Structural Analysis of Stiffening-Grid-Structures of Pressure Bulkhead by Finite Element Method

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Abstract

The air pressure at high altitude of earth's atmosphere is very less when compared to earth's atmospheric pressure. In the case of air vehicles (airplane), it is required to maintain the earth's atmospheric pressure inside the fuselage. The frontend and rear end of the fuselage of an air vehicle are enclosed by pressure bulkheads. Pressure bulkhead is one of the important aircraft structures and is used to prevent the pressurized air leakage inside the fuselage. However, the structural performance of pressure bulkhead is significantly influenced by its stiffness. It is one of the challenging tasks to maintain the desired stiffness of the pressure bulk head during its design. Hence, the present work is focused on the structural analysis of stiffening-grid-structures of pressure bulkhead by finite element method. The structural performance of stiffening-grid-structures integrated pressure bulk head is analyzed due to the pressurization from 6 psi to 9 psi. The results reveal that, the stiffening-grid-structure does have a significant influence on the structural performance of pressure bulkhead. Due to the integration of stiffening-grid-structure, the magnitude of deformations and stresses are considerably reduced in the pressure bulkhead. This in turn highlights the potentials of using stiffening-grid-structure in the pressure bulkhead of air vehicles.

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

1. Introduction

Air vehicles flies at high altitude of about 35000 – 40000 ft 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). Pressure bulkhead is one of the important structures and are used in every aircrafts. The two sides of the fuselage are enclosed using pressure bulkheads, it keeps the required air pressure inside the fuselage. Figure 1 shows the rear pressure bulkhead and its position in the aircraft.

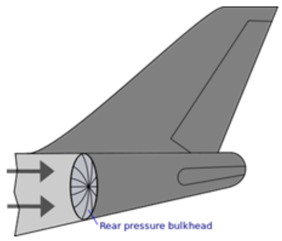


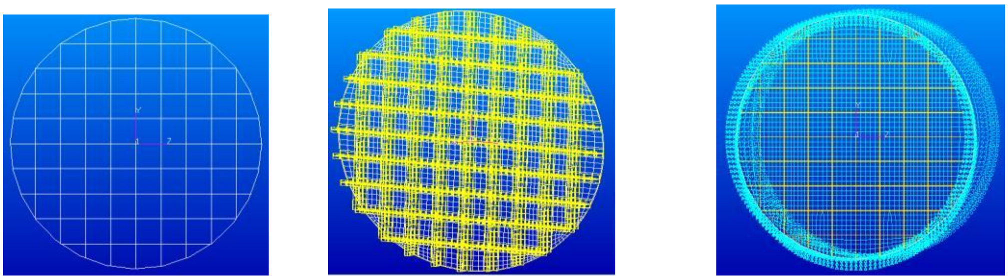
Figure 1 Pressure bulkhead

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. **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, the present work is focused on the structural analysis of stiffening-grid-structures of pressure bulkhead by finite element method.

2. Pressure Bulkhead Integrated with Stiffening-Grid-Structures

2.1 Square Stiffening-Grid-Structure Integrated Pressure Bulkhead

The 2D drawing of integrated pressure bulkhead with square stiffening-grid-structure is designed in CATIA V5- CAD software and then imported to the MSC PATRAN software to build its 3D meshed model and is shown in Figure 2 (a). The cell size of square stiffening-grid-structure is 100 mm was maintained throughout the surface of the face skin of 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 and boundaries are checked to get the accurate results. Figure 2 (b) shows the meshed finite element model of integrated pressure bulkhead. 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 2 (c) shows the load and boundary conditions applied to integrated pressure bulkhead.

