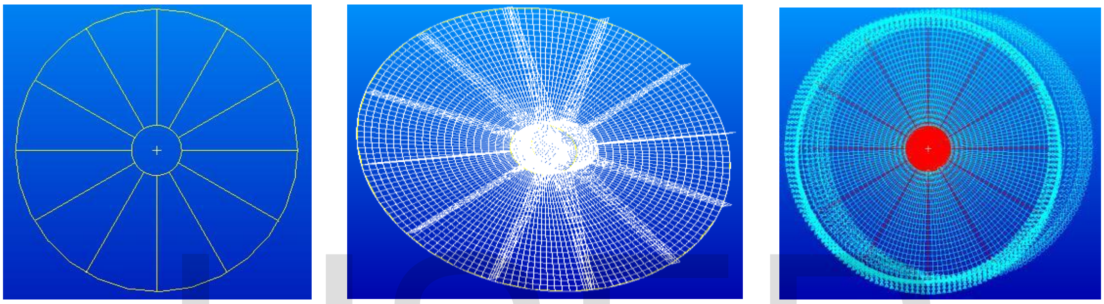
(a) Geometry **(b) Finite element model** **(c) Applied BCs**

Figure 12. Integrated radial pressure bulkhead having I-section

The structure is discrised by using four noded quadrilateral elements with aspect ratio of 5. Quality of the elements such as equivalence, quadrilateral element size, connectivity, boundaries and normals are checked to get the accurate results. Figure 12 (b) shows the meshed model of integrated pressure bulkhead with radial stiffeners having I-section. Aluminium 2024-T3 material is used design this structure. Properties like thickness, orientation, sections and material are assigned to the finite elements. The integrated pressure bulkhead is fixed to fuselage, that is why the skin nodes at circumference and the stiffener ends are constrained, The skin surface is loaded with differential pressure conditions. Figure 12 (c) shows the load and boundary conditions applied to integrated pressure bulkhead.

3.4.2 Integrated Radial stiffeners having rectangular cross-section

Pressure bulkhead with radial stiffener having rectangular cross section is modelled Using MSC PATRAN tool. The geometry of the integrated pressure bulkhead having rectangular cross section stiffener is shown in the Figure 13(a). Here to stiffen the skin, tappered rectangular cross section beams are radially integrated to the skin of the pressure bulkhead. The structure is discrised by using four noded quadrilateral elements with aspect ratio of 5. Quality of the elements such as equivalence, quadrilateral element size, connectivity, boundaries and normals are checked to get the accurate results. Figure 13 (b) shows the meshed model of integrated pressure bulkhead with radial stiffeners having rectangular cross section.



(a) Geometry **(b) Finite element model** **(c) Applied BCs**

Figure 13. Integrated radial pressure bulkhead having rectangular cross section

Aluminium 2024-T3 material is used design this structure. Properties like thickness, orientation, sections and material are assigned to the finite elements. The integrated pressure bulkhead is fixed to fuselage, that is why the skin nodes at circumference and the stiffener ends are constrained, The skin surface is loaded with differential pressure conditions. Figure 13 (c) shows the load and boundary conditions applied to integrated pressure bulkhead.

4. Results and Discussion

4.1 Riveted Radial Pressure Bulkhead

The rivited pressure bulkhead with radial stiffeners having tapered I-section will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms upto 6.65mm. Figure 14 shows the deformation of the riveted presssure bulkhead.

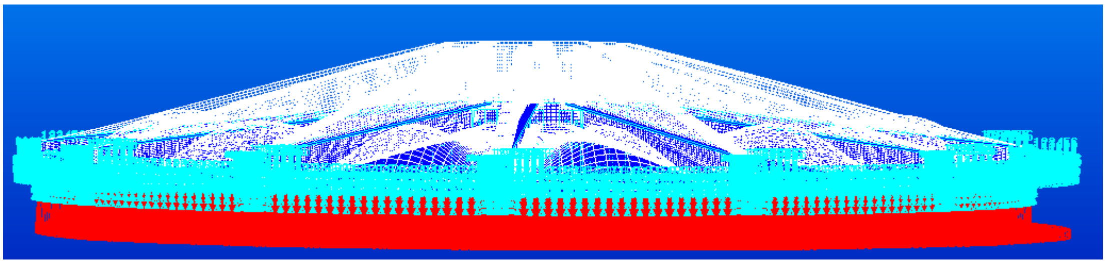


Figure 14 Deformation of riveted radial pressure bulkhead for 9psi pressure

Figure 15 shows the distribution of stresses in the rivited pressure bulkhead with radial stiffeners, when subjected to the pressure of 9 psi.

