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Stress Analysis and Fatigue Life Prediction for Splice Joint in an Aircraft Fuselage through an FEM Approach

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***Abstract---* Aluminum alloy 2024-T351 material is considered for all the structural elements of the panel for fabrication of the aircraft body. Force due to Cabin pressurization can be considered as one of the critical load cases for the fuselage structure. Fuselage experiences constant amplitude load cycles due to pressurization. Splice joints are used for the fuselage structure. Typical splice joint panel consisting of skin plates, doubler plate & a longitudinal stiffener is considered for the study. The project includes the stress analysis of a splice joint in a transport aircraft. A two-dimensional finite element-analysis will be carried out on the splice joint panel. Distribution of fasteners loads and local stress field at rivet locations will be studied using finite element analysis. The work also involves the modifications required to correct the boundary effects of the panel. The global finite element analysis of a segment of typical fuselage will be carried out. This global finite element analysis results can be considered bench mark for comparing the results from the splice joint panel analysis. Repeated finite element analysis will be carried out to get the response of the parent structure (fuselage) at the joint location. The response of the splice joint will be evaluated. The splice joint is one of the critical locations for fatigue crack to initiate. In this project prediction of fatigue life for crack initiation will be carried out at maximum stress location.**

***KEY WORDS*- SPLICE JOINT, DOUBLER, STINGER, BULKHEAD, FATIGUE, STRESS.**

I. INTRODUCTION

In assembling complex structures like military or commercial aircraft, riveted or bolted joints are primarily used as they offer many options to the designer. To satisfy fatigue requirements, the designer can either keep the stress levels below the endurance limit or ensure the slow crack growth life of the component is greater than the design service goal plus some factor of safety. The latter approach is most commonly used and relies on the ability to predict fatigue crack growth at fatigue critical locations. Fractographic information obtained from teardown and failure analysis of retired aircraft indicates that predicting growth of two unsymmetrical (different crack length and/or crack depth) corner cracks on opposite sides of a fastener hole is necessary [1, 2]. In a fracture mechanics context, the stress intensity factor, K, is required for such predictions [1].

A. Splice joint

A splice joint is a method of joining two members end to end in woodworking. The splice joint is used when the material being joined is not available in the length required. It is an alternative to other joints such as the butt joint and the Scarf joint Splice joints are stronger than unreinforced butt joints and have the potential to be stronger than a scarf joint. They are more visible than a scarf joint but may be preferred when more strength is required. Splices are therefore most often used when structural elements are required in longer lengths than the available material. The most common form of the splice joint is the half lap splice, which is common in building construction, where it is used to join shorter lengths of timber into longer beams.

B. Fatigue Definition

Fatigue is a phenomenon associated with variable loading or more precisely to cyclic stressing or straining of a material. Just as we human beings get fatigue when a specific task is repeatedly performed, in a similar manner metallic components subjected to variable loading get fatigue, which leads to their premature failure under specific conditions.

C. Fatigue loading

Fatigue loading is primarily the type of loading which causes cyclic variations in the applied stress or strain on a component. Thus any variable loading is basically a fatigue loading.

D. Fatigue Failure- Mechanism

A fatigue failure begins with a small crack; the initial crack may be so minute and can not be detected. The crack usually develops at a point of localized stress concentration like discontinuity in the material, such as a change in cross section, a keyway or a hole. Once a crack is initiated, the stress concentration effect become greater and the crack propagates. Consequently the stressed area decreases in size, the stress increase in magnitude and the crack propagates more rapidly. Until finally, the remaining area is unable to sustain the load and the component fails suddenly. Thus fatigue loading results in sudden, unwarned failure.

E. Fatigue Failure Stages

Thus three stages are involved in fatigue failure namely

-Crack initiation

-Crack propagation

-Fracture

Crack initiation: The following figure1 describes the architecture of system. Here every user needs to establish a connection with other user in the network to communicate with each other. This is done by sending request to the kernel for new channel. To start a connection

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• Areas of localized stress concentrations such as fillets, notches, key ways, bolt holes and even scratches or tool marks are potential zones for crack initiation.

• Crack also generally originate from a geometrical discontinuity or metallurgical stress raiser like sites of inclusions

Crack propagation

• As a result of the local stress concentrations at these locations, the induced stress goes above the yield strength (in normal ductile materials) and cyclic plastic straining results due to cyclic variations in the stresses. On a macro scale the average value of the induced stress might still be below the yield strength of the material.

