Journal of Mines, Metals and Fuels, 71(1): 19-23; 2023. DOI: 10.18311/jmmf/2023/33350

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

NACA Wing RIB Design and Optimization

Vasanth G*, Sunil Sunagad, Darshan S Mekali, Siddlingesh A U and Veeranna B Nasi

*M. S. Ramaiah Institute of Technology Bengaluru 560054, Affiliated to Visvesvaraya Technological University, Belgaum: MSRIT hostels (engg) Mathikere Bengaluru 560054. *E-mail: vasanthg0607@gmail.com, sunilsunagad2018@gmail.com, darshanmekali16@gmail.com, siddu.au12@gmail.com, vbnasi1964@gmail.com*

Abstract

Design of wings and wing ribs are of paramount importance in the field of aircraft manufacturing. The wing ribs need to have high strength and needs to be as light weight as possible. To achieve this a compromise needs to be made on the strength of the wing rib. As cut-outs are made in wing ribs the weight is reduced, but the strength also decreases along with that. This paper will deal with the above-mentioned problem and try to reach an optimal ground of design to make cut-outs through which strength remains almost the same as the wing rib without cut-out but the overall weight is reduced. Optimization of the wing rib designs will be reached by using different materials and different cut-out configurations. The wing rib with the best overall features such as weight, strength and price from the combination of different materials and cut-outs will be found.

Keywords: *Design and optimization, different cut-out configurations, Experimentation cost, Changing dimensions, Wing Rib.*

1.0 Introduction

Wing ribs are the structural component which provide the framework for the entire wing by combining spars and stringers. Wing ribs are plate like structures which provide the shape of the wing and they provide the strength to the wing.

Hence wing ribs need to have high strength. Since these are the building blocks for the wings and the provide the strength, the number of wing ribs used for each wing is at least 10. These wing ribs can weigh a lot and to reduce this weight, we make cut-outs. Along with reduction of weight, the strength must also be retained. With cut-outs it also provides space inside the wing for storage purpose (fuel storage). (Bairavi and Balaji, 2016) title "Design and Stress Analysis of Aircraft Wing Rib with various cut outs" they used CATIA v5 to design their wing ribs and analysed those designed through ANSYS. They designed wing ribs with elliptical, circular and rectangular cut- out and found the stress concentration of the wing ribs at the cut-outs, they also find the stress induced in the wing ribs. (Bindu and Ali, 2013) titled "Design and analysis of a typical wing rib for passenger aircraft". They used a single big cut-out in the wing rib design (designed through CATIA v5) and analysed through ANSYS and found the stress induced in the wing ribs (Kavya and Reddy, 2017) titled "Design and Finite Element Analysis of Aircraft Wing using Ribs and Spars". They analyse new materials for the wing such as S-glass, kevlar and boron fiber. They found that these materials can be used to make wing. They also suggested materials such as E-glass and carbon epoxy for future scope (Sharma and Garg, 2014) titled "Design and Analysis of Wing Rib of Aircraft Review". They design wing ribs with and without cut-out. They analyse these designs to find the stress and deformation due to air pressure.

The goal of this paper is to find the optimal ground in between making cut-outs reducing mass and retaining the strength. Find the optimal design configuration of the cut-outs and the best material which can be used for the wing rib out of all the materials selected for this paper.

Author for correspondence

2.0 Methodology

- Making assumptions.
- Load calculation.
- Design of wing Rib.
- Analysis of the final design.
- Listing the result and comparison between different cut-outs and different materials.

3.0 Assumption

This paper will be dealing with:
- NACA 2412, 0015 air foils.
- Chord length 1 meter.
- Rectangular type of wing, with wing span of 10 meters.
- Wing area 10 sq. meters.
- Plate type wing rib.
- Single sparred wing.
- Flight altitude 2000 meters.
- Cruising state of flight.
- Only aerodynamic loads, since most of the other loads are negligible under cruising condition relative to the aerodynamic load.
- Velocity of air 15 m/s.
- Number of wing ribs is 5. Assumptions used in FEA,
- Material properties are isotropic and homogenous.
- Analysis of wing ribs under linear static.
- Steady state analysis.

The materials used are shown in Table 1.

