IOSR Journal of Engineering (IOSR JEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 55-62

Design and Analysis of Wing Rib Using Finite Element Method

[1]J. Muthuraman, [2]Dr. M.Shankar, [3]M.Vivekanandhan
[1]PG Student, Department of Mechanical Engineering, Surya Group Of Institutions, Vikravandi, Villupuram, Tamil nadu-605 652
[2]professor, Department Of Mechanical Engineering, Surya Group of Institutions, Villupuram, Tamil nadu-605 652
[3]Assistant Professor, Department of Mechanical Engineering, Surya Group of Institutions Villupuram, Tamil nadu-605 652

Abstract: *In recent years, Composite materials have received considerable attention asalternatives to steel and aluminum as structural materials in the construction,automotive, marine and aerospace industries due to a variety of reasons; theseinclude a high strength-to-weight ratio, a high stiffness-to-weight ratio, corrosionand fatigue resistance, ease of handling, and ease of fabrication. Compositematerials have been employed due to their life-cycle cost competitiveness. Thisresearch paper deals with the design and analysis of aircraft structural wing-ribusing composite materials. The optimum design parameters for an aircraftstructural wing-rib are suitably selected based on the classical approach. The threedimensional structural wing-rib is designed based on the design parameters usingComputer Aided Design (CAD) software. The procedure of Finite ElementAnalysis and the detailed description about various Computer Aided Engineering(CAE) tools have been studied and implemented in this work. Designed threedimensional structural wing-ribs are exported to the CAE tool and Finite ElementModeling is prepared based on the design parameters. Composite Materialproperties and boundary conditions are executed with suitable conditions in CAEtool. Analysis is carried out for structural wing-ribs based on the various loadingconditions and various fiber orientations of composite materials. A complete set offinite element analysis were conducted on different fiber oriented compositesystems. Critical displacement and Stress tensor were obtained from FiniteElement Tool. The results are compared based on the fiber orientation.*

I. Introduction

Now a days, composite materials are used in large volume in various engineering structures including spacecrafts, airplanes, automobiles, boats, sports' equipment's, bridges and buildings. Widespread use of composite materials in industry is due to the good characteristics of its strength to density and hardness to density. The possibility of increase in these characteristics using the latest technology and various manufacturing methods has raised application range of these materials. Application of composite materials was generally begun only at aerospace industry in 1970s, but nowadays after only three decades, it is developed in most industries. Meanwhile, the automotive industry considered as a mother one in each country, has benefited from abilities and characteristics of these advanced materials. Along with progress in technology, metallic automotive parts are replaced by composite ones.

1.1 Properties of Composite Reinforcing Fibers.

Material	E (GPa)	σb (GPa)	εb (%)	P (Mg/m³)	E/ ρ (MJ/kg)	σb / ρ (MJ/kg)	Cost (Rs/kg)
E-Glass	72.4	2.4	2.6	2.54	28.5	0.95	61.6
S-Glass	85.5	4.5	2.0	2.49	34.3	1.8	1232-1848
Aramid	124	3.6	2.3	1.45	86	2.5	1232-1848
Boron	400	3.5	1.0	2.45	163	1.43	18480-24640
HS Graphite	253	4.5	1.1	1.80	140	2.5	3696-6160
HM Graphite	520	2.4	0.6	1.85	281	1.3	12320-36960

As seen in Table 1, [1] the fibers used in modern composites have strengths and stiffnesses far above those of traditional bulk materials. The high strengths of the glass fibers are due to processing that avoids the internal or surface flaws which normally weaken glass, and the strength and stiffness of the polymeric aramid fiber is a consequence of the nearly perfect alignment of the molecular chains with the fiber axis.

1.2 Aircraft Wing Ribs

In an aircraft, ribs are forming elements of the structure of a wing, especially in traditional construction. By analogy with the anatomical definition of "rib", the ribs attach to the main spar, and by being repeated at frequent intervals, form a skeletal shape for the wing. Usually ribs incorporate the airfoil shape of the wing, and the skin adopts this shape when stretched over the ribs.

For aerodynamic reasons the wing contour in the chord direction must be maintained without appreciable distortion. Unless the wing skin is quite thick, span wise stringers must be attached to the skin in order to increase the bending efficiency of the wing. Therefore to hold the skin-stringer 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 required. These structural units are referred to as wing ribs.