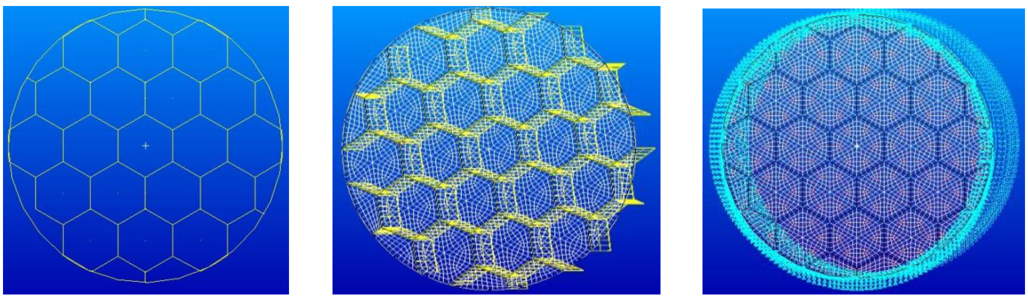


(a) Geometry (b) Finite element model (c) Applied boundary condition

Figure 2. Square Stiffening-Grid-Structure Integrated Pressure Bulkhead

2.2 Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead

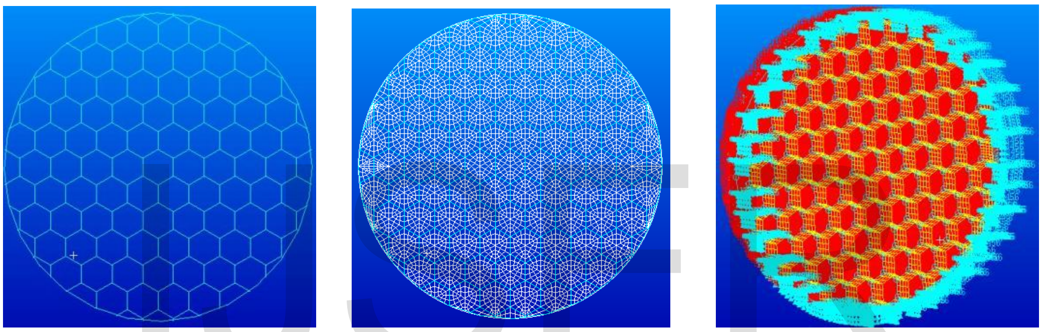
In the present work, honeycomb stiffening-grid-structure with 200mm cell size and 100 mm cells size were designed and investigated to determine the effect of cell size on the structural performance of pressure bulkhead. The 2D drawing of integrated pressure bulkhead with honeycomb stiffening-grid-structure having 200mm cell size, is designed in CATIA V5- CAD software and then imported to the MSC PATRAN software to build its 3D meshed model and is shown in Figure 3 (a). 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 and boundaries are checked to get the accurate results. Figure 3 (b) shows the finite element model of integrated pressure bulkhead with honeycomb stiffening-grid-structure having 200mm cell size. Honeycomb pressure bulkhead model is divided into several finite elements to solve the problem with accurate result, four noded quadrilateral elements are used to create finite elements, and the model is divided to 7098 finite elements with 7501 nodes. Skin and stiffeners are divided separately in which skin is divided into 3690 finite elements with 3775 nodes, and stiffeners are divided into 3408 elements with 3726 nodes. Aluminium 2024-T3 material is used to 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 3 (c) shows the load and boundary conditions applied to integrated pressure bulkhead.



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

Figure 3. Honeycomb stiffening-grid-structure of 200mm cell size integrated pressure bulkhead

The 2D drawing of integrated pressure bulkhead with honeycomb stiffening-grid-structure having 100mm cell size and is shown in Figure 4 (a). 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 and boundaries are checked to get the accurate results. Figure 4 (b) shows the finite element model of integrated pressure bulkhead with honeycomb stiffening-grid-structure having 100mm cell size. Honeycomb pressure bulkhead model is divided into several finite elements to solve the problem with accurate result, four noded quadrilateral elements are used to create finite elements, and the whole model is divided into 8436 finite elements and 9075 nodes. Skin is divided into 4592 finite elements with 4692 nodes. Stiffeners are divided into 3844 elements with 4383 nodes. Aluminium 2024-T3 material is used to 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 4 (c) shows the load and boundary conditions applied to integrated pressure bulkhead.

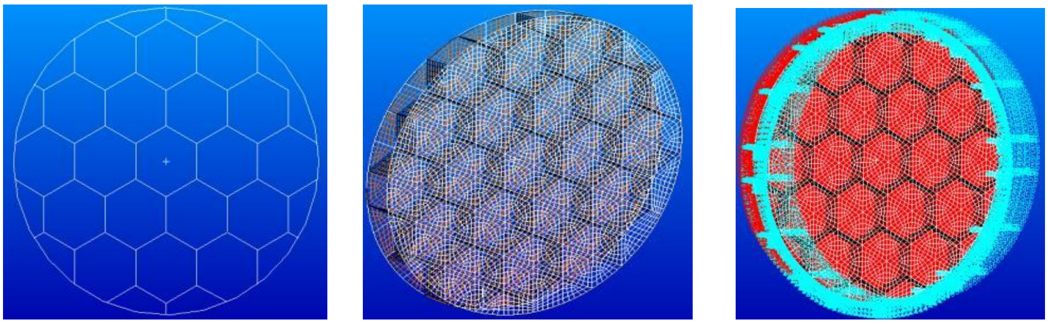


(a) Geometry (b) Finite element model (c) Applied BC

Figure 4. Honeycomb stiffening-grid-structure of 100mm cell size integrated pressure bulkhead

