A Detailed Study and Analysis of the fuselage splice joint panel with Multi Site Damage

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Abstract:

Safety is one of the primary concern in the aircraft industry today. Early Air crash investigators have proved that most of the aircraft accidents happened are due to the structural failure. The riveted splice joint in the fuselage structure is one of the critical locations in the aircraft. Aging aircraft may develop Multi Site Damage (MSD) that can reduce the structural integrity of the aircraft structure. Therefore, Multi Site Damage is one of the important aspects considered to ensure the safety of the air craft structure.

The current study includes a panel which represents the fuselage splice joint. The fuselage splice joint is a location where it experiences the uniform stress field at many rivet locations. The probability of fatigue cracks initiation at many rivet locations simultaneously is more at splice joint region. Finite Element Analysis of a segment of fuselage is carried out. The stress analysis results from the global analysis are considered as benchmark values to carry out local analysis of the panel. A riveted panel is considered to obtain the stress distribution near the joint. Fatigue cracks will emanate from the rivet holes simultaneously as they experience identical stresses due to internal pressure. In service the cracks in the fuselage will grow due to pressurization load cycling.

From the panel stress analysis, the magnitude and distribution of stresses near the rivet holes are captured. These stress results will be input for the fatigue and fracture evaluation of the structure at the splice joint.

***Keywords:* aircraft, splice joint, fatigue, multi-site damage, fuselage, finite element analysis**

1. INTRODUCTION:

An ideal aircraft structure would be designed so that every part fails at exactly the same limit load and fatigues at exactly the same number of cycles. And these failure conditions are selected so that they just cannot happen under normal operating conditions. The ideal structure also would have no margin above these conditions because that just means extra weight.

The airframe consists of the fuselage, which is the main component of the airplane, the wings, and the empennage. The empennage (sometimes called the "tail feathers") is the tail assembly consisting of the horizontal stabilizer, the elevators, the vertical stabilizer, and the rudder. The elevators are used to adjust, or control, the pitch (nose up/down attitude) of the airplane.

Airplanes are transportation devices which are designed to move people and cargo from one place to another. The fuselage, or body of the airplane, is a long hollow tube which holds all the pieces of an airplane together. The fuselage is hollow to reduce weight. As with most other parts of the airplane, the shape of the fuselage is normally determined by the mission of the aircraft.

1.1. C*abin Pressurization*:

Cabin pressurization is the active pumping of air into an aircraft cabin to increase the air pressure within the cabin. It is required when an aircraft reaches high altitudes, because the natural atmospheric pressure is too low to allow people to absorb sufficient oxygen, leading to altitude sickness and ultimately hypoxia.

The aircraft fuselage is pressurized and de-pressurized for each ground to air to ground transition, and thus creating a near constant amplitude fatigue cycle which ca initiate fatigue. Dependent on the number of accumulated fatigue cycles, fatigue cracking can be a problem for a fuselage structure. The risk of fatigue problem increases with the number of cycles if the hoop stress is above the endurance limit.

1.2. S*cope of Present Investigation*:

The two historical fuselage failures illustrates that similar accidents must be avoided which requires a profound understanding of the fatigue mechanisms involved, including analytical models to predict the fatigue behaviour of a fuselage structure. Dealing with all aspects involved is obviously outside the scope of the present investigation, which mainly concentrates on the fatigue of mechanically fastened riveted joints and its behaviour at the applied loading conditions.

1.3. *From fuselage to laboratory sized test specimen*:

The first step is to understand the complex loading conditions in a fuselage structure. The pressurization of the fuselage causes the structure to expand outward like simple ballon. This expansion creates the hoop stress in the circumferential and an axial stress in the longitudinal direction. Due to this complexity in structure, loading conditions and test set-up simplification to more simple test specimen is required.

With full pressurization, the skin and underlying structure will move outward. It is not too difficult to see that a frame or stiffener will not move the same distance as the skin would due to higher local stiffness, thus creating differences in outward movements and higher hoop stresses in the skin between the frames.

