Two bay crack arrest capability evaluation for metallic fuselage

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Abstract: Transport aircraft is a highly complex structure. The aircraft fuselage shell is composed of stressed skin, longitudinal stringers, and circumferential frames. The skin is connected to the stringers and frames mostly by rivets. The fuselage has a number of riveted joints and is subjected to a major loading of differential internal pressurization. When the fuselage is pressurized and depressurized during each take-off and landing cycle of aircraft, the metal skin of fuselage expands and contracts to result in metal fatigue. Due to the presence of a large number of rivet holes, the fuselage skin has a large number of high-stress locations and these are locations of potential crack initiation. The wide-bodied transport aircraft are designed to tolerate large fatigue cracks. This project focuses attention on damage tolerance design of a fuselage structure of transport aircraft. In this project, the stress intensity factor, quantifying the intensity of the stress field around a crack tip for a longitudinal crack under the pressurization load is studied. The objective of this project is to investigate crack initiation, crack growth, fast fracture and crack arrest features in the stiffened panel. The longitudinal crack is initiated from the rivet hole and stress intensity factor is calculated using modified virtual crack closure integral (MVCCI) method at each stage of crack propagation. In order to arrest crack propagation which is the capital importance of tear straps are used, which prevent the further crack propagation. In this project, the linear static stress analysis of the stiffened panel of a fuselage is performed using MSC NASTRAN solver. The pre-processing of the model is done by using MSC PATRAN software.

1. Introduction

Aircraft structure is the most apparent example where structural efficiency outcomes in lightweight and high operating stresses. An efficient structure must have three primary attributes: namely,

• The ability to perform its intended function,
• Adequate service life and
• The capability of being produced at a reasonable cost.

The essential piece of the flying machine structure incorporates of developed boards of sheets and stringers, e.g. wing and fuselage skin boards, fight networks and stiffeners. Regardless of all safety measures, breaks have emerged in a large number of these auxiliary components. These breaks lessen the firmness and the aggregate load-conveying limit of the structure. The fuselage is the primary structure in the airplane that controls team, travellers, and freight. A flying machine fuselage structure must be fit for withstanding many sorts of burdens and pushes, and in the meantime with low weight. The chief reason for the worries in this structure is the interior weight in high height sourced by the disparate lodge pressurization and reductions the outside weight with an expansion in elevation, however, the structure is subjected to different burdens, as bowing, torsion, warm loads, and so forth. In this task, the impact of inner weight when the fuselage displays a split is broke down. The customary airship fuselage is made out of the skin comprising of a barrel-shaped shell ordinarily 2 mm thick, roundabout casings and pivotal stringers, and regularly these parts are produced with an
aluminium compound and are associated by bolts. The skin of fuselage is to convey compartment pressurization and shear loads, longitudinal to convey the longitudinal strain and pressure stacks because of twisting. The casings is to keep up the fuselage shape and makes changes to loads into the skin, and pressurization of the fuselage is hold by the bulkheads which holds the concentrated burdens.

2. Finite Element Analysis (FEA)

FEM is one of the methods to solve problems in engineering and physics where we use mathematical equations. Problems can be solved which are complex in geometries, applying critical loadings, different materials where we can not apply the analytical approach.

Analytical approach Solution:
Idealization is one of the methods to carry out the Stress analysis for trusses, beams, and other simple structures
- The mass concentrated at the centre of gravity ($C_g$)
- Beam is simplified as the line segment
- Factor of safety was experienced by structural idealization based on results.

FEA : Design of geometry is the major complex problems for accuracy.
- Strength, heat transfer capability, fluid flow, etc are the parameters to understand the physical behaviours of a complex object.
- Prediction of the performance and behaviour of the design
- Calculation of safety margin
- Weakness for the design accurately is identified; and

![Engineering Analysis Tree](image)

**Figure 1**: Engineering Analysis Tree

2.1. Materials used for analysis

Choice of airship materials relies upon numerous contemplations, which can when all is said in done, be named taken a toll and auxiliary fulfilment. Material properties are given in the following table.

| Material property       | Property                           |
|-------------------------|------------------------------------|
| Density                 | Damage resilience                  |
| Young's modulus         | Corrosion, and so forth            |
| Fatigue quality         | Ultimate and Yield qualities        |
Table 1: Material properties

| Property       | Aluminum 2024-T3 | Aluminum 2117-T4 |
|----------------|------------------|------------------|
| Density        | 2.77 g/cm³       | 2.77 g/cm³       |
| Young’s Modulus(E) | 72 GPa     | 71.1 GPa         |
| Poisson’s Ratio(v) | 0.33        | 0.33             |
| Tensile Strength | 483 MPa   | 490 MPa          |
| Yield Strength  | 362 MPa         | 350 MPa          |
| Toughness       | 72.37 MPa√m    | 76.54 MPa        |

2.2. Stress analysis:
Stress analysis is the combination of the pre-handling, preparing and post-preparing stage. The pre-handling stage includes subtle elements of work, stack and limit operating conditions. From pre-handling post handling preparing is conveyed in Patran. The parts of the solidified board are fit by four gestured shell components. Skin of the hardened board coincides with shell components with unit viewpoint proportion. By using 3 to 4 gestured shell components casing was fitted. A Fine work is carry to a place at mouse gap of the edge to get precise outcomes. 3 gestured components are used for coherence from fine work district to the coursework area. The bolts are inserted on the skin to have the grip between the stringer & casings. Riveting is completed by choosing the hub on the skin and the comparable hub on the part. Bolts are empowered by utilizing shaft components demonstrated in the yellow shading appeared in Fig.2 and Fig.3. Perspective proportion thought to be lower than 5 in all components of the hardened board. Cross section is verified for any copy hubs and components. Below Table shows the quantity components & component sort on the solidified board.

