DESIGN AND ANALYSIS OF AN AIRCRAFT WING RIB FOR DIFFERENT CONFIGURATIONS

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Abstract – *Aircraft wing is that complicated structure found over the aircraft due to its complicated behavior towards the various loads and maneuvering. Stress concentration in an elastic body may be caused mainly by two mechanisms i.e. concentrated loads or forces acting on a body and geometrical discontinuities of a body such as holes or abrupt change of its surface geometry. In this project wing rib without cutout and wing rib with different cutouts are taken into consideration. In this project equivalent stresses and deformation for various cutouts such as circular, elliptical, triangular, and rectangular and without cut section are estimated using CATIA as designing software and ANSYS for analysis. The materials used for the project are aluminium 7075 and carbon epoxy. Therefore after the comparison of stress and deformation in various configurations, the best suitable configuration with the best material among above two mentioned is selected.*

***Key Words*: Aircraft Wing rib, cut-outs, stress, deformation, ANSYS**

1. INTRODUCTION

1.1 Wing rib

An aircraft must lift the weight of the aircraft, the fuel, the cargo and the passengers by itself in-order to fly. Most of the lift is generated by the wing to hold the plane in air. Structural parts of a wing are skin, ribs, stringers and spars. Among them wing rib is a very predominant part. For aerodynamic reasons the wing contours within the chord wise direction must be maintained without appreciable distortion. Internal structural support units are present in-order to hold the skin-stringer wing surface to contour shape, referred as "wing ribs". Wing rib plays an important by providing aerodynamic shape for the wing, load transfer and distribution and shear forces redistribution and it also limits the length of the stringers. The ribs are cut to allow fuel or equipment to pass through it. Wing rib with cutouts reduces the weight and it can withstand more load.

Wing ribs are the structural components which provide framework for wing by combining spar and stringers. They cover the area between the leading edge to the trailing edge of the wing. Wing ribs are an important part of wing as well as it can be used in elevators, rudders, ailerons and stabilizers.

Mostly wing ribs are made of wood or metals. Earlier aircrafts which were made of wood usually used wooden wing ribs. Spruce was used to manufacture wood ribs. There are three types of wood ribs, which are plywood web, lightened plywood web and truss type. The truss type wood rib is most applicable because of its light weight and high strength.

Also, aircraft with metal spar have metal ribs. Wood is no longer used in modern aircraft because of the availability of metallic and non-metallic materials which have high strength, light weight and corrosion resistance properties. Materials used in aircraft structure are aluminium, steel, titanium and their alloys. Aluminium alloys have low density values than steel alloys with great corrosion resistance properties. However steel alloys have higher elastic modulus and also high tensile stress. Titanium is strong, high corrosion resistive and light weight metal, modern aircraft parts are manufactured using titanium alloys. However due its high expense it is not appreciable to be used. Materials used in wing ribs are aluminium and steel alloys.

Wing ribs are given names according to their specialized location and functions which reflect their uniqueness. For example, nose rib or false rib are used to shape and strengthen leading edge and are located at forward of front spar. Nose ribs do not cover entire distance between leading edge to trailing edge of wing. Butt ribs are fixed at edges of wing which are attached to fuselage. Butt ribs also known as bulkhead rib or compression rib when it receives compression load to force the wing spar together.

1.2 Scope of the work and its importance

An attempt is made to design wing rib without and with cut-outs using different configuration to determine maximum stress and deformation it can withstand. The design of a replacement wing rib requires stress analysis. In engineering, stress analysis is a tool rather than a goal; the aim is to determine the stress and to predict the failure in materials subjected to forces or to increase the strength of the wing rib without increasing the weight. Stress analysis can be performed using conventional and analytical mathematical techniques, an experimental testing or computational simulation. Aluminium alloy, Aluminium

7075 T6 and Carbon Epoxy are considered as materials to do static structural analysis on wing rib without and with cut-out with different shape such as circular, elliptical and triangular, rectangular(with fillet).

2. LITERATURE SURVEY

Rahul Sharma and Garima Garg, [1] have investigated stress and displacement of wing rib with and without cut-outs of 1mm thickness within the application of 0.01Mpa air pressure. CATIA V5 and MSC NASTRAN-PATRAN are the tools utilized in this design and analysis. The work was focused on stress analysis and displacement of both the categories of wing ribs (with and without cut-outs). It had been found that the maximum deformation for wing rib without cut-out was less than the maximum deformation for wing rib with cut-outs. The advantage of wing rib with cut-out is that it is cheaper and lighter in weight than wing rib without cut-outs.

S Bairavi, Mr. Suresh Balaji, [2] in their paper they have come to the conclusion that when cut outs are present in aircraft wing ribs it creates stress concentration which eventually reduces the mechanical strength of the structure and in extreme cases may cause failure. In this paper the induced stress for ribs with circular, elliptical and rectangular cut outs have been found with the help of finite element software package ANSYS 14.

Mohamed Amine Bennaceur, Yuan-ming Xu and Hemza Layachi, [3] in their paper they have used the constrained natural element method to optimize the cutout in the wing ribs of a light aircraft by adopting three different configurations and showed that changing the configuration of cut out will increase the strength of wing rib. In the configuration with trapezoid holes, it leads to optimal stability performance to sustain shear load additionally.

Bindu H C, Muhammad Muhsin Ali H, [4] in their paper they have demonstrated to increase the critical buckling strength and reduced the weight of rib. Buckling analysis and linear static are performed on the idealized configuration using FEM packages. It was found that introducing circular holes in the wing rib enhances the buckling strength of it. As the number of holes increases the buckling strength of the wing rib also increases. Insertion of holes in the rib was found to be effective with the weight reduction compared to initial geometry. The maximum stress occurs around the holes and this factor must be considered.

Kannan. T, Mr. Veeranjaneyulu, [5] this research paper includes design and analysis of aircraft wing rib using different composite materials. Based on the classical approach, the optimum design parameters for an aircraft's wing rib have been suitably selected. Here they have used CAD software to design the three-dimensional aircraft wing rib. Analysis is done for structural wing rib for different loads and fibre orientation. Stress tensor and critical displacement were calculated from finite element tool. They have compared the results for different fibre orientation.

J.A. Newlin and Geo.W.Trayer, [6] they have conducted tests for many designs of wing ribs and these are compared with different types of sizes. Ribs of any size or proportion was discovered, once they were designed to induce a well-balanced construction and that they were manufactured carefully. They observed that reduction in weight of aircraft wing ribs is even more in efficient designs by greater proportional reduction in strength.

Guguloth Kavya, B C Raghukumar Reddy, [7] have demonstrated aircraft wing design in 3D modelling software and it is modified by adding ribs and spars. By applying three materials such as S Glass, Kevlar 49 and Boron Fiber, static structural analysis is done. Buckling analysis, modal analysis and FEM analysis are done on aircraft wing and aircraft wing with ribs and spars. They describe, that addition of wing ribs and spars increases the strength of wing and material S Glass gives better results.

