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Stress Analysis of an Aircraft Wing with a Landing Gear Opening Cutout of the Bottom Skin

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Abstract: In this paper, work is addressed to a stiffened panel of a landing gear opening cutout of a typical transport aircraft wing. Cut-outs required for fuel access and landing gear in the bottom skin of the wing will introduce stress concentration because the lower part of the wing is subjected to tensile force due to the upward bending of the wing during flight. The stress analysis of the landing gear opening cutout is carried out. This identifies the location of high tensile stresses which are the potential sites for fatigue crack initiation.

Keywords: aircraft, **stiffened panel, wing, cut-out, stress concentration, stress analysis, fatigue.**

1. INTRODUCTION

Aircraft is a vehicle that is able to fly by gaining support from the air. It needs to be strong and stiff enough to withstand the exceptional circumstances under which it has to operate. The main sections of an aircraft – the fuselage, tail and wing determine its external shape. The load bearing members of these main sections, those subjected to major forces, are called the airframe.

Cut outs are essential in airframe structures to provide the following:

- Fuel access cutout at the bottom skin of wing and fuselage.
- Inspection for maintenance (medium sized cut - outs called hand holes).
- Landing gear opening and retracting at the bottom skin of the wing or fuselage.
- Lightening holes in webs.
- Window cutout in fuselage.
- Accessibility for final assembly and maintenance. (e.g., man holes in wing lower surfaces, crawl holes in wing ribs, etc.)

Airframe engineers view any cut-outs in an aircraft with disfavor because these cut-outs not only increases the overall cost of aircraft and adds weight to the aircraft due to the reinforcement incurred in compensating for the cut-outs but also serve as stress concentration raisers due to the sudden or abrupt change in area. These stress raisers are a problem for both static and fatigue strength.

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. Fatigue cracks are most frequently initiated at sections in a structural member where changes in geometry, e.g., holes, notches or sudden changes in section, cause stress concentration.

This paper addresses the issues for a typical aircraft wing of transport aircraft. As the aircraft takes off, the aircraft bends upwards, this is due to the fact that the wing supports the total weight of the aircraft. Therefore the stress analysis of a wing under various load distributions that the airframe is going to be subjected is done. This identifies the locations of high tensile stresses which are the potential sites for fatigue crack initiation.

2. GEOMETRICAL CONFIGURATION

The geometric modeling of the stiffened panel with landing gear opening cut-out is carried out by using Solidworks 2013. The stiffened panel with landing gear consists of a panel with integrated stiffeners and cut-out with rivet holes. The number of stiffeners used in the stiffened panel is six. The Solidworks model of the stiffened panel with landing gear opening cut out is shown in the fig 1 below.

