Finite element analysis of aircraft wing utilizing various types of materials

Y V V Satyavathi [1], Dr.Chirra Kesava Reddy [2]

[1]Asst.Prof, Department of Mechanical Engineering, Rishi MS Institute of Engineering and Technology for Women, Near JNTUH, Kukatpally, Hyderabad, Telengana, India-500090

[2]Associate.Prof, Department of Mechanical Engineering, SRTIST, Ramananda Nagar, Nalgonda, Telengana, India-508004

Abstract - The structural component of aircraft which is being utilized for producing the lift during the flight is known as wing. The wing gets inclined during the initial stage at specific angle of attack. The lift force gets generated in the wing because of the pressure variation at top and bottom surfaces of the wing, this takes place when the flow is passing through it. The major goal of this analysis is to examine the wing of an aircraft utilizing the Carbon fiber reinforced polymer [CRFP], Glass fiber reinforced polymer [GRFP] and both gets compared with the A1 alloy for determining the appropriately suitable material for wing. The software which is utilized for designing the wing is solid modeling software CATIA V5 R20 and the method utilized for analyzing the technique is finite element method. This finite element method takes the help of ANSYS. Static structural analysis plays a major role in designing of the wing as it helps in determining the deformation, stress, and strain which is persuaded in the structure of the wing. The major aim of the modal analysis is to determine the natural frequency of the wing for the purpose of reducing the noise and overcoming the vibrations. Finally fatigue life analysis is carried out to find out the damage, life and factor of safety of the wing due to applied pressure loads. In this study, the trainer aircraft wing structure with skin, 2 spars and 15 ribs is considered for the analysis. The ribs are running from leading edge to trailing edge and 2 spars running longitudinally along the length of wing. Front spar is made "I" section and rear spar having "C" section according to design.

I. INTRODUCTION

The wing is mentioned to be a primary structural component of aircrafts which will be helpful in developing the lift force during the flight. When the engine present in the flight gets started working the air which will come out from the engine gets sucked into the compressor through the inlet pressure ratio at the exit of the compressor. After this the air and fuel present in the compressor gets mixed inside the combustion chamber and burnt. During sometimes high pressure and high temperature gases gets accelerated through the nozzle, at this condition force known as thrust force will be produced. This force helps in propelling the aircraft in forward motion. Because of this forward motion, air flow takes place in the wing, this flow will be aerodynamic in shape. Because of the aerodynamic shape of the wing including Bernoulli's principle the velocity of the flow gets reduced at bottom of the wing and becomes high at top of the wing. The lift gets produced because of the pressure variations present in the top and bottom surfaces of the wing [1]. As the wing is subjected to alternate repeated loading, it should consist of high strength to weight ratio. The major goal of this examination or the study is to determine the appropriate material which is suitable for the wing like composite which helps in replacing the conventional Aluminium 2024 T3 [Al-2024 T3]. Conventional Aluminium 2024 T3 [Al-2024 T3] is utilized for producing the skin of the wing. Airfoil is considered as the cross-section of the wing. The shape of the wing will be aerodynamic in shape, this shape helps in reducing the drag [3]. The aerodynamic efficiency of wing is expressed in terms of lift/drag ratio. The two other structural components which are present in aircraft are Fuselage and empennage. Fuselage houses passengers, crew, and cargo etc. Empennage gives the better stability to the aircraft during the flight. The name of the material which is majorly utilized while developing the structure of the aircraft is Aluminum. The approximate quantity of the aluminum material which is taken for developing the wing will be nearly 80% [5]. Composite material is made by taking the help of the two materials they are matrix and reinforcement material. Matrix helps in surrounding and binding the reinforcement material [6]. The matrix material which is utilized in this analysis is epoxy and fiber is considered as the reinforcement materials. The fiber may be either glass fiber or the carbon fiber or any other type of fiber. A composite laminate is an assemblage of layers of fibrous materials like carbon fibers, glass fibers, aramids lay in the matrix material which can be combined for providing the necessary specific and desired properties [9]. The formation of the laminate takes place when individual laminas gets stacked one above the other in the desired orientation. The load will be carried by the fiber which is embedded in the lamina in vatious orientations.