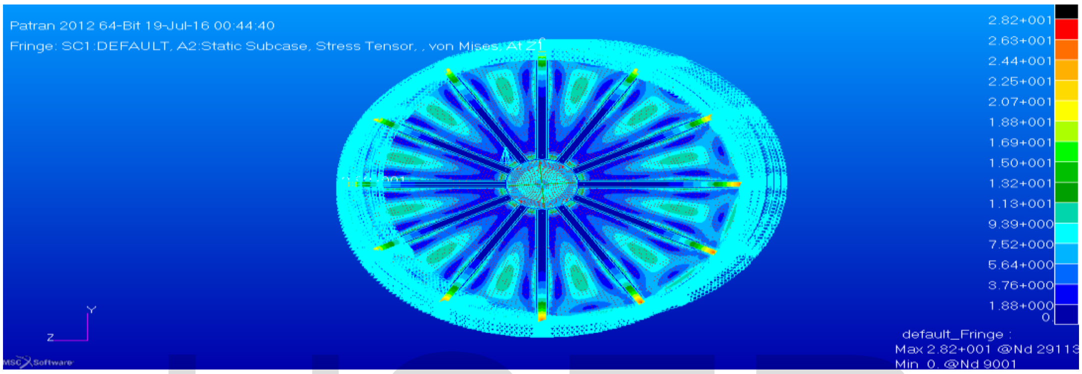


Figure 15 Stress induced in riveted radial pressure bulkhead for 9psi pressure

The maximum stress is found to be 28.2 kg/mm^2 (276.55 MPa). However, the ultimate tensile strenght of the aluminium 2024-T3 is 362 MPa. The induced stress level is found to be less than the allowable stress limit of the material used in the design of riveted pressure bulkhead. Hence, the riveted pressure bulkhead with radial stiffeners is considered to be safe design.Table 4.4 details the result summary of the effects of pressurization on deformation and stress level of rivited pressure bulkhead with radial stiffeners.

Table 4. Result Summary of Riveted Radial Pressure Bulkhead

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	6.65	276.55
8.5 (0.0583)	6.28	260.85
8.0 (0.0549)	5.91	246.14
7.5 (0.0515)	5.54	230.46
7.0 (0.0481)	5.17	209.76
6.5 (0.0446)	4.80	200.05
6.0 (0.0411)	4.43	184.36

4.2 Integrated Radial Pressure bulkhead having I-Section

The integrated pressure bulkhead with radial stiffeners having tapered I-section will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms upto 3.93 mm. Figure 16 shows the deformation of the integrated pressure bulkhead with radial stiffeners having I-section.

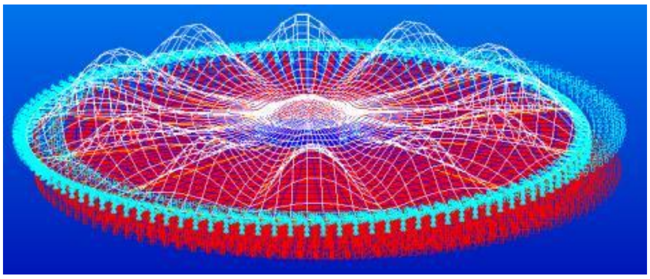


Figure 16. Deformation of integrated radial pressure bulkhead having I-section for 9psi load conditions

Figure 17 shows the distribution of stresses in the integrated pressure bulkhead with radial stiffeners having I-section, when subjected to the pressure of 9 psi.

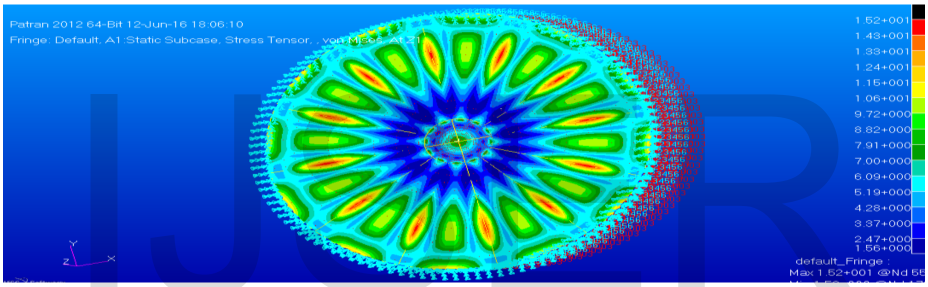


Figure 17. Stress induced in the integrated Radial pressure bulkhead having I-section for 9psi pressure

The maximum stress is found to be 15.2kg/mm^2 (149.06MPa). However, the tensile yield strenght of the aluminium 2024-T3 is 362 MPa. The induced stress level is found to be less than the allowable stress limit of the material used in the design of integrated pressure bulkhead with radial stiffeners having I-section. Hence, the integrated pressure bulkhead with radial stiffeners having I-section is considered to be safe design. Table 4.5 details the result summary of the effects of pressurization on deformation and stress level of integrated pressure bulkhead with radial stiffeners having I-section.

Table 4. Result Summary of Integrated Radial Pressure Bulkhead having I-Section

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	3.93	149.06
8.5 (0.0583)	3.71	140.24
8.0 (0.0549)	3.49	132.29
7.5 (0.0515)	3.28	123.56
7.0 (0.0481)	3.06	115.72
6.5 (0.0446)	2.84	107.87
6.0 (0.0411)	2.62	99.05

4.3 Integrated Radial Pressure bulkhead having rectangular Cross -Section

The integrated pressure bulkhead with radial stiffeners having rectangular cross section will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms upto 4.74 mm. Figure 18 shows the deformation of the integrated pressure bulkhead with radial stiffeners having rectangular cross section.

