Stress Analysis of the Fuselage Cabin Pressure Bulkhead and Evaluation of Different Geometrical Configurations

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***Abstract*— Many modern aircraft are being designed to operate at high altitudes. In order to fly at higher altitude, the aircraft must be pressurized. The designer of the structure has to come out with the minimum weight without compromising on the safety of the structure. Fuselage is a semi-monocoque construction. It is stiffened in both longitudinal and circumferential directions. The current project includes the evaluation of different geometrical configurations for the cabin pressure bulkhead through stress analysis approach. The fuselage is pressurized internally to create a sea level atmospheric pressure inside. This internal pressurization is considered to be one of the critical load cases during the design and development of the aircraft. For pressurization of the fuselage cabin, it is enclosed with pressure bulkheads in the front and rear ends. The wall of the cabin pressure bulkhead is stiffened in orthogonal directions. This stiffening can be provided by using either integrally machined stiffener or through discrete connection of stiffening member by rivets. Due to internal pressurization the cabin pressure bulkhead will undergo out of plane displacement. One surface of the pressure bulkhead will undergo tension and the other will undergo through compression simultaneously. The high tensile stress locations will be critical from the fatigue crack initiation point of view. Stress analysis will be carried out on cabin pressure bulkhead panel to identify the maximum tensile stress location. Fatigue cracks will always get initiated from the location of maximum tensile stress. Stress analysis will be carried out for two different geometrical configurations. In a metallic structure fatigue manifests itself in the form of a crack, which propagates. If the crack in a critical location goes unnoticed it could lead to a catastrophic failure of the airframe. Fatigue life to crack initiation at the location of highest tensile stress will be predicted using constant amplitude S-N data for the material used.**

Keywords*— *Transport aircraft, Fuselage, Pressure bulkhead, Internal pressurization, Finite element method, stress analysis, Fatigue life, Crack initiation.

I. INTRODUCTION (*Heading 1*)

The aircraft or airplane is used for transportation of people and goods from one place to another usually when the distance to be travelled is large. It is the fastest mode of commercial transport which flies at higher altitudes. Atmospheric pressure at the sea level is caused by the weight of air particles above the measurement level. As the altitude increases, the number of air particles above the measurement point decrease causing decrease in the pressure. This caused the reduction in the pressure inside the airplane fuselage cabin. This is because the pressures inside and outside the fuselage cabin are essentially the same. Due to this decrease in the air pressure inside the fuselage cabin, the passengers experience difficulty in breathing which in turn causes many psychological problems. Therefore, at high altitudes, the fuselage cabin is pressurized and hence the cabin and rear pressure bulkheads of the fuselage need to withstand this pressure. In the present work, stress analysis of cabin pressure bulkhead is performed and the design is modified in various iterations to strike the balance between weight and required strength of the pressure bulkhead. Here Aluminium is used as a material for pressure bulkhead due to its high strength to weight ratio. Various iterations are performed by changing the thickness of skin, adding stringers or stiffeners, changing the cross section of the stringers along with their thickness and changing pattern of attachment of stiffeners to the bulkhead. The optimal design will be the one which gives the required strength with minimum weight.

II. PROBLEM FORMULATION

A. *Configurations of 14-seater passenger aircraft*

TABLE 1. AIRCRAFT CONFIGURATIONS[4]

Specification	Value
Wing Span	14.70 m (48 ft 2.25 in)
Fuselage Diameter	1.95 m (6 ft 4.25 in)
Fuselage Length	13.90 m (45 ft 7.25 in)
Maximum Take-off Weight	6100 kg
Cruise Altitude	9100 m (29860 ft)
Range	400 km (216 n miles, 248 miles)
Wing Airofoil at Root	2.65 m (8 ft 8.25 in)
Wing Airofoil at Tip	0.85 m (2 ft 9.25 in)
Cruise Speed or Velocity	400 km/h (249 mph, 216 kt)
Crew	3 (Pilot, Co-Pilot, Flight Engineer)
Capacity	14 Passenger

