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Design and Analysis of Wing Rib of Aircraft Review

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ABSTRACT:The wing rib of an aircraft is a very critical part. It provides airfoil contour to the wing. Its principal role in wing structure is that to transfer load from skin to stringers or other parts of wing. However, the objective is to determine stress and displacement of the wing rib with and without cutouts which have thickness 1mm in the application of 0.01 MPa air pressure. The tools used in this design and analysis are CATIA V5 and MSC NASTRAN-PATRAN. On above conclusion, displacement and von mises stress results for both types of wing ribs are studied.

KEYWORDS:Al 7075-T6, CATIA V5, Cutouts, Displacement, FEA, Mises, NASTRAN, PATRAN, Rib, Stress, Von andWing.

I. INTRODUCTION

The wing of an aircraft is an airfoil section which provides lift to it for takeoff and landing. It has different shapes which depend upon the speed, function and type of an aircraft. Wing provides different flight characteristics such control, lift, balance and stability to an aircraft. Physically, it has four sides such as the front side is leading edge, rear side is trailing edge, top most side towards left is tip and side towards fuselage is root. Wing of an aircraft has six types such as tapered leading and straight trailing edge, straight leading and tapered trailing edge, tapered both leading and trailing edge, delta wing, sweptback wing and straight both leading and trailing edge wings. Skin, ribs, stringers and spars are the general parts in construction of the wing. However, the wing rib is a very predominant part among all mentioned above. The principal role of rib is to provide airfoil shape and transfer load from skin to stringers or other parts of wing. Wing ribs are usually manufactured from wood or metal. Nonetheless, in this design aluminium 7075 T6 is used. So, the objective is to determine stress and displacement of the wing rib with and without cutouts which have thickness 1mm with applied air pressure of 0.01 MPa by using CATIA V5 and MSC NASTRAN-PATRAN as design and analysis tools. As a result, the stress and displacement for wing rib with cutouts is 3.24 MPa at node 20760 and 0.45e-10 mm at node 172 respectively. Moreover, the stress and displacement for wing rib without cutouts is 4.82 MPa at node 680 and 1.7e-10 mm at node 7481 respectively. Thus, after validation of the wing rib we studied the results.

II. MATERIALS & METHODS

In this methodology, the wing rib of 1mm thick with and without cutouts is designed in part design module by using CATIA V5. The NACA 4-digit series 4412 is used for creating the airfoil contour with the help of MS excel spreadsheets and then did the finite element analysis in NASTRAN-PATRAN. Meshing is done in this analysis after importing the geometry into the MSC NASTRAN-PATRAN by using element shape of Quad, mesher of Paver type and topology of Quad4. The material properties of isotropic type is used with aluminium Al 7075 T6 in below topics the detailed material properties will be shown. The boundary conditions used for the analysis is that wing rib was fixed from translational and rotational movements with the application of air pressure 0.01 MPa. On conclusion, studied the results by comparing both ribs with and without cutouts. Following written are descriptions of the tools and methods used.

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III. DESIGN OF WING RIB

The designing of **wing rib without cutout** is done in CATIA V5 CAD software. In the generation of an airfoil shape of wing rib, NACA 4-digit series 4412 is used. This airfoil shape is created in CATIA V5 in the form of 25 points which is in upper and lower side of the camber line. The MS-excel spreadsheet is also used in the creation of airfoil points which is generated by macro coding. Following fig.1 shows the MS-excel spreadsheet used in creation of NACA 4-digit series 4412 airfoil contour.