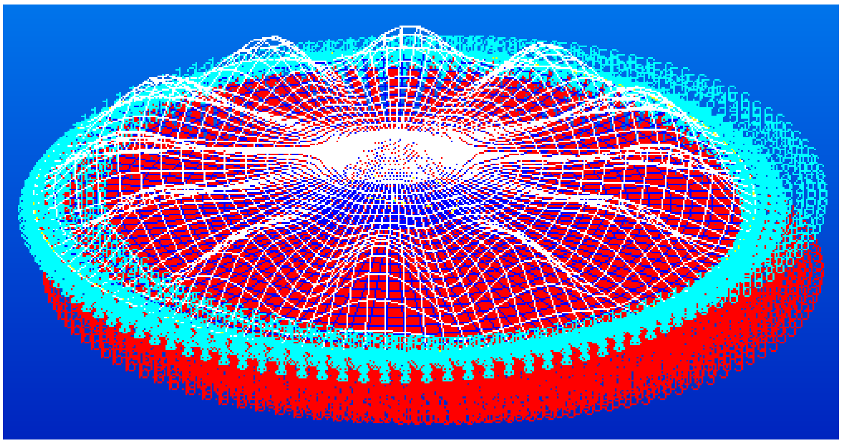


Figure 18. Deformation of the integrated radial pressure bulkhead having rectangular cross section

Figure 19 shows the distribution of stresses in the integrated pressure bulkhead with radial stiffeners having rectangular cross section, when subjected to the pressure of 9 psi.

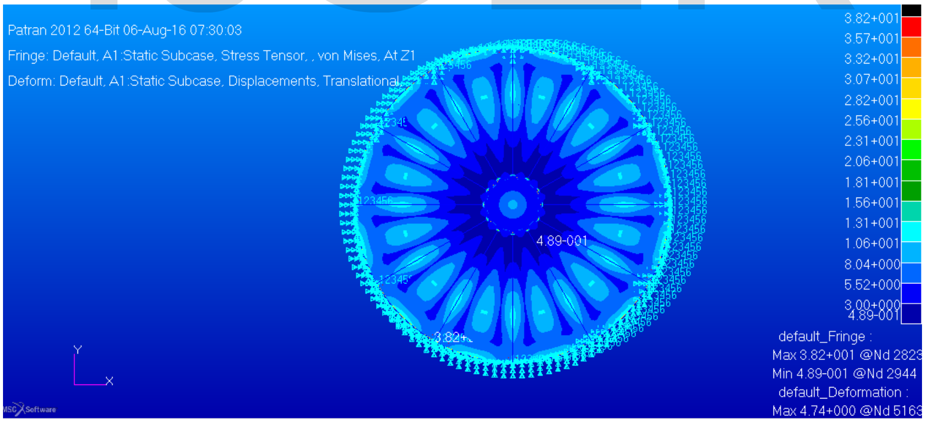


Figure 19. Stress induced in integrated radial pressure bulkhead having rectangle cross section for 9psi pressure

The maximum stress is found to be 38.2 kg/mm^2 (374.62 MPa). However, the tensile yield strenght of the aluminium 2024-T3 is 362 MPa. The induced stress level is found to be more than the allowable stress limit of the material used in the design of integrated pressure bulkhead with radial stiffeners having rectangular cross section. Hence, the integrated pressure bulkhead with radial stiffeners having rectangular cross section is considered as not a safe design.Table 4.6 details the result summary of the effects of pressurization on deformation and stress level of integrated pressure bulkhead with radial stiffeners having rectangular cross section.

Table 4. Result Summary of Integrated Radial Pressure Bulkhead having Rectangular Cross-Section

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	4.74	374.62
8.5 (0.0583)	4.48	354.02
8.0 (0.0549)	4.22	333.43
7.5 (0.0515)	3.95	312.83
7.0 (0.0481)	3.69	291.26
6.5 (0.0446)	3.43	270.66
6.0 (0.0411)	3.16	250.07

5. Conclusions

Investigation was carriedout to determine the significant influence of different types of stiffeners on the structural performance of pressure bulkheads of a fuselage of sky-span dragon aero plane due to the pressurization from 6 psi to 9 psi. Based on the results the following conclusion were drawn.

1. Stresses induced in integrated radial pressure bulkhead having I-section is significantly very less when compared to riveted radial pressure bulkhead and Integrated radial pressure bulkhead having rectangular cross-section.
2. The induced stresses due to the pressurization from 6 psi to 9 psi is less than the yield strength of the Aluminium 2024 –T3 material in the case of rivieted radial pressure bulkhead and integrated radial pressure bulkhead having I-section.
3. In the case of integrated radial pressure bulk head having rectangular cross-section, the induced stress exceeds the yield strength of Aluminium 2024 –T3.
4. Deformation is considerably less in the case of integrated radial pressure bulkhead having I-section and rectangular cross-section. However, deformation is more in the case of riveted radial pressure bulkhead due to the pressurization from 6 psi to 9 psi.

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