Fuselage stiffened panel (Monocoque Design) Damage tolerance analysis

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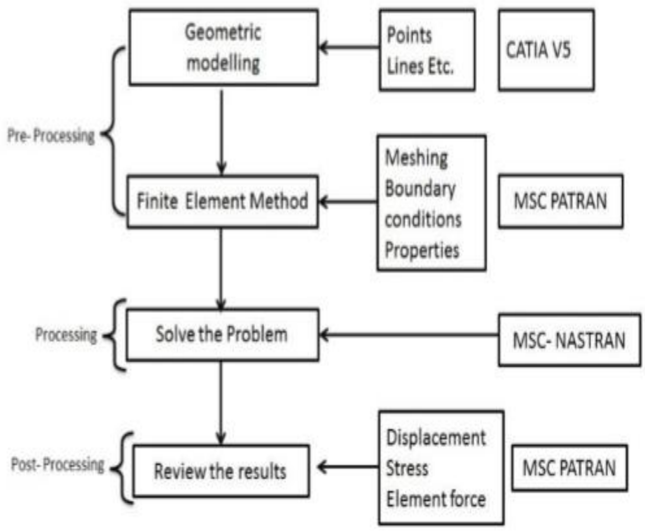
Abstract - Damage tolerance design philosophy is followed in the airframe design to achieve the minimum weight of the structure without compromising on the safety of the structure. This philosophy includes fail-safe design of the structure. Fuselage structure of the aircraft is made up of stressed skin, longitudinal longenors, and circumferential bulkheads. By riveting, the skin, longenors and bulkheads are connected. There are number of riveted joints present in the fuselage which is subjected to a major loading of internal pressurization. The objective of this project is to investigate crack initiation, crack growth, evaluation of stress intensity factor at the crack tip and crack arrest features in the stiffened panel under bi-axial stress field. 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. The stress intensity factor is calculated by damage tolerance analysis for uniaxial stress field and which compared with the facture toughness of the material. In this analysis only the frame is considered in the design of the fuselage and analysis is done considering only this conditions

1. Introduction

The structure of an aircraft is a highly complex one, which mainly consists of wings, fuselage and tail. The aircraft fuselage mainly composed of stressed skins, longitudinal stringers and frames. The structural efficiency of an aircraft results in light weight and high operating stresses. As an efficient structure aircraft must have three attributes primarily, one is its ability to perform the intended function, second adequate service life and third the capability of being produced at reasonable cost. The fuselage of an aircraft is the part that holds crew, passengers and cargo. Aircraft fuselage structure has to withstand many types of loads and stresses and at the same time light weight. The loading conditions of the airframes are very complex due to combination of several loads. The main and important load acting during flight service is the cabin pressurization for passenger comfort. When the aircraft is flown to higher altitudes cycles of pressurization and depressurization occurs. The difference between internal and external pressure at higher altitude creates high stresses in the structure that are conjugate with other loads. The pressurization cycles causes fluctuating loads in the aircraft fuselage. These fluctuating loads cause fatigue in the fuselage which manifests in the form of a crack which propagates. The cracks are originated from the critical locations of the fuselage panel. In this study the effect of crack in a fuselage is studied in the presents of internal pressure. The aircraft fuselage mainly consists of skin made by thin cylindrical shells, circular frames and axial stringers connected by rivets.

2. METHODOLOGY

The current study is done by using Finite Element Method approach. The Finite element method is a numerical technique used for solving engineering problems. The FEM is used to solve simple to complicated problems in engineering.