Setting up a test as large as a full-scale aircraft structure requires an enormous amount of time and money. Reducing full scale-test to a more simple, easier to understand test specimen such as barrel or fuselage panel including stiffeners and frames reduces the size of the test.

Stepping down to the level of component testing to understand the behaviour of the individual parts allows the researcher or designer to efficiently test multiple configurations of structural elements. Elimination of the stiffeners, frames and curvature reduces the structure to flat sheet longitudinal splice and circumferential butt joints.

1.4. S*tress analysis:*

Stresses in the joints can be obtained by different methods, well known methods are

1. Strain gage measurements
2. Finite element analysis
3. Photo elastic analysis

Finite element analysis gives a more complete picture of the strain and stresses of the joint. However it is easy to model such a joint completely.

The present analysis is dealt with the NASTRAN and PATRAN software. The pre-processing and post-processing is done by Patran and Nastran is a solver.

2. **E**XPERIMENTAL **D**ETAILS**:**

The typical fuselage structure was shown in the figure below. The global analysis of the structure is carried out to find the stress distribution. Riveted connection is the common feature in the built up airframe structure. The fatigue crack will initiate from the locations of the maximum tensile stress. The rivet hole locations are one of the stress concentration regions. Therefore rivet hole locations are the most probable location for the fatigue crack initiation. The fuselage splice joint is the location where it experiences the uniform stress field at many rivet locations in a row. Therefore fine meshing is done at the splice joint location to achieve the exactness of the stress. And the riveting is being done by 1D element

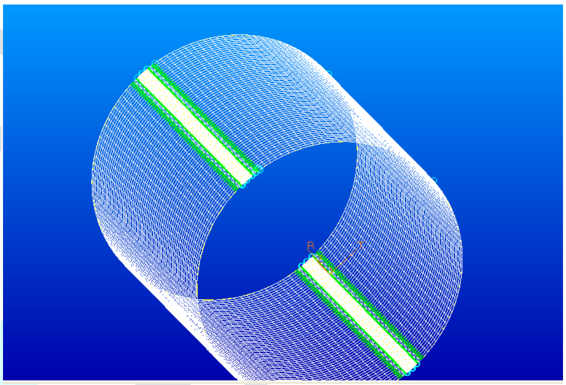


Fig: 1 fuselage structure

Load calculations and model dimensions:

- Total length of the fuselage = 3000mm
- Radius of the fuselage=1250mm
- Width of the splice plate=120mm
- Thickness of the plate and splice plate=2mm
- Cabin pressurization=6 psi

1 psi=0.0007kg/mm^2,

therefore 6 psi=0.0042kg/mm^2

Boundary conditions:

Both the ends of fuselage are constrained for rotation and translation and internal pressurization applied.

Hoop stress= pr/t

Hoop stress= 0.0042x1250/2

Hoop stress= 2.625kg/mm^2

The fuselage structure shows the stress distribution and elemental Hoop stress value in fig: 2a & 2b

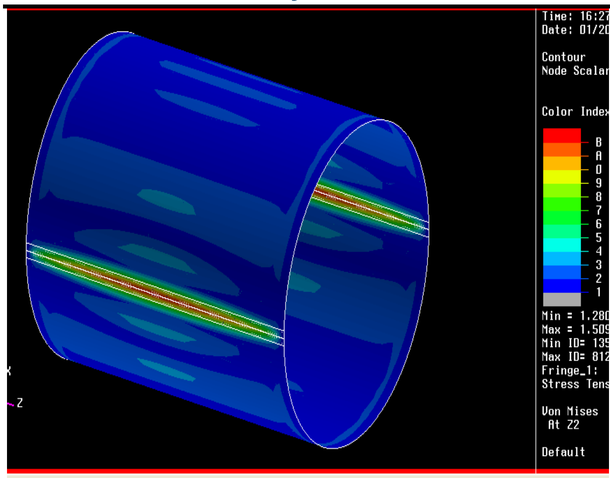


Fig: 2a, stress distribution

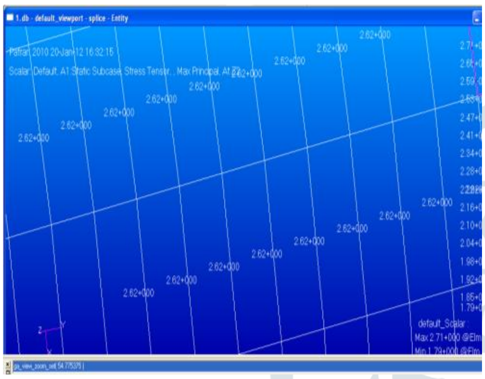


Fig: 2b, elemental hoop stress

It can be observed from the figure the stress is distributed uniformly but the maximum stress is experienced in the riveted splice joint region.

