FINITE ELEMENT ANALYSIS OF RIBS AND WING STRUCTURE OF BEECH AIRCRAFT

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Abstract: The objective of this paper is to perform the finite element analysis for wing structures of beech aircraft which is subjected to aerodynamic pressure loads. The requirements of the aircraft wings are High stiffness, High strength, High toughness and low weight. In this paper detailed design of aircraft wing structure with ribs placement is done and then stresses are estimated by using finite element methods with the help of PATRAN. Stress analysis of the whole wing section and root rib is carried out to compute the stresses at the wing and ribs due to applied pressure loads. It is shown that the designed wing could be used for high aerodynamic loads due to high stiffness of the wing.

IndexTerms - finite element analysis, aircraft structures, wing design, loads.

1. INTRODUCTION

For aerodynamic reasons the wing contour in the chord direction must be maintained without appreciable distortion. Unless the wing skin is quite thick, spar wise stringers must be attached to the skin in order to increase the bending efficiency of the wing. Therefore to hold the stringer and wing surface to contour shape and also to limit the length of stringers to an efficient column compressive strength, internal support or brace units are referred to as wing ribs. The ribs also have another major purpose, namely, to act as a transfer or distribution unit. All the loads applied to the wing are reacted at the wing supporting points, thus these applied loads must be transferred into the wing cellular structure composed of skin, stringers, spars, etc., and then reacted at the wing support points. The applied loads may be only the distributed surface air loads which require relatively light internal ribs to provide this carry through or transfer requirement, to rather rugged or heavy ribs which must absorb and transmit large concentrated applied loads such as those from landing gear reactions, power plant reactions and fuselage reactions. In between these two extremes of applied load magnitudes are such loads as reactions at supporting points for ailerons, flaps, and leading edge high lift units and the main landing gear. All these loads must be transferred into the wing structure composed of skin, stringers, spars, etc., and then reacted at the wing support points. The skin construction which forms the shell of the fuselage likewise needs internal forming units to hold the fuselage cross-section to contour shape, to limit the column length of the stringers and to act as transfer agents of internal and externally applied loads. Since a fuselage must usually have clear internal space to house the payload such as passengers in a commercial transport, these internal fuselage units which are usually referred to as frames are of the open or ring type. Fuselage frames vary in size and strength from very light former type to rugged heavy types which must transfer large concentrated loads into the fuselage shell such as those from landing gear reactions, power plant reactions, fuselage reactions, etc., the dead weight of all the payload and fixed equipment inside the fuselage must be carried to frames by other structure such as the fuselage floor structure and then transmitted to the fuselage shell structure. Since the dead weight must be multiplied by the design acceleration factors, these internal loads become quite large in magnitude.

Another important purpose or action of ribs and frames is to redistribute the shear at discontinuities and practical wings and fuselages contain many cut-outs and openings and thus discontinuities in the basic structural layout.

2. Modelling of wing and rib

The Beech craft Star ship is a twin-turboprop six- to eight-passenger pressurized business aircraft produced by Beech Aircraft Corporation. The Star ship is noteworthy for its carbon fibre composite airframe, canard design, lack of centrally located vertical tail, and pusher engine/propeller configuration. Carbon fibre composite was used to varying degrees on military aircraft, but at the time the Star ship was certified, no civilian aircraft certified by the US Federal Aviation Administration had ever used it so extensively. Beech chose carbon fibre composite for its durability and high strength-to-weight ratio. According to Beech, the Star ship weighs less than it would have if it were built from aluminium. Nonetheless, the empty weight of production aircraft exceeded the target by several thousand pounds.

Beech studied several configurations before settling on a canard configuration in early 1980. As configured, the Star ship is difficult to stall—the forward surface stalls before the main lifting surface, which allows the nose to drop and more-normal flight to resume.

A traditionally located vertical tail would have transmitted propeller noise into the airframe. In its place, directional stability and control is provided by rudders mounted in the winglets (Beech craft called them tip sails at the tips of the wings).
Mounting the engines so that the propellers are facing rearward, pushing rather than pulling the aircraft, has the potential of a quieter ride since the propellers are further from the passengers and because vortices from the propeller tips do not strike the fuselage sides. However, the propellers are operating in a turbulent airflow in the pusher configuration (due to airflow past the wings moving aft in vortex sheets) and high-velocity exhaust gasses are discharged directly into the props, thus the resulting external propeller noise is more choppy and raucous than otherwise.

2.1 WING SPECIFICATIONS:

2.1.1 Wing Area and Loadings:
Wing Area : 280.88 sq. ft.
Wing Loading : 53.0 lbs./sq. ft.

2.1.2 Aerofoil Used:

The chord length of the ribs from root,
Rib 1 chord length = 516mm.
Rib 2 chord length = 423mm.
Rib 3 chord length = 340mm.
Rib 4 chord length = 256mm.
Rib 5 chord length = 173mm.
Rib 6 chord length = 162mm.
Rib 7 chord length = 150mm.
Rib 8 chord length = 137mm.
Rib 9 chord length = 125mm.
Rib 10 chord length = 114mm.
2.1.3 2D Profile of the Wing:

![Fig 3: 2D-Sketch](image1)

![Fig 2: 2D-Profile](image2)

2.1.4 Wing Component Details:

- Number of Spars = 2
- Number of Ribs = 1
- Number of Stringer = 14
- Top Stringers - Z Section
- Bottom Stringers - L Section.