3. OBJECTIVES

The main objective of this present work is to consider the different criteria of wing rib in order to find out which criterion gives the most accurate strength predictions and to compare the same with different materials.

- Design of wing rib using air foil NACA 4412 series without and with cut-outs such as circular, elliptical, triangular, and rectangular with fillet.
- Computation of stresses on a wing rib structure without cut sections for two different materials by applying pressure force on it.
- Determination of deformation in wing rib section due to applied pressure force.
- Computation of stresses of a wing rib structure with cut sections using Circular, Elliptical, and Rectangular with fillet, Triangular with fillet configurations for same two different materials.
- Determining the deformation and plotting the same over the wing rib structure for the above mentioned conditions.
- Comparison of stress concentration factor and deformation factor for all the above conditions.

4. PROBLEM STATEMENT

In modern aircrafts wing ribs are cut to provide space for fuel tanks and other equipment to pass through it. Hence it reduces the weight of wing and also drag acting on wing. In this project wing rib with different cut-outs and without cut-out are considered for static structural analysis for particular pressure force. The problem is to find whether the wing rib with cut section or without cut section provides more strength against the pressure force.

5. METHODOLOGY

STEP 1: THE KNOWLEDGE AND PRE-REQUISITES

Studying the wide range of NACA series airfoils and selecting NACA-4412 airfoil for designing the wing rib. Identification of appropriate parameters required. This design is further analyzed using analysis software.

STEP 2: DETERMINATION OF VARIOUS CONFIGURATIONS

Identifying various wing ribs without cut-outs and with cut-outs such as circular, elliptical, rectangular and triangular sections of specified dimensions. Further these configurations are compared with each other for two different materials to get optimized solution.

STEP 3: DESIGNING THE WING RIB STRUCTURE

Designing of wing rib in NACA-4412 airfoil series using CATIA V5 software of different configurations such as without cut-out and with circular, rectangular, elliptical and triangular cut-outs.

STEP 4: ANALYSIS OF THE DESIGN

Analysis of the structure is done using ANSYS software. Equivalent stress and displacement for the given structure is determined and characteristic graphs are obtained for various configurations.

STEP 5: COMPARISON OF VARIOUS PARAMETERS

Stress, displacement and mass comparison is done for different materials and configurations. Hence the effective one among the configurations is resolved.

6. DESIGN

6.1 SELECTING AND IMPORTING OF AIRFOIL

Different airfoil of NACA series are studied and NACA-4412 is selected as it is advantageous over other airfoils because of its properties like flat lower airfoil surfaces and moderate flap deflections. Angle of Attacks are known to be quite beneficial in ground proximity.

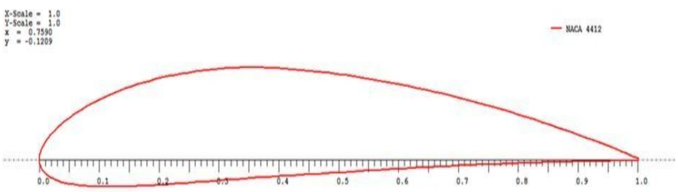

Fig-1: Airfoil NACA-4412

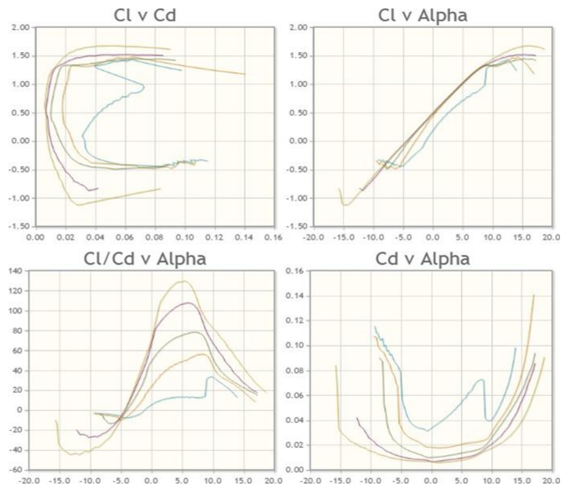

Fig-2: Graphs of NACA 4412 airfoil

For lift, having an angle of attack of 0 degree, gives a Cl (coefficient of lift) of 0.5, while having an angle of attack of 10 degree gives a Cl of around 1.5. For this airfoil, it has its maximum lift around 17-degree angle of attack. Around 19 degree, the airfoil stalls.

For drag, when the angle of attack is 0 degree, the smallest Coefficient of drag is obtained. It increases as angle of attack increases, which is important.

The Cl/Cd v Alpha chart is most important as it shows the angle of attack which is most efficient, where Cl and Cd are found to be highest and lowest respectively. For this airfoil, it peaks around an angle of attack of 5 degree. In plot of Cl/CD v Alpha, the graph which gives maximum value of Cl/Cd represents airfoil NACA 4412.

Chord(mm)-100, Radius(mm)-0, Thickness (%)-100, Origin (%)-0, Pitch(deg)-0

Table-1: Airfoil surface coordinates points

Sl.No	X(mm)	Y(mm)
01	100	0
02	98.3278	0.4668
03	93.411	1.77
04	85.5503	3.6484
05	75.242	5.7499
06	63.1596	7.7046
07	50.1174	9.1737
08	36.9724	9.8742
09	24.5557	9.3616
10	13.977	7.6589
11	6.0394	5.1876
12	1.2918	2.4848
13	0	0
14	2.1156	-1.8178
15	7.3581	-2.7324
16	15.3123	-2.8733
17	25.4443	-2.4866
18	37.1457	-1.9175
19	49.8826	-1.3960
20	62.7223	-0.8741
21	74.758	-0.4722
22	85.1604	-0.2197
23	93.1915	-0.0834
24	98.2648	-0.019
25	100	0

Table-2: Chord line coordinates points

X(mm)	Y(mm)
0	0
100	0

Table-3: Camber line coordinates points

X(mm)	Y(mm)
0	0
1.2918	1.2424
6.0394	1.34262
13.977	2.40462
24.5557	3.42054
36.9724	3.97413
50.1174	3.89362
63.1596	3.42255
75.242	2.64472
85.5503	1.71765
93.411	0.84469
98.3278	0.22424
100	0

The surface point of upper and lower side of camber line is imported from airfoil plotter to MS excel spread sheet. Macro coding generates airfoil points which is created in MS excel spread sheet are imported to CATIA V5 design software.