1.3 Types of Wing Ribs

There are several types of ribs. Based on manufacturing ribs are classified as

- Form-ribs
- Plate-type ribs
- Truss ribs
- Closed ribs
- Forged ribs
- Milled ribs

II. Literature Survey

RaminSedaghati et al (2006)

This paper explains the improvement of the available structural analysis modules and performs a structural design optimization of the wing box by adding an optimization loop around the analysis code. The objective is to design a wing-box more rapidly and automatically.

Muhammed Mushin el al (2013)

This paper explains about the usage of composite materials to reduce the weight. In order to increase the buckling strength of the plate,the number of holes has to be increased. Meanwhile stress in the component keeps on increased as the number of holes increased. A complete stress analysis for a wing rib subjected to different kinds of loading is introduced.

Pugazhenthi.et al (2013)

A monocoque aircraft wing is made of laminated composite with fiber angles in each ply aligned in different direction. Various airfoil thickness and ply angles were considered to study the effect of bending-torsion decoupling

Lohithet al (2014)

This paper discusses about the efficient design of Aircraft components that are required to reduce the cost. For components with compressive loading, ribs and stringer spacing and stringer cross-section play a major role for weight efficient design and weight.

III. Design Overwiew

The total rib design consideration is based on the airfoil section which is referred from above section. The total number of ribs, web and Rib panels are employed from various design configurations.

Number of spars = 2

Number of web = 2

Panels = 3

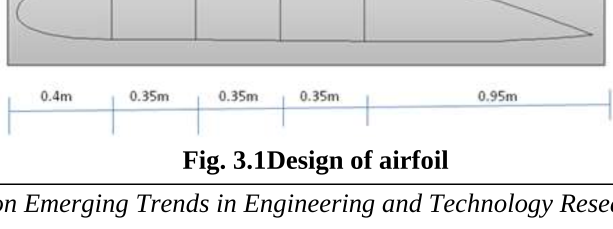


Fig. 3.1Design of airfoil

Thickness of skin = 0.02m

3.1 Wing Rib Aero foil Specifications

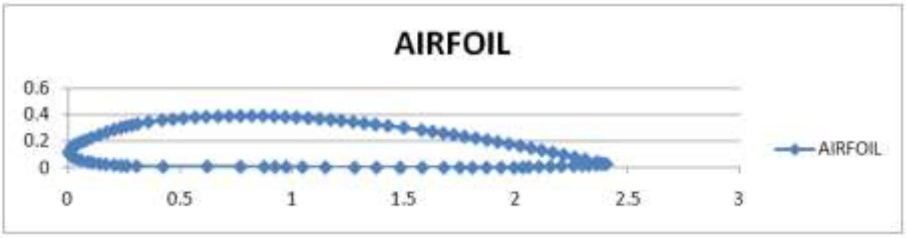


Fig. 3.2Wing Rib Aero foil

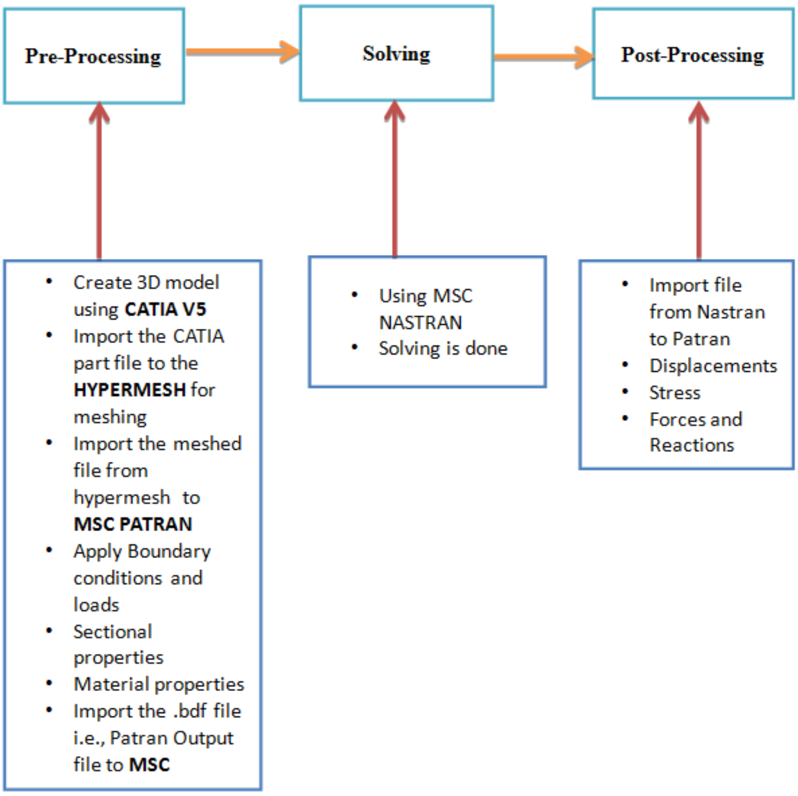
Length(m)	X	2.401824
Height(m)	Y	0.392986