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The outer contour of the aircraft cabin pressure bulkhead is Numerical Master Geometry (NMG), which is provided by Aerodynamic department after going through the category and requirement of an aircraft during conceptual design phase. This is shown in the figure below:

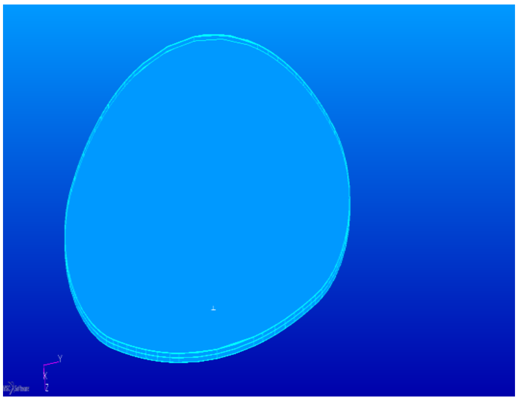

Fig. 1. Catia model of the cabin pressure bulkhead skin imported into Patran

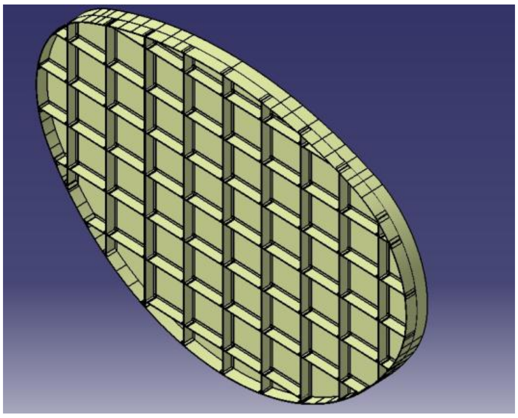

Fig. 2. Catia model of criss-cross pressure bulkhead

B. *Load Case (Pressurization)*

Cabin pressurization is the process of supplying the air or pumping the conditioned air to the fuselage cabin for creating a safe and comfortable environment for the passenger and crew members of the aircraft which is flying at higher altitudes. The fuselage cabin is pressurized using air compressors in the aircrafts and for spacecrafts it is carried out by cryogenic tanks. When the aircraft is flying at higher altitudes, the pressures outside and inside of the aircraft are the same. But at high altitude, the pressure is very low and hence the passengers will not be able to breathe easily. The air pressure at sea level is 14.7 psi whereas the pressure at an altitude of about 33000 ft, the air pressure is approximately 4 psi. At this low pressure, the passengers will not be able to breathe. Therefore, for comfortable breathing of the passengers, the pressure inside the fuselage needs to be increased. The cabin and rear pressure bulkhead need to withstand this high pressure. The pressurization is very necessary for the aircraft passengers to breathe easily especially above an altitude of 12500ft (3800m) to 14000ft (4300m) above sea level. Generally, for passenger comfort, the pressurization of the fuselage starts from 8000ft above sea level.

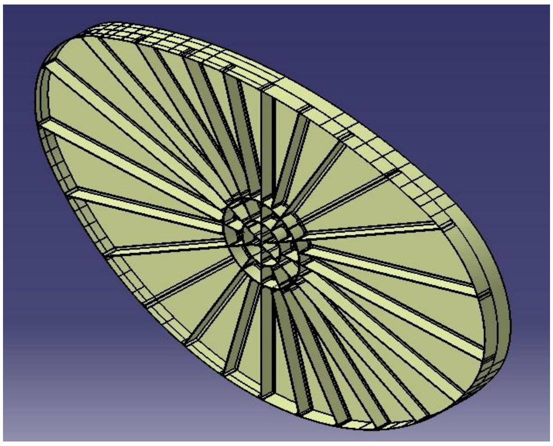

Fig. 3. Catia model of radial pressure bulkhead

C. *Material used*

In the present work Al-2024 T3 is assigned as the material for the aircraft fuselage cabin pressure bulkhead. Aluminum alloys have best combination of lightness, strength, workability, versatility, cost effectiveness, ability to recycle, stylishness, weld ability and durability. The aluminum material with strong alloys easily bears extra pressure and stresses developed in the aircraft flying at higher altitudes. The aluminum resists corrosion due to which there is no need to paint the aircraft, which in turn reduces the weight.