4.0 Load Calculation

- Using U.S. Standard Atmospheric Properties 1976 at 2000 meters altitude, the density of air is 1.00649 kg/m^3 and viscosity of air is 1.74645 × E-05 Ns/sq. m.
- Reynolds number is given by,
- $\mathrm{Re} = \dfrac{\text{density} \times \text{length} \times \text{velocity}}{\text{viscosity}}$
- Re = 1.00649 × 1 × 151.74645 × E-05
- Re = 864459.3318 (Turbulent flow)

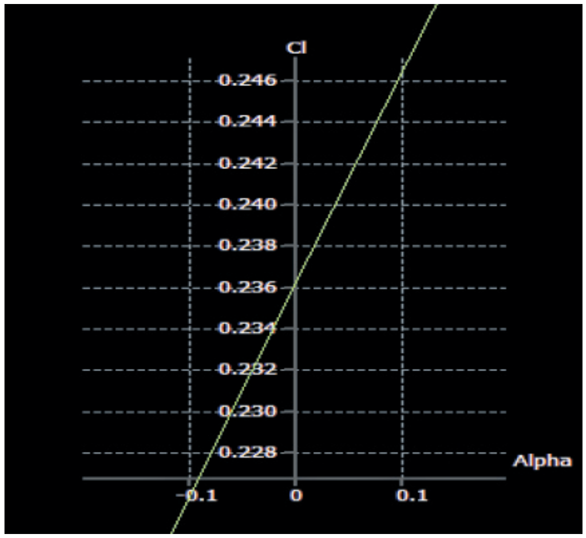

Figure 1: Coefficient of lift (Cl)

- Using XFLR5 software for 2412 air foil and for the above Reynolds number, running an analysis to find the coefficient of lift from 12.5 to 12.5 degree of attack angle we get a coefficient of lift of 0.236 as seen from the Fig.1.
- For comparison's sake we'll be using the same coefficient of lift to the NACA 0015 too.
- Now to find out the lift force,
- F = 1 × density × sq.(velocity) × Cl × A2
- F = 0.5 × 1.00649 × sq. (15) × 0.236 × 10
- F = 267.223 N
- This lift force is what generated from the wing skin transmitted to the wing ribs and then to the wing spars which support the whole aircraft.
- Since we have considered 6 wing ribs, Load on each wing rib will be F/6, which is 44.5371 N
- FOS selection needs to be >7, since failure of this component may lead to death.
- FOS selected is 8
- Maximum force on the wing rib now is, Fmax = 44.5371 × 8 = 356.29 N = 350 N.
- The maximum force calculated here will be used for both 0015 and 2412 wing ribs for comparison's sake.

Table 1: Material table used

	Material	Elastic modulus (GPa)	Yield strength (MPa)	Poisons ratio	Density (kg/m^3)
1	Balsa Wood	3.4	21.6	0.23	160
2	Carbon Epoxy	70	520	0.30	1600
3	Al 7075- T6	71.7	503	0.33	2804
4	Ti-Al6-V4	96	930	0.36	4620

5.0 Design of The Wing RIB

Design software used is Fusion360.

- The NACA air foil coordinates are imported.
- The air foil shape is extruded to get a 5mm thick plate of the same shape.
- The plate is split into 2 plates each of 2.5 mm thick.
- The left surface of the left plate and right surface of right plate is shelled by 1mm.
- This leads to a design of 2mm thick plate with 5mm extension at the edge of the entire air foil shape as shown in Figure 2.
- A hole of diameter 50mm is made at a distance of 100mm from the leading edge on the mean chord line.
- Following this, cut-outs are made in the wing ribs of appropriate dimensions as shown in Figure 2.

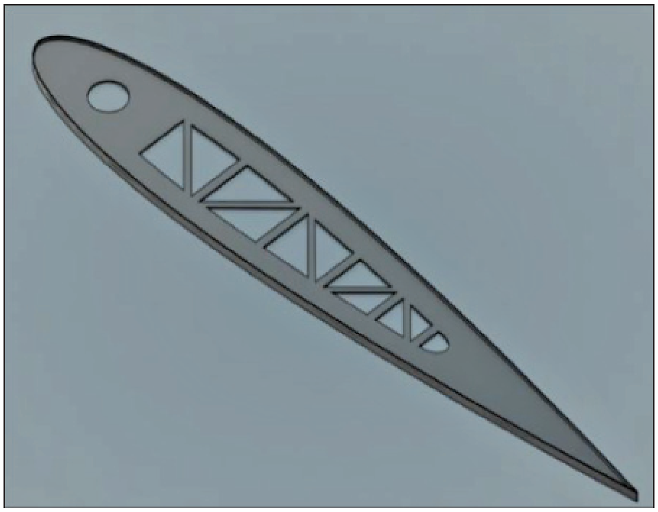

Figure 2: Wing rib of triangular cut-out

Each cut-out was made with 3 different cut-out dimensions and the best set of dimensions were chosen. For example, circular cut-out, 3 wing ribs made with circular cut-out of diameter 50mm, 60mm and 70mm were made and analysed. Based on the criteria of reduction in mass and reduction in stress, 60mm cut-out was chosen.