2.3 Sandwich pressure bulkhead with Honeycomb Core Stiffening-Grid-Structure

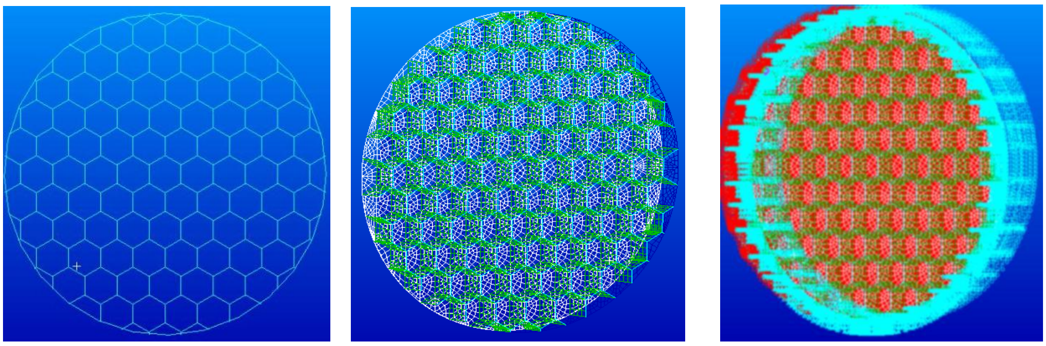
Sandwich structure considered in the development of pressure bulkhead is an arrangement of which the stiffening grid honeycomb core structure is placed in between the two circular face skins. The 2D drawing of integrated pressure bulkhead with honeycomb stiffening-grid-structure having 200 mm cell size, is designed in CATIA V5- CAD software and then imported to the MSC PATRAN software to build its 3D meshed model and is shown in Figure 5 (a). The sandwich 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, and boundaries are checked to get the accurate results. Figure 5 (b) shows the finite element model of sandwich pressure bulkhead integrated with honeycomb core stiffening-grid-structure having 200 mm cell size. Aspect ratio is maintained to check the failed element and the quality parameters like equivalence, boundaries, connectivity and duplicates are verified to get the actual result. The bulkhead is divided into 10788 elements with, 11276 number of nodes. Aluminium 2024-T3 material is used design this structure. Properties like thickness, orientation, sections and material are assigned to the finite elements. Both the skins of the integrated sandwich pressure bulkhead are fixed to fuselage, and the skin surface which is exposed to the inner side of the fuselage will be subjected to the differential pressure conditions. Figure 5 (c) shows the load and boundary conditions applied to sandwich pressure bulkhead integrated with honeycomb core stiffening-grid-structure having 200 mm cell size.



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

Figure 5. Sandwich pressure bulkhead integrated with honeycomb stiffening-grid-structure of 200mm cell size.

Sandwich structure considered in the development of pressure bulkhead is an arrangement of which the stiffening grid honeycomb core structure is placed in between the two circular face skins. The 2D drawing of integrated pressure bulkhead with honeycomb stiffening-grid-structure having 100 mm cell size, is designed in CATIA V5- CAD software and then imported to the MSC PATRAN software to build its 3D meshed model and is shown in Figure 6 (a). The sandwich structure is discrised by using four noded quadrilateral elements with aspect ratio of 5.



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

Figure 6. Sandwich pressure bulkhead integrated with honeycomb stiffening-grid-structure of 100mm cell size.

The structure is meshed and finite elements are induced. This consists of 1310 elements and 13836 number of nodes. Figure 6 (b) shows the finite element model of Integrated sandwich pressure bulkhead with honeycomb grid stiffenes having 100 mm cell size. Quality of the elements such as equivalence, quadrilateral element size, connectivity and boundaries are checked to get the accurate results. Aluminium 2024-T3 material is used design this structure. Properties like thickness, orientation, sections and material are assigned to the finite elements. Both the skins of the integrated sandwich pressure bulkhead are fixed to fuselage, and the skin surface which is exposed to the inner side of the fuselage will be subjected to the differential pressure conditions. Figure 6 (c) shows the load and boundary conditions applied to sandwich pressure bulkhead integrated with honeycomb core stiffening-grid-structure having 100 mm cell size.