• This further increases the stress levels and the process continues, propagating the cracks across the grains or along the grain boundaries, slowly increasing the crack size.

• As the size of the crack increases the cross sectional area resisting the applied stress decreases and reaches a thresh hold level at which it is insufficient to resist the applied stress.

Final fracture: As the area becomes too insufficient to resist the induced stresses any further a sudden fracture results in the component.

II. LITERATURE REVIEW

"Fatigue damage in aircraft structures not wanted but tolerated" Jaap Schijve [2 and 3]: It has been a long road to arrive at the present culture of dealing with fatigue and fatigue damage tolerance of aircraft structures. Some accidents were milestones along the road. New concepts were proposed related to structural design, materials, production techniques, inspection procedures and load spectra The present paper is a personal impression of evaluating experience, design aspects, predictions and experiments.

"Experimental/numerical technique for aircraft fuselage structures containing damage" by Padraic E. O'Donoghue, Jinsan Ju[4] : Fracture mechanics has always been a major problem for the aircraft industry as designers must ensure that catastrophic events such as fuselage failure will never occur. the work programme includes an extensive series of testing and analysis of aircraft fuselage panels containing pre-existing cracks."New techniques for detecting early fatigue damage accumulation in aircraft structural components" by Curtis A. Rideout and Scott J. Ritchie[5] : The remaining safe operational life of flight critical aircraft structural components prior to crack initiation and detection is currently estimated by fatigue and fracture models supplemented by destructive testing. To more accurately assess the remaining life of a structural component prior to the initiation of a detectable crack, a non-destructive inspection process that measures fatigue damage accumulation is required.

"Post-buckling simulation of an integral aluminum fuselage panel subjected to axial compression load**"** by Sun Weimin, Tong Mingbo, Guo Liang, and Dong Dengke[6] : Results from an experimental and analytical study of a curved stiffened panel subjected to axial compression load are presented. Nonlinear analysis was carried out and validated by the experimental results.

III. AIRCRAFT CABIN PRESSURIZATION

Aircraft are flown at high altitudes for two reasons. First, an aircraft flown at high altitude consumes less fuel for a given airspeed than it does for the same speed at a lower altitude because the aircraft is more efficient at a high altitude. Second, bad weather and turbulence may be avoided by flying in relatively smooth air above the storms. Many modern aircraft are being designed to operate at high altitudes, taking advantage of that environment. In order to fly at higher altitudes, the aircraft must be pressurized. It is important for pilots who fly these aircraft to be familiar with the basic operating principles. In a typical pressurization system, the cabin, flight compartment, and baggage compartments are incorporated into a sealed unit capable of containing air under a pressure higher than outside atmospheric pressure. On aircraft powered by turbine engines, bleed air from the engine compressor section is used to pressurize the cabin. Superchargers may be used on older model turbine-powered aircraft to pump air into the sealed fuselage. Piston-powered aircraft may use air supplied from each engine turbocharger through a sonic venturi (flow limiter). Air is released from the fuselage by a device called an outflow valve. By regulating the air exit, the outflow valve allows for a constant inflow of air to the pressurized area [2].

IV. GEOMETRIC CONFIGURATION OF THE FUSELAGE

A segment of the fuselage is considered in the current study. The structural components of the fuselage are skin, bulkhead and Stiffeners. Geometric modeling is carried out by using CATIA V16 2012 software. The total length of the structure is 1500mm and diameter is 2200mm. It contains 3nos Z section (Bulkhead) and 32nos L section (Stiffeners).

