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Stress Analysis & Optimization of Pressure Bulkhead using Finite Element Techniques

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ABSTRACT

Aircrafts are designed such that they cruise at higher altitude with structural stability. Generally when aircraft cruise above 8000ft from Mean Sea Level (MSL), the oxygen level inside the cabin reduces. Hence, cabin pressure is generally maintained atcabin altitude pressure of 8000ft i.e., 10.91psi or less [4].In aircrafts,Longitudinal and Hoop stresses combined with flight and ground loading conditions are the important structural loading criteria for cabin pressurization. To maintain this pressure at greater altitudes pressure bulkhead are inevitable in aircrafts. Tight seal of pressurized interior is necessary to take up and transfer all the forces into the fuselage structure that result from the pressure on the two opposite side of the bulkhead. Hence, it is provided in both front and rear portion of an aircraft. In the present study,only front pressure bulkhead of a typical civil aircraft has been considered for structural analysis and to select a suitable optimized stringer sectionfor minimum weight criterion, without forgoing the structural integrity. Front Pressure Bulkhead with flat skin and stiffeners in both horizontal and vertical directionarranged in grid shape has been created using high performance finite element pre-processor software called Altair Hypermesh. Finite Element StressAnalysis (FEA) was carried out using post-processor MSC-NASTRAN.Commercially available standard sections which are being used in aircraft industry are considered for structural analysis. Twelve different stringer sections, three each of I, C, Z and T sections made up of three different aluminium alloy materials are used as stringers in front pressure bulkhead and are analysed to select a suitable economical section. Based on the investigation, it has been found that Tsection stringer of aluminium alloy Al 7075 with ultimate stress of 575MPa was suitable.Pressure Bulkhead with T section as stringer was furtheroptimized.The obtained optimized flat panel with T section, was analyzed with widely used Carbon Fiber Reinforced Polymer CFRP composite material and its results were compared and reported.
Keywords—Pressure Bulkhead; Altitude Pressure; Fuselage; Stress Analysis: Stringer; Pressurization.

I. INTRODUCTION

When aircrafts cruise above 8000ft from MSL, the oxygen level inside the cabin reduces as pressure decreases at higher altitudes resulting pressure difference between air inside and outside the cabin. Pressure difference of air has to be regulatedandmaintained to supply sufficient oxygen for occupants to breathe normally and move around the cabin at high cabin altitudes. The internal cabin pressure depends on the cruise altitude and comfort of the occupants. Fuselage pressurization is an important structural loading which includes longitudinal and hoop stresses which is combined with flight and ground loading conditions. Cycling from unpressurised to pressurized zone and back again in each flight that causes metal fatigue needs to be maintained along with the pressure difference. To maintain this pressure at greater altitudes pressure bulkhead are provided. They are load bearing structures. Concentrated loads are distributed into the structure and also stresses around structural discontinuities are redistributed. It is necessary for pressure bulkhead to tight seal the pressurized interior for taking up and further transmitting all the forces into the fuselage structure that result from the pressure on the two opposite sides of the bulkhead. Hence, it is provided both in the front and rear portion of an aircraft, termed as front pressure bulkhead located near cockpit and rear pressure bulkhead located near tail of an aircraft respectively. Pressure Bulkhead are also classified based on shape namely, flat pressure bulkhead and hemispherical/dome shaped pressure bulkhead. Selection between flat and dome shaped bulkhead generally

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depends on the availability of the space, size of the cross- section area that is to be enclosed. In this study, only front pressure bulkhead of a typical civil aircraft has beenconsidered for the analysis to utilize the available resources to serve its desired function with structural integrity and for minimum weight.

II. LITERATURE REVIEW

Apicella (2007) has created finite 4-noded shell element model of front bulkhead which was made up of composite skin with seven vertical stiffeners. The structure was clamped and pressure load was applied to the composite skin. Linear Static analysis was carried out to calculate strain in particular points. It was proved thatFE analysis can give good results as given by the built ones if they are modelled with same boundary condition like size, shape, load etc. Finite Element Method was recommended for complex materials like composites to model more accurately similar to built one.