3.2 Material Properties:

Properties of a carbon/epoxy lamina are considered for this analysis. Material properties are referred from "DEPARTMENT OF DEFENSE HANDBOOK" in composite materials handbook volume 3. Polymer matrix composites materials usage, design, and analysis. The material properties are mentioned below.

1. Young's modulus along axis 1 (E_1) = 172 Gpa
2. Young's modulus along axis 2 (E_2) = 12 Gpa
3. Shear modulus (G_{12}) = 4.5 Gpa
4. Poisson's ratio (ν_{12}) = 0.30
5. Density (ρ) = 1550 kg/m3
6. Stress in axis 1 (F_1) = 760 Mpa
7. Stress in axis 2 (F_2) = 28 Mpa
8. Stress in axis 12 (F_{12}) = 62 Mpa
9. Thermal expansion along axis 1 (α_1) = 0.54x10-6 mm/mm/C°
10. Thermal expansion along axis2 (α_2) = 35.1x10-6 mm/mm/C°

3.3 Problem Solving Process



4. ANALYSIS OF WING RIB

Since shell element is having 6 Degrees of freedom, all 6 Degrees of freedom is constraint at the spar locations.

4.1 X Component Stress

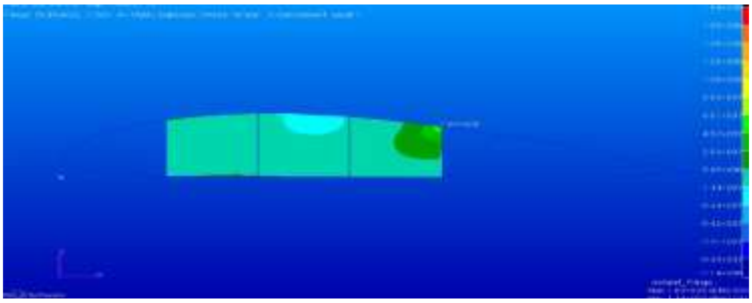


Fig. 4.1X Component Stress

a) Max. Tension Stress = 1.84E8 Pascal,
b) Max. Compression Stress = -1.14E8 Pascal

4.2 Y Component Stress

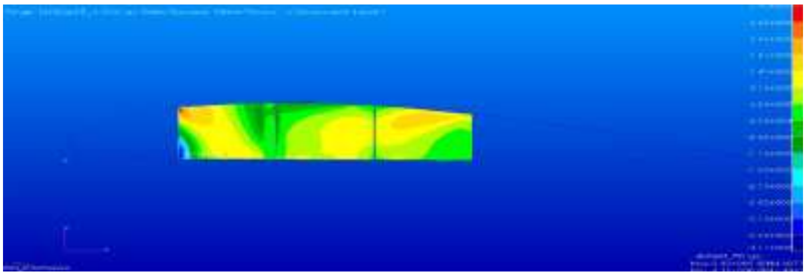


Fig.4.2Y Component Stress

a) Max. Tension Stress = 3.42 E6 Pascal,
b) Max. Compression Stress = -4.11E6 Pascal

