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Damage Tolerance analysis of a Fuselage Stiffened Panel with a Broken Frame

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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. The most common cause of structural failures is fatigue under service loading. Fatigue c racks can initiate and propagate to critic al dimensions leading to a catastrophic failure of the air frame. The current airframe design concepts permit a fatigue crack to initiate from a manufacturing flaw early in service life and propagate. But it should not lead to a catastrophic fail u re of the aircraft.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 analysis will be carried out with a frame broken condition. A Finite element analysis approach will be followed in this investigation. Geometrical dimensions representative of actual aircraft in service will be considered. The material used for the stiffened panel will be taken as 2024-T3 aluminum alloy.A panelstrength diagram will be derived from the stress analysis of this cracked stiffened panel with an frame broken conditionIn this analysis only the frame is considered in the design of the fuselage and analysis is done considering only this conditions with a broken frame.

Key words: Stiffened panel, Stress intensity factor, Fatigue crack, Finite element analysis, Fail-safety, Catastrophic failure.

I. INTRODUCTION

Aircraft Structure also known as aircraft frame is a good example for an efficient structural design which is a result of light weight which is subjected to high operational stresses. Most effective Air craft frame should have three main features, specially the structure should have flexibility to perform in the conditions it is designed for, it should give acceptable service life and can be manufactured at an afford able price. 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.. In spite of all the precautions taken during design and manufacturing of the air craft c racks will appear in several components of air craft which are subjected to high operational stress . The cracks which are created by the high operational stresses will reduce the stiffness of the structure which results in the reduction in the load carrying capacity of the structure.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.

II. COMPONENTS OF AIRCRAFT STRUCTURE

A. Fuselage

The fuselage, or body of the air plane, is a lengthy hollow tube like structure, to which all the members of the air craft, is assembled too. The fusel age is designed as a hallow member so that the w eight of the air craft structure as compared to the other members and also to the crew, passengers and cargo are placed inside this hallowed structure. The design of the fusel age is made according the application of the aircraft. An airbus and cargo liner aero planes encompasses a wider body to hold the most variety of passengers and the cargo. The pilot's cabin is an secured cockpit which is fixed at the front of the fusel age. Then the Passengers and shipment or cargo compartment are fixed at rear of the air craft and the wings of the air craft holds the fuel , wings also produces a lift which is required during flight.The design of fusel age which is an efficient circular cross-section helps to maintain the internal pressure within the air craft. The fusel age is a thin shell structured which is supported by Longerons and stringers and is supported by many bulk heads which is a transverse frames fixed at regular intervals along the length. The fusel age skin carries the shear stresses created by torques and transverse forces, hooped stresses created by internal pressures.

III. METHODOLOGY

The finite element method is a numerical technique for solving engineering problems. It is most powerful analysis tool used to solve simple to complicated problems.

