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Research Paper

STRESS ANALYSIS OF A REAR PRESSURE BULKHEAD OF THE FUSELAGE STRUCTURE AND FATIGUE LIFE ESTIMATION

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Fuselage is a primary structural component used for accommodating passengers in transport aircrafts. Normally fuselage is a built-up structure with structural members along longitudinal and circumferential directions. The skin used for the structure is a thin member with orthogonal stiffening. The design of these structures is a challenging field as the designer has to come out with the minimum weight without any compromise on safety of the structure. The current paper deals with the stress analysis of the pressure bulkhead at the rear end in the fuselage structure. Fuselage experiences a small percentage of lift loads, but the dominating load on the fuselage is the Inertia load. When the aircrafts fly over high altitude an internal pressurization is applied to create the sea level atmospheric pressure inside the fuselage cabin. This internal pressurization is considered to be one of the critical load cases in the design and development of the aircraft. A rear pressure bulkhead with all stiffening members is considered in this analysis. Due to internal pressurization the rear pressure bulkhead will undergo out of plane bending. One surface of the pressure bulkhead will undergo tension and the other will undergo compression simultaneously, as a result the stiffening members attached to the rear pressure bulkhead will also undergo tension and compression modes. Because of the built up construction one of the rivet locations will have more tensile stress. The high tensile stress locations will be critical from the fatigue crack initiation point of view. If the crack in a critical location goes unnoticed it could lead to a catastrophic failure of the airframe. A Stress analysis is carried out on rear pressure bulkhead panel to identify the maximum tensile stress location. 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: Fuselage, Pressure bulkhead, Internal pressurization, Finite element method, Stress analysis, Fatigue life, Crack initiation

INTRODUCTION

This thesis work related to the rear pressure bulkhead connected to the fuselage structure. The alternate pressurization causes some amount of stress concentration inside the rear pressure bulkhead which may leads to the

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failure of the air craft, here the stress analysis of the entire stiffening members of the rear pressure bulkhead was carried out using the NASTRAN software, from that the maximum stress concentrated area was identified and the fatigue life of the rear pressure bulkhead also estimated. When the aircraft is flying above 8000 ft altitude the internal pressurization is applied to create a sea level atmospheric pressure inside the fuselage cabin. This internal pressurization is considered to be one of the critical load cases during the design and development of the aircraft. On increasing the altitude the pressure value also increases, the applied pressure may cause the concentration of stress at a particular region and if this stress concentration is not identified that will leads to the catastrophic failure of the air craft. On August 12, 1985, JAL flight 123, a B-747 (Aircraft Accident Investigation Report, 1987) bound for Osaka Airport, went out of control 12 minutes after the take-off from Haneda Tokyo International Airport, as it approached cruising height of 7,200 m, because of fatigue failure of the aft bulkhead, followed by the structural failure of the vertical fin, resulting the crash at Mt. Osutaka, Ueno, Gunma Prefecture after 32 minutes of irregular flight. By this accident, 520 of the 524 passengers and crew on board were killed, making it the worst single aircraft accident in the world.

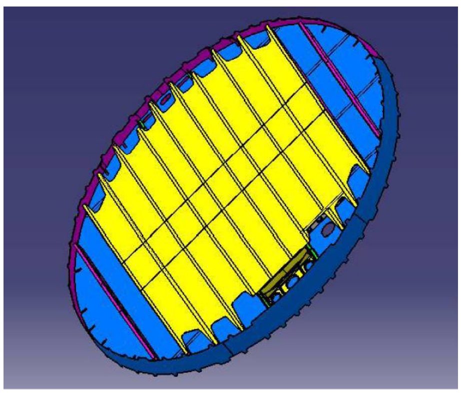
AIRCRAFT CABIN PRESSURIZATION

When the aircraft flying above 8000 ft altitude the pressure level inside the fuselage decreases which causes abnormalities in the body conditions of the passengers. So for maintaining the atmospheric pressure level inside the fuselage, an internal pressurization is given, here the pressure variations starting from 6.5 psi to 9 psi was considered and for each increase in pressure the analysis of the rear pressure bulkhead carried out using the nastran software for finding out the magnitude of the maximum stress and its location.