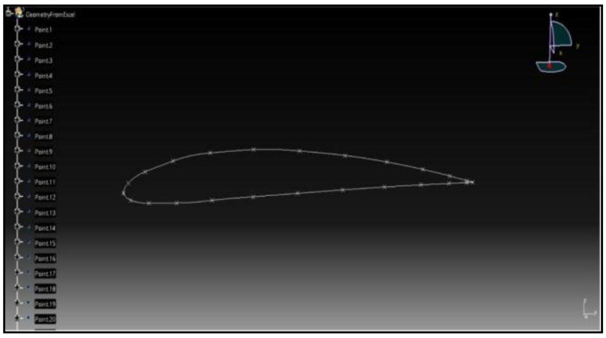

Fig-3: Imported airfoil shape

6.2 DESIGNING OF WING RIB

6.2.1 WING RIB WITHOUT CUTOUTS

After selecting and importing the airfoil as mentioned in the above step, designing is done using CATIA V5 CAD software. The thickness of 4 mm is given to airfoil shape obtained. At the leading and trailing edge required sketch is drawn to cut and get required wing rib structure. Main rib is given 1 mm thickness using cut-out tool. Due to this folding will be created along the edges of wing rib as shown in figure.

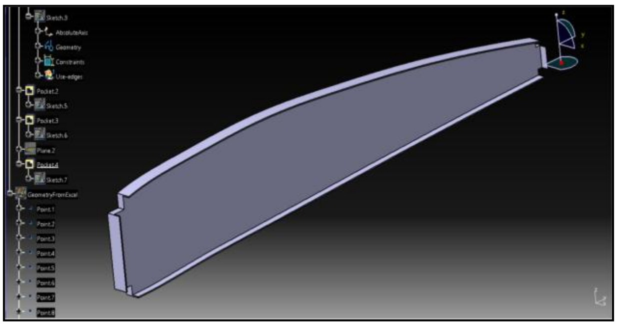

Fig-4: Wing rib without cut-out

Table-4: Dimension of wing rib design

Thickness of main rib	1.0mm
Length of the rib	70.0mm
Width of the folding	2.0mm
Width of front edge	11.3mm
Width of rear edge	4.1mm
Corner cut out at front edge	4*3.5 mm
Corner cut out at rear edge	1.5*1.5mm

6.2.2 Wing rib with cut section of different configurations

Another model of wing rib with cut section is designed in same way as wing rib without cut section. Same procedure is followed to obtain shapes such as circular, elliptical, rectangular with fillet and triangular with fillet as shown in figures below.

1. **Circular cut section**

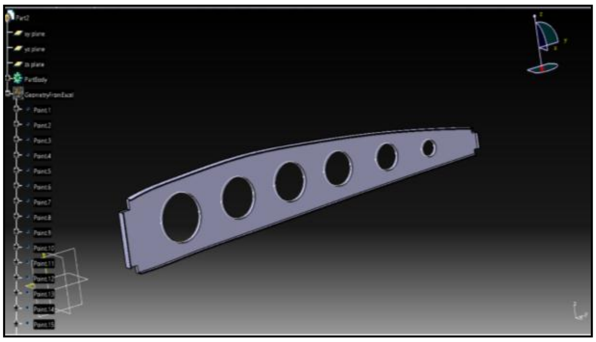

Fig-5: Wing rib with circular cut sections

Sketch of six circles with different diameter and different spacing are drawn on main surface of wing rib to get circular cut section on wing rib. The specified dimensions of circular cut section are as follows:

Table-5: Dimension of circular cut section in wing rib

DIAMETER	SPACING OF CIRCLES
Circle 1- 2.5mm	8.0mm from rear part of wing rib
Circle 2- 4.0mm	5.0mm from circle 1
Circle 3- 5.2mm	5.0mm from circle 2
Circle 4- 5.9mm	4.0mm from circle 3
Circle 5- 6.3mm	4.2mm from circle 4
Circle 6- 7.6mm	4.5mm from circle 5

2. **Elliptical cut section**

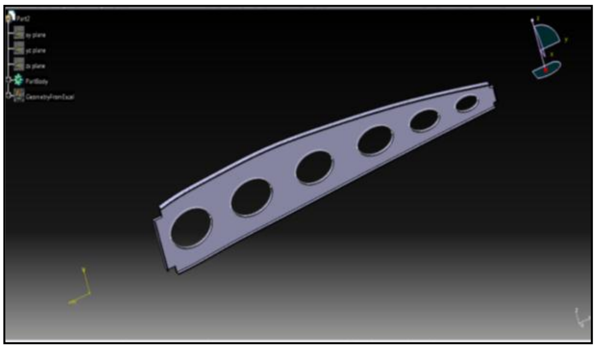

Fig-6: Wing rib with elliptical cut sections

Sketch of six ellipses with different minor and major axes and different spacing are drawn on main surface of wing rib to get elliptical cut section on wing rib. The specified dimensions of elliptical cut section are as follows:

Table-6: Dimension of elliptical cut section in wing rib

SL.NO	MAJOR AXIS	MINOR AXIS	SPACING
Ellipse 1	8.4mm	3.0mm	2.25mm from front edge
Ellipse 2	8.4mm	2.8mm	4.32mm from ellipse 1
Ellipse 3	7.6mm	2.5mm	5.90mm from ellipse 2
Ellipse 4	7.21mm	2.2mm	5.16mm from ellipse 3
Ellipse 5	6.0mm	1.6mm	3.55mm from ellipse 4
Ellipse 6	4.6mm	1.2mm	3.40mm from ellipse 5

3. Rectangular cut section with fillet

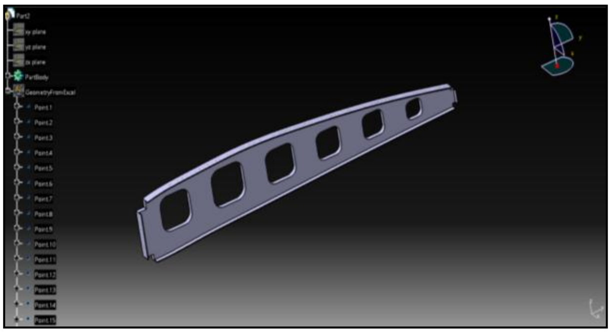

Fig-7: Wing rib with rectangular cut sections (with fillets)

Sketch of six rectangular with different dimensions and different spacing with fillet are drawn on main surface of wing rib to get rectangular cut section with fillet on wing rib. The specified dimensions of rectangular cut section with fillet are as follows,

Table-7: Dimension of rectangular cut section with fillet in wing rib

SL.NO	DIMENSI-ON	SPACING	FILLET RADIUS
Rectangle 1	6.5*6.5mm	4.67mm from front edge	1.7mm
Rectangle 2	7.0*7.0mm	5.0mm from rectangle 1	1.8mm
Rectangle 3	6.2*6.2mm	5.0mm from rectangle 2	1.5mm
Rectangle 4	5.2*5.2mm	5.0mm from rectangle 3	1.3mm
Rectangle 5	4.6*4.6mm	5.0mm from rectangle 4	1.2mm
Rectangle 6	3.4*3.4mm	5.0mm from rectangle 5	1.0mm