6.0 Analysis of the Design

Analysis is accomplished through ANSYS. ANSYS Workbench 2021 was used in static structural type. The design made in Fusion 360 is imported through .iges format.

Once these steps are done, the model is meshed with appropriate size and shape. The shape chosen is Quadratic CST element with element size restricted to 0.1m. Since further reduction in the size results in very small order of increase in stress.

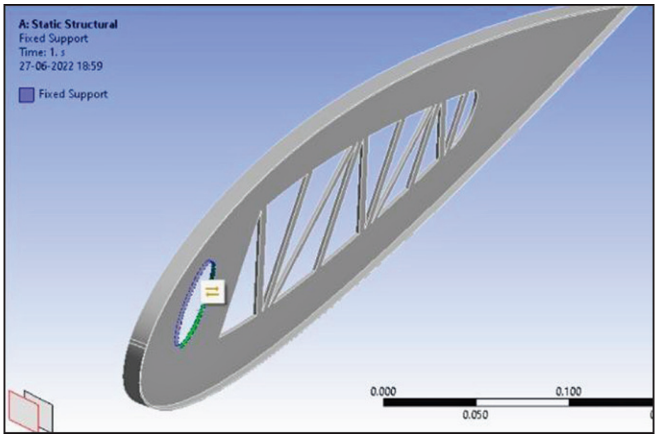

Figure 3: Wing spar hole is fixed

Defeature size is chosen to be 1.5 micrometre. Resulting in number of nodes being approximately 5000 and number of elements being approximately 4000.

The wing rib is fixed at the spar hole as shown in the Figure 3, the spar goes through this hole. Since spar supports the entire wing, it is rigid and hence provides a fixed support to the wing rib.

The region around the spar hole is also the region where maximum stress is induced.

The lift force acts on the bottom surface of the wing rib. The load is applied here in upward direction as shown in Figure 4, since lift force acts in upward direction.

Once the load is applied, it is time to ascertain the result required through this analysis. The goal is to find the best type of cut-out and material configuration based on strength, deformation and mass. Finding strength of a wing rib is possible experimentally or it can be done through awfully long numeric analysis due to the complicated shape and ever changing dimensions at each point. Experimentation cost is high and analysis for strength consumes a lot of time. Instead in this paper the strength is estimated based on the stress. If induced stress of a design is lesser in comparison with former, then the later design is said to have higher strength. So, the