Similarly, a local analysis was done which represents the fuselage splice joint panel. Fig: 3a &3b shows the local analysis panel and meshed structure.

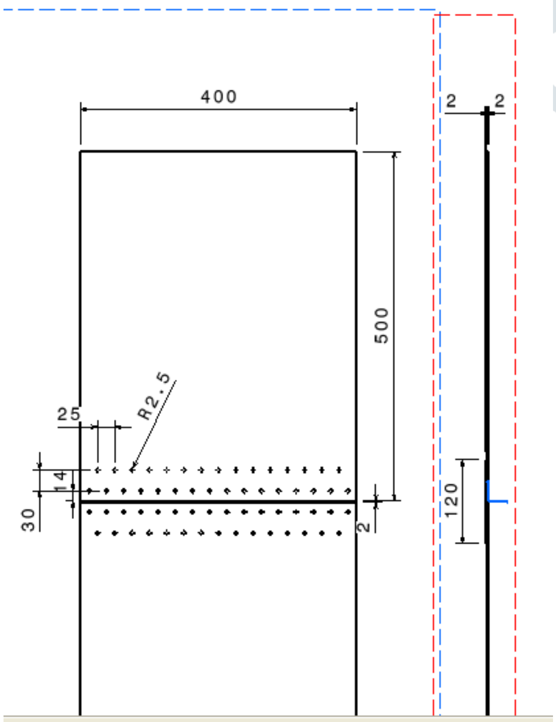


Fig: 3a, local analysis panel

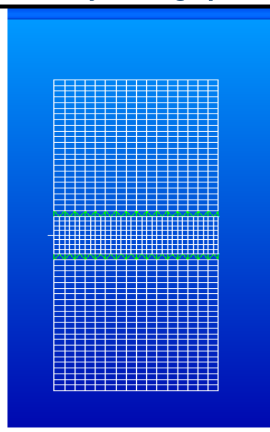


Fig: 3b, meshed structure of the panel

Loading and boundary conditions for the local analysis of the panel:

Length of the panel=1000mm

Width of the panel=400mm

The total load acts on the fuselage structure from the global analysis is found as 2100 kg. This total load is converted into uniformly distributed load (UDL) and applied at the top side of the panel.

UDL= Total load/Width of the plate

UDL=2100/800

UDL=5.25 kg/mm

Uniformly distributed load of 5.25 kg/mm was applied at top end of the plate and other end is fixed. A two dimensional linear static stress analysis is carried out using finite element analysis software MSC Patran and MSC Nastran. Mesh independent stress magnitudes are obtained through iterative mesh refinement process. Aluminium 2024-T351 is well-known aluminium alloy is used for the panel analysis.

The panel shows the stress distribution and elemental hoop stress value in fig 4a and 4b.