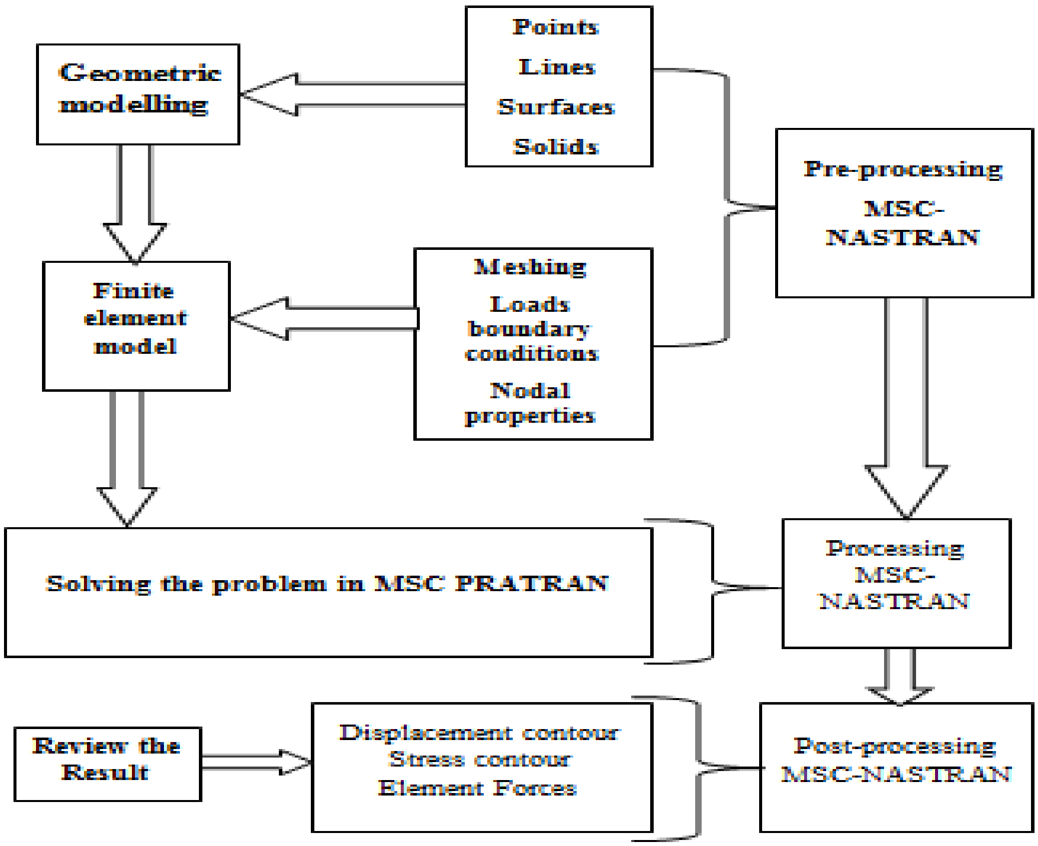

Figure 1: Steps in Finite Element Analysis

The pre-processing stage involves the preparation of nodal co-ordinates & its connectivity, meshing the model, load & boundary conditions and material information for finite element models carried in MSCAs shown in above process chart firstly the geometric modeling has to be done by using cad software. In the Pre-processing step the Finite Element Model made up in MSC-NASTRAN, it has been done by meshing, load, boundary condition and properties. In the processing stagethe following tasks are performed like modification and solution of equations resulting in the evaluation of nodal variables ,stiffness generation , run in MSC- NASTRAN. The results representations is generally is done in the post process in g stage, in which we basically read the results the deformed con figurations, elemental stress e s and forces etc.

IV .Geometrical and Finite Element Modeling Of Stiffened Panel

A. Geometrical Modeling

Fuselage is having radius of 200.0 mm and length of the fusel age is 45-00 mm. The stiffened panel is a cut of the fuselage structure. The stiffened panel represents the generic in fuselage structure. The stiffened panel dimensions are 200-0 mm in the longitudinal direction and 29.00 mm in transverse direction. The thickness of the stiffened panel skin is 1.6 mm. The stiffened pan el has five

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bulk heads with 50 8 mm spacing. The distance between two bulk heads is called as one bay, so that the stiffened panel having five bays. Length of the bulkhead is 290.0 mm.

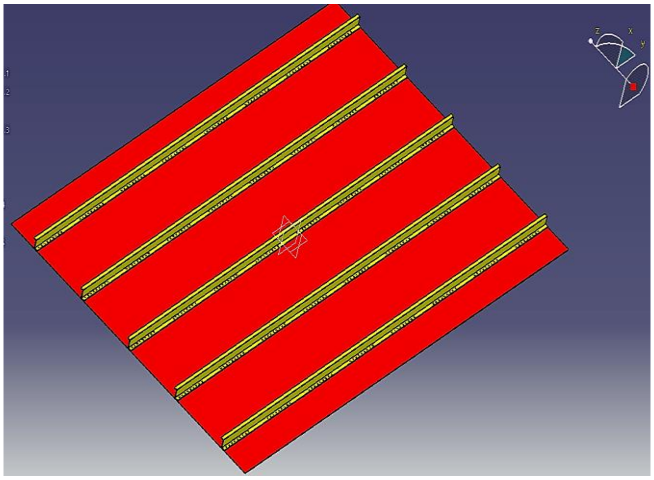

Figure 2: CAD model of the stiffened panel

B. 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[2]

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

C. Finite element modeling

Four noded shell elements are used in the meshing of stiffened panel. S kin 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 number of nodes. Fine mesh is performed at the centreo f 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. Element model details