4. Triangular cut section with fillet

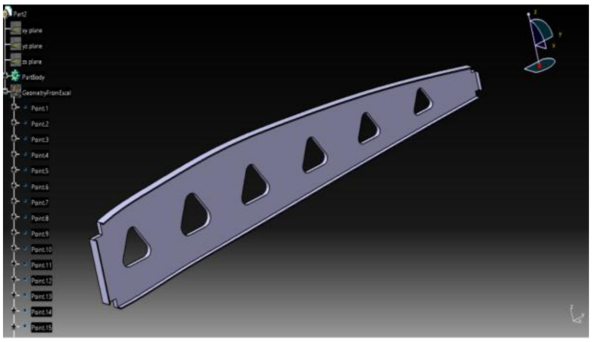

Fig-8: Wing rib with triangular cut sections (with fillets)

Sketch of six triangular cut sections (with fillet) with different dimensions and different spacing are drawn on main surface of wing rib to get triangular cut section with fillet on wing rib. The specified dimensions of triangular cut section with fillet are as follows,

Table-8: Dimension of triangular cut section with fillet in wing rib

Triangle	Dimension	Spacing	Fillet Radius
Triangle 1	6.4*6.4*6.4mm	3.6mm from front edge	0.9mm
Triangle 2	7.1*7.1*7.1mm	4.25mm from triangle 1	1.2mm
Triangle 3	6.4*6.4*6.4mm	4.25mm from triangle 2	0.9mm
Triangle 4	5.7*5.7*5.7mm	4.95mm from triangle 3	0.8mm
Triangle 5	5.0*5.0*5.0mm	4.65mm from triangle 4	0.7mm
Triangle 6	4.3*4.3*4.3mm	5.35mm from triangle 5	0.6mm

7. ANALYSIS

7.1 Grid independency test

A grid independence test is computing the solution on successively finer grids. The difference between two refinements is taken as a measure of the accuracy of the coarser among the two. Grid independent study is important in analysis for certain geometry to get right answer. Filtering the grid and checking for total deformation we find that for about 45,000 elements the values don't vary considerably affecting the output. This value is chosen to improve accuracy and reduce computational time.

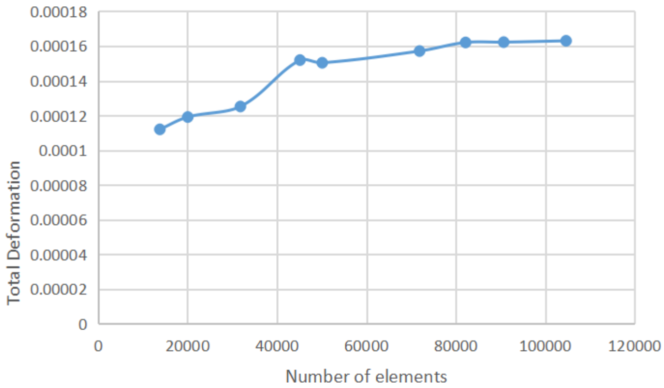

Fig-9: Grid independency test for wing rib

7.2 Meshing of the imported geometry

A. Meshing of wing rib without cut-out

The design imported to ANSYS is meshed using edge sizing and face meshing method. The elements are of tetrahedral order. Number of nodes and elements are 496599 and 45145 respectively.

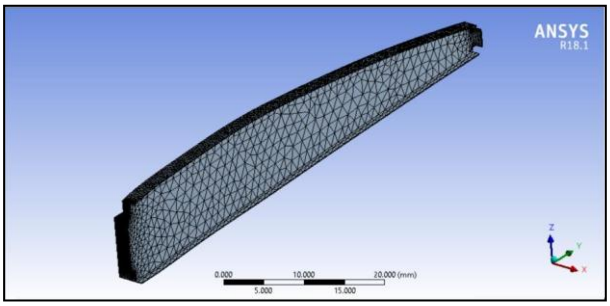

Fig-10: Meshing of wing rib without cut-outs

Element quality:

The Element quality provides a composite quality metric that ranges between 0 and 1. This metric is based on the ratio of the volume to the sum of the square of the edge lengths for 2D quad/tri elements, or the root of cube of the sum of square of the length of the edges for 3D elements. A value of 1 indicates an ideal cube or square while a value of 0 indicates that the element features a zero or negative volume. The average element quality of our mesh is 0.7814 which lies between 0 to 1, all the elements lie in a range of 0 to 1 as shown in the bar graph above.

Jacobian ratio:

The Jacobian ratio is a measurement of the shape of a given element compared to that of an ideal element. If an element has a bad quality Jacobian ratio, the element may not map well from element space to real space, thereby making computations based on the element shape less reliable. The ideal shape of an element depends on element type. An element with a Jacobian ratio <= 0 should be avoided. A Jacobian ratio whose value is close to 1 is best. The average

Jacobian ratio of all the elements in our mesh is 0.99858 which is near to 1.

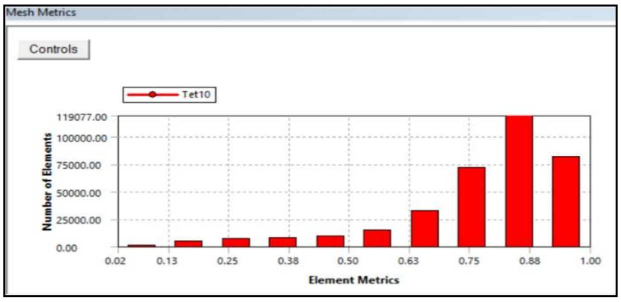

Fig-11: Element quality graph for wing rib

Mesh Metric	Element Quality
Min	1.8785e-002
Max	0.99999
Average	0.7814
Standard Deviation	0.17153

Fig-12: Mesh metric for Element Quality

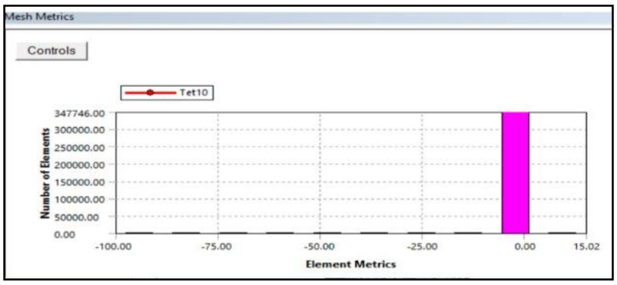

Fig-13: Jacobian ratio graph for wing rib

Mesh Metric	Jacobian Ratio (MAPDL)
Min	-100.
Max	15.02
Average	0.99858
Standard Devi...	0.45567

Fig-14: Mesh Metric for Jacobian Ratio

B. Meshing of wing rib with circular cutouts

The design imported to ANSYS is meshed using edge sizing and face meshing. The elements are of tetrahedral order. Number of nodes and elements are 276099 and 47286 respectively.