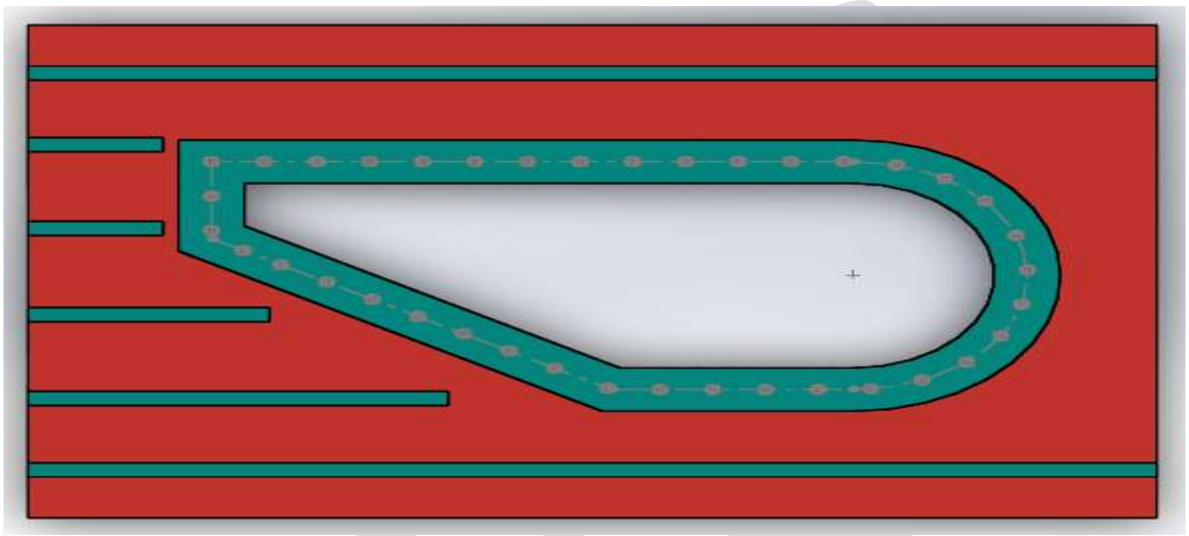

Fig 1 : CAD model of stiffened panel with landing gear opening cut out

3. MATERIAL SPECIFICATION

Aluminum alloys have a low density while their tensile properties are low compared to steels, they have excellent strength to weight ratios. The 2024 alloys have excellent fracture toughness and slow crack growth rate as well as good fatigue life. They are most widely used in the lower skin of the aircraft because during flight the lower skin will be undergoing fatigue loading due to the cyclic tensile stresses acting on the lower skin of the aircraft.

The material considered for the landing gear cutout part is Al 2024–T3, with the following properties.

- Young's Modulus, E = 72 GPa
- Poisson's Ratio, = 0.33
- Density = 27.7 KN/m^3
- Yield Strength = 362 MPa
- Ultimate strength = 483 MPa

4. LOAD ACTING ON THE STIFFENED PANEL WITH LANDING GEAR OPENING CUTOUT

The class of the aircraft is 8 seater civilian transport aircraft. And the load case is Level flight load with maximum speed.

Span of the wing = 7060 mm = 7.06 m

Total weight of the aircraft = 1800kg = 17.658 KN

Design load factor = 3g.

Therefore load acting on the aircraft = 5400 kg = 52.974 KN

Factor of safety = 1.5

Ultimate load acting on the aircraft = 8100 kg = 79.461 KN

According to the distribution of the lift load on the wing and the fuselage.

The wing experiences 80% of the lift load and the remaining 20% of the lift load is experienced by the fuselage.

Total load acting on the wings = 80% of 79461N

= 0.8 x 79461 = 63568.8 N

Load acting on each wing = 31784.4 N =31.7844 KN

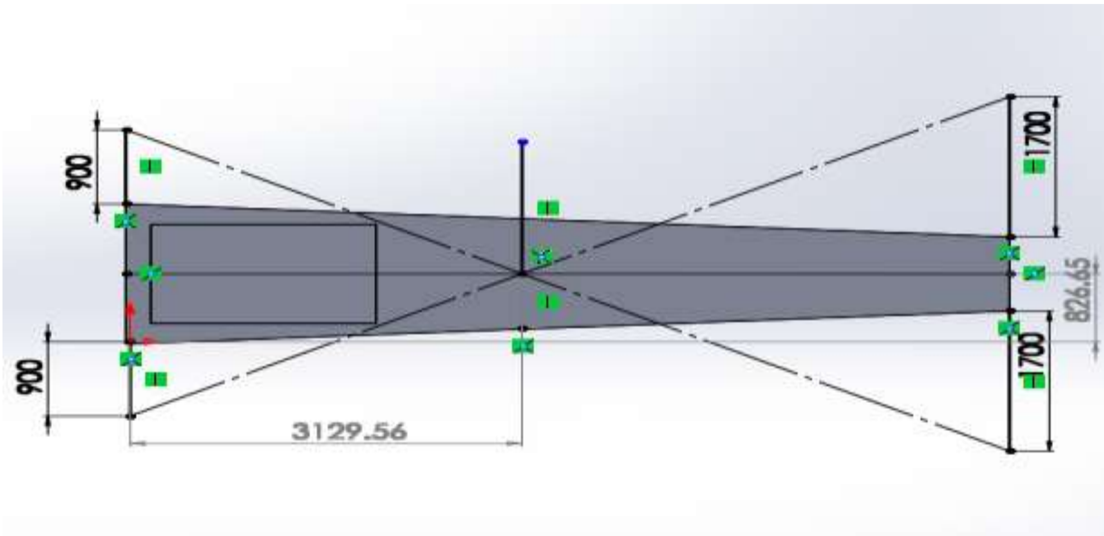

Fig 2 : Wing structure with landing gear opening cutout

The resultant load is acting at a distance of 3130 mm (from aerodynamic calculations from the root of the wing).

