Design and Finite Element Analysis of Wing Root Attachment for Two Seater Passenger Aircraft

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Abstract—Aircraft is a highly complex flying structure. Generally passenger aircraft undergoes nominal manoeuvring flights. During the flight, when the maximum lift is generated, wings of the aircraft will undergo stress at the location of the attachment brackets. The attachment is used to carry all type of wing load to this frame. So, the wing root attachments should be high strength enough to carry the load transferred from wing. In the present research work, an attempt has been made for designing the wing root attachment frame for two seated passenger aircraft using four stringers. First we need ensure the static load carrying capability of the wing root attachment bracket. Later, the wing root fittings were designed with different iterations by adding number of stringers with varied calculations. Finally fatigue analysis was conducted to find out the stress acting on the attachment with the life expectancy calculations. By adding the stringers, the fatigue/stress will be less for wing roots and the life expectancy of wing root attachment will also increase (more than 2 folds). The methodology of Finite Element Method (FEM) has been implemented and analyzed in the present work for stress and fatigue. An attempt has been made to estimate life expectancy of the wing root attachment under fatigue analysis. The design was carried out using Catia V5 tool. The analyzing part of this research work is done using the NASTRAN-PATRAN package and the results were reported.

Key words: Wing root attachment, FEM, wing load, Catia, Mse Nastran & Patran, Fatigue

I. INTRODUCTION

There are many aspects of design of aircraft structures are available from the literature. For modern commercial transport aircraft, the design must incorporate clear aerodynamics shapes for long range flight near or at supersonic speeds, and/or wings to open up like parachutes at very low speeds. The wings must serve as fuel tanks and engine support structures. All structures must withstand hail and lightning strikes, and must operate in, and be protected against corrosive environments indigenous to all climates [1]. The aircraft are the members that can transverse frames to enable it to be resist bending, compressive and vehicles which are able to fly by supported by the air. An aircraft counts the gravity force by using the static lift or by the dynamic lift of an airfoil.

Wings are airfoils that, when moved rapidly through the air, create lift. They are built in many shapes and sizes. Wing design can vary to provide certain desirable flight characteristics. Controlling of wing at various operating speeds, the amount of lift generated, balance, and stability will change as the shape of the wing is altered. Aircraft designers have designed several wing types that have different aerodynamic properties. These have different shapes and attached to the aircraft body at different angles at different points along the fuselage.

Based On wing Position [3]:

- Low wing - mounted on the lower fuselage.
- Mid wing - mounted approximately half way up the fuselage.
- High wing - mounted on the upper fuselage. When contrasted to the shoulder wing, applies to a wing projecting slightly above the top of the fuselage.

A bulk head is a structural member of an aircraft fuselage, of which a typical fuselage has a series from the nose to the empennage, typically perpendicular to the longitudinal axis of the aircraft. The primary purpose of bulkhead is to establish the shape of the fuselage and reduce the column length of stringers to prevent instability. Formers are typically attached to longerons, which support the skin of the aircraft with wing root attachment which has to be fork attachment with lugs. Lugs are mainly structural elements in aircraft structure that are widely used in connecting different components of the airframe. For ex. fuselage attachment, landing gear links etc.[3]

The catastrophic failure may occur to the lug attachment of the bracket in the aircraft[2]. Therefore, Finite Element Analysis of static and experimental data helps the designer to calculate the life of the aircraft structure from the catastrophic failure. So it is most important to establish the design criteria and then analysis various methods to ensure the damage tolerance of wing root attachment bracket.

II. DESIGN PARAMETERS

- The outer surface of the fuselage is decided by NMG (Numerical Master Geometry). [4] and number of passenger seats inside a system initialisation, performance studies, and aerodynamic studies.
- Thickness of the bulk head depends upon the load carrying capacity of the frame.
- Flange size is depends upon the attachment of the frame to the skin and stress is generated from the flange.
- The stiffness on the web depends on the bulking criteria on the bulkhead.
- Lug size is guided by the fork attachment of the wing fittings.

III. GEOMETRICAL CONFIGURATION

The wing root attachment and dimension of the frame is considered for the present study is as shown in the figure 1. It consists of bulkhead with the attachment of lugs which consists of holes which will be connected to spar.
IV. MATERIAL SPECIFICATION

The selection of aircraft materials depends on its cost and performance [5]. This includes initial material cost, manufacturing cost and maintenance cost. The key material properties are related to maintenance cost. The structural performances considered are:

- Density
- Stiffness
- Strength
- Durability
- Damage tolerance
- Corrosion

A combination of various materials like alloys can be used for wing root attachment. Commonly the alloy used is aluminium alloy Al 2024-T4 with the below mentioned properties.