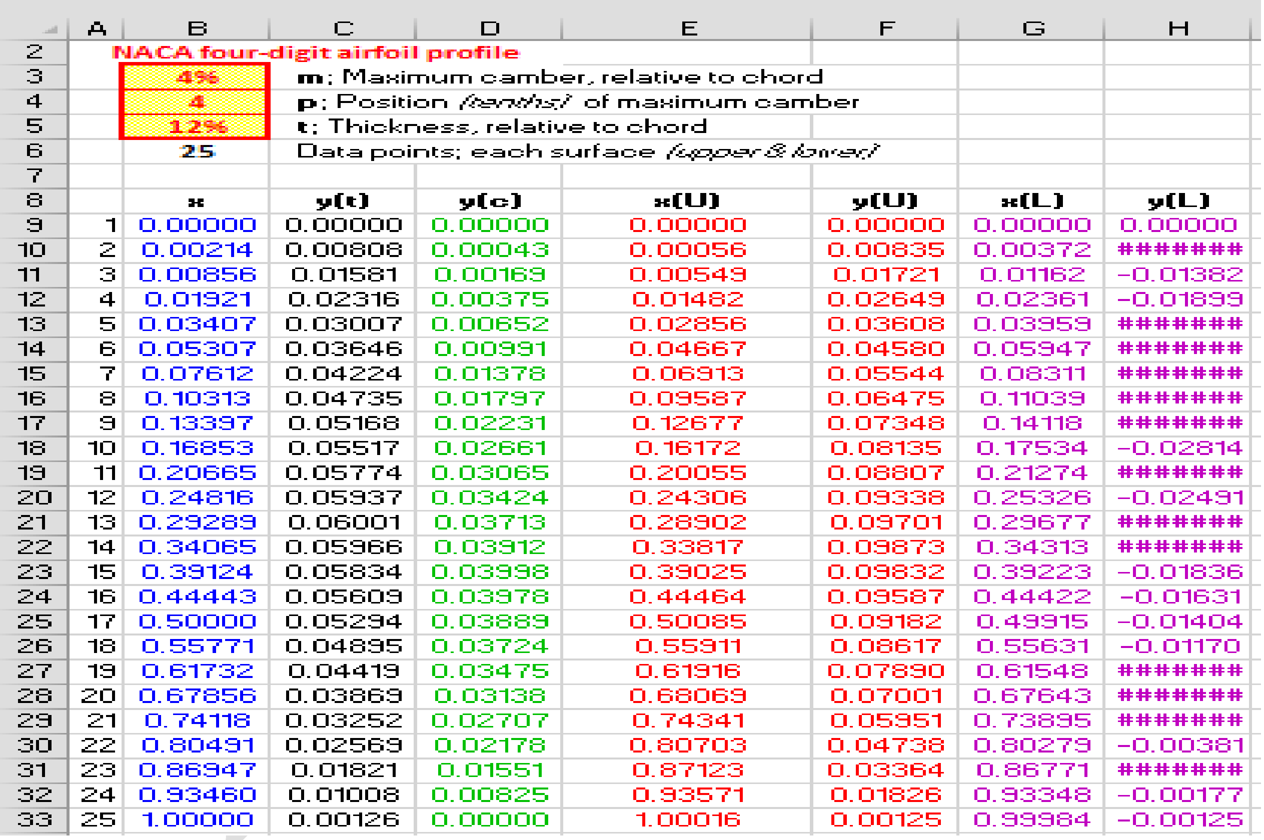
Calculations of NACA 4-digit Series Airfoil for Point Creation in Spreadsheet:

- The NACA 4-digit series is defined by four digits, e.g. NACA 4412: m=4%, p=4/10, t=12%
- The equations for point generation are given below and fig.1 shows the spreadsheet for these points as:

$$yt = (\frac{t}{0.2})(0.2969\sqrt[2]{x} - 0.126x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4,$$

$$yc = \left(\frac{m}{p^2}\right)(2px - x^2); for\ x \le p,$$

$$yc = \left(\frac{m}{(1-p)^2}\right)((1-2p) + 2px - x^2); for\ x > p$$



	A	B	C	D	E	F	G	H
2		NACA four-digit airfoil profile						
3		4%	m; Maximum camber, relative to chord					
4		4	p; Position (tenths) of maximum camber					
5		12%	t; Thickness, relative to chord					
6		25	Data points; each surface (upper & lower)					
7								
8		x	y(t)	y(c)	x(U)	y(U)	x(L)	y(L)
9	1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10	2	0.00214	0.00808	0.00043	0.00056	0.00835	0.00372	########
11	3	0.00856	0.01581	0.00169	0.00549	0.01721	0.01162	-0.01382
12	4	0.01921	0.02316	0.00375	0.01482	0.02649	0.02361	-0.01899
13	5	0.03407	0.03007	0.00652	0.02856	0.03608	0.03959	########
14	6	0.05307	0.03646	0.00991	0.04667	0.04580	0.05947	########
15	7	0.07612	0.04224	0.01378	0.06913	0.05544	0.08311	########
16	8	0.10313	0.04735	0.01797	0.09587	0.06475	0.11039	########
17	9	0.13397	0.05168	0.02231	0.12677	0.07348	0.14118	########
18	10	0.16853	0.05517	0.02661	0.16172	0.08135	0.17534	-0.02814
19	11	0.20665	0.05774	0.03065	0.20055	0.08807	0.21274	########
20	12	0.24816	0.05937	0.03424	0.24306	0.09338	0.25326	-0.02491
21	13	0.29289	0.06001	0.03713	0.28902	0.09701	0.29677	########
22	14	0.34065	0.05966	0.03912	0.33817	0.09873	0.34313	########
23	15	0.39124	0.05834	0.03998	0.39025	0.09832	0.39223	-0.01836
24	16	0.44443	0.05609	0.03978	0.44464	0.09587	0.44422	-0.01631
25	17	0.50000	0.05294	0.03889	0.50085	0.09182	0.49915	-0.01404
26	18	0.55771	0.04895	0.03724	0.55911	0.08617	0.55631	-0.01170
27	19	0.61732	0.04419	0.03475	0.61916	0.07890	0.61548	########
28	20	0.67856	0.03869	0.03138	0.68069	0.07001	0.67643	########
29	21	0.74118	0.03252	0.02707	0.74341	0.05951	0.73895	########
30	22	0.80491	0.02569	0.02178	0.80703	0.04738	0.80279	-0.00381
31	23	0.86947	0.01821	0.01551	0.87123	0.03364	0.86771	########
32	24	0.93460	0.01008	0.00825	0.93571	0.01826	0.93348	-0.00177
33	25	1.00000	0.00126	0.00000	1.00016	0.00125	0.99984	-0.00125