The maximum bending moment at the wing root = 31784.4 x 3130 =99.485 x 10^6 N-mm

The B.M at the root of the wing box = 31784.4 x 2930 = 93.12 x 10^6 N-mm

The load at tip of the wing box = 93.12x 10^6/1200 = 77607 N

The total edge length of the cutout where load is applied = 1800 mm

Total UDL load applied for the component = 77607/1800

= 43.115 N/mm

5. FINITE ELEMENT ANALYSIS

5.1 Introduction

Today the finite element method (FEM) is considered as one of the well established and convenient technique for the computer solution of complex problems in different fields of engineering: civil engineering, mechanical engineering, nuclear engineering, biomedical engineering, hydrodynamics, heat conduction, geo-mechanics, etc. From other side, FEM can be examined as a powerful tool for the approximate solution of differential equations describing different physical processes.

The success of FEM is based largely on the basic finite element procedures used: the formulation of the problem in variational form, the finite element discretisation of this formulation and the effective solution of the resulting finite element equations. These basic steps are the same whichever problem is considered and together with the use of the digital computer present a quite natural approach to engineering analysis.

5.2 Finite element model of a stiffened panel with landing gear opening cutout

The stiffened panel with landing gear opening cutout model is first prepared in the Solid works 2013 modeling software and then extracted into the software where finite element meshing and analysis is carried out. The software used for analysis here is MSC NASTRAN. Finite element meshing is carried out for all the components of the stiffened panel.

The Fig 3 shows the details of the finite element mesh generated on each part of the structure using MSC NASTRAN.

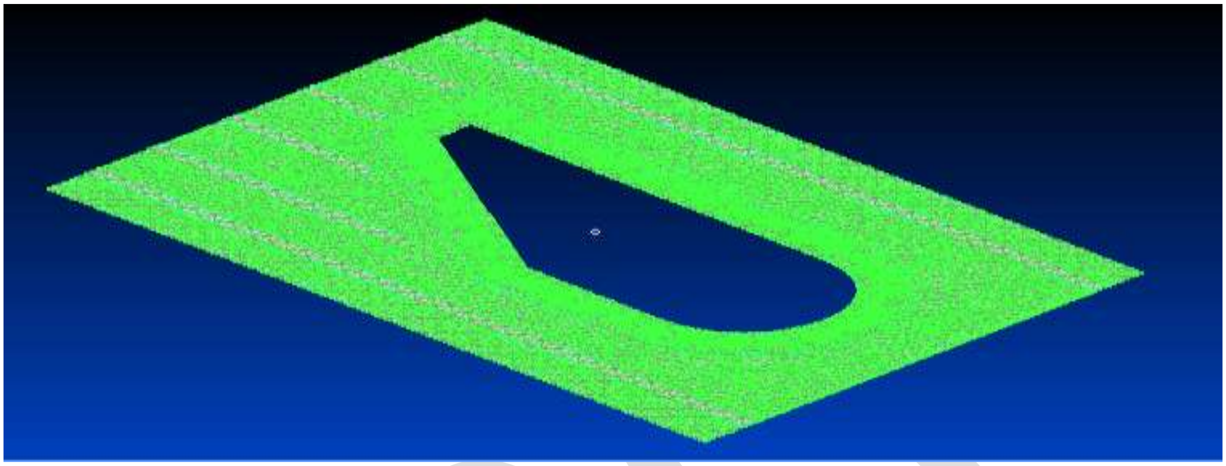

Fig 3 : Finite element meshing of stiffened panel with LG opening cutout

6. LOADS AND BOUNDARY CONDITIONS

The loads and boundary conditions are applied. The boundary conditions are fixing one end of the stiffened panel by constraining all the 6 degrees of freedom. To avoid bending, the translation in the direction perpendicular to the stiffened panel, ie z direction is constrained for all nodes of the stiffened panel. And the uniformly distributed load of 43.115 N/mm is applied on the other end of the stiffened panel. The loads and boundary conditions applied to the finite element model of the stiffened panel with landing gear opening cutout are shown in the Fig 4.