3. Results and Discussion

3.1 Square Stiffening-Grid-Structure Integrated Pressure Bulkhead

Results reveals that, the square stiffening-grid-structure integrated pressure bulkhead will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms up to 4.43 mm. Figure 7 shows the deformation of the square stiffening-grid-structure integrated pressure bulkhead. Figure 8 shows the distribution of stresses in the square stiffening-grid-structure integrated pressure bulkhead, when subjected to the pressure of 9 psi.

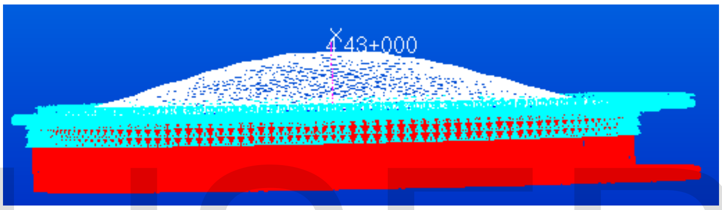


Figure 7. Deformation of the square stiffening-grid-structure integrated pressure bulkhead

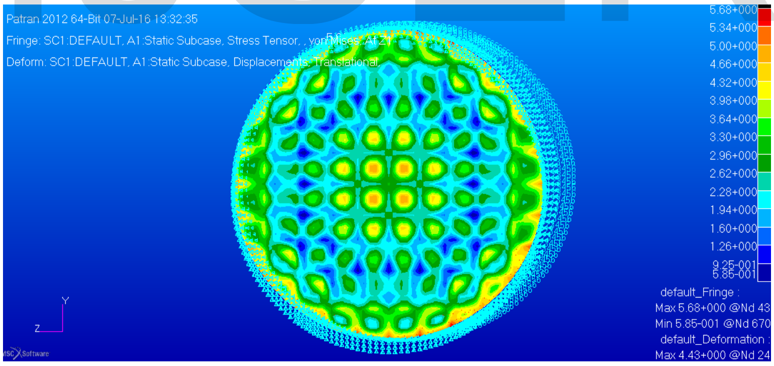


Figure 8. Stresses distribution in square stiffening-grid-structure integrated pressure bulkhead

The maximum stress is found to be 55.70 MPa. However, the tensile yield strength 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 square stiffening-grid-structure integrated pressure bulkhead. Hence, the square stiffening-grid-structure integrated pressure bulkhead is considered to be safe design. Table 1 details the result summary of the effects of pressurization on deformation and stress level of square stiffening-grid-structure integrated pressure bulkhead.

Table 1. Result summary of square stiffening-grid-structure integrated pressure bulkhead

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	4.43	55.70
8.5 (0.0583)	4.18	52.56
8.0 (0.0549)	3.97	49.92
7.5 (0.0515)	3.69	46.39
7.0 (0.0481)	3.44	43.35
6.5 (0.0446)	3.20	40.21
6.0 (0.0411)	2.95	37.12

3.2 Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead

The integrated pressure bulkhead with honeycomb grid stiffeners having 200mm cell size will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms upto 3.68 mm. Figure 9 shows the deformation of the integrated pressure bulkhead with honeycomb grid stiffeners having 200mm cell size. Figure 10 shows the distribution of stresses in the integrated pressure bulkhead with honeycomb grid stiffeners having 200mm cell size, when subjected to the pressure of 9 psi.

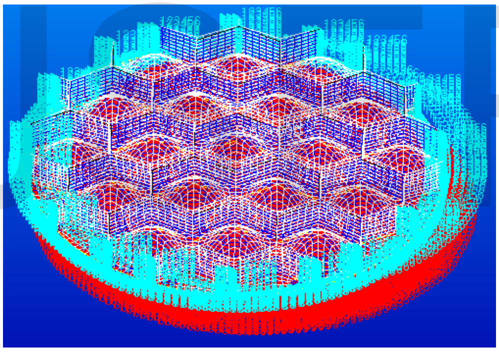


Figure 9. Deformation of the Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead with 200 mm cell size