Fig.1 MS-excel spreadsheet with NACA 4-digit series 4412 airfoil contour Points

- Where t is maximum thickness as a percentage of the chord, m is maximum camber as a percentage of the chord, p is the chord wise position of the maximum camber as a tenth of the chord.
- The final coordinates for the airfoil upper surface (xu, yu) and lower surface(xl, yl) are given by:

$xu = x - yt(\sin\theta)$
$yu = yc + yt(\cos\theta)$
$xl = x + yt(\sin\theta)$

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$yl = yc - yt(\cos\theta)$

Where, $\theta = \arctan(\frac{\Delta yc}{\Delta x})$

After transferring the NACA 4-digit series points into CATIA V5, design of airfoil contour is created in part design module by using various geometry tools. In following fig.2 shows the rib model without cutout, table.1, table.2 shows characteristics & centre of gravity and inertia & principle moments of wing rib without cutouts respectively:

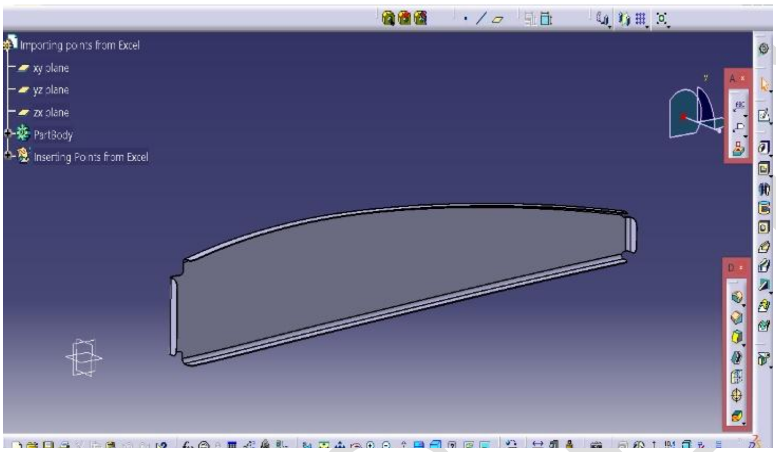


Fig.2 Wing rib without cutout in CATIA V5

Characteristics and C.O.G of Wing rib without cutouts:

Characteristics		**Center Of Gravity, G**	
Area =	0.117m2	Gx =	612.624 mm
Mass =	1.171kg	Gy =	48.916 mm
Surfacic Mass=	10kg_m2	Gz =	-19 mm

Table.1 Characteristics and Center of Gravity of wing rib

Inertia and Principle Moments of wing rib without cutouts:

Inertia/G				**Principle Moment/ G**	
IoxG=	0.002 kgxm2	IxyG=	2.638e-004 kgxm2	M1=	0.002 kgxm2
IoyG=	0.075 kgxm2	IxzG=	0 kgxm2	M2=	0.075 kgxm2
IozG=	0.077 kgxm2	IyzG=	0 kgxm2	M3=	0.077 kgxm2