The pre-processing stage is the primary step in Finite element analysis. This step includes geometric modelling to create the geometry and finite element modelling to create the FE model. This includes the preparation of nodal coordinates and its connectivity, meshing of the model, giving boundary conditions, and material properties. This was done by using MSC PATRAN software. The next stage is the processing stage which includes stiffness generation, modification and solution of equations resulting in the evaluation of nodal variables. MSC –NASTRAN software is used in the solving stage. The final stage is the post-processing stage which deals with the presentation of results, typically the deformed configurations, elemental stresses and forces etc

3. Geometrical and Finite Element Modeling

Fuselage is having radius of 2000 mm and length of the fusel age is 4500 mm. The stiffened pan el is a cut of the fuselage structure. The stiffened panel represents the generic in fusel age structure. The stiffened panel dimensions are 2000 mm in the longitudinal direction and 2900 mm in transverse direction. The thickness of the stiffened panel skin is 1.6 mm. The stiffened pan el has five bulk heads with 508 mm spacing. The distance between two bulk heads is called as one bay, so that the stiffened pan el having five bays. Length of the bulkhead is 2900 mm.

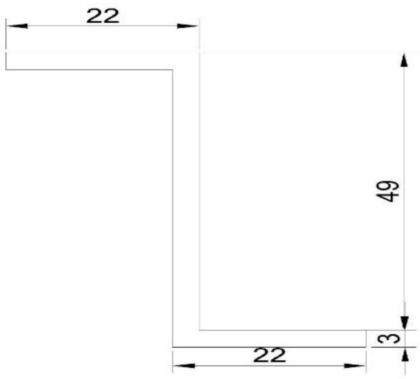


Figure 2:-2D Sketch -of-Frames

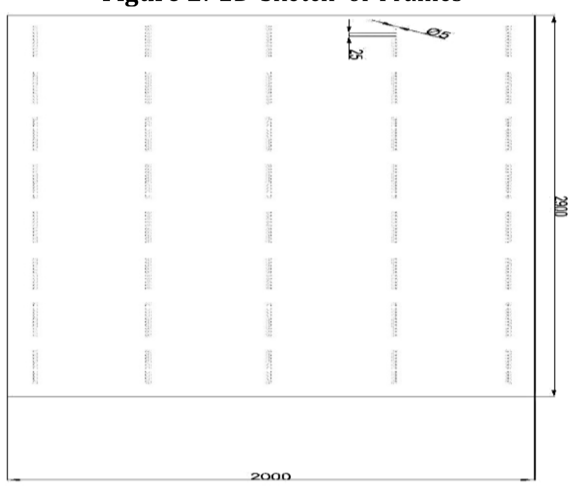


Figure 3: Sketch of Skin with rivet Frame

3.1 Material Specification

Mechanical properties of the skin, stiffening members and rivets are required for finite element models. There is little information on the material properties of skin, stiffening members, and rivet material in the literature. Aluminium 2024-T3 is used for components fusel age and rivet. Table 1 describes few material properties used for analysis

Table 1: Material properties used for the analysis[9]

Property	Aluminium 2024-T3
Density	2.77g/cm3
Young's modulus	70Gpa
Ultimate tensile Strength	483Mpa
Tensile yield strength	362Mpa
Poisson's ratio	0.33
Fracture Toughness	90.8 MPa √m

3.2 Finite element modeling

Four noded shell elements are used in the meshing of stiffened panel. Skin of the Stiffened panel is meshed by shell elements with aspect ratio unity. A frame of the stiffened panel is meshed by shell elements of four numbers of nodes. Fine mesh is performed at the center of the skin where the crack will initiate, element size of 0.5 is maintained at the crack tip, and core mesh element size is maintained at 8.33 the stiffened panel is meshed by element containing four nodes known as quad element.

Table 2: Finitely Element model details

Parts of the stiffend panel	Types of Elements	No. of Elements	Aspect Ratio<5
Skin	QUAD 4	220688	1
Frames	QUAD 4	6400	1.2
Rivet	Beam	330	

Load case: Internal cabin pressurization

Circumferential Stress (Hoop Stress):-
Tensile forces acting in the circumferential direction is equivalent to tensile stress ie Hoop stress developed in circumferential direction
P=Cabined differential pressured = 10 psi = 0.007 kgs/mm2
r = fusel age radius = 2000 mm.
t= Stiffened plate thickness = 1.6 mm
The hoop stress = p×r/t
= 0.007×2000/1.6
The hoop stress= 8.75 kg/mm2
As the skin was represented by 2-D finite element, the force per unit length of
stiffened panel replicates the force on stiffened panel due to hoop stress.
Force on skin due to hoop stress = (Hoop stress x Area of cross section)
= (8.75×2866.671×1.6)
= 40,133.394 kg