GEOMETRIC MODELLING

A rear pressure bulkhead with all stiffening members is considered for the analysis. The stiffening members include Z sections, C sections, L sections. These sections were chosen because, due to the internal pressurization bending is always happens in the stiffening members. Moment of inertia and bending moment are related, for the above stiffeners moment of inertia were maximum so for these sections bending moment is minimum. Figure 1 below shows the geometric model of the rear pressure bulkhead.

Figure 1: Geometrical Model of Rear Pressure Bulk Head



Geometrical specification of the rear pressure bulkhead was given in the Table 1. The material used for the manufacturing of the RPB was Al 2024-T351.

Table 1: Thickness of Various Parts

S. No.	Part	Dimension	Material
1.	Top Skin	5.0	AL alloy
2.	Bottom Skin	3.5	AL alloy
3.	Main Stiffeners	3.5	AL alloy
4.	C and Z Section	3.5	AL alloy
5.	Connecting Skin	3.5	AL alloy
6.	Integrated Section	3.5	AL alloy

Rear pressure bulkhead has stiffening members like Z sections, C sections, L sections, etc (Figure 2). For the Finite Element Modelling of each stiffening member, from the geometric model each section was posted separately in PATRAN and the required edges were extracted. After that meshing was done in between the edges by using both quad and tria elements. L section has a web portion and a flange portion for the web portion, from the geometrical model the bottom edges were extracted and those lines were translated up to the thickness of the web in the upward direction, for the flange portion similarly the inner edges were extracted and those lines were translated in outward direction up to the thickness of the flange.

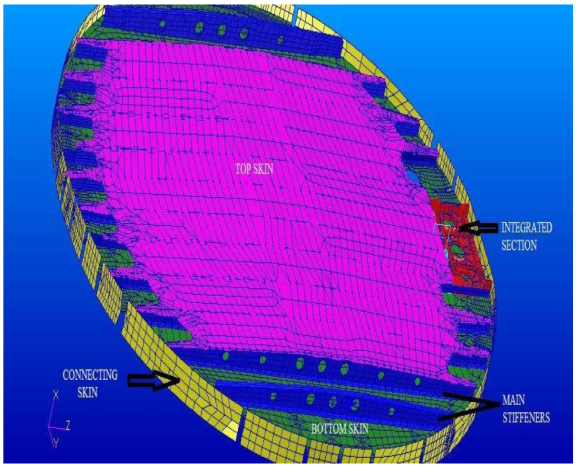
Boundary Conditions and Load

All degree of freedom at the end which connects the RPB and the fuselage was fixed. And the load condition was the pressure load acting at the entire top skin.

STRESS ANALYSIS OF REAR PRESSURE BULKHEAD

Stress analysis of rear pressure bulkhead at different load condition starting from 6 psi to 9 psi was done with NASTRAN software.

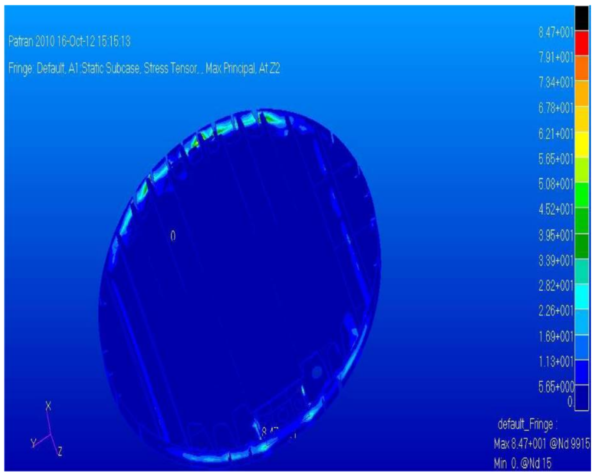
Figure 2: Finite Element Model of Rear Pressure Bulk Head



RESULTS AND DISCUSSION

The first iteration results are shown in Figure 3.

Figure 3: Results of First Iteration



At first the analysis was done with 0.0042 kg/mm^2 pressure (6 psi) and the maximum principal stress that was found to be 84.7 kg/mm^2 at bottom skin but the ultimate tensile strength of the aluminum alloy is 45 kg/mm^2 so the value obtained from the first iteration itself was on the very much higher side, so it is clear that the structure will fail in the first load itself.

The Table 2 shows the stress values at different sections of rear pressure bulkhead.

