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FINITE ELEMENT ANALYSIS OF AIRCRAFT WING USING ALUMINUM ALLOYS

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ABSTRACT

The aircrafts airfoil is the one that determines the soothing maneuvers between an airflow and lift. The airfoil design must be swafted is such manner that it generates a maximum lift angle without breaking up the successive layers of the aerodynamic characters. This research is initiated by scrutinizing various articles and research papers across the relevant field to suit appropriate alloys. Thereby this paper focuses on NACA 64A21X series airfoil coordinates and these modelled wings were referred from referral journals. The same was later compared with our chosen materials of Aluminum 2055 T85, 7475 T351 and ideal materials like Epoxy Carbon woven, Epoxy E- Glass, Epoxy S- Glass and Al 2024 T3 for differentiation of data. Initially the CAD models were retrieved under standard formats and discretized under fine meshes of hexahedral elements. The same model is made to undergo series of static analysis, modal analysis cum fatigue test. The data retrieved from post analysis is later analyzed by schematically formulating in tabular columns and charts. On further, comparisons are done to understand its behavior. Finally, the chosen materials of Aluminum 2055 T85 and 7475 T351 when incorporated with wing design yielded improved results.

Keywords: NACA, Airfoil, Lift Angle, Epoxy, Hexahedral Elements, Fatigue Test.

I. INTRODUCTION

The evolution of aircrafts wing era dates back to 19th century, were mankind had extensive curiosity on the existence and improvisation of it. This curiosity magnitude rose consecutive over all the period of time due to modernization of technologies. Upon referring the pattern from piloting a basic manual aircraft to completely unmanned aerial vehicle, there is always an upper hand for endless research work for their wing's structural improvements. On disintegrating the complex wing structure, we end up to the basic 2D curvature regions of the wing i.e., airfoil geometry. Numerous geometry profile has been widely accepted throughout the globe, and the lead who assigns this nomenclature is NACA organization who fortify this research across aeronautical field. Extensive research is dominantly available for determining the behavior of the wing structure when assigning light weight with high stiffness characteristics. Use of aluminum alloys across this aeronautical field have played vital role right from the beginning.

This research study has been initiated from choosing NACA-64A21X series of airfoil geometry. By generating a 3D CAD model of the chosen airfoil geometry and assigning various aluminum alloys and composite materials across the FEA tools. Determine their behaviors across assigning notorious loads, gives us the insight of how the material responds to such activities. These data are vital for engineers to stick on to which material optimization holds good within their radar of choices. In order to comparatively study 2 categories of models are set for this research work i.e., custom models and ideal models. Their extrapolated details have been listed along the material assigning section listed at forthcoming topic.

II. RESEARCH GAP

On conducting various literature survey and literature review across the wing modification based on material variation, the following points were concluded with regard to this research study:

- The wing model of NACA-64A21X series are still available to conduct test for varying material property along with orthotropic and major light weight alloys.
- Current trend on modified alloys of Aluminum can be assigned to observe the mechanical behavior of wing profiles.

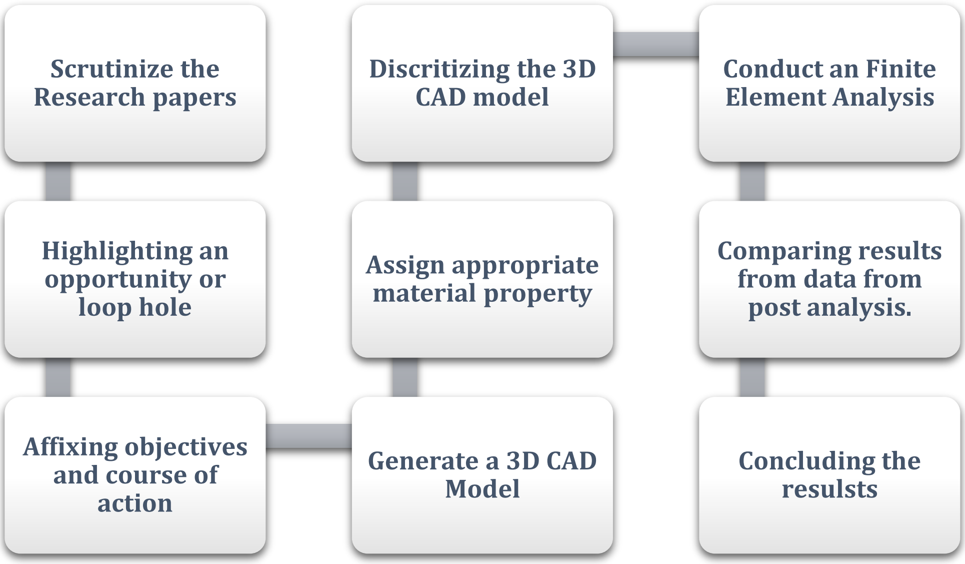
- ❖ The above assigned material wings can be subjected to static analysis and dynamic analysis test under virtual simulations.