D. *Finite Element Mesh*

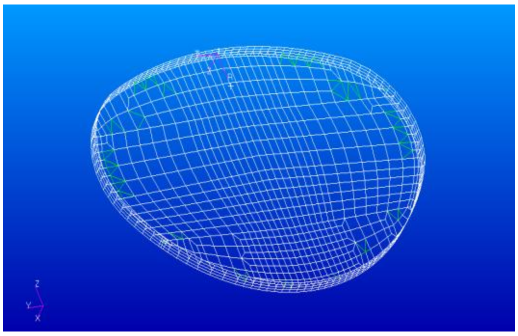

Fig. 4. Finite Element Mesh of Cabin Pressure Bulkhead

The bulkhead model is meshed to properly for the analysis. This model is imported from Catia design software because it is very difficult to create and handle models with complex geometries in Patran. The parts from imported model are grouped for easy meshing. Ease group is divided into a number of elements while meshing. Care should be taken while choosing the shape of the elements, for greater accuracy, square or nearer to square elements should be assigned. TRIA elements, if used, should not be more than 5% of the total elements used for meshing. The QUAD elements will fail when one or more of the following conditions are not satisfied: aspect ratio < 5, wrap angle ≤ 0.05, skew angle $\leq$

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300, taper ≤ 0.5, normal offset ≤ 0.15 and tangent offset ≤ 0.15. TRIA elements will fail when one or more of the following conditions are satisfied: aspect ratio ≤ 5, skew angle ≤ 10, normal offset ≤ 0.15 and tangent offset ≤ 0.15. After meshing is complete, loads and boundary conditions are assigned to the model. Material properties such as Young's modulus, Poisson's ratio, etc. are then assigned to the model along with the material thickness. After completing these activities analysis icon should be clicked, and if "no analysis is required" dialogue is appeared, the model can be imported into Nastran for the analysis.

E. Loads and Boundary Conditions

For the analysis, 6psi of pressure, which corresponds to the design load limit, is applied to the Z1 face of the cabin pressure bulkhead, which is the top face and faces towards the passengers, to determine the stresses developed in the bulkhead. The nodes of the flange are fixed to constraint their motion in all the directions

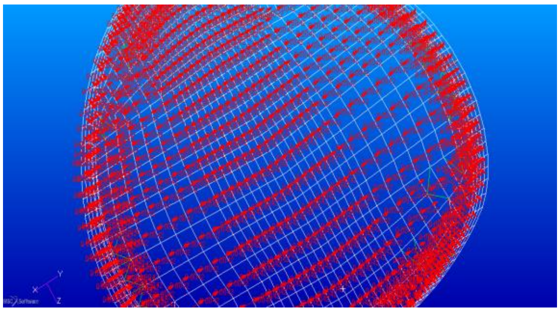

Fig. 5. Load on Cabin Pressure Bulkhead

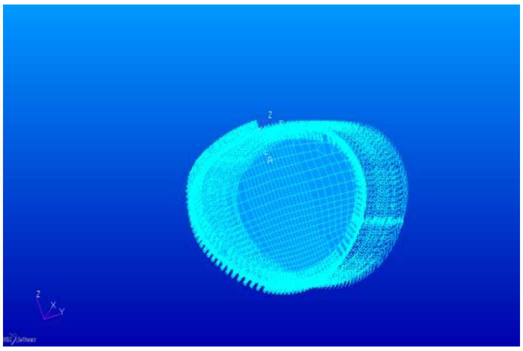

Fig. 6. Boundary Condition of Cabin Pressure Bulkhead

III. RESULTS AND DISCUSSION

After the analysis, the results are visualized in Patran which is shown in fig.12. The stress in the bulkhead is 96.72 kg/mm2, which is far more than the limiting value of 35 kg/mm2. Hence design modifications must be incorporated to reduce the stress. Also, care should be taken while doing so, so that the weight of the bulkhead is optimum.