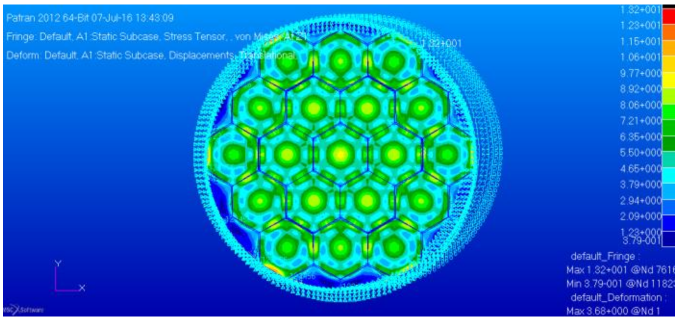


Figure 10. Stresses distribution in Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead with 200 mm cell size

The maximum stress is found to be 13.2kg/mm^2 (129.45MPa). However, the tensile yield strength 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 honeycomb grid stiffeners having 200mm cell size. Hence, the integrated pressure bulkhead with honeycomb grid stiffeners having 200mm cell size is considered to be safe design. Table 4.9 details the result summary of the effects of pressurization on deformation and stress level of integrated pressure bulkhead with honeycomb grid stiffeners having 200mm cell size.

Table 2. Result summary of Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead with 200 mm cell size

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	3.68	129.45
8.5 (0.0583)	3.48	122.58
8.0 (0.0549)	3.28	114.74
7.5 (0.0515)	3.07	107.87
7.0 (0.0481)	2.87	101.02
6.5 (0.0446)	2.66	93.36
6.0 (0.0411)	2.46	86.20

The integrated pressure bulkhead with honeycomb grid stiffeners having 100mm cell size will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms upto 0.913 mm. Figure 11 shows the deformation of the integrated pressure bulkhead with honeycomb grid stiffeners having 100mm cell size. Figure 12 shows the distribution of stresses in the integrated pressure bulkhead with honeycomb grid stiffeners having 100 mm cell size, when subjected to the pressure of 9 psi.

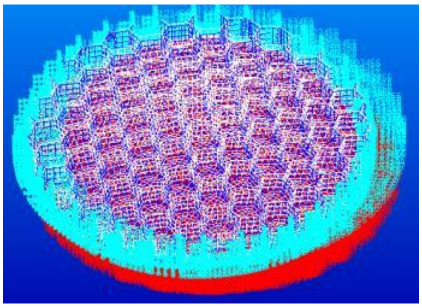


Figure 11. Deformation of the Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead with 100 mm cell size

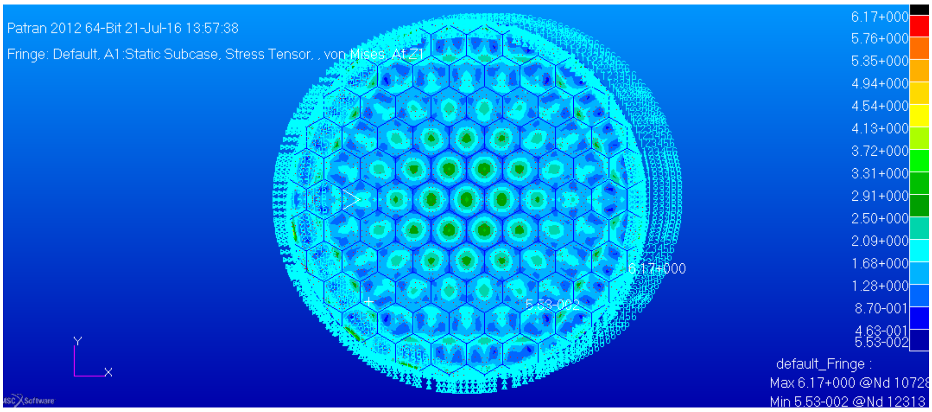


Figure 12. Stresses distribution in Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead with 200 mm cell size

The maximum stress is found to be 6.17 kg/mm^2 (60.51MPa). 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 honeycomb grid stiffeners having 100 mm cell size. Hence, the integrated pressure bulkhead with honeycomb grid stiffeners having 100mm cell size is considered to be safe design. Table 3 details the result summary of the effects of pressurization on deformation and stress level of integrated pressure bulkhead with honeycomb grid stiffeners having 100mm cell size.