III. OBJECTIVE

The main objective taken along the venture of this research study is listed below:

- ❖ To study and encapsulate the behavior of static analysis and dynamic behavior in trainer aircraft wing structure of NACA-64A21X airfoil series.
- ❖ Compare aluminum alloy of 2055 T85 and 7475 T7351 series with ideally chosen materials of Epoxy E-Glass, Epoxy S-Glass, Epoxy carbon woven and Al 2024 T3 by observing their behaviors in FEA analysis.
- ❖ Justify the retrieved data from post analysis and concluding the aforementioned wings performance with use of 2055 T85 and 7475 T735 materials across the aircraft industry.

IV. METHODOLOGY



V. MODELING AND ANALYSIS

1. Generate an appropriate 3D CAD model

In accordance with this study an augmented 3D model had to be virtually crated for analysis purpose under computational type. Thereby a powerful modelling tool of CATIA V5 is used for generating a wing structure of a trainer aircraft with structural topology consisting of 15 ribs and 2 spars with skin. On further retravel it is made sure that the "I" section and rear spar having "C" section.

The complete airfoil coordinates retrieved from the website of NACA and later by using "View Macros" options from Microsoft Excel. The data were arranged to be in a tabular form and excessive data were removed using tools to enforce a limit data for 400 co-ordinate data points.

Later the airfoil shape is generated in CATIA by table file and converting from Excel macros. Airfoil is divided into 15 numbers and was later divided in equal distances from our reference plane. the Thickness of the sections and the distance were considered to be 100 mm.

The front and rear spar completely designed according with the holes and manipulated with assumptions made during assembly. Later the complete design is ensured as a wing structure. The next step is converting the aforementioned files to my ".igs" format. The reason is the ANSYS software can only read ".igs" format for analysis and meshing purposes. In this current study a total of 6 analysis are performed with the use of a standard trainer aircraft wing structure. The airfoil root is taken with reference from NASA website aggregates NACA-64A215 and Airfoil tip of NACA-64A210. For the future references a ".dwg" of drafting file is converted ".pdf" formats are made and the same is presented in below pictures.

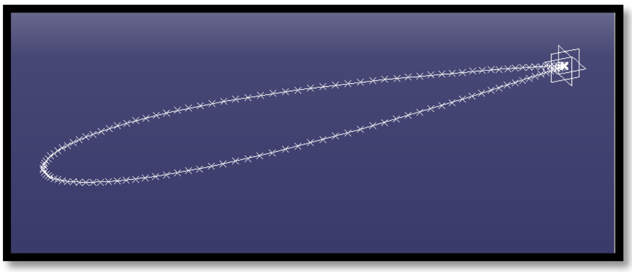


Fig.1.1 Airfoil spline data in CATI V5

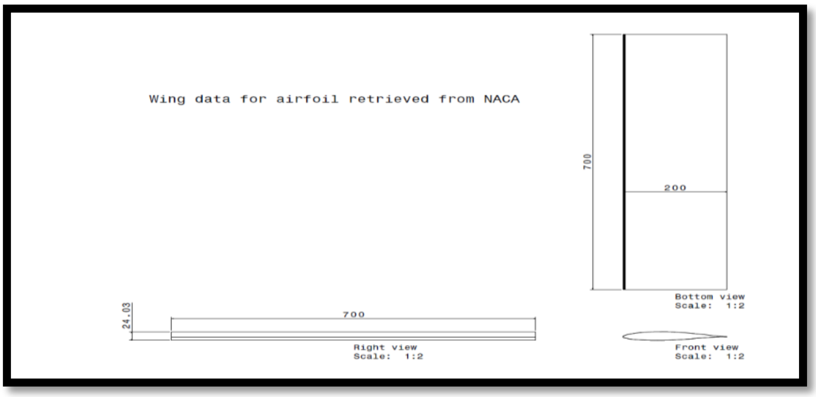


Fig.1.2 Airfoil draft data retrieved from NACA

Table.1.1 Specification for design of Airfoil used in this study

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

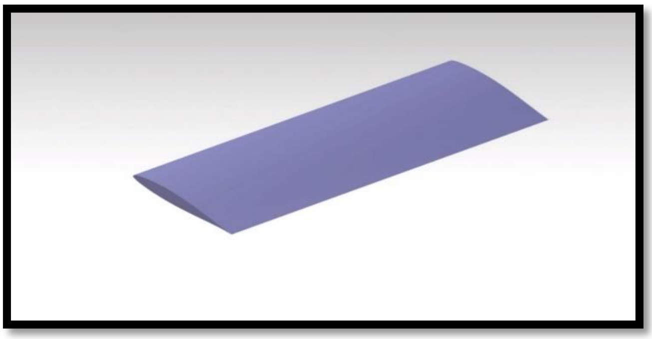


Fig.1.3 Airfoil rendered image of actual model

2. Define and apply material property

In the current study, a total of 6 materials are chosen for analysis for the behavior of the materials. These will feature the raw data post analysis and emit the actual behavior under static analysis. Since there are presence of orthotropic materials it's a must that the tensile, compressive, yield properties caries in accordance with the orientation of the fibers and axis. Thereby it is ensured that the property is induced with considering in all x,y and z axis respectively.