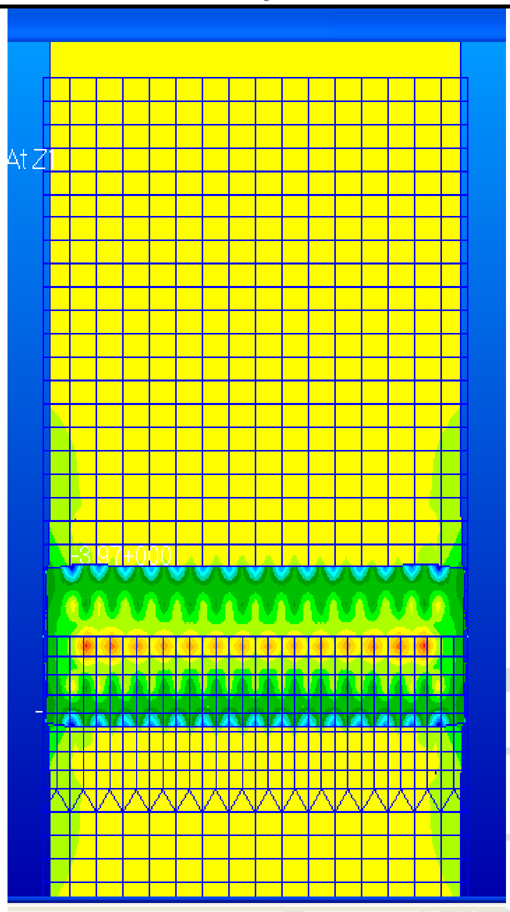


fig: 4a, stress distribution

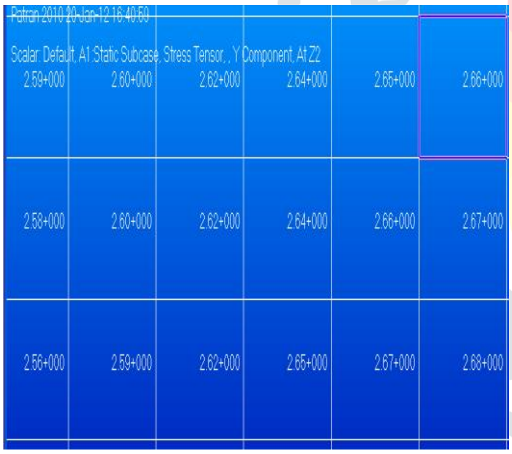


fig: 4b, elemental hoop stress

It can be observed that the same Hoop stress value is experienced in both global and local analysis by applying same boundary conditions. Even the rivet loading are similar in both the cases. This is the indication to proceed further. In reality rivet holes will be present. So the stress analysis of panel with rivet holes was carried out with the same applied boundary conditions.

Fig: 5a shows the meshed model of the panel with the 2D rivet loading.

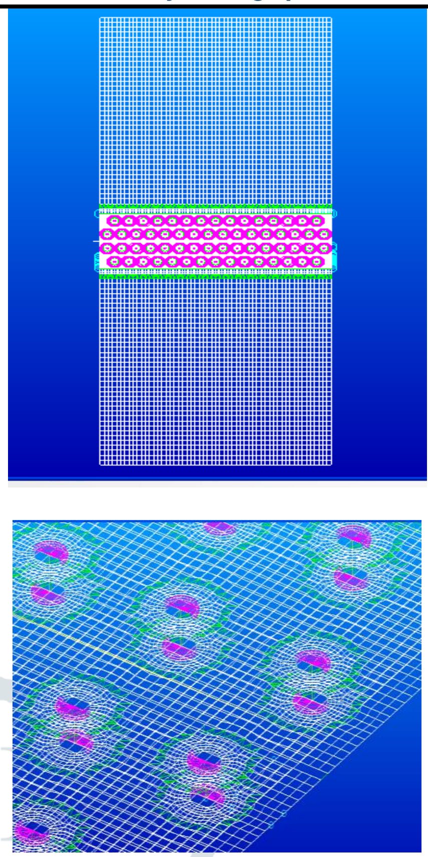


Fig: 5a, meshed panel with riveted loading.

3. **R**ESULTS AND **D**ISCUSSION:

The panel with the riveted hole shows the uniform stress distribution in fig: 6a

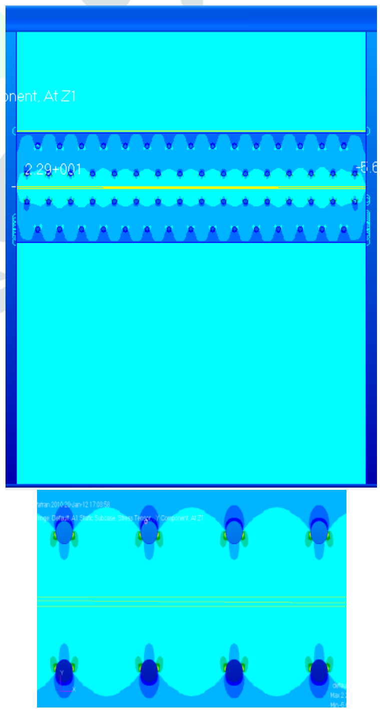
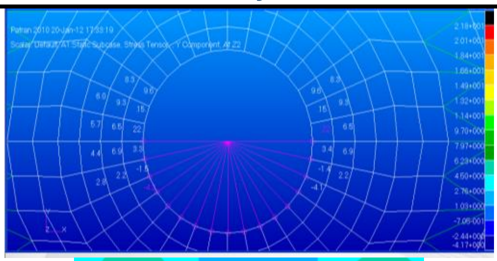


Fig: 6a, uniform stress distribution at many rivet locations in the panel

It can be observed from the figure, the stress is distributed uniformly throughout the panel. The uniform stress of 22 kg/mm^2 is experienced in all rivet hole locations. Fig: 6b shows the stress value in red colour at one of the rivet hole location.



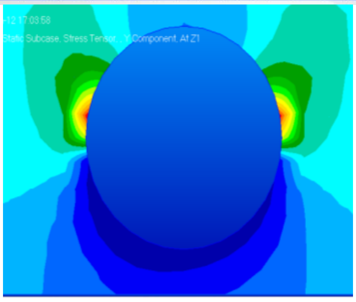


Fig:6b, stress value of 22kg/mm^2 is shown in one of the rivet hole.

4. CONCLUSIONS:

Based on the analysis of the experimental data and the calculated parameter, the following major conclusions are drawn:

a. Global finite element analysis of a segment of a typical fuselage structure was carried out with 6 psi applied pressure.
b. With the same applied pressure to the local analysis of the panel, similar Hoop stress value with exact elemental stress distribution was experienced.
c. The stress analysis of the panel with the riveted hole was carried out with same applied boundary conditions and uniform stress distribution is experienced at all rivet hole locations.
d. The uniform stress of 20 kg/mm^2 is experienced in all rivet hole locations. And this is the indication for the Multi-Site Damage.
e. From the panel stress analysis, the magnitude and distribution of stresses near the rivet holes are captured. These stress results will be input for the fatigue and fracture evaluation of the structure at the splice joint.

5. REFERENCES:

1. Schijve.J, “Fatigue of aircraft materials and structures”, International journal of fatigue, vol 16, 1994, pp 21-32.
2. Wanhill.R , “Some practical considerations for fatigue and corrosion damage assessment of ageing aircraft”, nlr technical publication tp 96253 l.1996
3. Schijve. J, “Multiple-site damage in aircraft fuselage structures”, fatigue and fracture of engineering materials structures, vol 18, number 3, 2003, pp 329-344.
4. Sih. G.C and Barthelemy, “Mixed mode fatigue crack growth predictions. engineering fracture mechanics”, vol 13, 1998, pp 657-666
5. Hsu.Y.C, “The infinite sheet with two radial cracks from cylindrical hole under inclined tension or in-plane shear”, International journal of fracture, vol 13, 2004, pp 839-845.
6. Urban.M.R, “Analysis of the fatigue life of riveted sheet metal helicopter airframe joints”, International journal of fatigue, vol 25, 2003, pp 1013-1026.
7. Wanhill.R.J.H. et al, “Fatigue and corrosion in aircraft pressure cabin lap splices”, International journal of fatigue, vol 23, 2001, pp 337-347.
8. Brown.A.M. et al, “ Simulating fretting contact in single lap splices” ,International journal of fatigue, vol 31, 2009, pp 375-384.
9. Rans.C.D. et al, “ Assessing the effects of riveting induced residual stresses on fatigue crack behavior in lap joints by means of fractography” ,International journal of fatigue, vol 31, 2009, pp300-308.
10. Lucas F.M.Silva et al. “Multiple-site damage in riveted lap-joints: experimental simulation and finite element prediction”, International journal of fatigue, vol 22, 2000, pp 319-338.