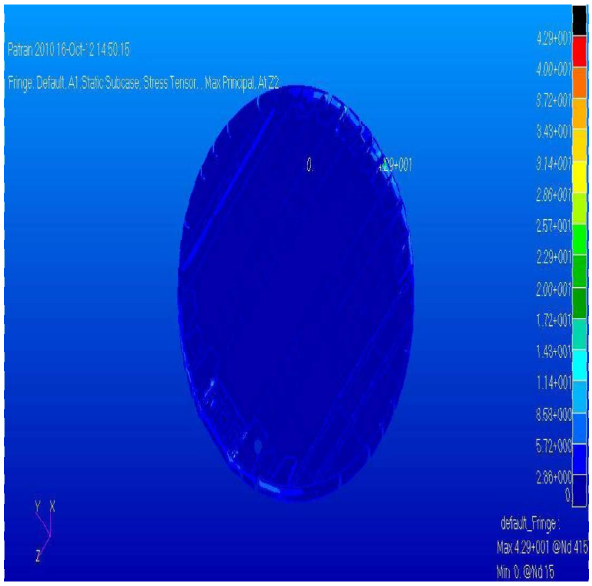
Table 2: Max.Principal Stress Values

Sections	Max.Principal Stress (kg/mm^2)
Bottom Skin	84.70
Top Skin	5.66
Z Section	3.76
C Section	11.60
Main Stiffeners	37.70
Integrated Section	5.72
Connecting Skin	44.30

Design Osptimization

From the first iteration itself it was clear that some modifications are needed to decrease the stress level on the bottom skin, for that modifications/corrections in model, loading, dimension are required. Corrections in model includes check for any errors in FE model of rear pressure bulkhead like orientations of the rivets and the directions in which the bottom skin to bottom flange rivets were constrained and the application of displacement constraints in the connecting skin, direction of application of applied load, etc. After modification of FE model it is found that the stress value is still on higher side so much refinements is needed on highly stress concentrated region, but after all these corrections the stress value is not on a safe limit so some corrections are needed in the dimensions, mainly in the thickness of bottom skin. The thickness of bottom skin increased from 3.5 mm to 4 mm and the analysis was performed the results obtained shows the decrease in stress at the bottom skin, So the thickness of the bottom skin is gradually increased until the max principal stress goes below the max tensile stress limit value, and the value of thickness for which the stress value falls below the max tensile stress value is 5 mm. The optimized value of the bottom skin thickness was 5 mm. Stress contours obtained for 5 mm thickness of bottom skin was given in Figure 4.

Figure 4: Stress Contours of Optimized Model



Here the max. principal stress value is 42.9 kg/mm^2 which was within the max. tensile stress limit value but for the initial pressure force this value was obtained. It is not possible to increase the thickness of the bottom skin again because which will cause the increase in weight of the total aircraft. So it needs some thorough evaluation on the location of the maximum tensile stress. Location of the max. principal stress is given in Figure 5.

The max. principal stress was located in the bottom skin region and was concentrated on particular rivet location Red wire frame in Figure 6 indicates the bottom flange and blue one was the bottom skin, the bottom flange and bottom skin are connected by rivets. At one of those rivets locations the stress was concentrated which is pointed on the Figure 6. The elemental stress values at the max. principal stress location is shown in Figure 7.

Figure 5: Stress Concentrated Region at the Bottom Skin

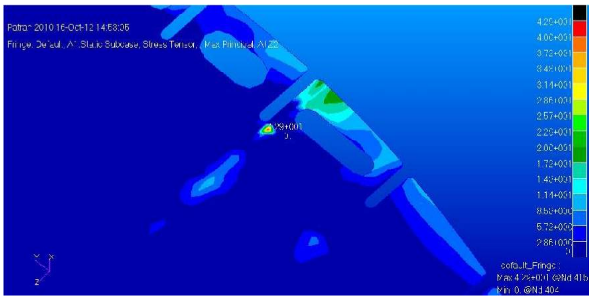


Figure 6: Wire Frame Model of Stress Concentrated Region

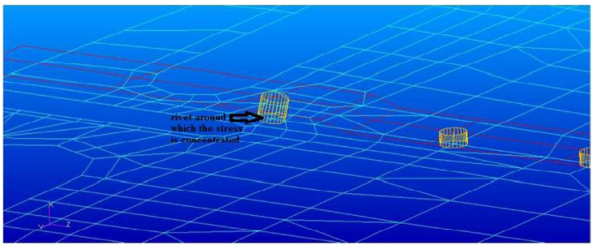
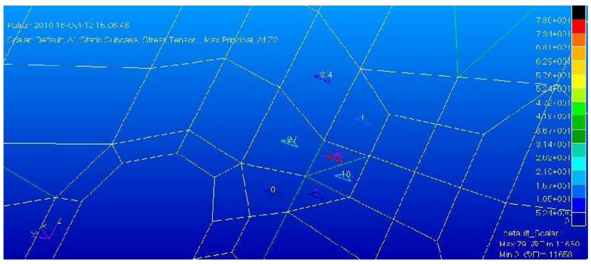