Table.1.2 Ideal materials referred from research papers

Materials	Epoxy-Carbon Woven	Epoxy E-Glass	Epoxy S-Glass	Al-2024 T3
Ex (Gpa)	61.34	45	50	73.1
Ey (Gpa)	61.34	10	8	
Ez (Gpa)	6.9	10	8	
μ(xy)	0.04	0.3	0.3	0.33
μ(yz)	0.3	0.4	0.4	
μ(zx)	0.3	0.3	0.3	
Gxy(Gpa)	19.5	5	5	26.6
Gyz(Gpa)	2.7	3.846	3.486	
Gzx(Gpa)	2.7	5	5	
Tensile Yield Strength (Mpa)	430	490	490	280
Tensile Ultimate Strength (Mpa)	1450	450	489	430
ρ(kg/m^3)	1420	2000	2000	2770

In this structural simulation, a modal analysis will help us to understand the global behavior of the system. By performing a modal analysis first, it is possible to: Identify the natural frequencies and modal shapes of the system. It helps to predict the dynamic responses that this system will have. Thereby this system of model its subjected to modal analysis and a series of mode frequencies are retrieved.

Table. 1.3 The primary materials used for this analysis under Custom Models

Materials	Aluminium 2055 T85	Aluminium 7475 T7351
E (Gpa)	68.5	71.7
μ (poison's ratio)	0.32	0.3
G (GPa)	25	27
Tensile Yield Strength (Mpa)	538	496
Tensile Ultimate Strength (MPa)	565	520
ρ(kg/m^3)	2710	2810

In this research study a fatigue tests are performed to measure the reduction in stiffness and strength of materials under repeated loading and to determine the total number of load cycles to failure. Here, a fatigue tests are performed by repeated tension–tension, compression– compression, tension-compression or other combinations of cyclic loading. The data for S-N curve values are procured from referring various journals and verified articles across academicians. As some materials failure at lesser cycle compared to the non-similar material, there are predominant change in cycle ranges and load values across the tabulated columns.

Table.1.4 Representation S-N values for fatigue test for various materials used in this research study

Al 2024 T3

Alternating Stresses (Mpa)	Cycles
140	50000
128	1.00E+05
120	1.50E+05
112	2.00E+05
110	2.50E+05
108	3.00E+05

Epoxy E Glass

Alternating Stress MPa	Cycles
379.2	1000
275.8	10000
241.3	1.00E+05
137.9	1.00E+06
68.95	1.00E+07

7475 T7351

Alternating Stress MPa	Cycles
240	10000
200	1.00E+05
160	1.00E+06
100	1.00E+07
60	1.00E+08

Epoxy S glass

Alternating Stress MPa	Cycles
827.4	1000
413.7	10000
358.5	1.00E+05
344.7	1.00E+06
262	1.00E+07

2055 T84 Aluminium

Alternating Stress MPa	Cycles
310.3	10000
262	1.00E+05
206.8	1.00E+06
158.6	1.00E+07

Epoxy Carbon Woven

Alternating Stress MPa	Cycles
800	10
780	100
700	1000
620	10000
600	1.00E+05
520	1.00E+06

Among them our primary custom models material are Aluminum 2055 T85 and 7475 T351, as these are developed and iterated in the metallurgical industry with a boom in mechanical property as they stand out among the other alloys in need of aircraft industries. On the other hand, the Epoxy Carbon woven, Epoxy E-Glass, Epoxy S- Glass and Al 2024 T3 materials were allocated from referred journals.

For our better understanding the nomenclatures of following materials models are modified according, so that it is utilized along the venture of this study at ease and understanding:

- **Ideal Model A : Al 2024 T3**
- **Ideal Model B : Epoxy E-Glass**
- **Ideal Model C : Epoxy Carbon Woven**
- **Ideal Model D : Epoxy S- Glass**
- **Custom Model A : Aluminium 2055 T85**
- **Custom Model B : Aluminum 7475 T7351**

3. Discretization of the 3D CAD model

The meshing tool adapted for discretizing the modelled wing is ANSYS Workbench 17.1. Discretization of elements are completely Hexa dominant characters with refined mesh elements along the entire body of the wing panels. A completely program-controlled mesh approach is taken in consideration as the explicit characters of the model adhere to the boundary surfaces of the body even along the sharp trailing edges of the winged airfoil section. Relevance features are substantially kept under medium state with active assembly in an initial size seed condition. Along the trailing edges the smoothing of meshed nodes are controlled medium condition. Under mesh control the default growth rate of element rate is 1.2.