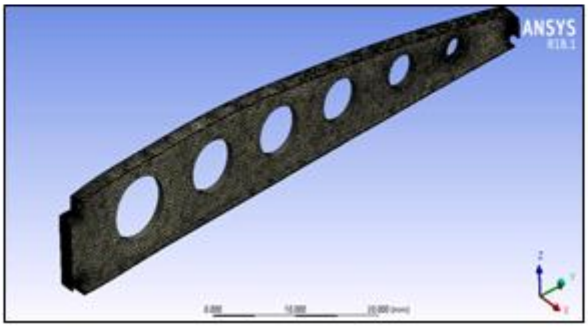

Fig-15: Meshing of wing rib with circular cut-outs

C. Meshing of wing rib with elliptical cut-outs

The design imported to ANSYS is meshed using edge sizing face meshing. The elements are of tetrahedral order. Number of nodes and elements are 147183 and 46342 respectively.

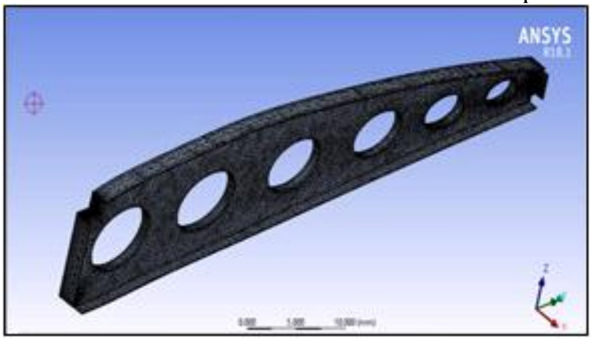

Fig-16: Meshing of wing rib with elliptical cut-outs

D. Meshing of wing rib with rectangular cut-outs

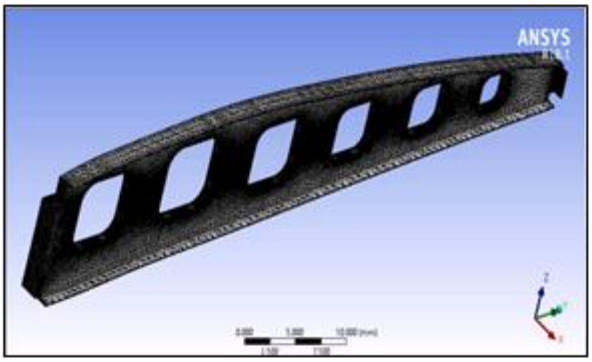

Fig-17: Meshing of wing rib with rectangular cut-outs

The design imported to ANSYS is meshed using edge sizing and face meshing. The elements are of tetrahedral order. Number of nodes and elements are 836968 and 46180 respectively.

E. Meshing of wing rib with triangular cut-outs

The design imported to ANSYS is meshed using edge sizing and face meshing. The elements are of tetrahedral order. Number of nodes and elements are 440519 and 45700 respectively.

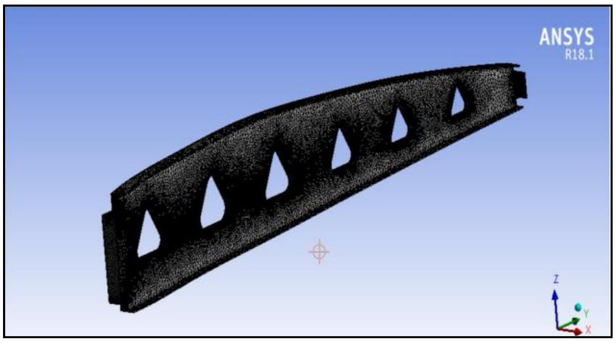

Fig-18: Meshing of wing rib with triangular cut-outs

7.3 Boundary conditions

The boundary conditions applied are fixed translational and rotational movements with all the six degrees of freedom of the wing rib are constrained. Air pressure or aerodynamic load of 0.1MPa is applied on the upper flange as shown in fig.

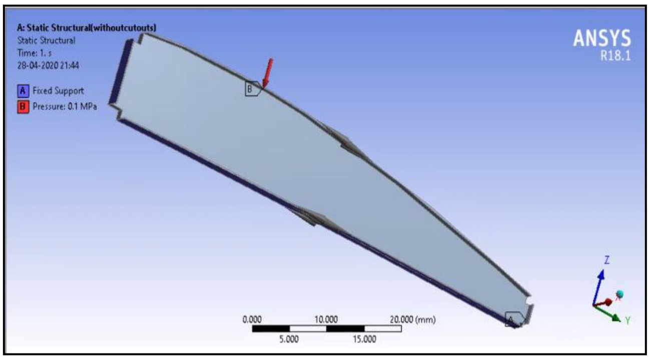

Fig-19: Boundary conditions and load applied on wing rib

The materials used are Aluminum 7075 T6 and Carbon Epoxy. The material properties are given as shown in table 9.

Table-9: Material Properties of Al 7075-T6 and Carbon Epoxy

Sl. No	Properties	Al 7075-T6	Carbon Epoxy
1	Density (kg m-3)	2804	1600
2	Ultimate Tensile Strength (MPa)	572	597
3	Yield Tensile Strength (MPa)	503	520
4	Modulus of Elasticity (GPa)	71.7	70.0
5	Poisson's Ratio	0.33	0.30

Mass and volume of wing rib without cut-outs and wing rib with circular cut-outs is given in the table below:

Table-10: Mass and volume of different configurations

	Mass (kg)		**Volume (mm^3)**
	Al 7075 T6 ($\times10^{-3}$)	**Carbon Epoxy ($\times10^{-4}$)**	
Without cutouts	1.9122	10.496	681.96
Circular cutouts	1.5157	8.3265	540.56
Elliptical cutouts	1.4774	8.1143	526.9
Rectangular cutouts	1.4111	7.7499	503.24
Triangular cutouts	1.6855	9.257	601.1

8. Results

8.1 Analysis of stress and deformation over the wing rib without cut- outs

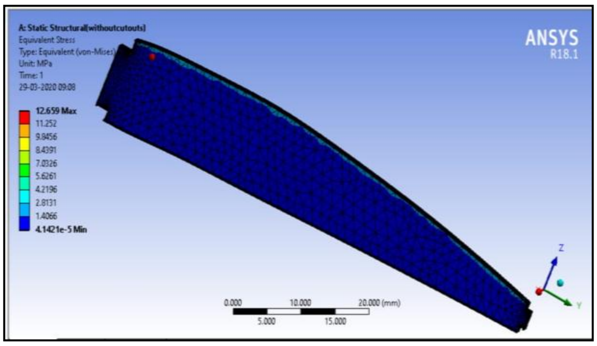

Fig-20: von-Mises Stress of wing rib without cut-outs for Al 7075 T6

Solution is obtained for equivalent (von-Mises) stress and total deformation over the wing rib. The maximum equivalent stress obtained is 12.659MPa and 17.342MPa for Al 7075-T6 and Carbon Epoxy respectively. The maximum deformation obtained is 1.5742×10^{-3} mm and 7.1541×10^{-3} for Al 7075 -T6 and Carbon Epoxy respectively. The equivalent stress and the total deformation plot are as shown in the figure.