1. Young's modulus, $E = 71000 \text{ N/mm}^2$
2. Density, $\rho = 2780 \text{ kg/mm}^3$
3. Poison's Ratio, $\mu = 0.33$
4. Yield Strength, $\sigma_y = 385 \text{ N/mm}^2$
5. Ultimate Strength, $\sigma_u = 485 \text{ N/mm}^2$

V. LOAD CALCULATION FOR WING ROOT ATTACHMENT BRACKET

- Aircraft Type: 2 seater Passenger aircraft
- Total weight of aircraft = 1633 N
- Load Factor considered in design = 4g condition
- Design Limit Load on the structure = 4 x 1633 = 6532 N
- Design Ultimate load = 6532 x 1.5 = 9798 N

VI. FINITE ELEMENT ANALYSIS

The finite element method is a numerical technique for solving engineering problems which is described by partial differential equations or can be formulated as functional minimization. A domain of interest is represented as an assembly of finite elements. This finite elements are determined in terms of nodal values of a physical problem is transformed into a discretized finite element problem with unknown nodal values. This is explained in figure 3.

A finite element model is the completely idealization of the entire model including the node location, the element, physical and material properties, loads and boundary conditions. The purpose of the finite element model is to make a model that behaves mathematically as being modelled and creates appropriate input files that can be solved. In finite elements libraries selected 4 node QUARDRILATERAL shell elements (QUARD4) and also for the stringers have considered 1D property of rod elements as mentioned in figure 4.

VII. FINITE ELEMENT MODEL OF THE WING ROOT ATTACHMENT BRACKET

FE model of the wing root attachment bracket is as shown in Figure 5. Meshing is carried out by using CQUARD shell elements through ISO mesh. Triangular
elements are used for the transition between the coarser to finer mesh.

Fig. 5: The 2D mesh Displayed in 3-D form to visualize the thickness of the member in the model.

VIII. THE LOADS AND BOUNDARY CONDITIONS OF THE WING ROOT ATTACHMENT BRACKET
The loads and boundary conditions along with the finite element model as shown in the figure 7.1. Since the bulkhead is attached to the fuselage, we need to arrest all degrees of freedom in the fixed end i.e. translational movements in x, y, z directions. The other end should not be arrested in any direction since its free end. When the lift weight is generated in the aircraft, half of the bulkhead has to be arrested in all degrees of freedom. And for the load which has to applied tensile and compressive load on the attachment joint of the bracket has to be considered as shown in the figure 6.

Fig. 6: Load and Boundary conditions applied to the wing root attachment bracket.

IX. THE FINITE ELEMENT ANALYSIS AND STRESS ANALYSIS IN WING ROOT ATTACHMENT BRACKET
The stress values at the lug hole and the displacement contours are shown in figures 9.1. The maximum principal stress of 134N/mm$^2$ is applied at the midpoint of the root section. Total of 4 iterations were considered for the analysis purpose. In the first iteration, no stringers were considered (included). In the subsequent iterations, stringers were considered (one added in each iterations). The stress values were calculated by adding stringers on horizontal and vertical to the bulkhead in the 4th iteration. Maximum and minimum principal stress has obtained from the analysis is used as the input for the fatigue calculations. Figures 7, 8 and 9 shows the FEM analysis of displacement contour, von mises stress and maximum principal stress value of wing root attachment.

Fig. 7: Displacement contour of wing root attachment bracket
Fig. 8: Von mises stress of wing root attachment bracket
Fig. 9: Maximum Principal stresses of wing root attachment bracket

X. RESULTS AND DISCUSSIONS
The stress contour indicates a Maximum principal stress of 134N/mm$^2$ at one of the rivet hole of the bracket for number of iterations done for reducing the stress. The maximum stress value obtained is within the yield strength of the material which is called as Reserve Factor(RF). The point of the maximum principal stress is the possible location with which the crack initiation in the structure due to fatigue loading. Fig. 10 shows, as the number of stringers increased (4), the maximum principal stress decreases which in turn increases the life expectancy of the wing root attachment.
XI. CONCLUSIONS

In the present research work, stress analysis of the wing root attachment bracket is carried out and maximum tensile stress is identified at one of the lug attachment holes. FEM approach is used for the stress analysis of the wing root attachment bracket. Validation is done for several iterations that are carried out to obtain below the yield strength of the material. A fatigue crack normally from the location of the maximum principal stress in the structure, further fatigue life estimation can be carried out to predict the life of the airframe component.

XII. REFERENCES


<table>
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<th>NO. OF ITERATIONS</th>
<th>MAXIMUM PRINCIPAL STRESS (N/MM$^2$)</th>
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<tr>
<td>1</td>
<td>626</td>
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<tr>
<td>2</td>
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Table 1: Convergence requirements

Fig. 10: Maximum Principal stress v/s No. of iterations