Figure 7: Elemental Stress Values at the Bottom Skin



From the above stress contour it was clear that the stress was not equally distributed between the elements, some elements have no stress distribution. It is mainly because of the limitations of the NASTRAN software, in NASTRAN the rivets were modelled using beam elements. Since the pressure was perpendicular to the plane of rear pressure bulkhead skin load will get transferred through this beam elements only so it act as a concentrated load, i.e., here the stress is transferred to the bottom skin only through the rivets, which were modelled with the beam elements and the stresses were concentrated at that beam element region. In actual case factors like thickness of the sections, friction between the section which also helps in the evenly distribution of the stress but in NASTRAN the thickness was not a factor during the distribution of loads between two sections and in NASTRAN the load distribution is only through the connecting member and here it was the rivet. The average elemental stress values were taken for the max. principal stress regions, on taking the avg; elemental stress at the bottom skin region the stress value was reduced to 20.48 kg/mm^2. Stress magnitudes at other sections were given in Table 3.

From the Table 3 it was clear that all the stress at different sections were within the safe limit and it will not goes beyond the limit value for the max applied pressure (9 psi). Here the max value is obtained in the connecting skin region for that value of max.

Table 3: Max.Principal Stress Values of Optimized Model

Sections	Max.Principal Stress (kg/mm^2)
Connecting Skin	27.00
Bottom Skin	20.48
Main Stiffeners	26.00
Z Section	3.52
Integrated Section	3.32
L Section	6.38
Top Skin	3.56

Stress the fatigue life has to found out. Displacement contours at the maximum tensile stress region of the rear pressure bulkhead shown in Figure 8.

Figure 8: Displacement Contours of Optimized Model

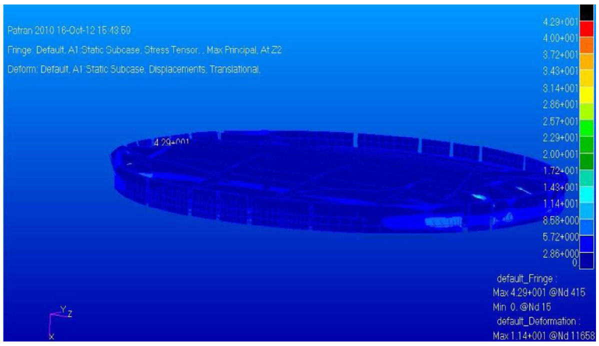
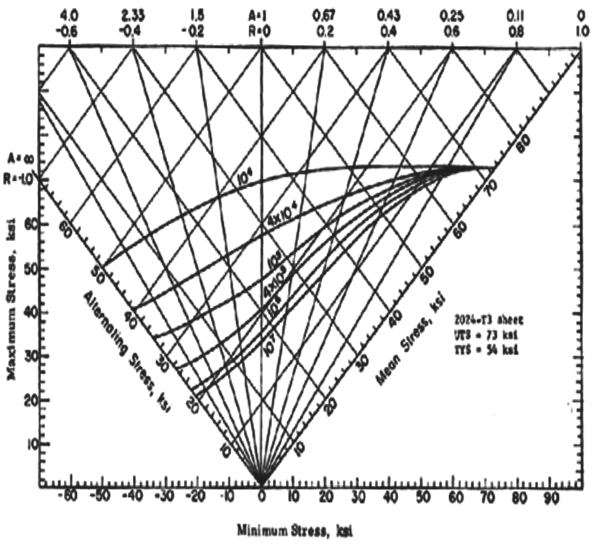


Figure 9: Stress No. of Cycles Graph



Fatigue Life Calculation

From the stress-no of cycles graph (Figure 9) the no of cycles to initiate a crack found out and was tabulated in Table 4.

The experimental load cycles to initiate a crack at different applied pressure was also given in Table 5.