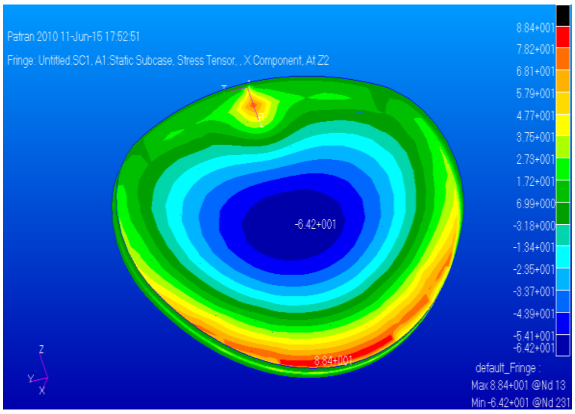

Fig. 7. Maximum Stress Location

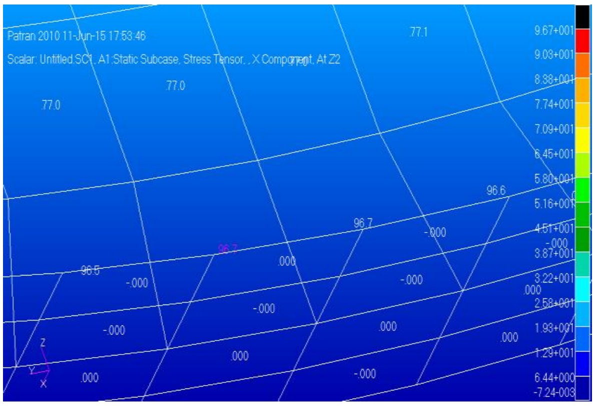

Fig. 8. Maximum Localized Stress

A. Design Modification through Iterative Analysis Approach

The stresses and weight of the bulkhead are optimized by performing various iterations by varying skin thickness. The process is continued till bulkhead with optimum strength to weight ratio is obtained. The maximum stresses developed in the bulkhead after optimization through iterations are shown below:

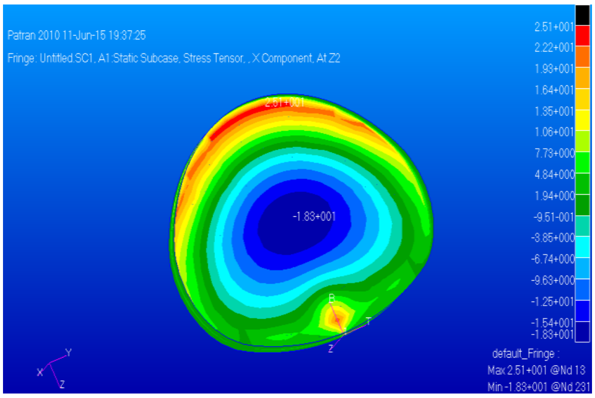

Fig. 9. Maximum Stress in the Bulkhead

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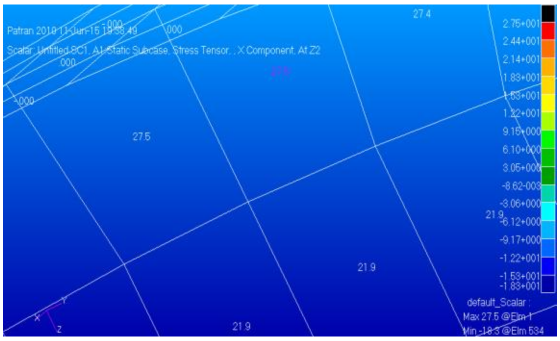

Fig. 10. Maximum Stress in the Bulkhead

The results of various iterations performed by varying the skin thickness and by placing various stringers are tabulated as shown in the tables below:

TABLE I. MAXIMUM STRESSES AND THEIR LOCATIONS FOR VARIOUS ITERATIONS ALONG WITH THE WEIGHT

	Iteration No. I	**Iteration No. II**	**Iteration No. III**	**Iteration No. IV**
Skin Thickness in mm	4	8	6	7.5
Deformation in mm	290	36.4	86.1	44.2
MTS in kg/mm2	96.72 x-component at Z2 face	24.1 x-component at Z2 face	42.3 y-component at Z2 face	27.5 x-component at Z2face
Location of Stress	At the Edge of the skin	At the Edge of the skin	At the Edge of the skin	At the Edge of the skin
Weight in kg	20.32	40.63	30.48	38.09

To further optimize the bulkhead to reduce the weight, analysis is performed iteratively by applying the criss-cross stringers to the bulkhead by varying the cross-section of the stringers and thickness of the skin. The maximum stresses developed in the skin and stringers after optimization through the iterations are shown in the figures below:

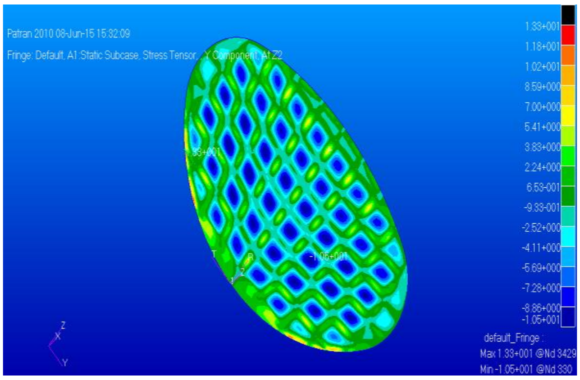

Fig. 11. Maximum Stress in the Skin of the Bulkhead

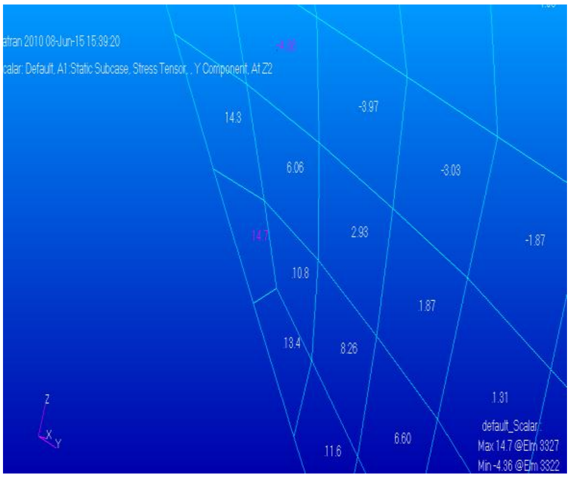

Fig. 12. Maximum Localized Stress in the Skin of the Bulkhead

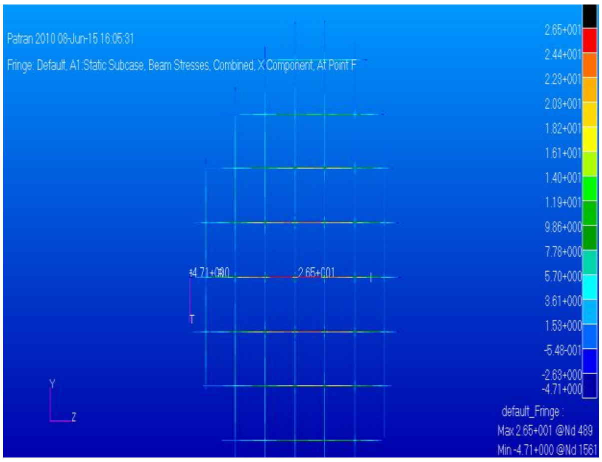

Fig. 13. Maximum Stress in the Criss-cross Stringer

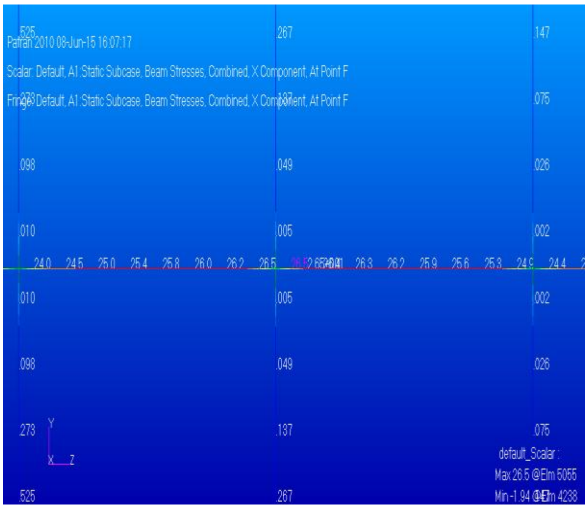

Fig. 14. Maximum Localized Stress in the Criss-cross Stringer