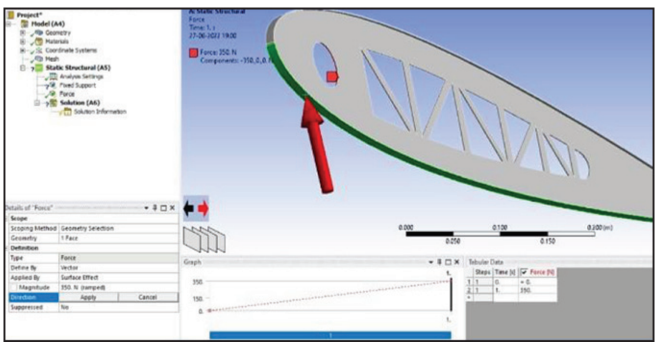

Figure 4: Load applied on the wing rib

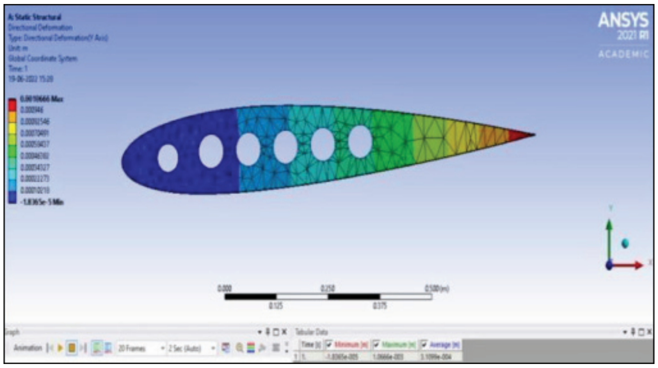

Figure 5: directional deformation in Y direction

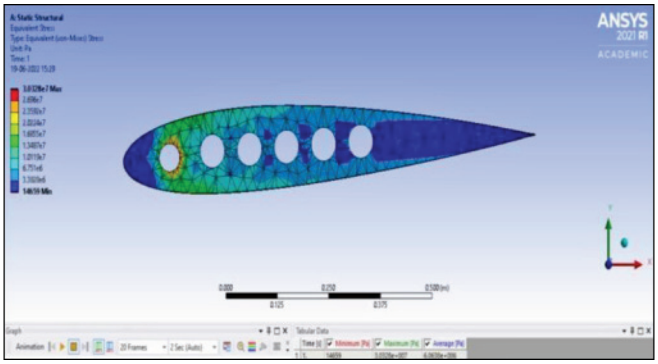

Figure 6: von-Mises (Equivalent) stress

relative strength of each of the wing rib can be found by using this method. Mass is found using ANSYS.

To find this we will be finding the equivalent stress (von-mises) induced in the design due to the load.

To find the deformation, we will use directional deformation in Y direction.

For wing rib with circular cut-out made of carbon epoxy the result will look like as shown in the Figures 5 and 6.

7.0 Listing the Result

The Table 2, lists the result for NACA 2412 wing rib. The abbreviations are used in the Table 2.

M-Material

A-Aluminium alloy

B- Balsa wood

C-Carbon epoxy T-Titanium alloy

The comparison graph for NACA 2412 wing rib with different cut-out made up of different material From Table 2 can be seen in the Figure 7.

Note: Wing ribs made up of Balsa wood is eliminated from the graph since it has already exceeded its elastic limit in terms of stress and its deformation is very high. Balsa wood is not suitable for a material saving design. And since its mass is very low it can be used in a dense design like making a wing completely out of Balsa wood instead of making wing ribs.

Similar result can be seen in Wing Ribs of NACA0015 Wing rib.

Table 2: NACA 2412 result

M	Cut-out	Def (mm)	Stress (MPa)	Mass (kg)
A	W/t out	1.5	28.7	0.60784
	Circular	1.29	30.2	0.5285
	Diagonal	1.14	40.2	0.48072
	Triangular	1.35	29.6	0.47809
	Rectangular	0.981	40	0.47874
B	W/t out	20.3	29.2	0.034684
	Circular	21.7	30.6	0.030161
	Diagonal	26.8	39.8	0.02743
	Triangular	23.6	30.3	0.027281
	Rectangular	28	39.9	0.027318
C	W/t out	0.999	28.9	0.34684
	Circular	1.07	30.3	0.30161
	Diagonal	2.68	40.1	0.2743
	Triangular	2.36	29.8	0.27281
	Rectangular	2.8	39.8	0.27318
T	W/t out	0.737	28.6	1.0015
	Circular	0.786	30.1	0.87091
	Diagonal	0.969	40.4	0.79205
	Triangular	0.854	29.4	0.78273
	Rectangular	1.01	40.2	0.7888