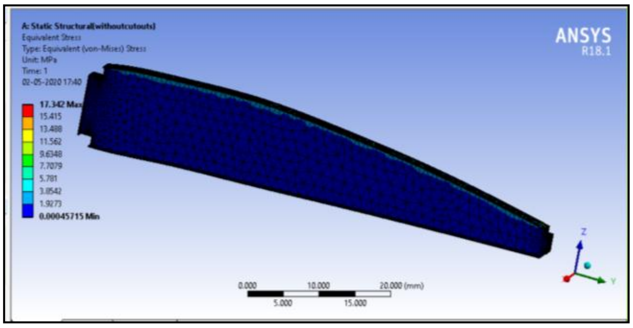

Fig-21: von-Mises Stress of wing rib without cut-outs for Carbon Epoxy

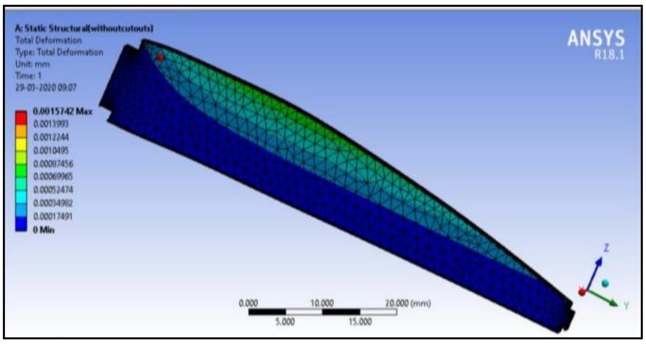

Fig-22: Total deformation of wing rib without cut-outs for Al 7075 T6

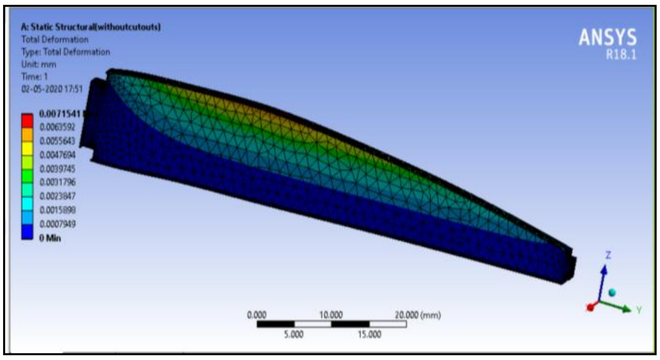

Fig-23: Total deformation of wing rib without cut-outs for Carbon Epoxy

8.2 Analysis of stress and deformation over the wing rib with circular cut-outs

Solution is obtained for equivalent (von-Mises) stress and total deformation over the wing rib. The maximum equivalent stresses obtained are 14.788MPa and 20.394MPa for Al 7075-T6 and Carbon Epoxy respectively. The maximum deformation obtained is 2.2526×10^{-3} mm and 12.794×10^{-3} mm for Al 7075 -T6 and Carbon Epoxy respectively. The equivalent stress plot and total deformation plot are as shown in the figure below.

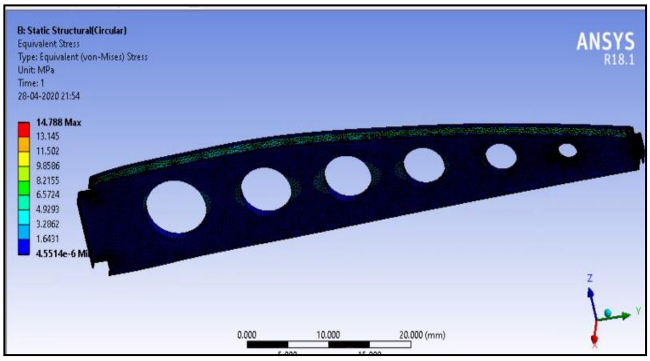

Fig-24: von-Mises Stress of wing rib with circular cut-outs for Al 7075 -T6

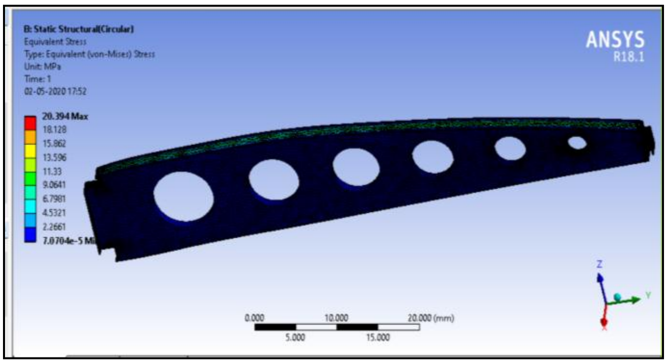

Fig-25: von-Mises Stress of wing rib with circular cut-outs for Carbon Epoxy

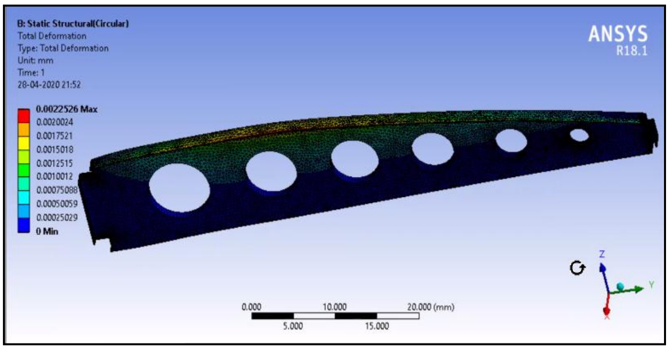

Fig-26: Total Deformation of wing rib with circular cut-outs for Al 7075 –T6

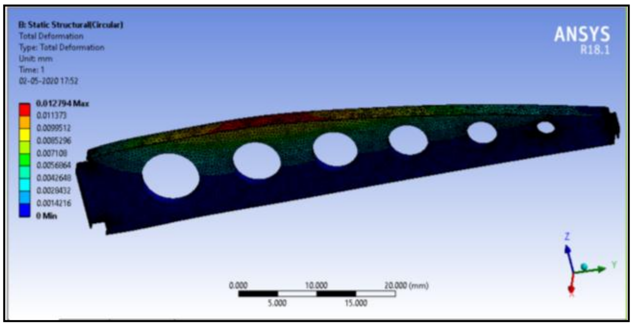

Fig-27: Total Deformation of wing rib with circular cut-outs for Carbon epoxy

8.3 Analysis of stress and deformation over the wing rib with elliptical cut-outs

Solution is obtained for equivalent (von-Mises) stress and total deformation over the wing rib. The maximum equivalent stresses obtained are 12.392MPa and 14.368MPa for Al 7075 -T6 and Carbon Epoxy respectively. The maximum deformations obtained are 2.3521×10^{-3} mm and 13.506×10^{-3} mm for Al 7075 -T6 and Carbon Epoxy respectively. The equivalent stress plot and total deformation plot are as shown in the figure below.