Table 2: Finite Element model (FEM)

| Product description | Element Type | elements | Aspect ratio less than 5 |
|---------------------|--------------|----------|--------------------------|
| Panel Skin           | QUAD-4       | 66810    | 1.1                      |
| Panel Frame          | QUAD-4,TRIA-3| 38424    | 2.11                     |
| Panel Stringer       | QUAD-4       | 42190    | 1.02                     |
| Panel Rivet          | BEAM         | 1330     | ---                      |

Figure 2- FE model of the 5 stiffened panel
Figure 3- Stiffened panel with rivets
3. Crack Arrest Capability

The utilization of tear lashes is a gainful method for expanding the proceeding with the quality of harmed boards. A shaky quick break can be limited to a neighbourhood giving a territory of low worry in front of the split tip. The break tip stretch is diminished as an extended piece of the straightened out load is moved into the backlash. With tear tie to give progression over the hole, the feeling of anxiety in the basic zone is lessened to beneath the halfway anxiety, consequently diminishing the likelihood of an exhaustion split beginning. Likewise, the tear strip can be utilized as twisting the material to extend the casing soundness and static quality.

3.1. Design of the Tear Strap:

Lash is essentially shaped for capturing skin breaks. The thickness of the lash is 1.2 mm and width 50 mm and fixed in the middle of the base rib of edge and skin appeared in Figure. Aluminium 2024-T3 is the material used for tear tie.

4. Crack propagation stage

A straight static anxiety thinks about is worked for the solidified boards having tear lash for various break lengths keeping the equivalent stacking condition. The anxiety power factor assumes a noteworthy part of the break development period, which is controlled by utilizing MVCCI strategy.

| Crack length | ∆u  | Forces at crack Tip(F) | Energy release rate | SIF, $K_I$ FEA | SIF, $K_I$ FEA in MPa/m |
|--------------|-----|------------------------|-------------------|----------------|------------------------|
| 50           | 0.512 | 777.35                | 3.147             | 11.45          | 16.25                  |
| 100          | 0.516 | 777.34                | 3.149             | 14.76          | 20.95                  |
| 250          | 0.528 | 1110.6                | 6.465             | 21.08          | 29.93                  |
| 400          | 0.544 | 1369.4                | 9.859             | 26.02          | 36.94                  |
| 650          | 0.575 | 1709.4                | 16.36             | 32.65          | 46.36                  |
| 800          | 0.594 | 1843.6                | 17.72             | 35.09          | 49.82                  |
| 950          | 0.609 | 1831.6                | 17.72             | 34.88          | 49.52                  |
| 1000         | 0.611 | 1676.2                | 14.92             | 32.01          | 45.45                  |

It is watched that the esteem stretch power factor is 16.25 Maim at the break length of 50 mm. The most extreme anxiety force factor is 50.53 Maim found at the split length 901 mm. The estimation of stress power factor value is reduced to 45.45 Maim at the break length of 1000 mm because of the nearness of tear tie in the area of the casing in the wake of considering the streamlined features and different burdens.
5. Results and Discussion

The linear static stress analysis of the panel has been drifted out. By using the internal pressure of 6 psi crack propagation was studied on stiffed panel with and without tear lash. For different crack lengths SFI value is calculated.

5.1. Crack propagation on the panel

For different crack lengths and SIF values the graphs are plotted shown below. As the crack length is increased the SIF values also increases. Finally, when the crack reaches nearer to the frame, the value of SIF slightly tends to decrease. From this i have calculated the SIF Value as 13.10 at the crack length of 50mm and increases upto 39.67 as the crack length is increased to 950 mm

![Figure 5: Variation of SIF as a function of crack length](image)

5.2. Role of tear strap to arrest crack propagation

SIF versus different crack lengths for both stiffened panel configuration is plotted shown in Fig. 6. The value of SIF 13.10 Maim at the crack length of 50 mm and increases to 39.67 Maim as crack approaches to 950 mm and then decreases to 39.67 Maim at frame location. After introducing tear strap, the value of SIF is 11.45 Maim at the crack length of 50 mm. The topmost value of SIF 35.59 Maim is instituted at the crack length of 900 mm and then SIF minimised to 32.01 Maim at the point of the truss. This interprets that, there is the reduction in value of SIF. This indicates crack arrest capability of the stiffening member using the arresting feature in the fast fracturing crack with considering the aerodynamic and other loads acting on the fuselage.

![Figure 5: Variation of SIF as a function of crack length](image)
Figure 6- SIF VS Crack length

Conclusion

- At rivet hole of the skin the maximum tensile stress was observed.
- One more observation is made longitudinal crack was formed from the location rivet placed.
- Stress intensity factor approach was used to estimate the crack propagation.
- The maximum stress intensity factor value is 56.33 Mpa for length of 950cm.

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