II. MATERIALS AND METHODS

For achieving the clear analysis, the developers considered skin, spars and ribs as their trainer aircraft wing structures. The quantity of ribs present in this wing structure is 15 and two spars with skin are taken. If observed front spar consists of "I" section and the rear spar consists of "C" section

Table 1: Input parameters of wing design

Parameters	Dimensions
Root Chord	2400 mm
Tip Chord	700 mm
Semi span length	5500 mm
Exposed Length of wing	4750mm
Airfoil $(root)$	NACA-64A215
Airfoil (Tip)	NACA-64A210
Front Spar	18-25% of chord
Rear Spar	62-70% of chord

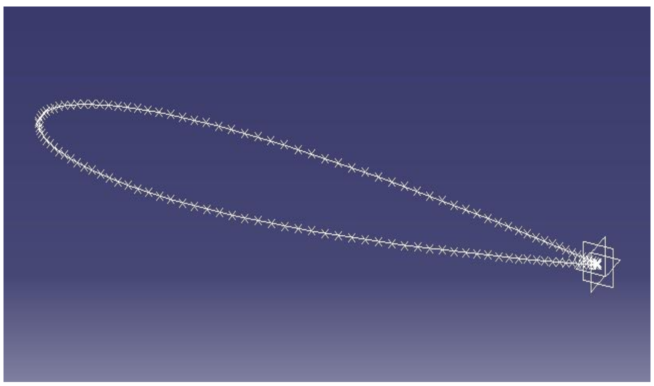

Fig 1: Airfoil Co-ordinates

The airfoil co-ordinate has been taken from the NASA website and then exported it to Microsoft Excel. By taking the help of the macros the developers shaped the airfoil in Catia format. The airfoil basically partitioned into 15 sections at an equal distance from the reference plane with thickness of 100mm [3]. The creation of the frontspar, rearspar, and holes are done with respect to the assumptions. For importing the CAT file into the analysis workbench, the file should be initially converted into IGS format.

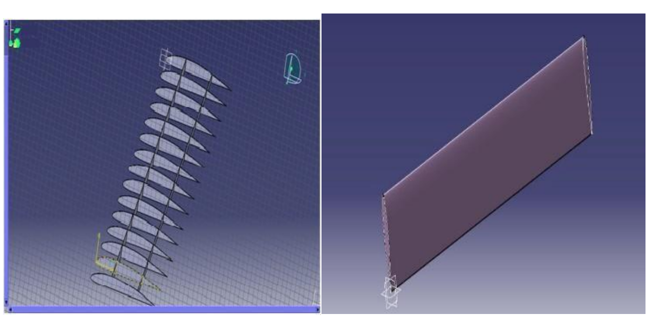

Fig 2: Wing Structure

2.1 Characteristics of the material

Ex, Ey and Ez are considered as the young's modulus along the X, Y, and Z directions respectively. μ(xy), μ(yz), μ(zx) are Poison's ratio in xy, yz, and zx plane respectively. Gxy, Gyz and Gzx are modulus of rigidity in xy, yz and zx plane respectively. The properties of the material are taken from various research papers which are [3, 4, 7, 8, 10] and get matched with the library known as Ansy library.

Table 2: Material Properties

Materials	Epoxy - carbon	Epoxy-Carbon	Epoxy	EpoxyS -	Al-2024 T3
	UD	Woven	EGlass	Glass	
Ex(Gpa)	**121**	**61.34**	**45**	**50**	
Ey(Gpa)	**8.6**	**61.34**	**10**	**8**	**73.1**
Ez(Gpa)	**8.6**	**6.9**	**10**	**8**	
μ(xy)	**0.27**	**0.04**	**0.3**	**0.3**	
μ(yz)	**0.4**	**0.3**	**0.4**	**0.4**	**0.33**
μ(zx)	**0.27**	**0.3**	**0.3**	**0.3**	
Gxy(Gpa)	**4.7**	**19.5**	**5.0**	**5.0**	
Gyz(Gpa)	**3.1**	**2.7**	**3.846**	**3.486**	**26.6**
Gzx(Gpa)	**4.7**	**2.7**	**5.0**	**5.0**	
ρ(kg/m^3)	**1490**	**1420**	**2000**	**2000**	**2770**

2.2 Boundary conditions

The figure 3 represents the loads and boundary conditions including the finite element model. One of the ends will be fixed in the wing as it is embedded inside the fuselage and other end is left free with degree freedom. The value of the pressure applied for the bottom surface of the wing is 500Pa. Center of the pressure is nothing but the point at which entire pressure is considered to be working [2].