Venkatesh et al (2009) has introduced the concept of integrating the dome with the fuselage frame using cocuring technology, which eliminates stress concentrations due to holes, reduced assembly time and associated costs. CSIR-NAL has played a key role in the development of cocured composite structures for both military and civil aircraft structures. This type of construction resulted in Lower manufacturing cost, no long term corrosion issues, fasteners reduction and 50% weight reduction as compared to metallic design.

Krishnan S et al (2013) has carried out stress analysis of pressure bulkhead with stiffeners. It undergoes plane bending due to internal pressurization and due to stiffening, one of the surface of bulkhead will undergo tension and the other compression simultaneously. This analysis was done in MSC- NASTRAN software to know principal stresses at various points and compared with damage fraction of pressure bulkhead which was found to be safe.

III. GEOMETRY OF FRONT PRESSURE BULKHEAD

Flat front pressure bulkhead of a typical civil aircraft surface with stringers are considered for analysis. The geometrical shape of flat front pressure bulkhead with fuselage skin considered for the analysis is shown in Figure 1. The various structural sub-components of the front pressure bulkhead obtained from open literature was bulkhead ring, flat skin and stringers as shown in Figure 2. The bulkhead ring gets attached to the fuselage skin all around circumference. The average diameter of pressure bulkhead was 1.35m. The bulkhead ring was made up of aluminium alloy plate of 40mm width and thickness of 3mm[5].

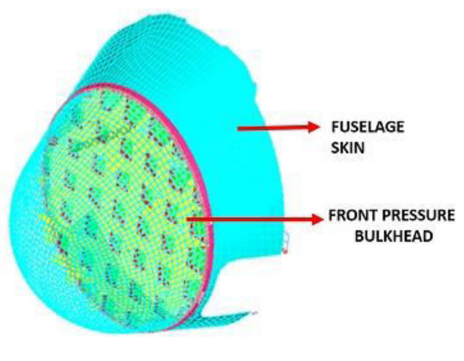

Figure 1: Front Pressure Bulkhead with Fuselage skin

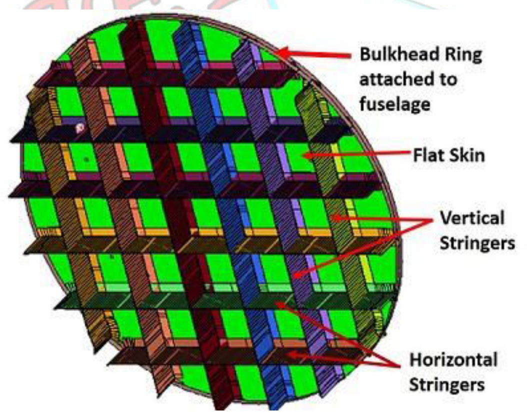

Figure 2: Geometrical Model of Front pressure Bulkhead

IV. FE MODEL ANDANALYSIS OF THE FRONT PRESSURE BULKHEAD

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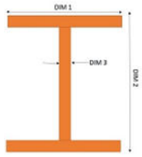
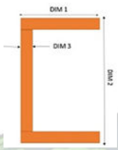
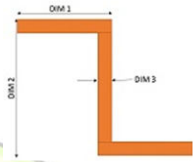
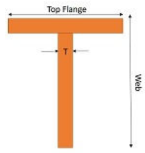
FE model of the front pressure bulkhead is created by using CQUAD4 and CTRIA3 elements of MSC NASTRAN. MSC NASTRAN has been used as FE solver. The FE model along with stringersas shown in Figure 2.Based on the commercially available standard stringer sections [6], 12 stringer sections of various aluminium alloys were considered for analysis. The standard stringer sections I, C, Z and Tconsidered for the analysis are tabulated in Table 1.For each standard stringer section, FE models were created separately and analysed by assuming the appropriate material and sectional properties. Stringers of front pressure bulkhead along with skin were also modelled as 2D quadrilateral elements with spacing of 100mm c/c.

