Wing Rib Stress Analysis of DLR-F6 aircraft

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Abstract: A wing rib plays a vital role on the geometry, shape and the construction of the aircraft wing structure. Wing ribs are in the form of aerofoils and impart required shape to the wing. Wing ribs are also used to reduce the length of the stringers, they are used to support the skin-stringer combination. This paper explores the complete stress analysis of wing rib of DLR-F6 aircraft subjected to different loads. There are two different methods used in the design and analysis of the wing rib used in the DLR-F6 aircraft. There are two different approaches used in the design of aircraft wing rib. They are shear resistant plate girder and incomplete diagonal tension field. The deformations and the stresses in the ribs due static loads are calculated using Ansys software. The von-misses failure stresses and the deformations are within the allowable limits and the design is found to be safe under static loads.

1. Introduction

The light weight structures are used in the aircraft construction. The thickness of the structural components is small and capable of resisting tensile and shears loads. Thin walled sections used in the aircraft structures are poor in compression compared to the shear. The buckling strength of the thin walled section can be improved by longitudinal stringers which resist the in-plane compressive loads and small transverse distributed loads the skin [1]. The wing structure consists of spars, ribs, stringers and the skin. The aircraft wing rib provides support to the skin structure and transfer the loads from the skin, stringers to the spars. Aluminium alloys are widely used to fabricate the aircraft wing ribs.

There are two different methods [3] used in the design and analysis of the wing rib used in the DLR-F6 aircraft. In the first method the wing rib is considered as a shear resistant plate girder that will not buckle or yield under the applied loads. In a shear resistant plate girder design the web stiffeners are removed from the structure and the rib is made with standard flanged lightening holes. The second method is the incomplete diagonal tension theory [5] in which the web carries the additional tensile load after it buckles. The aircraft structure of DLR-F6 is illustrated in the figure.

1.1 DLR-F6 Aircraft Geometry: The aircraft geometrical properties and load details are taken from DLR-F6 aircraft [1]. The body co-ordinate system is denoted by X, Y, Z axes on the aircraft. The wing with nacelle is represented by x and z translations of 13.661 in. and -1.335 in respectively with a dihedral of 4.787 degrees.
Figure 1. Layout of DLR-F6 aircraft

The nacelle is dispersed at a distance of 8.189 in. from the wing root and the wing semi span is 23.057 in. The wing is constructed from the number of by a number of airfoil sections placed at different stations along the wing span as shown in Figure (2). The geometry of the airfoil at each station is selected based on the aerodynamics and holds the shape of the wing.

Figure 2. Wing geometry of DLR-F6 aircraft

The properties of the wing geometry are

Wing reference area $S=90148 \text{ in.}^2$

The average chord length of the wing $= C_{av} = 97.746$ in.

The mean aerodynamic chord length $= C_{mac} = 111.18$ in.

2. Types of Ribs

- Form Ribs.
- Plate-type Ribs.
- Truss Ribs.
- Forged Ribs.
- Milled Ribs
Form-ribs are fabricated from the sheet metal and bent into its shape. This profile is placed on the skin, just like a stringer, but then in the other direction. Plate-type ribs are made from the sheet-metal and the rib has upturned edges and weight-saving holes. Truss ribs [6] consists of truss members joined together. The ribs may be light or heavy in design which makes them suitable for a wide range of loads. Closed-ribs are constructed from profiles and sheet metal and are suitable for closing off sections of the wing (e.g.: the fuel tank). Here too, particular care must be taken with the joints and this type of rib is also suitable for application in a variety of loading conditions.

Forged ribs profiles are fabricated by using heavy press. Heat treatment process is required to relieve the stresses developed in the rib [4]. Forged ribs are widely used near undercarriage where the applied loads are very high.

Milled ribs are machined from a solid plate using milling machining process. The strength of the rib is high compared to the form and truss ribs but it is heavy [7]. It can be manufactured to the close tolerances and with good the surface finish.

![Types of ribs](image)

**Figure 3.** Types of ribs

### 3. Construction of the wing rib

Wing rib is a lateral structural member of the wing structure. It provides required aerodynamic shape to the wing structure. Ribs are placed along the wing span and the rib spacing depends on the wing loading, number of wing fuel tanks and the lift distribution. The shape of the wing rib is similar to the airfoil and radial holes are made to reduce the weight of the wing structure. The wing skin-stringer panels and rib assembly is [9] different for different wing configurations. The ribs may be riveted to the skin or spot welded to the skin or glued to the skin and welded to the spars.

![Wing rib construction](image)

**Fig 4.** Wing rib construction

The Loads Acting on the Wing rib are as follows

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3
External aerodynamic loads
Inertial loads
Crushing loads
Bending loads
Compressive loads
Concentrated loads

4. Wing Rib model

A wing Rib said to be lightly loaded when it is subjected to the aerodynamic loads. When the rib is subjected to concentrated loads transferred to its structural from fuel tanks supporting points, control surfaces i.e flaps, ailerons…etc, armament supporting points…etc[6] is considered a moderately loaded rib. A heavily loaded rib is similar to the bulkhead and it carries concentrated forces from landing gears and power plant nacelles supporting points. The design procedure [8] of the wing rib depends mainly on its type of loading and operating conditions. The design methods used in the wing rib design are Shear Resistant Plate Girder, Incomplete Diagonal Tension beam.

The modeling of the wing rib is performed using CATIAV6.0. The figure5 depicts the CATIA model for the design and analysis of the rib. The wing rib models with the lightening holes are shown in the fig6.

![Figure 5 Wing rib model](image-url)
Material Properties:
Material: Aluminium-alloy ALCAD-2045-T36.

Chemical Composition:
- Copper: 0.1%
- Manganese: 0.05%
- Zinc: 0.1%
- Aluminium: 99.75%

Mechanical properties:
- Young’s modulus: 0.75*10^5 N/mm^2.
- Density: 2770 kg m^3
- Poisson’s ratio: 0.33.
- Yield strength: 160 N/mm^2.
- Ultimate strength: 260 N/mm^2.

5. Static Analysis of the Wing Rib

The static analysis of wing rib is performed using ANSYS software. In the static analysis of the rib, the leading and trailing edges of the rib are fixed and the concentrated loads are applied. The deformation due to the applied loads is high at the leading edge and the deformation is less at the trailing edges. The deformation at the trailing edge is almost zero and can be neglected. The maximum deformation occurs near the radiating holes due to the stress concentration. The maximum deformation due to the applied load is 0.83744mm. The von-Mises stress for the rib under the given loading conditions is 25.69Mpa. The values von-Mises stresses and strains are under the limits theories of failures.
6. Conclusion

The wing rib stress analysis of DLR-F6 aircraft subjected to different loads has been performed using ansys. The material selected for the analysis is Aluminium-alloy ALCAD-2045-T36. The stresses obtained from the analysis are compared with the analytical values. There is a good agreement between the theoretical. The rib is analyzed for the maximum load conditions. The stresses obtained from the analysis are within the safe limits. This work can be extended to the ribs with different materials and different working conditions.

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