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TABLE II. MAXIMUM STRESSES AND THEIR LOCATIONS FOR VARIOUS ITERATIONS ALONG WITH THE WEIGHT (WITH CRISS-CROSS STRINGERS)

	Iteration I	Iteration II	Iteration III	Iteration IV	Iteration V	Iteration VI
Skin Thickness in mm	2	1.8	1.5	1.5	1.5	1.5
Deformation in mm	12.3	9.82	14.6	8.86	9.73	10.8
MTS in Skin in kg/mm2	25.41	17.7	21.5	13.1	12.9	14.7
Location of Stress in Skin	y-component in Z2 face at the Middle	y-component in Z2 face at the Edge	x-component in Z2 face at the Edge	y-component in Z2 face at the Edge	y-component in Z2 face at the Edge	y-component in Z2 face at the Edge
MTS in Stringer in kg/mm2	35	28.8	36.7	20.9	22.7	26.5
Location of Stress in Stringer	x-component in F face at the Middle	x-component in C face at the Middle	x-component in F face at the Middle	x-component in C face at the Middle	x-component in F face at the Middle	x-component in F face at the Middle
Weight in kg	16.02	15.51	13.47	17.01	16.71	15.25

The strength to weight ratio of the bulkhead is further optimized by placing radial stringers. The iterations are performed by varying the thickness of the skin and cross-section of the stringers. The maximum stresses developed in the skin and stringers after optimization are shown below:

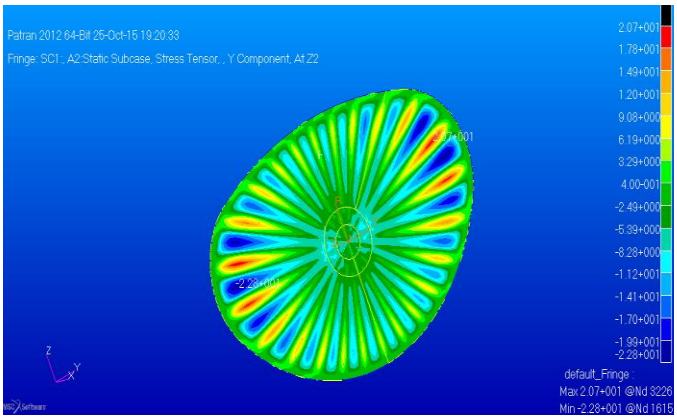

Fig. 15. Maximum Stress in the Skin

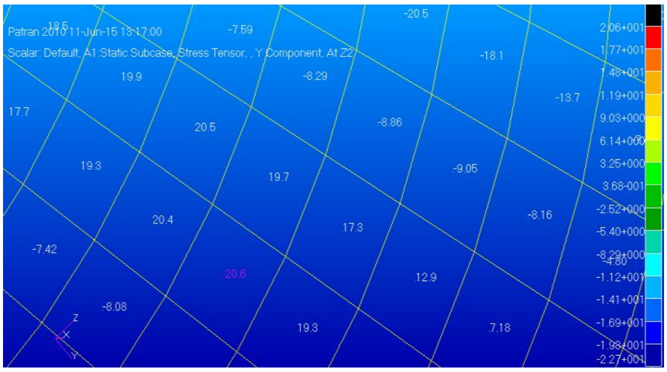

Fig. 16. Maximum Localized Stress in the Skin

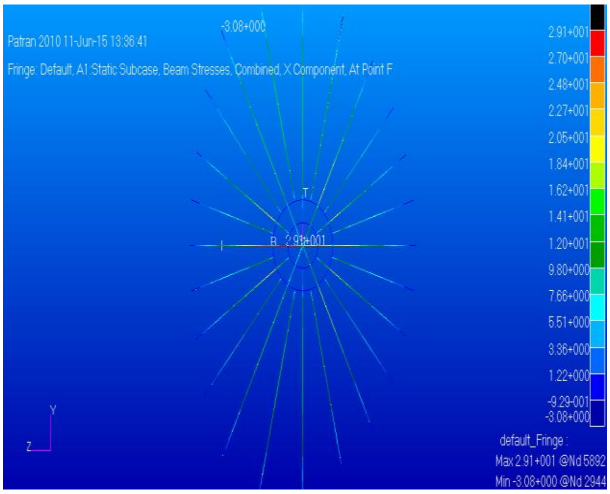

Fig. 17. Maximum Stress in the Radial Stringers

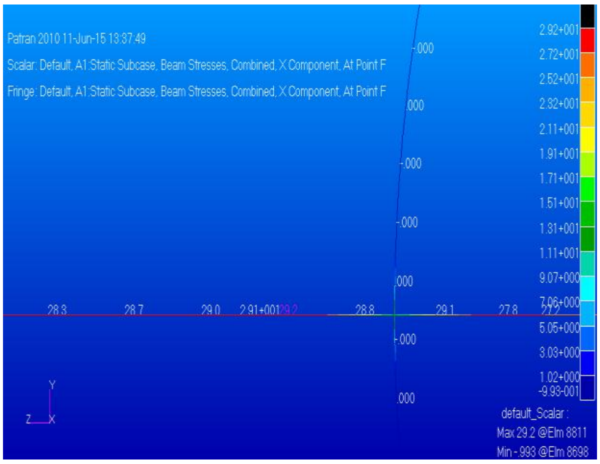

Fig. 17. Maximum Localized Stress in the Radial Stringers

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TABLE III. MAXIMUM STRESSES AND THEIR LOCATIONS FOR VARIOUS ITERATIONS ALONG WITH THE WEIGHT (WITH RADIAL STRINGERS)

	Iteration No. I	Iteration No. II	Iteration No. III	Iteration No. IV	Iteration No. V
Skin Thickness in mm	1.5	1.5	1.5	1.5	1.3
Deformation in mm	32.5	32.5	11.1	9.45	12.8
MTS in Skin in kg/mm2	28.3	27.1	15.4	15.2	20.6
Location of Stress in Skin	x-component in Z2 face at the Edge	x-component in Z2 face at the Edge	x-component in Z2 face at the Edge	y-component in Z2 face at the Edge	y-component in Z2 face at the Edge
MTS in Stringer in kg/mm2	85.4	83.7	36.1	28.5	29.2
Location of Stress in Stringer	x-component in F face at the Middle	x-component in F face at the Middle	x-component in C face at the Middle	x-component in F face at the Middle	x-component in F face at the Middle
Weight in kg	10.49	10.51	12.768	14.13	13.302

IV. CONCLUSION

Stress analysis is performed on a 14-seater passenger aircraft cabin pressure bulkhead by considering stresses generated due to the pressure difference inside and outside the cabin at higher altitudes. Iterative analysis is performed by varying the skin thickness and stringer cross-section. The radial pressure bulkhead with skin thickness 1.3 mm, as given in the iteration number five of the result table, is found to be optimum.

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