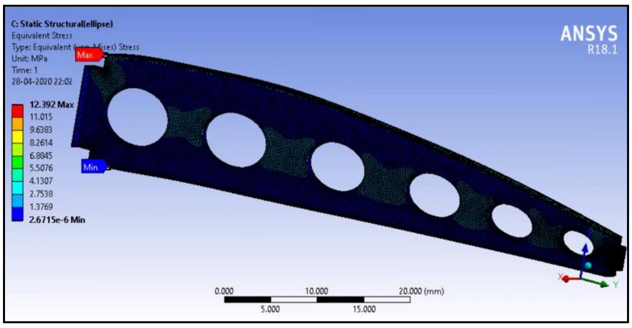

Fig-28: von-Mises Stress of wing rib with elliptical cut-outs for Al 7075 -T6

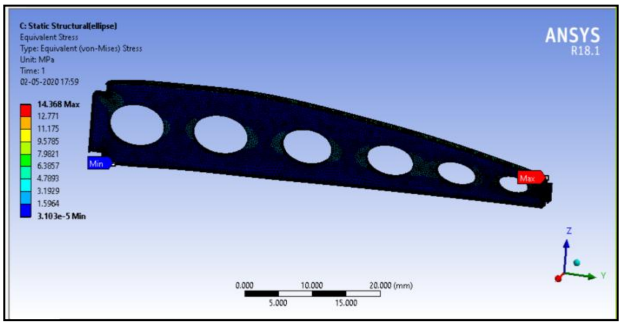

Fig-29: von-Mises Stress of wing rib with elliptical cut-outs for Carbon Epoxy

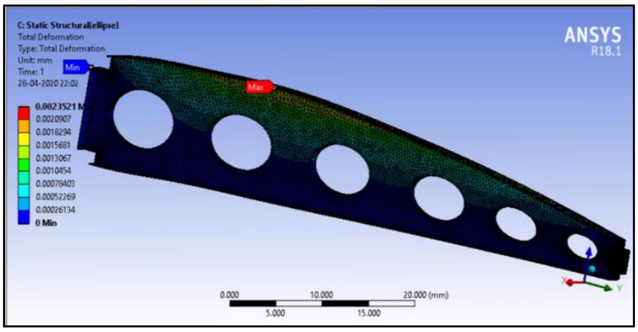

Fig-30: Total Deformation of wing rib with elliptical cut-outs for Al 7075 -T6

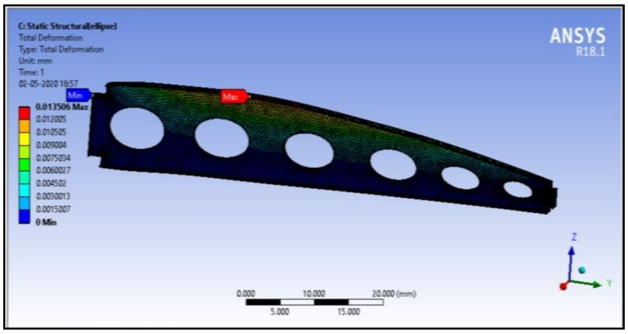

Fig-31: Total Deformation of wing rib with elliptical cut-outs for Carbon Epoxy

8.4 Analysis of stress and deformation over the wing rib with rectangular cut-outs

Solution is obtained for equivalent (von-Mises) stress and total deformation over the wing rib. The maximum equivalent stress obtained is 12.544MPa and 16.055MPa for Al 7075 -T6 and Carbon Epoxy respectively. The maximum deformation obtained is 2.3955×10^{-3} mm and 14.142×10^{-3} mm for Al 7075 -T6 and Carbon Epoxy respectively. The equivalent stress plot and total deformation plot are as shown in the figure below.

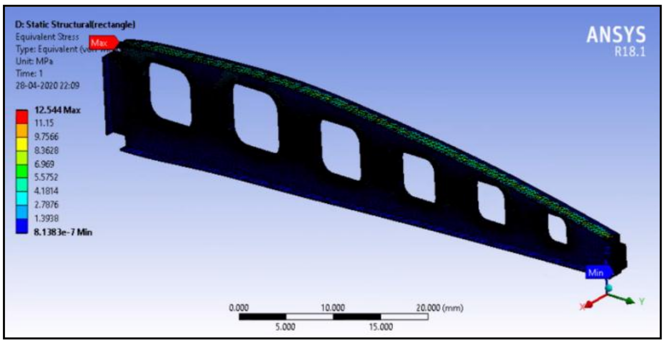

Fig-32: von-Mises Stress of wing rib with rectangular cut-outs for Al 7075 -T6

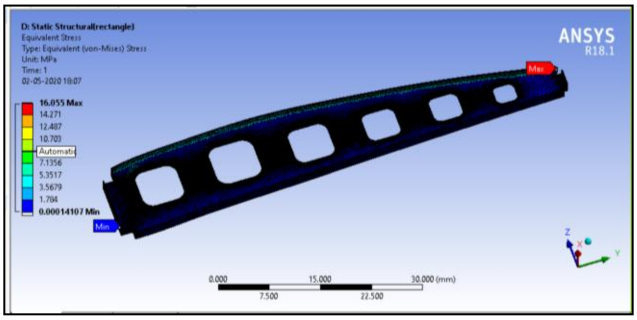

Fig-33: von-Mises Stress of wing rib with rectangular cut-outs for Carbon Epoxy

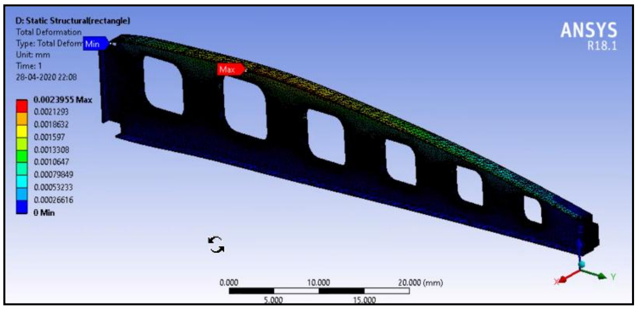

Fig-34: Total Deformation of wing rib with rectangular cut-outs for Al 7075 -T6

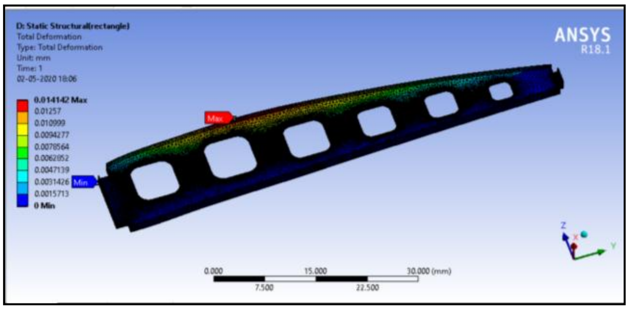

Fig-35: Total Deformation of wing rib with rectangular cut-outs for Carbon Epoxy

8.5 Analysis of stress and deformation over the wing rib with triangular cut-outs

Solution is obtained for equivalent (von-Mises) stress and total deformation over the wing rib. The maximum equivalent stresses obtained are 12.214MPa and 19.813MPa for Al 7075-T6 and Carbon Epoxy respectively. The maximum deformation obtained are 1.936×10^{-3} mm 10.297×10^{-3} mm for Al 7075-T6 and Carbon Epoxy respectively. The equivalent stress plot and total deformation plot are as shown in the figure below.