4. MVCCI METHOD

The stress intensity factor near the crack tip is calculated by using Modified Virtual Crack Closure integral method (MVCCI). The MVCCI method is based on the energy balance [4, 5]. Stress Intensity Factor (SIF) is calculated for fracture mode from equation:

$$K = \sqrt{GE}$$

Where G is the energy release rate, K is the stress intensity factor and E is the modulus of elasticity. The energy release rate can be calculated based on Irwin assumption [13] that the energy released in the process of crack expansion is equal to work required to close the crack to its original state as the crack extends by a small amount . The simplified form of this equation is written as,

$$G = (F \times \Delta u)/(2 \times \Delta a \times t) N/mm$$

F is forces at the crack tip in kg, Δa is the elemental edge length near the crack tip in mm, t is the thickness of the skin in mm, Δu is the crack opening displacement in mm. The crack tip Force is calculated by means of adding the two elemental forces above the crack tip. Crack opening displacement is calculated by means of subtracting the two elemental displacement values at the crack tip.

4.1 Calculation of SIF for Stiffened Panel

For crack length 50 mm

$$G = (F \times \Delta u)/(2 \times \Delta a \times t) N/mm$$

$$= (46.610 \times 0.0194) / (2 \times 0.5 \times 1.6)$$

$$= 0.05366\ N/mm$$

$$K = \sqrt{GE}$$

$$= \sqrt{0.05366 \times 7000}$$

$$= 20.46408\ kg/mm^2\sqrt{mm}$$

$$= 18.922\ (Mpa\ \sqrt{m})$$

Table 3: SIF of Stiffened Panel

crack length	COD ΔV in mm	Crack tip Force F, in N	Energy release rate in N/mm G	MVCC SIF, Mpa√m
50	0.0194	46.610	0.5366	18.922
100	0.0230	58.269	0.8822	24.499
150	0.0292	69.390	1.2346	28.802
200	0.0328	79.216	1.5671	33.365
250	0.0361	87.291	1.9962	36.715
300	0.0392	94.846	2.2536	39.849
350	0.0421	102.988	2.6988	42.812
400	0.0449	108.796	2.9717	45.636
450	0.0476	115.305	3.3408	48.335
500	0.0492	122.543	3.72481	49.922
550	0.0526	127.517	4.1816	53.399
600	0.0549	134.215	4.47815	55.763
650	0.0563	138.615	4.83914	58.002
700	0.0583	143.640	5.2898	59.286
750	0.0602	148.183	5.5460	62.970
800	0.0626	151.997	5.8967	63.553
850	0.0628	154.629	6.0519	64.647
900	0.0641	155.694	6.1124	65.070
950	0.0613	151.827	5.8589	64.313
990	0.0539	133.349	4.5139	54.7119