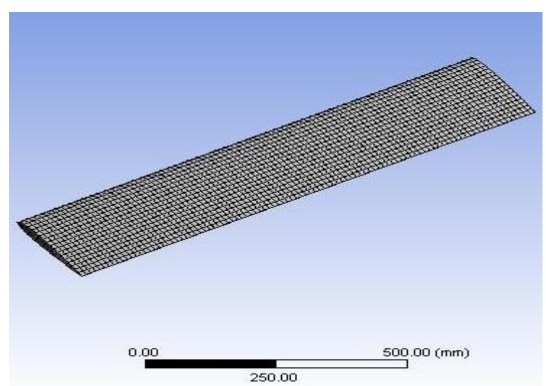

Fig 3: Mesh

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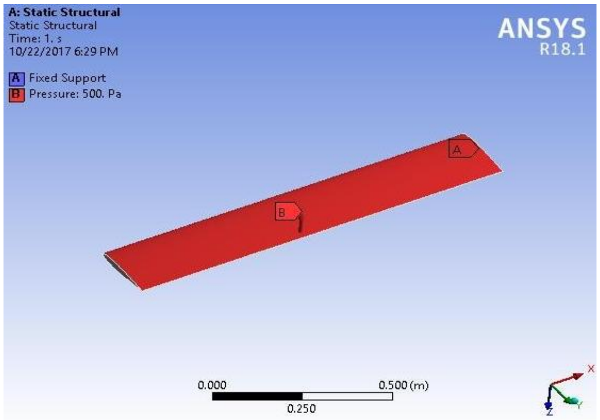


Fig 4: Boundary Condition

III. RESULT AND ANALYSIS

3.1 Static structural results

Materials	Total Deformation (mm)	Equivalent stress (Mpa)	strain
Epoxy-carbon UD	**4.223**	**16.225**	**0.00016508**
Epoxy S-glass UD	**9.8794**	**16.145**	**0.00040288**
Aluminum	**6.7377**	**16.034**	**0.00022722**
Epoxy-carbon	**7.9845**	**15.709**	**0.00030371**
Woven Epoxy E-glass	**10.943**	**15.943**	**0.00044117**

Table 4a: Mathematical structural analysis under various speed levels for Epoxy–carbon UD

Material	**speed km/hr**	**Total deformation mm**	**Equivalent stress [Mpa]**	**Equivalent strain**
Epoxy–carbon UD	200	4.1013	17.382	0.00018043
Epoxy–carbon UD	400	4.1106	48.259	0.00048840
Epoxy–carbon UD	600	4.1501	102.69	0.00010383
Epoxy–carbon UD	800	4.2540	179.16	0.00181151
Epoxy–carbon UD	1000	4.451	277.62	0.00280721

Table 4b: Mathematical structural analysis under various speed levels for Epoxy S-glass UD

Material	**speed km/hr**	**Total deformation mm**	**Equivalent stress [Mpa]**	**Equivalent strain**
Epoxy S-glass UD	200	9.7966	20.068	0.00049880
Epoxy S-glass UD	400	9.8664	62.051	0.00153883
Epoxy S-glass UD	600	10.086	133.82	0.00331862
Epoxy S-glass UD	800	10.597	234.77	0.00582183
Epoxy S-glass UD	1000	11.611	364.71	0.00904401

Table 4c: Mathematical structural analysis under various speed levels for Aluminum 2024 T3

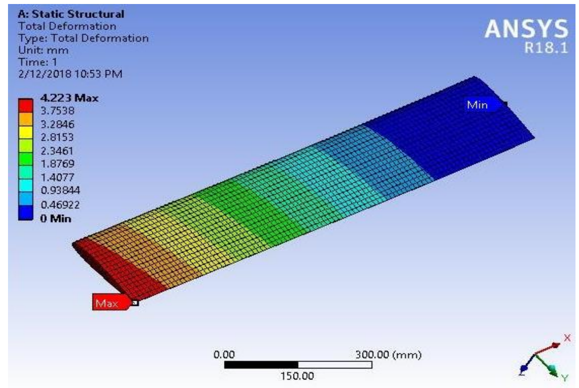
Material	**speed km/hr**	**Total deformation mm**	**Equivalent stress [Mpa]**	**Equivalent strain**
Aluminum 2024 T3	200	6.6401	25.051	0.00035280
Aluminum 2024 T3	400	6.7384	84.141	0.00118511
Aluminum 2024 T3	600	7.0510	183.79	0.00258862
Aluminum 2024 T3	800	124. 94	321.76	0.00453193
Aluminum 2024 T3	1000	462.41	502.04	0.00707101