TABLE 1 : Assigned Aluminium Sectional type and its properties:

Aluminium Alloy	SECTION TYPE											
												
	DIM1	**DIM2**	**DIM3**	**DIM1**	**DIM2**	**DIM3**	**DIM1**	**DIM2**	**DIM3**	**DIM1**	**DIM2**	**DIM3**
Al 6061	59.19	76.2	4.32	44.45	127	4.83	68.26	76.2	6.35	30.8	30.8	6.35
Al 2024	50.04	75.92	1.6	38.66	101.6	1.6	38.1	25.4	3.17	38.66	101.6	1.6
Al 7075	50.8	101.6	3.18	34.93	88.9	3.96	85.85	91.95	6.35	66.04	101.6	2.54

Section Type	Mass, kg		
	Al 6061	**Al 2024**	**Al 7075**
I	71.381	28.844	57.621
C	84.824	29.223	55.386
Z	106.491	30.941	129.865
T	34	24.432	40.826

V. LOADS AND BOUNDARY CONDITIONS

An Ultimate Pressure of magnitude 16.5 Psi [Limiting Pressure (10.91Psi) x Factor of Safety (1.5) = Ultimate Pressure (16.5Psi)] has been considered as per FAR 25 specifications. This pressure was applied normal to the inside surface of components using PLOAD4 card. For pressure bulkhead analysis,all degrees of freedom were restrained at the region where the bulkhead gets connected to the fuselage.

VI. RESULTS AND DISCUSSION

Linear static analyses for an applied ultimate pressure of 16.5psi on flat panel pressure bulkhead for all the twelve standard stringers sections with constant skin thickness of 1.6mm were carried out. The related stresses and displacements were obtained and found to be within the allowable range. Similarly, the variation of FE mass for each of the standard stringer sections were determined and are tabulated in Table 2. These values are graphically represented in Figure 3

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Table 2: Mass of front pressure bulkhead for different section type and material

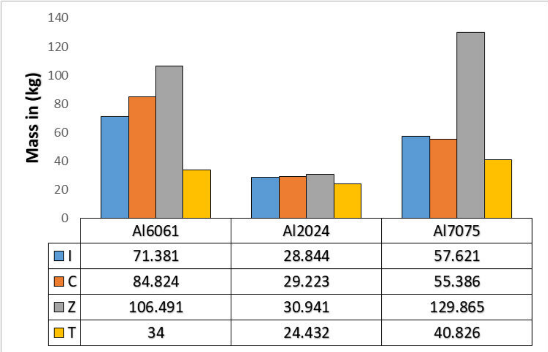

Figure 3: Graphical representation of FE mass of pressure bulkhead for all the three Al alloys and 12 standard stringer sections

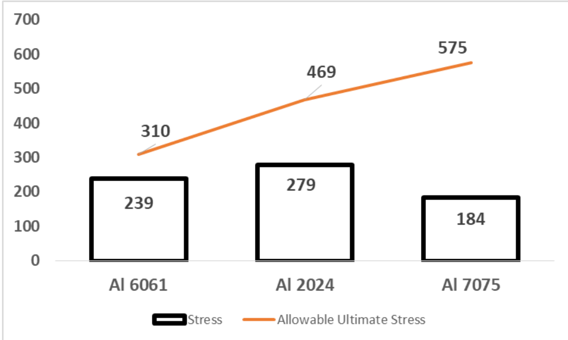

Figure 4:Graph representing stress variation of pressure bulkhead with T section stringers of different material

From the above Table 2 and Figure 4 we can say that the T sections is most suitable having a minimum FE mass compared to other standard stringer sections such as I, C, Z sections. Though the above Table 2 and Figure 3 specifies T section is most suitable with minimum FE mass, standard T sections considered for analysis comprised of three different sections of three different aluminum alloy materials, having three different allowable stress values. In view of this, a linear static analysis was carried out for all these allowable stress values, and the results are plotted for all these three materials and obtained stresses against the allowable stress values is shown in above Figure 5.