Table.2 Inertia and Principle Moment

Another model of **wing rib with cutouts** is also designed on the same way as wing rib without cutout designed in Catia V5. In following fig. 3 shows the rib model with cutouts, table.3, table.4 shows characteristics & centre of gravity and inertia & principle moments of wing rib with cutouts respectively:

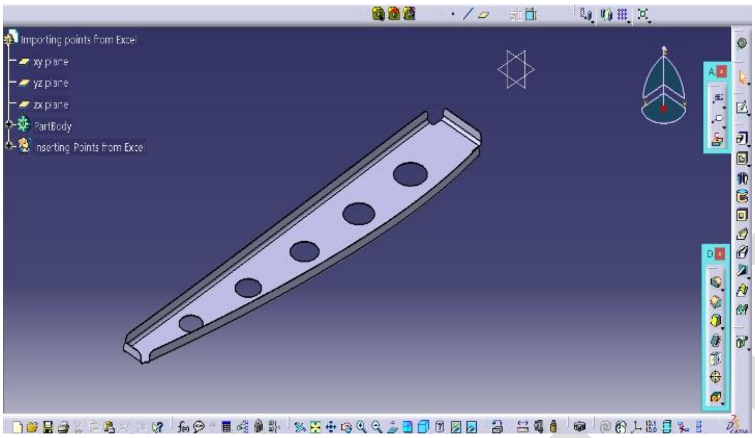


Fig.3 Wing rib with cutouts in CATIA 5

Characteristics and C.O.G of Wing rib with cutouts:

Characteristics		Center Of Gravity, G	
Area =	0.103 m2	Gx =	611.462 mm
Mass =	1.028 kg	Gy =	48.714 mm
Surfacic Mass=	10kg_m2	Gz =	-19mm

Table.3 Characteristics and Center of Gravity of wing rib

Inertia and Principle Moments of wing rib with cutouts:

Inertia/G				Principle Moment/ G	
IoxG=	0.002 kgxm2	IxyG=	2.166e-004 kgxm2	M1=	0.002kgxm2
IoyG=	0.068 kgxm2	IxzG=	0 kgxm2	M2=	0.068kgxm2
IozG=	0.07 kgxm2	IyzG=	-1.084e-019 kgxm2	M3=	0.07kgxm2

Table.4Characteristics and Center of Gravity of wing rib

IV. FINITE ELEMENT ANALYSIS OF WING RIBS

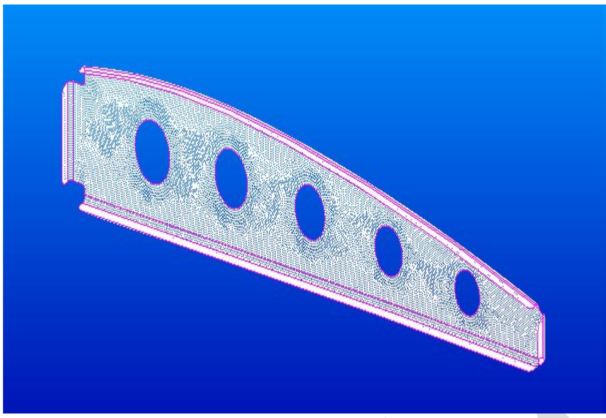
Assumptions for FEA

- Material properties was isotropic and homogeneous.
- Analysis of both wing ribs was linear static.
- Steady state analysis was carried out.
- Wing rib from both side was fixed in this analysis.

Finite element analysis of both wing ribs was used for observing the structural behavior of both of them by using the structural static analysis. The FEA's chief intention is only to show the behavior of both wing ribs in the form of stress and displacement analysis. After performing the analysis test, results of both wing ribs with and without cutouts are compared.

Meshing

The meshing is very important for the analysis of any structural object or body. Meshing is the process of discretization of a body into smaller pieces for accuracy of the results. The web or group of nodes and elements is known as mesh. Basically, there are two types of meshing are used one is Quad and another one Tria. In the meshing of both wing ribs Quad type is used. In the failure of elements, verification of certain parameters are required. The verification of wing rib elements, boundaries, connectivity need to be verified. In this meshing, 2d element is used with the reason of third side of rib is very smaller than other two sides.By using the boundary check option in meshing module, prevention of free nodes in the element of wing rib is done which is also very necessary for bonding of the elements.In following fig.4 and fig.5 is the meshing of both wing ribs with and without cutouts:



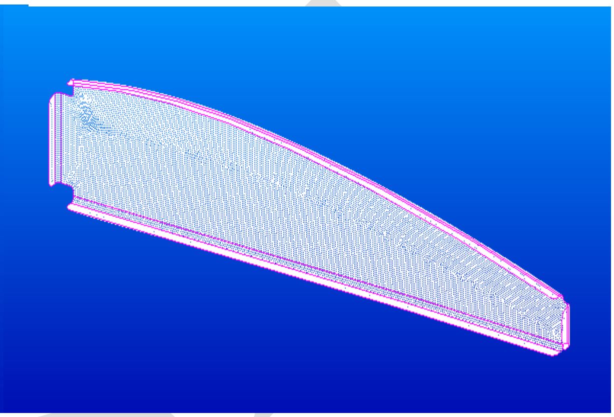


Fig.4 Meshing of Wing rib with cutoutsFig.5 Meshing of Wing rib without cutouts

Material Properties

Al 7075 T6 material is used for the both wing ribs which is very common for aircraft structural parts. In the following table.5 its mechanical and physical properties are shown:

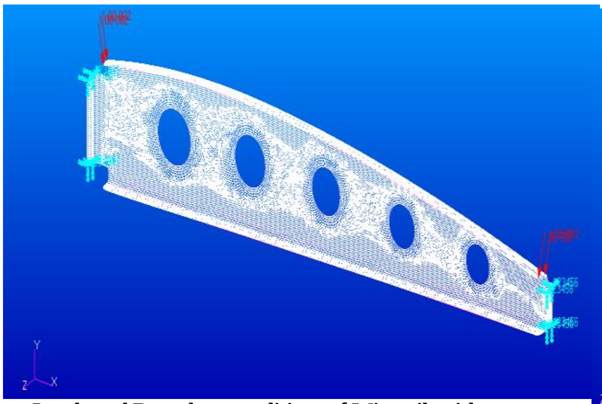
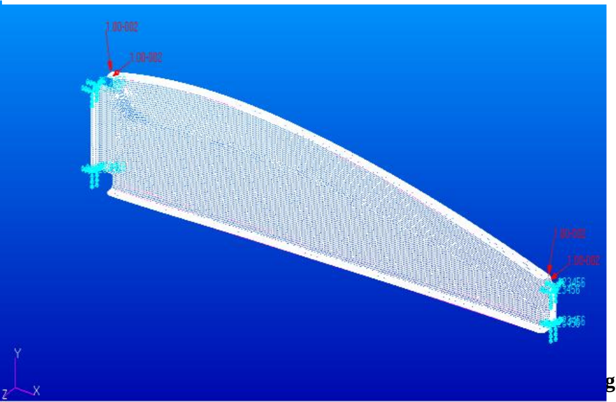
Sr. No.	Physical and Mechanical Properties	Values
1.	Density	2.81 g/cc
2.	Ultimate Tensile Strength	572 MPa
3.	Yield Tensile Strength	503 MPa
4.	Modulus Of Elasticity	71.7 GPa
5.	Poisson’s Ratio	0.33
6.	Shear Modulus	26.9 GPa

Table.5 Material Properties of Al 7075 T6

Loads and Boundary Conditions

- Aerodynamic load or pressure due to air on both wing ribs is 0.01 MPa.
- All six degrees of freedom of both wing ribs is fixed or constraint.
- Direction of applied pressure due to air is in downward y-axis on upper flange of both wing ribs.

Following are the fig.6 and fig.7 which shows loads and boundary conditions on both wing ribs:

g.6 Loads and Boundary conditions of Wing rib with cutouts

Fig.7 Loads and Boundary conditions of Wing rib without cutouts

V. EXPERIMENTAL RESULTS

Displacement Plot of Rib without Cutouts:

In fig. 8 displacement plot of the wing rib without cutout of thickness 1mm shows when air pressure of 0.01 MPa on upper flange is applied. As a result, in the response of applied air pressure maximum displacement observed is 1.70e-10mm at node 680 on the mid of wing rib without cutouts is given as:

Displacement Plot of Rib with Cutouts:

In fig. 9 displacement plot of the wing rib with cutouts of thickness 1mm shows when air pressure of 0.01 MPa on upper flange is applied. As a result, in the response of applied air pressure maximum displacement observed is 4.50e-10mm at node 172 on the mid wing rib without cutouts is given as:

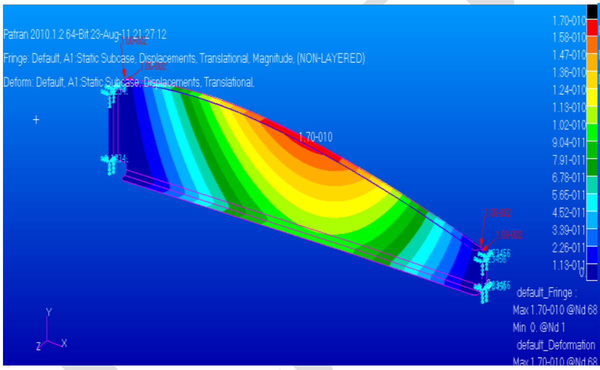


Fig.8 Displacement Plot of Wing rib without Cutouts

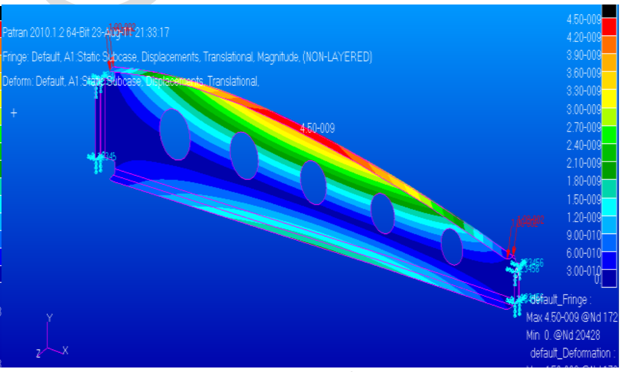


Fig.9Displacement Plot of Wing rib with Cutouts

Von Mises Stress Plot of Rib without Cutouts:

In fig. 10 von mises stress plot of the wing rib without cutout of thickness 1mm shows when air pressure of 0.01 MPa on upper flange is applied. As a result, in the response of applied air pressure maximum von mises stress observed is 0.482 MPa at node 7481 on the both ends of wing rib without cutouts is given as:

Von Mises Stress Plot of Rib with Cutouts:

In fig. 11 von mises stress plot of the wing rib without cutout of thickness 1mm shows when air pressure of 0.01 MPa on upper flange is applied. As a result, in the response of applied air pressure maximum von mises stress observed is 3.24 MPa at node 20760 on the both ends of wing rib without cutouts is given as:

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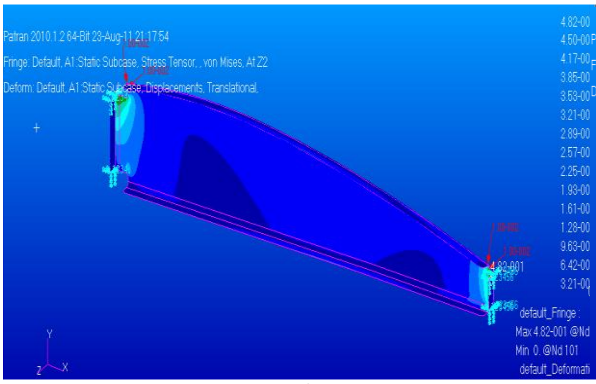

Fig.10Von Mises Stress Plot of Wing rib without Cutouts

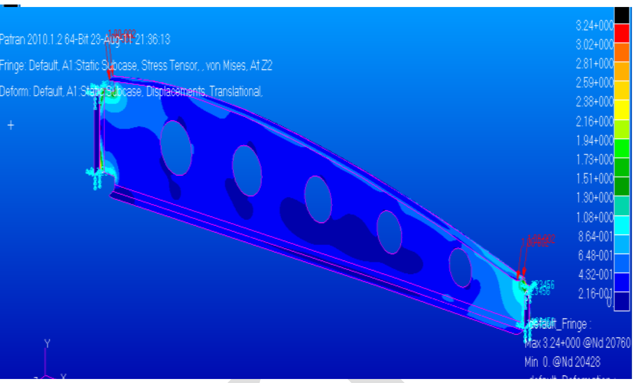

Fig.11Von Mises Stress Plot of Wing rib with Cutouts

VI. CONCLUSION

On conclusion, the work presented here depict the structural analysis of design of wing rib with and without cutouts when air pressure of 0.01 MPa is applied. This work was focused on the displacement and stress analysis of both types of wing ribs. The maximum deformation for wing rib without cutouts was less than the maximum deformation for wing rib with cutouts. Moreover, the maximum von mises stress for wing rib without cutouts was less than the maximum von mises for wing rib with cutouts. As a result, the advantage of wing rib with cutout is that it is lighter in weight and less expensive than wing rib without cutouts but in case of safety both types of wing ribs was safe.

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