Table 4d: Mathematical structural analysis under various speed levels for Epoxy–carbon Woven

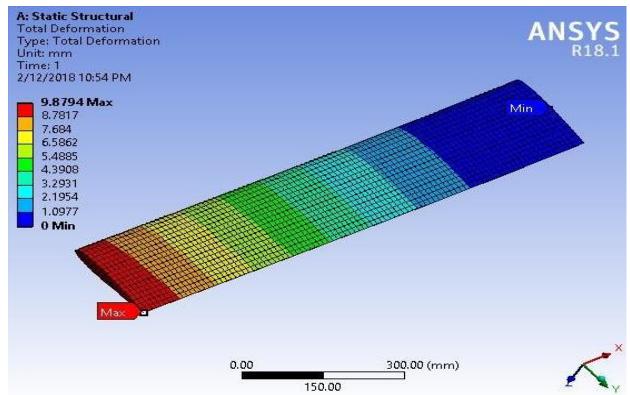
Material	speed km/hr	Total deformation mm	Equivalent stress [Mpa]	Equivalent strain
Epoxy–carbon Woven	200	8.2013	17.080	0.00033361
Epoxy–carbon Woven	400	8.2590	46.266	0.00089541
Epoxy–carbon Woven	600	8.3816	98.275	0.00190540
Epoxy–carbon Woven	800	8.6483	171.33	0.00331470
Epoxy–carbon Woven	1000	9.1602	265.43	0.00513490

Table 4e: Mathematical structural analysis under various speed levels for Epoxy E-glass

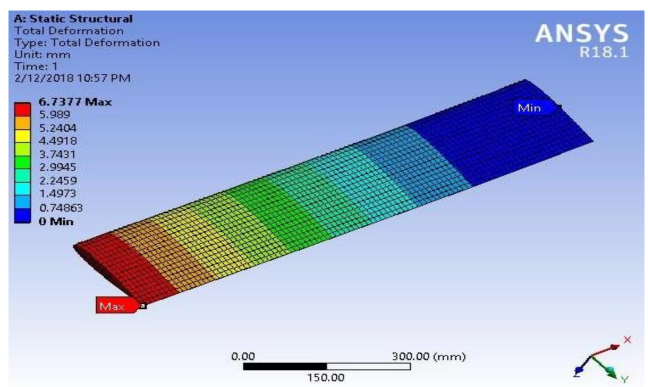
Material	speed km/hr	Total deformation mm	Equivalent stress [Mpa]	Equivalent strain
Epoxy E-glass	200	10.847	20.066	0.00054441
Epoxy E-glass	400	10. 927	62.048	0.00168010
Epoxy E-glass	600	11.175	133.82	0.0032340
Epoxy E-glass	800	11.749	234.77	0.00635650
Epoxy E-glass	1000	12.886	364.70	0.00987450



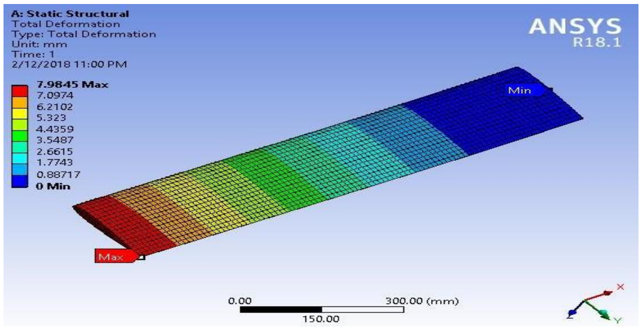
(a): Total deformation utilizing Epoxy-Carbon UD



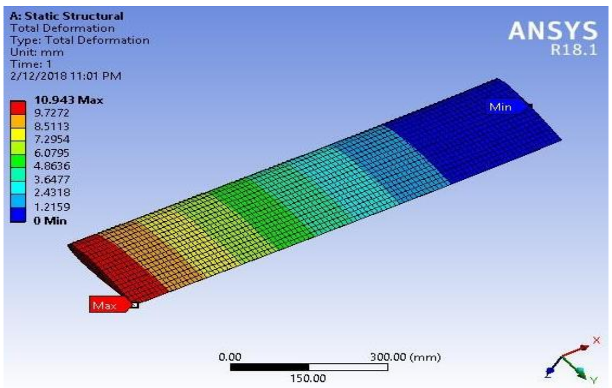
[b]: Total deformation utilizing Epoxy S-Glass