Table 3. Result summary of Honeycomb Stiffening-Grid-Structure Integrated Pressure Bulkhead with 100 mm cell size

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	0.913	60.51
8.5 (0.0583)	0.862	57.74
8.0 (0.0549)	0.811	53.74
7.5 (0.0515)	0.761	50.41
7.0 (0.0481)	0.710	47.07
6.5 (0.0446)	0.659	43.64
6.0 (0.0411)	0.608	40.31

3.3 Sandwich pressure bulkhead with Honeycomb Core Stiffening-Grid-Structure

The sandwich pressure bulkhead integrated with honeycomb core stiffening-grid-structure of cell size 200mm will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms upto 2.62 mm. Figure 13 shows the deformation of the sandwich pressure bulkhead with honeycomb core stiffening-grid-structure of cell size 200mm. Figure 14 shows the distribution of stresses in the sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure of cell size 200mm, when subjected to the pressure of 9 psi.

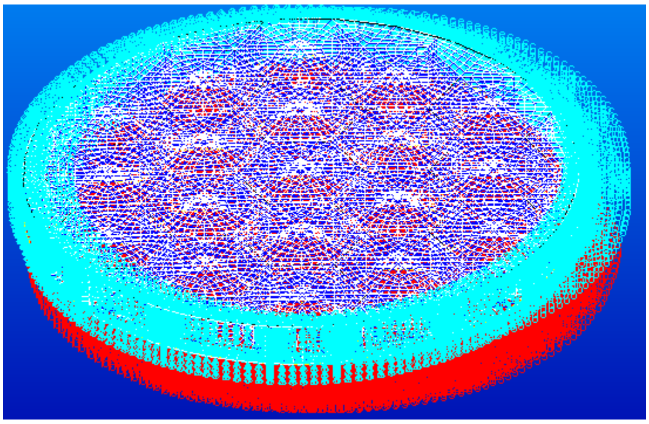


Figure 13. Deformation of the Sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure with 200 mm cell size

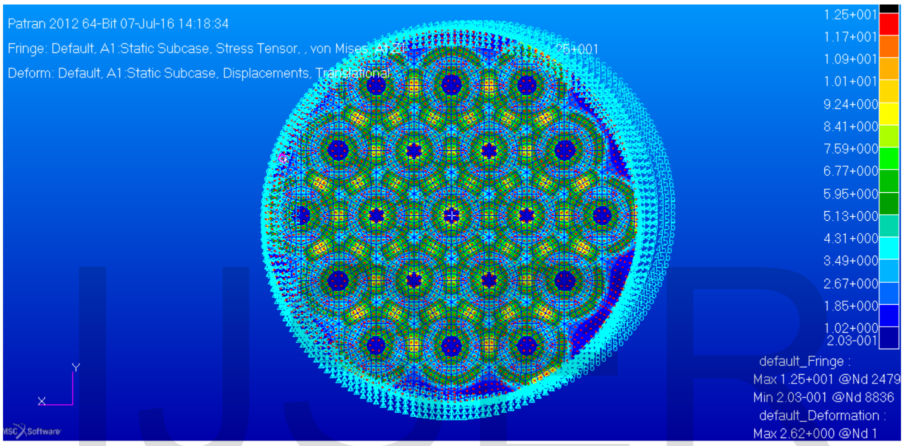


Figure 14. Stresses distribution in Sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure with 200 mm cell size

The maximum stress is found to be 12.5 kg/mm^2 (122.58MPa). 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 sandwich pressure bulkhead of cell size 200mm. Hence, the sandwich pressure bulkhead of cell size 200 mm is considered to be safe design. Table 4 details the result summary of the effects of pressurization on deformation and stress level of sandwich pressure bulkhead of cell size 200mm.

Table 4. Result summary of Sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure with 200 mm cell size

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	2.62	122.58
8.5 (0.0583)	2.47	115.72
8.0 (0.0549)	2.33	108.85
7.5 (0.0515)	2.18	101.99
7.0 (0.0481)	2.04	95.52
6.5 (0.0446)	1.89	88.65
6.0 (0.0411)	1.75	81.88

The sandwich pressure bulkhead integrated with honeycomb core stiffening-grid-structure of cell size 100mm will undergo out-of-plane deformation due to pressurization. The bulkhead when subjected to 9 psi, will deforms upto 0.375 mm. Figure 13 shows the deformation of the sandwich pressure bulkhead with honeycomb core stiffening-grid-structure of cell size 100mm. Figure 14 shows the distribution of stresses in the sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure of cell size 100mm, when subjected to the pressure of 9 psi.