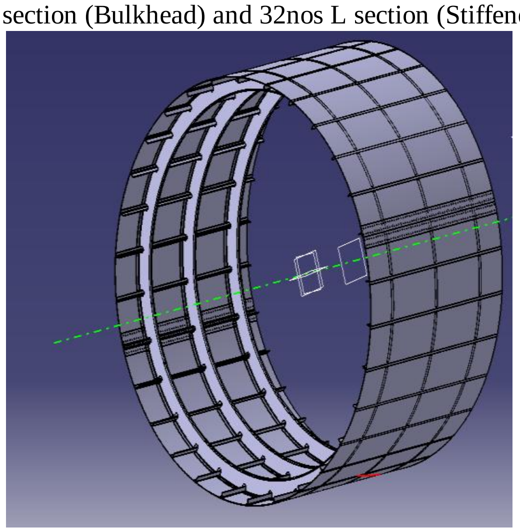

Fig: 1 geometric configuration of aircraft fuselage

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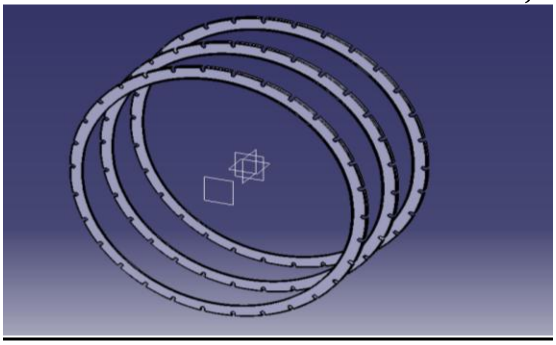

Fig: 2 Z sect stiffeners

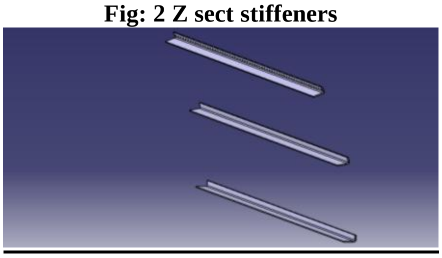

Fig: 3 L sect stiffeners

V. METHODOLOGY

- Solution by FEM method
- Analytical Investigation

Solution by FEM method: The project work involves the analysis of the splice joint using software's MSC/NASTRON & MSC/PATRON. Also, fatigue prediction of splice joint would be carried out.

Software's used

1. MSC/NASTRON & 2.MSC/PATRON

A two-dimensional finite element-analysis will be carried out on the splice joint panel. Distribution of fasteners loads and local stress field at rivet locations will be studied from finite element analysis. The work also involves the modifications required to correct the boundary effects of the panel. The global finite element analysis of a segment of typical fuselage will be carried out. This global finite element analysis results will be bench mark for comparing the results from the splice joint panel analysis. Repeated finite element analysis will be carried out to get the response of the parent structure (fuselage) at the joint location. The response of the splice joint will be evaluated through finite element analysis.

VI.RESULTS

Displacement contour of fuselage structure

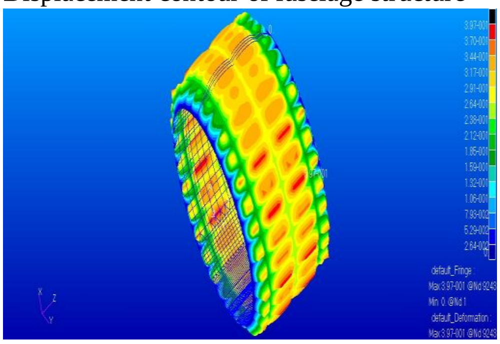

Fig.4. displacement contour of fuselage structure

Stress contour of fuselage structure

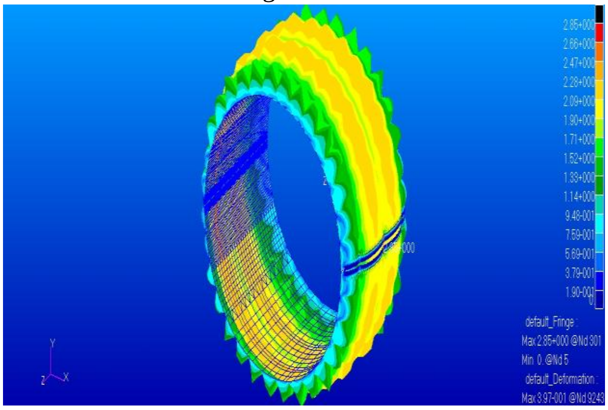

Fig.5. Maximum stress of 2.85 kg/mm2 exists in doubler plate

VII. CONCLUSION

In order to improve the aircraft life and make it defect free, stress analysis and fatigue life prediction is carried out on aircraft structure through FEM approach. A FEM approach is followed by the stress analysis of aircraft structure, the internal pressure is one of the main load that the fuselage needs to hold. Stress analysis is carried on structure to identify maximum stress location in the structure. Local analysis is carried out at maximum stress location for fatigue life prediction.

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