[c]: Total deformation utilizing Alluminium 2024 T3



[d]: Total Deformation utilizing Epoxy-carbon Woven



[e] Total Deformation utilizing Epoxy E-Glass

3.2 Result of the Modal Analysis

The study of dynamic properties present in the vibrating structures is specified to be the modal analysis. It is highly utilized for finding the continuous structural members natural frequency. One has to acquire very less frequency as an output for better working. If there is lesser frequency then the vibrations will also be less and vice versa. If observed from the modal analysis the UD which consists of highest natural frequency is Epoxy-carbon UD. If the frequency is high, then it leads to the delay in the resonance.

Table 5: Natural Frequency [HZ] for various materials

Mode shape	EpoxyCarbon UD	Epoxy S glass	Aluminum 2024 T3	EpoxyCarbon Woven	EpoxyE glass
1	20.136	11.205	11.446	14.698	10.636
2	95.864	69.375	71.416	91.124	65.959
3	124.56	83.381	91.407	118.07	83.099
4	149.56	87.626	159.48	177.87	83.444
5	295.95	191.28	198.73	250.95	182.07
6	339.32	253.22	385.80	480.17	252.29

Table 6: Maximum amplitude[mm] of vibration

Mode shape	EpoxyCarbon UD	Epoxy S glass	Aluminum 2024 T3	EpoxyCarbon Woven	EpoxyE glass
1	0.84036	0.7176	0.60774	0.84665	0.7172
2	1.38780	0.8117	0.61325	0.85416	0.7855
3	1.10660	1.3689	0.60580	0.84461	1.3456
4	0.79319	0.7027	1.08580	1.50790	0.7043
5	1.63000	0.7843	0.62033	0.85557	0.7491
6	1.61390	1.4494	0.63568	0.90700	1.4152

3.3 Fatigue Life Analysis results

Table 7: Fatigue life Analysis data

Materials	Life	Damage	Factor of Safety
Epoxy-Carbon UD	1e8	10	5.1696
Epoxy-Carbon Woven	1e8	10	5.2869
Aluminum 2024-T3	1e8	10	5.2344
Epoxy S-Glass	1e6	1000	5.4533
Epoxy E-Glass	1e6	1000	5.4533

3.4 Results

As per the calculations which are done on the basis of the requirement of the design, the modeling of wing of a trainer aircraft with 15 ribs and 2 spars was done by taking the help of the CATIA V5R20. CATIA V5R20 is a designing software. the finite element examination is done for determining the various parameters like deformation, stress, strain, frequency and wing's lifetime. The structural examination is done by taking the help of the materials like Epoxy-Carbon UD, Epoxy-Carbon Woven, Epoxy S-Glass, Epoxy E-Glass and Aluminum 2024-T3. These materials are brought into action in the device by using the structure known as ANSYS Static structure. The modal analysis is done for determining the frequency and maximum amplitude of vibration of wing for the same material. From the outcomes executed in the examination the developers came into a conclusion that epoxy-carbon is highly efficient and appropriate material for this analysis as compared with the aluminum 2024-T3. This is because it provides good strength to the device, consists of low weight, and deformation is as minimum as possible. If observed in graph 1 one can come to understand that if the rotational speed increases then the deformation and stress value also gets increased and vice versa. But for the aluminum 2024-T3 the deformation curve abruptly increases beyond 00rad/sec. different mode shapes have been designed from the modal analysis for various materials for the purpose of determining the natural frequency and highest better amplitude of vibration. The count of different mode shapes is 6. Lower the frequency lesser the vibration. Hence lowest frequency is taken into the consideration. The results will not be similar to all the products. The results get varies with respect to the type of the aircraft wing utilized and the design of the air craft wing.

IV. CONCLUSION

For the results acquired one can come to a conclusion that Epoxy-Carbon UD consists of efficient structural features as compared with the other materials. Deformation will be less, strength is high, and consists of very light weight as compared with the remaining materials. Hence, Epoxy-Carbon is appropriate for designing the aircraft wing.

As future enhancement, different materials can be tested with different boundary conditions to find more suitable materials with good aerodynamic and structural characteristics, number of main load carrying members can be changed and analysis can be performed.

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