4.3 XY Component Stress

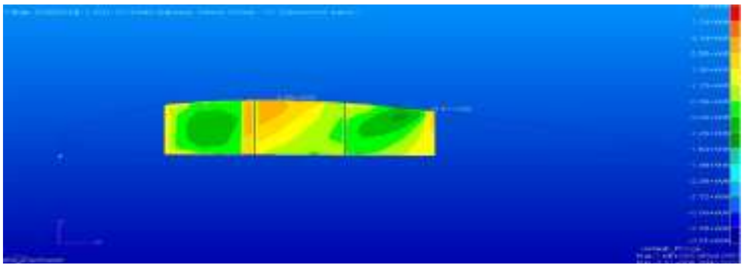


Fig.4.3XY Component Stress

a) Max. Tension Stress = 1.65E6 Pascal,
b) Max. Compression Stress = -3.81E6 Pascal

4.4 X Component Stress

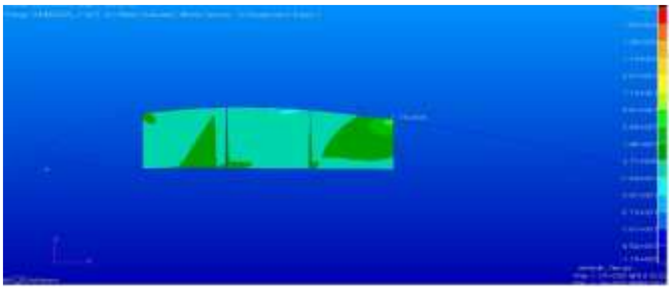


Fig.4.4X Component Stress

a) Max. Tension Stress = 1.7E8 Pascal,
b) Max. Compression Stress = -1.15E8 Pascal

4.5 Y Component Stress

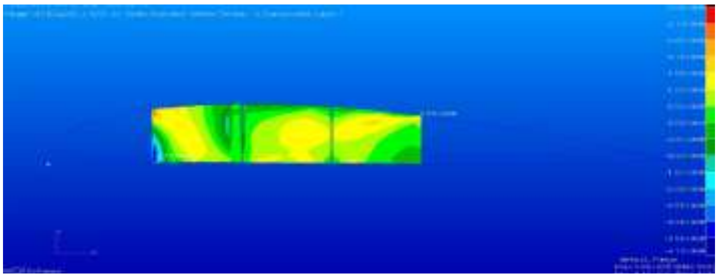


Fig.4.5Y Component Stress

a) Max. Tension Stress = 3.65E6 Pascal,
b) Max. Compression Stress = -4.10E6 Pascal

4.6 XY Component Stress

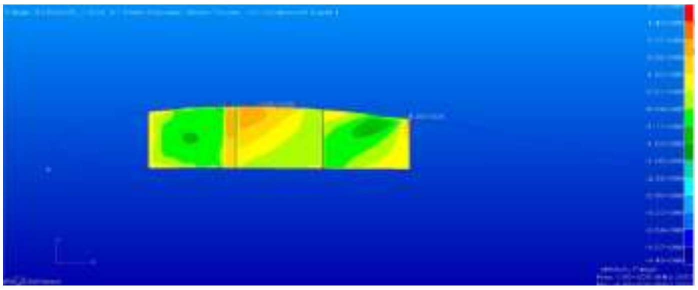


Fig.4.6 XY Component Stress

a) Max. Tension Stress = 1.85E6 Pascal,
b) Max. Compression Stress = -4.49E6 Pascal

IV. Result Validation

5.1 ITERATION 1: 0/45/90/90/45/0

Orientation Detail		X Direction		Allowable considered	RF in tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/45/90/90/45/0	Layer 1	204295152	-120383104	760000000	3.72	6.31	3.72
	Layer 2	34252396	-37941276	760000000	22.19	20.03	
	Layer 3	22130704	-36845248	760000000	34.34	20.63	
	Layer 4	65532040	-40580336	760000000	11.60	18.73	
	Layer 5	55600776	-49659020	760000000	13.67	15.30	
	Layer 6	133911024	-174860992	760000000	5.68	4.35	

Orientation Detail		Y Direction		Allowable considered	RF in tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/45/90/90/45/0	Layer 1	3930982	-4663110.5	28000000	7.12	6.00	2.50
	Layer 2	11004487	-5261050	28000000	2.54	5.32	
	Layer 3	11202616	-6974120.5	28000000	2.50	4.01	
	Layer 4	9815930	-6444062.5	28000000	2.85	4.35	
	Layer 5	9027870	-6150916	28000000	3.10	4.55	
	Layer 6	11115873	-7396589.5	28000000	2.52	3.79	