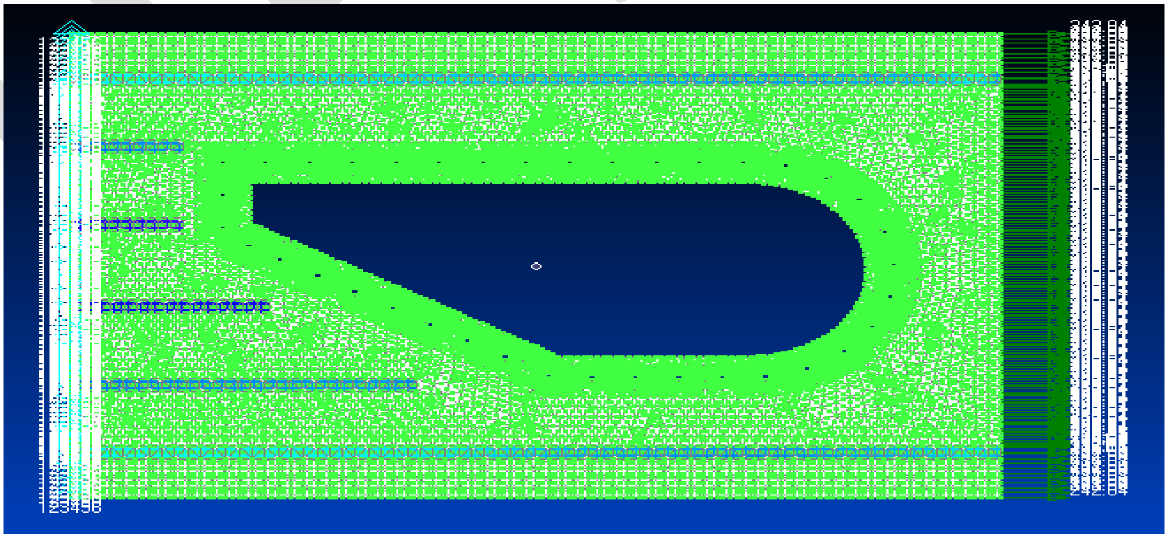

Fig 4: Loads and Boundary conditions applied to the stiffened panel with landing gear opening cutout

7. STRESS AND DISPLACEMENT ANALYSIS OF A STIFFENED PANEL WITH LANDING GEAR OPENING CUTOUT

Once load and boundary conditions are applied to the finite element model, stress analysis is done to find the maximum stress concentrated region. Also the maximum displacement of the stiffened panel is found out using the analysis. The Fig 5 shows the stress analysis and the Fig 7 shows the displacement analysis of the stiffened panel with landing gear opening cutout.

From the analysis, the maximum stress obtained is 42.99 N/mm^2 and the maximum displacement is 2.5 mm for the applied boundary condition and uniformly distributed load of 43.115 N/mm. The Fig 6 shows the maximum stress region, in this model the maximum stress concentration takes place at the rivet hole as shown in the figure.

The maximum stress concentration region, we can say that crack will get initiated from that maximum stress location and propagate perpendicular to the applied load direction.