From the Figure 5, we can say that, Standard T section [101.6 (web) x 66.04 (flange) x 2.54 (thickness)] made up of aluminum alloy 7075 shows a von Mises stress value of 184 MPa., whereas the ultimate allowable stress value for this aluminum alloy is 575 MPa. This implies that this standard stringer section can be further optimized for minimum weight criterion. Hence, we have selected T section [101.6 (web) x 66.04 (flange) x 2.54 (t)] of aluminium alloy 7075 for optimization.

A. Optimization of Flat panel Pressure bulkhead with Standard T section:

By the method of reducing the number of stringers were carried for the optimization of the pressure bulkhead. The stringers were reduced from 26 to 13 by increasing the c/c spacing of stringer from 100 mm to 200mm as shown in Figure 5. And the results of Stresses and displacement contours were obtained and are shown in Figure 6 and 7. A maximum displacement of 9.86 mm and von mises stress of 435MPa were observed. FE mass of the pressure bulkhead was 22.231 kg. This optimized pressure bulkhead proved to be economical from both structural and stability aspect.

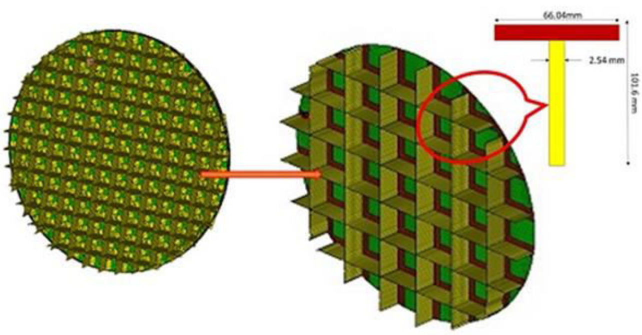

Figure 5: FE model of pressure bulkhead with best stringer section before and after optimization

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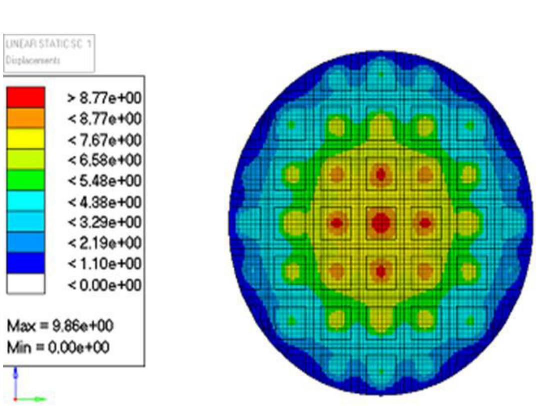

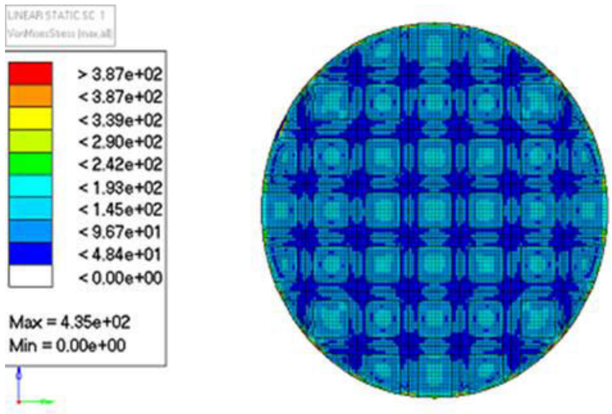

Maximum Displacement = 9.86 mm

Maximum Von mises stress = 435MPa

Figure 6 : Displacement contour of Al 7075 Pressure Bulkhead with T section Stringer

Figure 7: Stress contour of Al 7075 Pressure Bulkhead with T section Stringer

In order to compare this Optimized pressure bulk of aluminum alloy, with that of a composite material, the optimized bulkhead was modeled and analysed with a CFRP materialfor skin thickness of 1.8mm and web thickness of 2.4mm. The material properties of the Composite materials obtained from open literature are shown in Table 3 were utilized for the analysis.