2.2 DIMENSIONS OF WING COMPONENTS:

2.2.1 Spar Flange:

![Fig 5: Cross Section of Spar Flange](image3)
2.2.2 Top Stringers:

In aerospace industries Z section are commonly used because of its very good rigidity and in top of the wing needs more bending resisting, because of pressure in the bottom of the wing.

![Cross Section of Top Stringers](image)

Width (W) = 15mm.
Height (H) = 3mm.

2.2.3 Bottom Stringers:

![Cross Section of Bottom Stringers](image)

Width (W) = 3mm. Height 1 (H1) = 2mm. Height 2 (H2) = 4mm. Thickness (t) = 1mm.

2.3 3D MODEL OF THE WING:

![3D Model of Wing](image)

2.4 3-D MODEL OF RIB:

![3D Model of Rib](image)
.4.1 DIMENSIONS OF RIB:

Fig 10: Cross Section of Rib Flange

Width (W) = 15mm. Height (H) = 2mm.

3.1 ANALYSIS DESCRIPTION AND ASSUMPTIONS

The FE model of wing box is made up of 1D and 2D mesh. Root rib meshed in wing box and also detailed as an individual component. Sub modelling approach has been used for analysing.

Wing and root rib has been modelled using the combination of CBAR, CBEAM, CQUAD and CTRIA elements. The CTRIA elements are used to represent the stiffness of the joint and the CQUAD elements are used to represent the surface and the CBAR, CBEAM are used to represent the stringers and rib flange.

The wing box FEM has 9216 DOF (degrees of freedom) and comprises the finite elements shown in the table below.

Number of Grids – 1536

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Numbers</th>
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<tr>
<td>CBAR</td>
<td>752</td>
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<tr>
<td>CBEAM</td>
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<tr>
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<td>1729</td>
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<tr>
<td>CTRIA3</td>
<td>33</td>
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</tbody>
</table>

3.1.1 RIBS:

Rib webs has been modelled using quad and tria elements and rib flanges has been meshed using bar elements. Rib webs has been represented with either one or two quad elements across its depth and bar elements has been used at top and bottom of the quad elements.

3.1.2 SPAR:

Like ribs spar webs has been represented using quad elements and flange has been represented using bar elements. In front spar two quad elements has been used to represent the web and one quad element has been used to represent the web.
3.2 MATERIALS:
Beech craft aircraft wing is made up of aluminum alloy. The properties aluminum alloy AL2024 T3411 has been considered. Since the alloy has good strength and good fatigue characteristics. The following are the properties of the aluminum alloy.

Table 2: Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Young’s Modulus</td>
<td>70000 MPa</td>
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<tr>
<td>Poisson’s Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Density</td>
<td>2.89E-9 Kg/mm³</td>
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3.3 LOADS AND BOUNDARY CONDITIONS:
Entire root rib outer nodes have been arrested in all 3 translations as the beech craft wing is attached to fuselage through the box structure. 3 degrees of freedom in rotation has not been arrested since the rotations will be restricted by differential translations.

3.4 Loading:
Cruising condition was assumed for analysis and no fuel pressure is used. Hence only pressure loads has been applied for analysis. Positive pressure value of 1 N/mm² was applied at bottom surface and negative pressure of 0.5N/mm² was applied on top skin.
1. RESULTS OF WING ANALYSIS:

Fig 17: Displacement in the Wing.

Fig 18: Stress in the Wing.

Maximum displacement = 8.65mm

Maximum Stress = 3.96 x 10^2 N/mm^2

Minimum Stress = 9.41 x 10^-1 N/mm^2
4.1 DETAILED ANALYSIS OF ROOT RIB:

Root rib has been analyzed using sub modeling approach. CQUAD4 elements are used to mesh the surfaces. The load values have been taken from wing model and applied in root rib. The root rib FEM has 8406 DOF (degrees of freedom) and comprises the finite elements shown in the table below.

Number of Grids – 1401

<table>
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<tr>
<td>CBEAM</td>
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<tr>
<td>CQUAD4</td>
<td>1288</td>
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<tr>
<td>CTRIA3</td>
<td>0</td>
</tr>
</tbody>
</table>
The leading edge and the trailing edge of the rib were arrested in 6 degrees of freedom which means both the sides are fixed.

4.2 Pressure Loading:

Cruising condition was assumed for analysis and no fuel pressure is used. Hence only pressure loads has been applied for analysis. Positive pressure value of 1.5 N/mm² was applied at bottom surface and negative pressure of 1.5 N/mm² was applied on top surface.

4.3 Results of Rib Analysis:

Displacement in the rib = 4.23 x 10⁻³ mm.

Maximum Stress = 2.27 x 10² N/mm².

Minimum Stress = 1.43 x 10⁻¹ N/mm².
2. Conclusions

In this paper, the new design of wing section with ribs is modelled and analysis is carried out to compute stresses using PATRAN. From the above results we can conclude that at the above assumed loading conditions and constraints aircraft wing structure will not fail due to the aerodynamic pressure loads. The results obtained are optimum. The result has shown that the new designs can withstand high aerodynamic loads. The effect of other aeroelastic loads acting on the wing can substantially change the results, so the current project can be extended by applying different boundary conditions in the future.

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REFERENCES