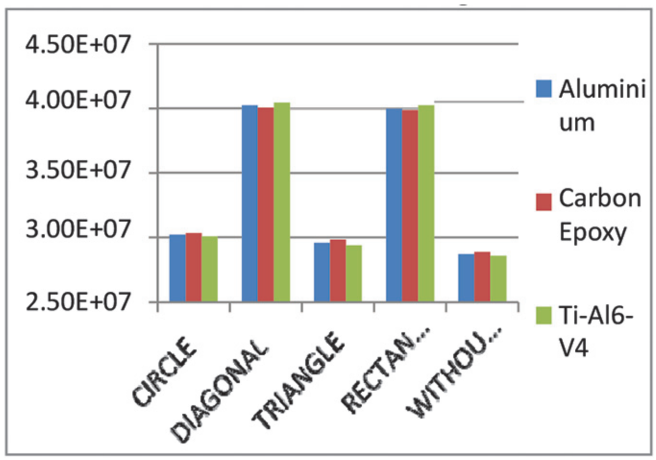

Figure 7: NACA2412 wing rib stress induced

8.0 Conclusions

The goal was to pick an optimal cut-out configuration and material best suited for the wing rib through analysis since both cannot be achieved simultaneously i.e., reduce. mass through cut-outs and maintain same strength. Wing ribs with triangular cut-out reduce mass by almost 21% in each case, and has induced stress just a little higher than the induced stress of wing rib without cut-out in each case. This suggests that the strength of the wing rib with triangular cut-out is on par or almost equal to the wing rib without cut-out which can be seen in Figure 8. And this is achieved together with reduced mass by almost 21%. Figure 8 is a graph plotted between the relative strength (Based on stress i.e., the inverse of the induced stress) and the sections.

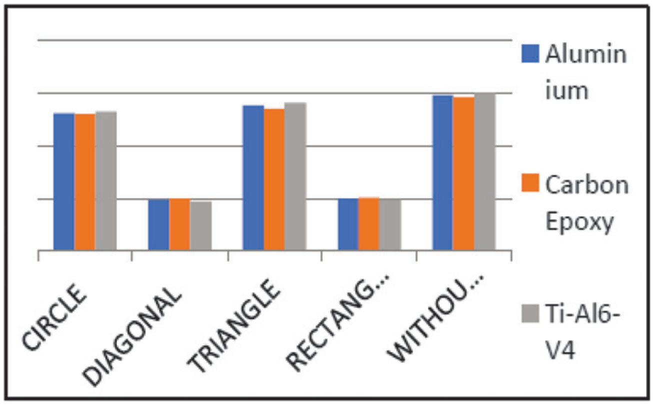

Figure 8: NACA2412 wing rib relative strength

Various aluminium alloy varieties of 7 series are currently used in manufacturing the wings of the aircrafts. Balsa wood was used in earlier days, although it is still used in some small-scale aircrafts it has been completely replaced by metals and composite materials. Wing ribs made of carbon epoxy is the next best material, its strength is almost equal to wing ribs made of aluminium added with lesser weight than aluminium alloys. It can be used as a replacement for the current aluminium alloys. Although it comes with a downside, it is not isotropic and homogenous. But with excellent manufacturing standards quality of the composite can be improved significantly to overcome this. Titanium is the best out of all the materials chosen in terms of strength, but mass of these wing ribs is comparatively higher than all of the other materials. Along with that the major challenge in using this material is its high cost. Hence it is scarcely used in specific applications which require high strength.

9.0 Future Scope

- In an ever-growing world the number of composite materials increase every day, new materials can be tested.
- More accurate result can be obtained if other loads like crushing, compression and inertial loads are considered.
- New cut-out configurations can be used

10.0 References

1. Bairavi and Balaji, (2016): "Design and Stress Analysis of Aircraft Wing Rib with various cut outs" https://www.worldwidejournals.com/indian-journal-of-applied-research (IJAR)/fileview/April_2016_1459503605
2. Bindu and Ali, (2013): "Design and Analysis of a Typical Wing Rib for passenger Aircraft". https://1library.net/document/zgxn5r2q-design-analysis-typical-wing-rib-passenger- aircraft.html
3. Kavya and Reddy, (2017): "Design and Finite Element Analysis of Aircraft Wing Using Ribs and Spars https://1library.net/document/zlnwv7lq- design-finite-element-analysis-aircraft-using- guguloth-raghukumar.html
4. Sharma and Garg, (2014): "Design and Analysis of Wing Rib of Aircraft Review" https://1library.net/document/z3n3lj9q-design-analysis-wing-rib-aircraft- review.html.
5. Bannaceur, Xu and Layachi, (2017): Wing Rib Stress Analysis and Design Optimization Using Constrained Natural Element.https://iopscience.iop.org/article/10.1088/1757-899X/234/1/012018/pdf.
6. Dharmendra,Chaitanya K J, Ayesha Sameera, Khyati Kavathiya, Monika K M "Design and Analysis of an Aircraft Wing Rib for Different Configurations", *International Journal of innovative Research in Science and Engineering*, Vol. https://www.irjet.net/archives/V7/i6/IRJE T-V7I635.pdf.
7. Ramin Sedaghati, Mostafa S.A. Elsayed, (2006): "Wing Rib Stress Analysis and Design Optimization. MOSAIC Project, CRIAQ 4.1-TASK 6.