Table3: Material Property of composite Material:

Elastic Modulus, E_{11}	150 GPa
Elastic Modulus, E_{12}	9 GPa
Poisson's Ratio, v_{12}	0.35
Density	1.6 E-6 kg/mm^3
Shear Modulus, G_{12}	4 GPa

The displacement plots for this CFRP composite material are shown in Figure 8.

Maximum Displacement = 12.3 mm

Figure 8: Displacement contour of composite Pressure Bulkhead with T section Stringer

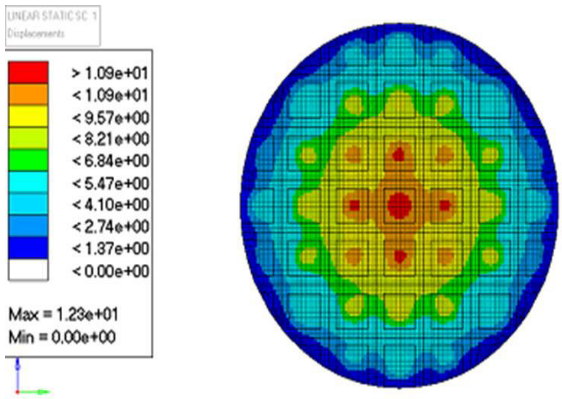

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Figure 9: Graph representing variation of mass of two different materials for pressure bulkhead

A comparative table of displacement, stresses and FE masses for both optimized pressure bulkhead with aluminium alloy and CFRP composite materials are tabulated in the Table 4.

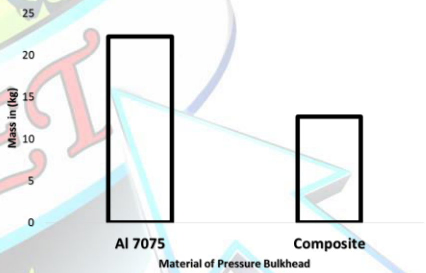
TABLE 4:Analysis Result of Pressure Bulkhead of Aluminium and Composite Material

Material	Mass, kg	Displaceme nt, mm	Von Mises Stress, N/mm^2	Failure Index
Al 7075	22.231	9.86	435	-
Composite	12.64	12.3	-	0.8

From the Table 4 we can conclude that flat pressure bulkhead with T stringers of CFRP composite material to be economical from the weigh criterion with weight saving of 56 percentage when compared to optimized aluminium alloy pressure bulkhead. And the same is shown in Figure 9.

VII. CONCLUSION

From the detailed FE analysis of the pressure bulkhead with 12 standard section of 3 different aluminium alloy materials, T section is most suitable with minimum FE mass when compared to other standard stringer sections such as I, C, Z sections.Standard T section [101.6 (web) x 66.04 (flange) x 2.54 (thickness)] made up of aluminum alloy 7075 was found more structurally stable out of three different T sections of three different aluminum alloy materials, having three different allowable stress values.Hence, T section [101.6 (web) x 66.04 (flange) x 2.54 (t)] of aluminium alloy 7075 was used for optimization for minimum FE mass criterion.By optimization of pressure bulkheadnumber of stringers was reduced from 26 to 12 and proved to be economical from both structural and stability aspect.It is also proved that flat pressure bulkhead with T stringers of CFRP composite material to be economical from the weight criterion with weight saving of 56 percentage when compared to optimized aluminium alloy pressure bulkhead.



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