Parts of the stiffened panel	**Types of Elements**	**No. of Elements**	**Aspect Ratio<5**
Skin	QUAD 4	220948	1
Frames	QUAD 4	6400	1.2
Rivet	Beam	330	

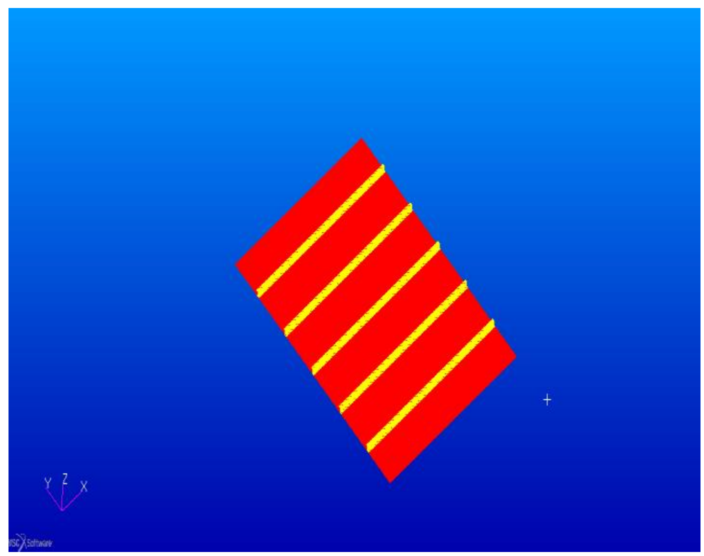

Figure 3: Finite Element Modeling of the stiffened panel

D. 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

In the Linear Static Stress Analysis of the stiffened panel, the internal pressured is

Acting tensile in nature. The circumferential hoop stresses and the longitudinal stresses developed in the fusel age (cylindrical Shelled Structure) are equal to t ensile stresses of the stiffened paneled. The tensile load can be calculated by using the hoop stress developed in the stiffened panel.

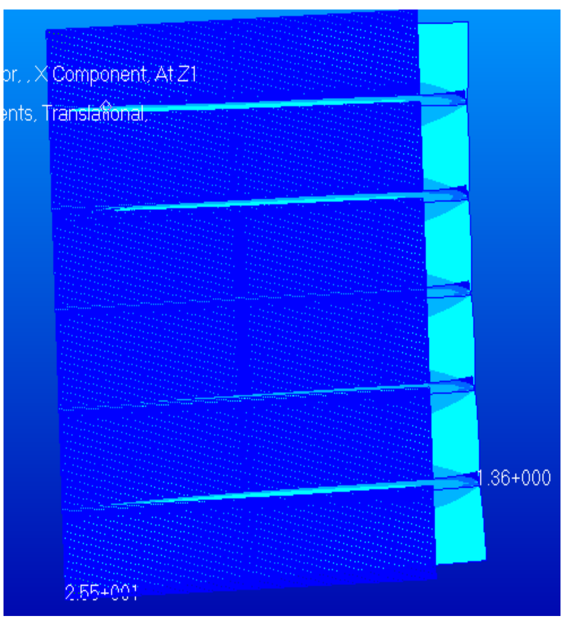

Figure 4: deformation of stiffened panel

E. Stiffened Panel with broken of the frame

In the stiffened panel the hoop stress will be acting in a tensile stress pattern across the cross section of the stiffened panel. The tensile load is got due to the hoop stress developed in the model acting on the corresponding cross sectional This tensile stress is uniformly distributed over the cross section. Uniformly distributed tensile load is applied on the stiffened panel in longitudinal direction .this uniformly distributed load is applied on edges of skin and Frame in the longitudinal direction. At other end, all the edge nodes of stiffened panel and the frame are constrained in all six degree of freedom (three translations and three rotations) Initially the dametolerance analysis will be carried out for a panel with no failure of the frame normal to the crack line.the frame will be broken at centre of the stiffen panel where crack is intiated

V. MVCCI METHOD

Modified Virtual Crack Closure Integral (MVCCI) method is used to determine

stress intensity factor for different crack lengths in the stiffened panel. MVCCI method is based on the energy balance

$$G = \frac{F \times \Delta u}{2 \times \Delta a \times t} N/mm$$

Where F is forces at the crack tip, Δu is crack opening displacement (COD), t isthickness of the skin and Δais elemental edge length near the crack tip.