Orientation Detail		XY Direction		Allowable considered	RF in tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/45/90/90/45/0	Layer 1	2114860.75	-3821076.75	68000000	32.15	17.80	13.50
	Layer 2	3272625.25	-5038519.5	68000000	20.78	13.50	

	Layer 3	3380191.5	-1443327.125	68000000	20.12	47.11	
	Layer 4	3495811.75	-2087791.75	68000000	19.45	32.57	
	Layer 5	3457449	-4239710	68000000	19.67	16.04	
	Layer 6	3659359.25	-4261850.5	68000000	18.58	15.96	

5.2 ITERATION 2: 0/30/60/60/30/0

Orientation Detail		X Direction		Allowable considered	RF in Tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	pa			
0/30/60/60/30/0	Layer 1	192549280	-123007712	760000000	3.95	6.18	3.95
	Layer 2	69458016	-64437180	760000000	10.94	11.79	
	Layer 3	20166458	-48855852	760000000	37.69	15.56	
	Layer 4	43831444	-39433676	760000000	17.34	19.27	
	Layer 5	67212280	-77829688	760000000	11.31	9.76	
	Layer 6	121874760	-174610160	760000000	6.24	4.35	

Orientation Detail		Y Direction		Allowable considered	RF in Tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	pa			
0/30/60/60/30/0	Layer 1	4563441	-6965412	28000000	6.14	4.02	1.43
	Layer 2	8806789	-5237697.5	28000000	3.18	5.35	
	Layer 3	11700238	-6887546.5	28000000	2.39	4.07	
	Layer 4	10424863	-7000794.5	28000000	2.69	4.00	
	Layer 5	16429572	-7601491.5	28000000	1.70	3.68	
	Layer 6	19588588	-10125427	28000000	1.43	2.77	

Orientation Detail		XY Direction		Allowable considered	RF in Tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/30/60/60/30/0	Layer 1	2469168.5	-4569447	68000000	27.54	14.88	11.53
	Layer 2	3372395.5	-5707910	68000000	20.16	11.91	
	Layer 3	2840255.75	-2287847.5	68000000	23.94	29.72	
	Layer 4	4735513.5	-2391659.5	68000000	14.36	28.43	
	Layer 5	3474274.25	-4966677	68000000	19.57	13.69	
	Layer 6	4069480	-5899166.5	68000000	16.71	11.53	

5.3 ITERATION 3: 0/15/30/30/15/0

Orientation Detail		X Direction		Allowable considered	RF in Tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/15/30/30/15/0	Layer 1	179293568	-125930264	760000000	4.24	6.04	4.24
	Layer 2	98628808	-85629480	760000000	7.71	8.88	
	Layer 3	27107882	-21690516	760000000	28.04	35.04	
	Layer 4	43506060	-28955076	760000000	17.47	26.25	
	Layer 5	69719672	-98682888	760000000	10.90	7.70	
	Layer 6	103801240	-163448720	760000000	7.32	4.65	

Orientation Detail		Y Direction		Allowable considered	RF in Tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/15/30/30/15/0	Layer 1	6726740	-11302622	28000000	4.16	2.48	1.00
	Layer 2	4029955.75	-5564220.5	28000000	6.95	5.03	
	Layer 3	8808876	-4189188.5	28000000	3.18	6.68	
	Layer 4	15708963	-7521310.5	28000000	1.78	3.72	
	Layer 5	22994844	-11484183	28000000	1.22	2.44	
	Layer 6	28113520	-14592349	28000000	1.00	1.92	

Orientation Detail		XY Direction		Allowable considered	RF in Tension	RF in Compres-sion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/15/30/30/15	Layer 1	2800086.5	-6192761	68000000	24.28	10.98	9.20

/0	Layer 2	3846558.25	-7388821.5	68000000	17.68	9.20	
	Layer 3	4420469.5	-6851313.5	68000000	15.38	9.93	
	Layer 4	4523442.5	-6548990.5	68000000	15.03	10.38	
	Layer 5	5133705	-7323011.5	68000000	13.25	9.29	
	Layer 6	5545407	-7165525.5	68000000	12.26	9.49	