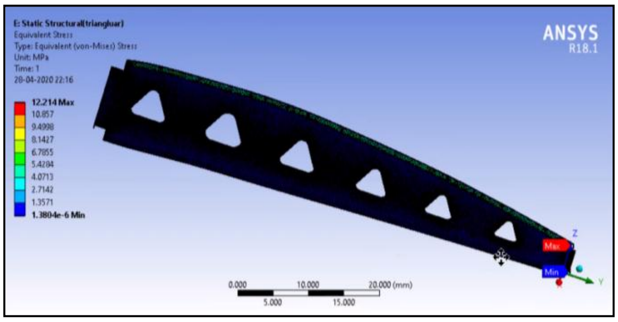

Fig-36: von-Mises Stress of wing rib with triangular cut-outs for Al 7075 -T6

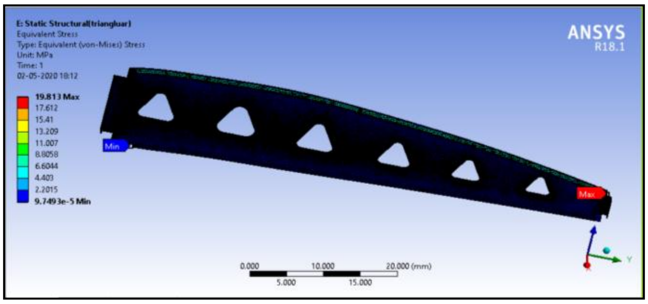

Fig-37: von-Mises Stress of wing rib with triangular cut-outs for Carbon Epoxy

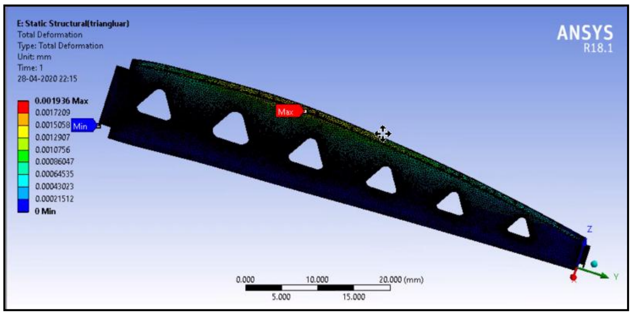

Fig-38: Total Deformation of wing rib with triangular cut-outs for Al 7075 T6

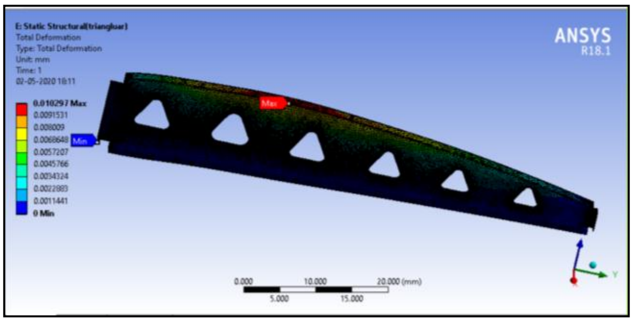

Fig-39: Total Deformation of wing rib with triangular cut-outs for carbon epoxy

8.6 COMPARISON OF WING RIB WITHOUT CUT-OUTS AND WING RIB WITH CUT-OUTS

Maximum Equivalent (von-Mises) Stress and Maximum Total Deformation are compared

Table-11: Comparison of Stress

	Equivalent Stress (MPa)	
	Al 7075 T6	**Carbon Epoxy**
Without cut-outs	12.659	17.342
Circular cut-outs	14.788	20.394
Elliptical cut-outs	12.392	14.368
Rectangular cut-outs	12.544	16.055
Triangular cut-outs	12.214	19.813

Table-12: Comparison of Deformation

	Deformation (mm) ($\times 10^{-3}$)	
	Al 7075 T6	**Carbon Epoxy**
Without cut-outs	1.5742	7.1541
Circular cut-outs	2.2526	12.794
Elliptical cut-outs	2.3521	13.506
Rectangular cut-outs	2.3955	14.142
Triangular cut-outs	1.936	10.297

From table 11 and 12 we get to know that the maximum deformation of wing rib without cut- outs is less compared to that of wing rib with circular cut-outs. Moreover, the stress in wing rib without cut-outs is less than the wing rib with circular cut-outs. The mass of wing rib with circular cut-outs is lesser than the mass of wing rib without cut-out.

9. CONCLUSIONS

- From the above project it was found that inserting the circular hole in the plate enhance the strength of the wing rib.
- Inserting holes in the rib found out to be effective with weight reduction compared to the initial geometry and other configurations with cut sections.
- The maximum stress occurs around the holes and it is to be considered as the critical region in the later stages.
- And also, materials used for aircraft wings are mostly metallic alloys. In this project, the materials used are Al 7075 T6 and carbon epoxy.

Strength/Weight Ratio = ultimate strength/Density

Al 7075-T6: = (572*10^6 N/mm^2) / (2804)

= 203994.289 N-m/kg

Carbon Epoxy: = (597*10^6 N/mm^2) / (1600)

= 373125.000 N-m/kg

From the above data it is concluded that carbon epoxy has more strength to weight ratio compared to that of Aluminium 7075-T6. So instead of metallic alloys like Al 7075-T6 we can also use carbon epoxy.

10. FUTURE SCOPE

In the present thesis, the load considered for analysis is only air pressure. But more loads will be acted on spars like upward bending loads resulting from the wing lift force that supports the fuselage in flight, fuel carried in the wings, and wing-mounted engines if used, Drag loads dependent on airspeed and inertia, Rolling inertia loads and Chord wise twisting loads due to aerodynamic effects at high air-speeds often associated with washout, and control reversal can be done using ailerons. The effect of these forces on the wing can substantially change the results, so the present work can be extended by applying the above forces also.

- Try using different materials which can reduce the weight.
- The number of cut sections, distance and other configurations can be modified.
- Meanwhile the von-Mises stress in the component keeps on increasing as the numbers of cutouts are increased.

11. REFERENCES

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