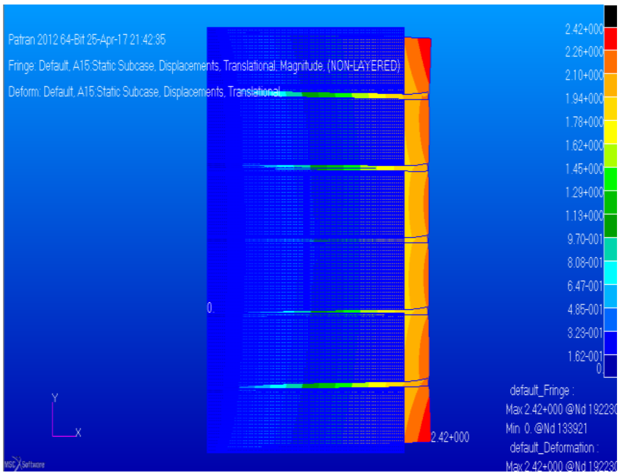


Figure 4: deformation of stiffened panel

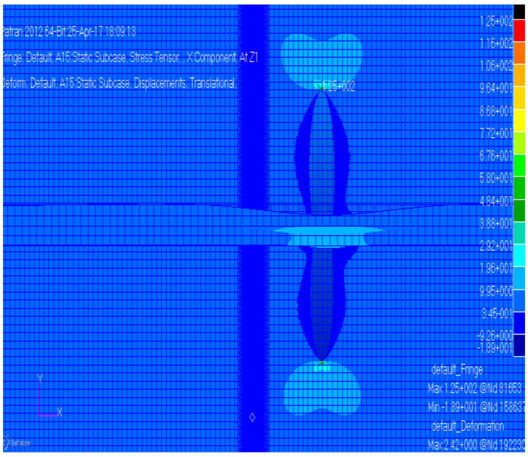


Figure 5: maximum stress location of stiffened panel

As shown in table it is observed that Stressed intensity factor is a function of crack length. As crack length increases the Stressed intensity factor also increases but Stressed intensity factor decreases when crack comes near to the Frame. For crack length 950mm the corresponding SIF is 64.313/√m and for crack length 990 mm the corresponding SIF is 54.711Mpa/√m.

Behavior of crack in the stiffened panel

For stiffened under uniaxial stress field he Stress intensity factor was calculated for various crack lengths. Graph was plotted for Stressed intensity factor Vs different crack lengths shown in fig 6 .From the graph it is observed that the Stressed intensity factor(SIF) of the stiffened pan el increases constantly with increase in the crack length. When the crack ncomes near to the frames, the Stress intensity factor value decreases.

Ⅵ Results and Discussion

The linear static stress analysis of the stiffened panel was carried out. Internal pressurization was considered as a load case for the project. A differential internal pressure of 10 psi was considered for the current problem. Initiation of the crack in the stiffened panel was studied for uniaxial loading with no failure of the frame and broken frame. The stress intensity factor value was calculated for the stiffened panel with different crack lengths.

Behaviour of crack in the stiffened panel with broken frame

For stiffened panel under uniaxial stress field the SIF was calculated for different crack lengths. The graph was plotted for SIF vs different crack lengths shown in Fig.6. It is observed that, SIF increases progressively with increase in the crack length. Whenever the crack comes nearer to the frames, the value of SIF keeps decreasing. It found that, the value of SIF 11.35137√m at crack length of 5 mm and increases to 80.9102 MPa√m as crack approaches to 900 mm and then decreases to 69.44309 MPa√m at near frame location. From the graph it is indicated that SIF value reduces as crack reaches the frame.

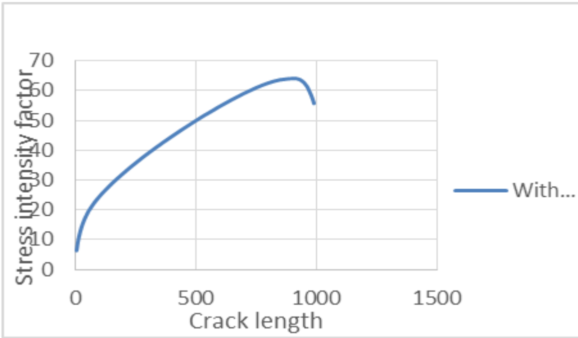


Figure 5: Crack length Vs SIF

Ⅶ Conclusion

The current investigation includes the evaluation of a fusel age-stiffened panel for its damage tolerance capability with one of its frames in the broken condition. The cracking location is idealized as a flat stiffened panel with a skin crack subjected to uniaxial tensile loading the material used for the stiffened panel will be taken as 2024-T3 aluminum alloy. Stressed intensity factor (SIF) were calculated for various incremental c racks from 10 mm to 1000 mm. The maximum value of stress intensity factor broken frame analysis is 80.9 MPa √mm at a c racking length of 900 mm, the Stressed intensity factor(SIF) to reduce as C rack length goes near the frame location The maximum value of stress intensity factor 80.9 MPa√m for a broken frame in the Sif is much less than the Fracture toughness of Al .This indicates that fusel age is safe for internal Pressurization of 10 psi and the design is safe.

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