5.4 ITERATION 4: 0/10/20/20/10/0

Orientation Detail		X Direction		Allowable considered	RF in Tension	RF in compre-ssion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/10/20/20/10/0	Layer 1	104393488	-89248568	760000000	7.28	8.52	7.28
	Layer 2	38472724	-37782780	760000000	19.75	20.11	
	Layer 3	42568296	-28734526	760000000	17.85	26.45	
	Layer 4	68067544	-39001244	760000000	11.17	19.49	
	Layer 5	88975800	-52174960	760000000	8.54	14.57	
	Layer 6	88975800	-52174960	760000000	8.54	14.57	

Orientation Detail		Y Direction		Allowable considered	RF in Tension	RF in compre-ssion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/10/20/20/10/0	Layer 1	4674236	-5815850.5	28000000	5.99	4.81	0.91
	Layer 2	9276381	-3727066.75	28000000	3.02	7.51	
	Layer 3	17279400	-4981698	28000000	1.62	5.62	
	Layer 4	24612872	-8970546	28000000	1.14	3.12	
	Layer 5	30613728	-12451080	28000000	0.91	2.25	
	Layer 6	30613728	-12451080	28000000	0.91	2.25	

Orientation Detail		XY Direction		Allowable considered	RF in Tension	RF in compre-ssion	Critical RF
		Max Stress	Min Stress				
		Pa	Pa	Pa			
0/10/20/20/10/0	Layer 1	3696555.75	-7645084.5	68000000	18.40	8.89	7.67
	Layer 2	4580710.5	-7645262	68000000	14.84	8.89	
	Layer 3	4975556.5	-7817925	68000000	13.67	8.70	
	Layer 4	5858518.5	-8304328	68000000	11.61	8.19	
	Layer 5	6583196	-8865250	68000000	10.33	7.67	
	Layer 6	6583196	-8865250	68000000	10.33	7.67	

V. Conclusion

6.1 RF COMPARISON FOR DIFFERENT PLY ORIENTATIONS

Most reliable ply orientation based on stresses in X, Y & XY Components is 0/45/90/90/45/0

ITERATIONS	Ply Orientation	Critical RF in X direction	Critical RF in Y direction	Critical RF in XY direction
Iteration 1	**0/45/90/90/45/0**	**3.72**	**2.50**	**13.50**
Iteration 2	0//30/60/60/30/0	3.95	1.43	11.53
Iteration 3	0/15/30/30/15/0	4.24	1.00	9.20
Iteration 4	0/10/20/20/10/0	7.28	0.91	7.67

6.2 DEFLECTION PLOTS FOR DIFFERENT PLY ORIENTATION

ITERATIONS	Ply Orientation	Resultant deflection in mm
Iteration 1	**0/45/90/90/45/0**	**1.91**
Iteration 2	0//30/60/60/30/0	1.93
Iteration 3	0/15/30/30/15/0	1.99
Iteration 4	0/10/20/20/10/0	1.99

Minimum Resultant deflection = 1.91 mm

Based on stresses in X, Y and XY directions, iteration 1 gives more reliable than any other ply orientation. Based on Resultant deflection values, iteration 1 gives minimum resultant deflection value of 1.91 mm. Hence it is reasonable to conclude that iteration 1 is more reliable ply orientation for modeling of composite wing-rib. We can conclude that ply orientation of 0/45/90/90/45/0 is safer based on strength values of the composite wing ribs.

References

[1]. The Design Of Airplane Wing Ribs- Naca Report No. 345
[2]. By J.A. NewlinAndGeo.W.Trayer – Forest Products Laboratory
[3]. Department Of Defence Handbook – Hdbk17-1f – Polimer Matrix Composites Guidelines For Characterizaton Of Structural Material
[4]. RaminSedaghati, Ph.D, P.Eng. (Jun 2006) 'Wing Rib Stress Analysis And DesignOptimization'
[5]. Bindu ,Muhammad Muhsin Ali, (Feb 2013) 'Design And Analysis Of A Typical Wing Rib For Passenger Aircraft'
[6]. Arunkumar K. N.1 And Lohith N.2, (Jul 2013)'Effect Of Ribs And Stringer Spacings On The Weight Of Aircraft Composite Structures'
[7]. Dr.R.Rajappan, V.Pugazhenthi, (Apr 2014) 'Finite Element Analysis Of Aircraft Wing Using Composite Structure'