Calculation of SIF for Stiffened Panel with broken of the frame

1) For crack length 50 mm

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

= (75.29517×0.03099) / (2×0.5×1.6)

=1.477923N/mm

$$K = \sqrt{GE}$$

=√1.477923× 7000

=36.61 kg/mm2√mm

=32.53092 (Mpa √m)

The above calculation is carried for different crack length considering a known load. The stress intensity factor value is calculated by using MVCCI method for the stiffened panel. The stress intensity factor is tabulated in steps of 50 mm crack length shown in Table 3.

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	0.03099	75.295	1.477923	32.53092
100	0.03846	95.436	2.170415	38.08079
150	0.04330	105.22	2.97484	44.97619
200	0.04726	116.90	3.524142	46.99396
250	0.05080	123.54	3.855043	52.58059
300	0.05409	133.57	4.582065	53.90979
350	0.05719	141.16	5.110205	57.05484
400	0.06015	145.41	5.642527	62.0611
450	0.06300	155.36	6.178212	64.94383
500	0.0657	160.04	6.716317	65.71429
550	0.0683	166.45	7.253763	68.37101
600	0.0708	172.55	7.785145	72.9013
650	0.0732	178.31	8.103838	73.2881
700	0.075	183.60	8.796185	75.4848
750	0.0772	188.29	9.243643	77.42786
800	0.0788	194.03	9.609415	78.98114
850	0.0797	192.24	9.629238	81.9003
900	0.0797	193.32	9.63162	82.9102
950	0.0783	190.89	9.29736	78.50851
990	0.0685	168.43	7.268637	68.44309

As shown in table it is observed that, variation of SIF is a function of crack length. As crack length increases the SIF also increases but when crack comes near to the Frame SIF decreases. For crack length 940mm the corresponding SIF is 80.9102/√m and for crack length 990 mm the corresponding SIF is 69.44309Mpa/√m.

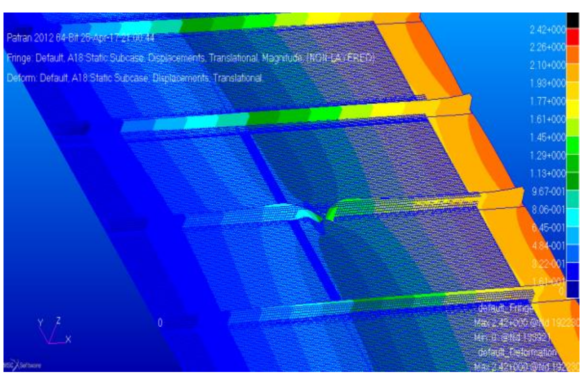

Figure 5: deformation of stiffened panel with broken frame

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.

A. 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.

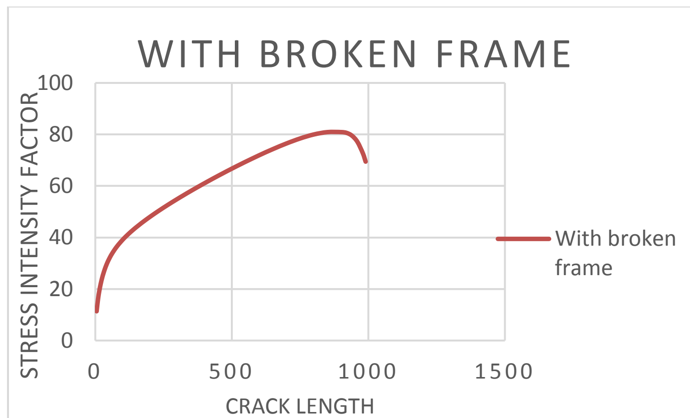

Figure 6: Crack length Vs SIF With broken frame

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 loadingthe 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 80.9MPa √mm at a c racking length of 900 mm, the Stressed intensity factor(SIF) to reduce as C rack length goes near the frame locationThe 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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