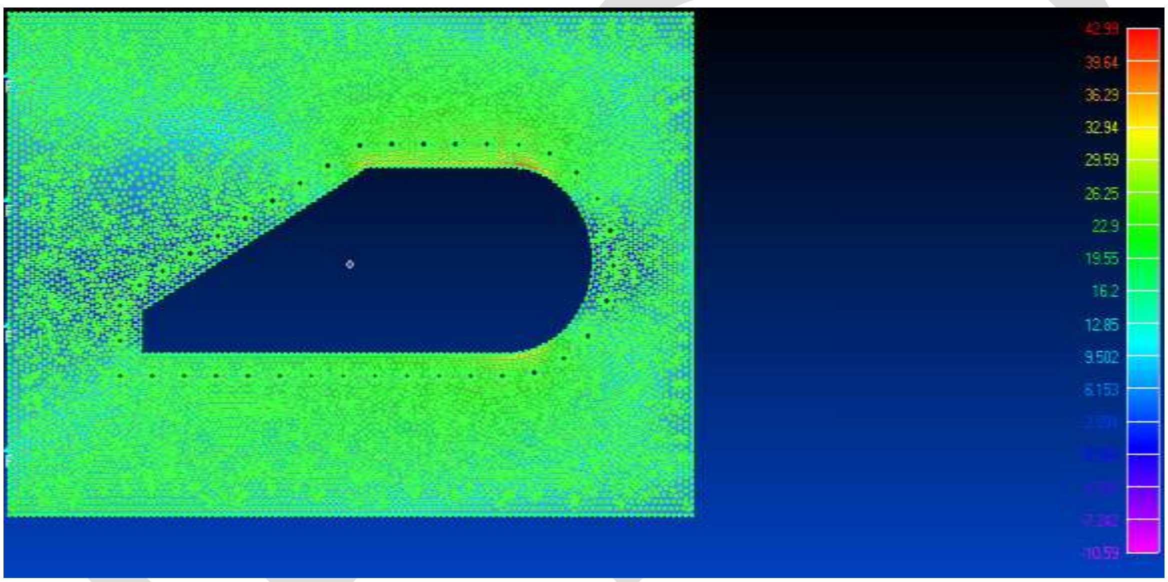

Fig 5: Stress analysis of the stiffened panel with LG opening cutout

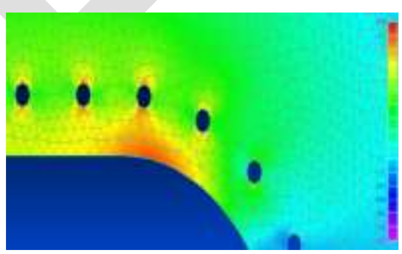

Fig 6: Maximum Stress location in the stiffened panel cutout

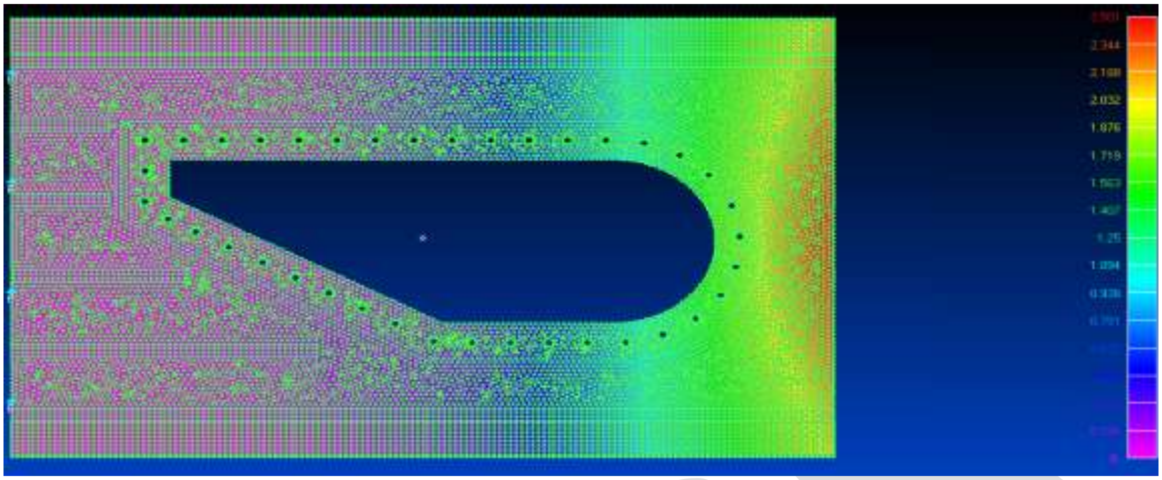

Fig 7 : Displacement contour of the stiffened panel with landing gear opening cutout

8. RESULTS AND DISCUSSIONS

The stress contour indicates a maximum stress of 42.99 N/mm2 at landing gear opening cutout of wing bottom skin as shown in the figure 6. The maximum stress value obtained is within the yield strength of the material. The point of maximum stress is the possible location of crack initiation in the structure due to fatigue loading.

9. CONCLUSIONS

- Stress analysis of the landing gear cutout of wing bottom skin is carried out and maximum tensile stress is found out.
- FEM approach is followed for the stress analysis of the landing gear cutout of wing bottom skin .A validation for FEM approach is carried out by considering a plate with a circular hole.
- Maximum tensile stress of 42.99N/mm^2 and maximum displacement of 2.5mm is observed in the landing gear cutout of wing bottom skin.
- The maximum tensile stress is acting near the rivet holes, the rivet holes are the stress raisers. A fatigue crack normally initiates from the location of maximum tensile stress in the structure, if these stresses are undetected then they may lead to a sudden catastrophic failure and result in loss of life.

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