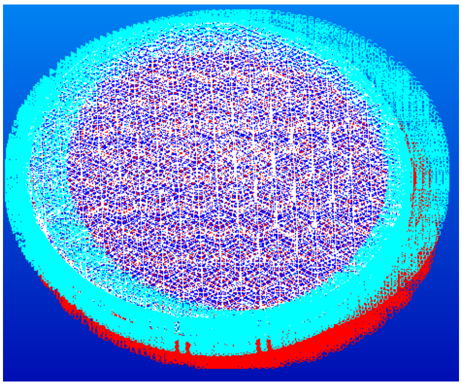


Figure 13. Deformation of the Sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure with 100 mm cell size

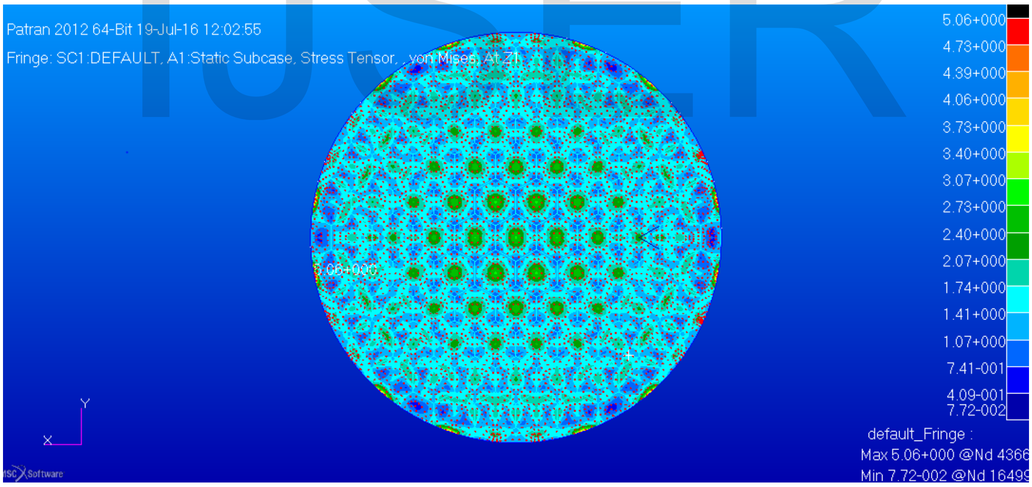


Figure 14. Stresses distribution in Sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure with 100 mm cell size

The maximum stress is found to be 5.06kg/mm2 (49.62MPa). 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 sandwich pressure bulkhead of cell size 100mm. Hence, the sandwich pressure bulkhead of cell size 100mm is considered to be safe design. Table 5 details the result summary of the effects of pressurization on deformation and stress level of sandwich pressure bulkhead of cell size 100mm.

Table 5. Result summary of Sandwich pressure bulkhead integrated honeycomb core stiffening-grid-structure with 100 mm cell size

Pressure, Psi (MPa)	Deformation, mm	Stress, MPa
9.0 (0.0618)	0.375	49.62
8.5 (0.0583)	0.354	46.88
8.0 (0.0549)	0.333	44.13
7.5 (0.0515)	0.312	41.29
7.0 (0.0481)	0.291	38.54
6.5 (0.0446)	0.271	35.79
6.0 (0.0411)	0.250	33.05

4. Conclusions

Investigation was carried out to determine the significant influence of different types of stiffeners on the structural performance of pressure bulkheads of a fuselage of air vehicles due to the pressurization from 6 psi to 9 psi. Outcome of the results reveal that,

1. The deformations and stresses induced in all the types of pressure bulkheads due to the pressurization from 6 psi to 9 psi, are significantly influenced by the integrated stiffening-grid-structures.
2. The magnitude of stresses induced due to the pressurization are found to be less when compared to the yield strength of Aluminium 2024 T-3 material.
3. Sandwich pressure bulkhead with honeycomb grid stiffeners with 100 mm honeycomb cell size depicted minimum deformation of 0.375 mm, when compared to all other types of pressure bulkheads. Further it was observed that, deformation of sandwich pressure bulkhead was significantly affected by the cell size of honeycomb structure.

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