Damage fraction (D) = n/N

Table 4: No. of Cycles to Failure from Graph

Stress (ksi)	No. of Cycles (n)
38	10^6
42	4×10^5
45	3×10^5
48	10^5
51	8×10^4
54	6×10^4
57	3×10^4

Table 5: No. of Load Cycles to Initiate a Crack at Different Applied Pressure

Stress (ksi)	No. of Cycles (n)
38	26,000
42	11,500
45	10,000
48	2,300
51	1,700
54	1,300
57	1,000

D_1 = 26000/10^6

= 0.026

Total damage,

$(D_1 + D_2 + D_3 + D_4 + D_5 + D_6 + D_7) = 0.16326$ (when this value equals to '1' then only the failure occurs).

Then we are considering a scatter factor of 3.

Then the total damage is multiplied with scatter factor, i.e.

Total damage = 0.16326x3

= 0.48978

1/0.48978 = 2.04

The results above shows that for a scatter factor of 3 the total damage is 0.48978,It can conclude that it was a failsafe design with a safty factor of 2.04.

CONCLUSION

This work deals with the stress analysis of a rear pressure bulkhead of the fuselage structure on the basis of the crack initiating point of view. The stress analysis was done with the NASTRAN software. From the initial iteration it was found out that some modifications are needed on the bottom skin of the rear pressure bulkhead to make it as a failsafe design for that gradually the bottom skin thickness increases and for every increase in thickness the analysis was carried out and finally obtained an optimum value. Due to some limitations of the NASTRAN software the distribution of stress between the stiffening members were not even so for obtaining the exact stress values the avg. elemental stress at each stiffening members were taken and the max. principal stress location also found out. For that value of max. principal stress the damage fraction of the rear pressure bulkhead also found out. From that value it is clear that the design of the rear pressure bulkhead is safe one.

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REFERENCES

1. Aircraft Accident Investigation Report (1987), Aircraft Accident Investigation Commission, Ministry of Transportation of Japan.
2. Barter S A *et al.* (2012), "Typical Fatigue-Initiating Discontinuities in Metallic Aircraft Structures", *International Journal of Fatigue*, Vol. 41, pp. 11-22.
3. Duquesnay D L *et al.* (2003), "Fatigue Crack Growth from Corrosion Damage in 7075-T6511 Aluminium Alloy Under Aircraft Loading", *International Journal of Fatigue*, Vol. 25, pp. 371-377.
4. Garbatov Y *et al.* (2012), "Fatigue Reliability Assessment of Riveted Lap Joint of Aircraft Structures", *International Journal of Fatigue*, Vol. 43, pp. 54-61.
5. Ji H D *et al.* (2001), "Ultimate Strength Analysis of Corrugated Bulkheads Considering Influence of Shear Force and Adjoining Structures", *Journal of Constructional Steel Research*, Vol. 57, pp. 525-545.
6. Kobayashi H (1987), "On the Examination Report of the Crashed Japan Airline Boeing 747 Plane-Failure Analysis of the Rear Pressure Bulkhead", *Journal of the Japan Society of the Safty Engineering Saftey Engineering*, Vol. 26, pp. 363-372.
7. Molent L *et al.* (2012), "Verification of an Individual Aircraft Fatigue Monitoring System", *International Journal of Fatigue*, Vol. 43, pp. 128-133.
8. Nadakkatti M M *et al.* (2004), "A Review on Stress Analysis of the Fuselage Structure and Study of the Effect of

Overload on Fatigue Crack Growth”, *International Journal of Fatigue*, Vol. 43, pp. 435-444.

9. Nagaraja Iyyer *et al.* (2007), “Aircraft Life Management Using Crack Initiation and Crack Growth Models – P-3C Aircraft Experience”, *International Journal of Fatigue*, Vol. 29, pp. 1584-1607.

10. Raymond K *et al.* (2005), “Innovative Laser Heating Methodology Study for Crack Growth Retardation in Aircraft Structures”, *International Journal of Fatigue*, Vol. 27, pp. 245-253.

11. Simmons M C *et al.* (2006), “Pulse Pressure Loading of Aircraft Structural Panels”, *Journal of Thin Walled Structures*, Vol. 44, pp. 496-506.

12. Venkatesh S *et al.* (2010), “Design, Development and Certification of Composite Rear Pressure Bulkhead for a Light Transport Aircraft”, 18th International Conference on Composite Materials.