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A total of 5045 nodes were generated across the model with elemental range of 897. Under mesh control property, the multizone is adapted with Hexa mapped mesh type with default sweep elemental size.

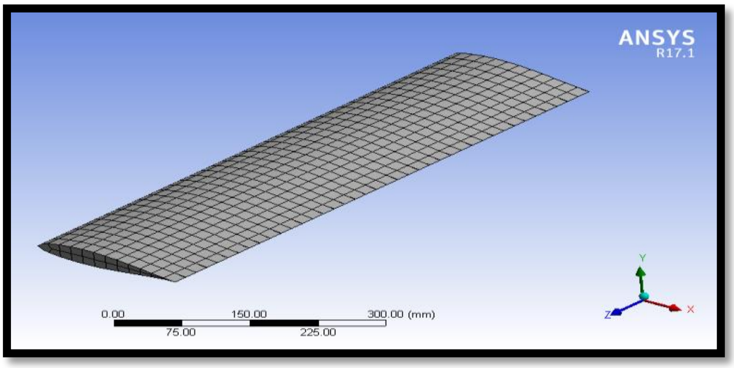

Fig.1.4 Discretized model of a wing unit under ANSYS workbench software.

4. Performing Finite Element Analysis

ANSYS Workbench 17.1 a powerful FEA tool was utilized for this research study. The first and primary details like boundary conditions needs to be encapsulated prior analysis step.

Here the end support is fixed along the flat end portion rigs of the wingspan as depicted below. This fixed location resembles the wing end being attached to the main middle fuselage of the trainer aircraft. This region is rigidly encastre along on one of the either end of wing.

Upon applying fixed support across one end of the wing, the next step is to apply an instant pressure of 500Pa (5e-4 Mpa) across top surface of the wing body. It must be noted that the application of pressure be initiated either in top surface or bottom surface as the topology and geometry of the wing is completely symmetry in structure. A surface effect of pressure is applied along the surface of the wing. The magnitude of pressure is under controlled ramped condition.

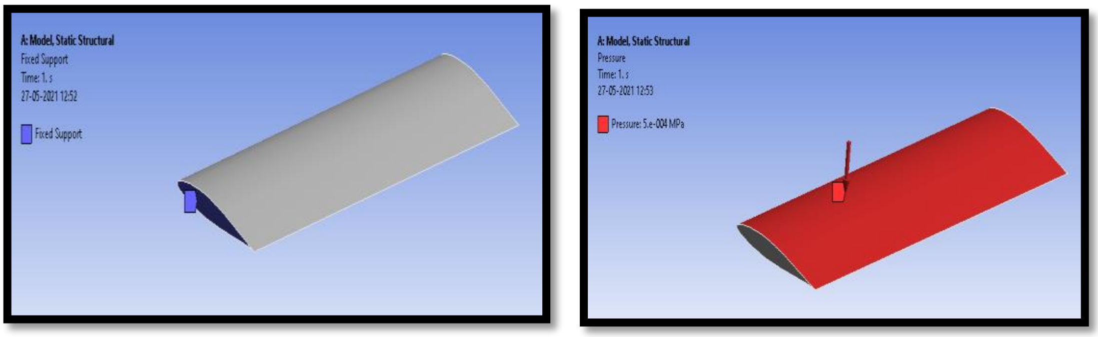

Fig.1.5 Fixed support at the end of wing attachment (left image) and Illustration of pressure application across wing structure (right image)

Under static structural analysis setting the parameter for large deflection is ensured to be turned on. This feature is enabled because there is much possibility that the magnitude of deflection among the wingspan would be enormous in behavior. Further on from inducing the 2 boundary conditions, the parameters or behavior of the wing needs to be investigated by retrieving data like static analysis of total deformation, equivalent elastic strain, equivalent stress, fatigue test (life, damage, Factor of Safety) and dynamic analysis under Modal analysis of first total deformation. No pre-stress condition is enabled along the ventures of analysis procedure. To determine a fatigue, test an S-N data was introduced at material assigning section, which aids at determine the alternating stress behavior of the body. A complete constant amplitude load of fully reversed condition is chosen across the test rigs. Mean stress correction theory of nullified S-N is adapted, as the behavior of the material is dynamic in action, and later on further study Goodman or Soderberg theory may be considered to predict even precise variation in values.

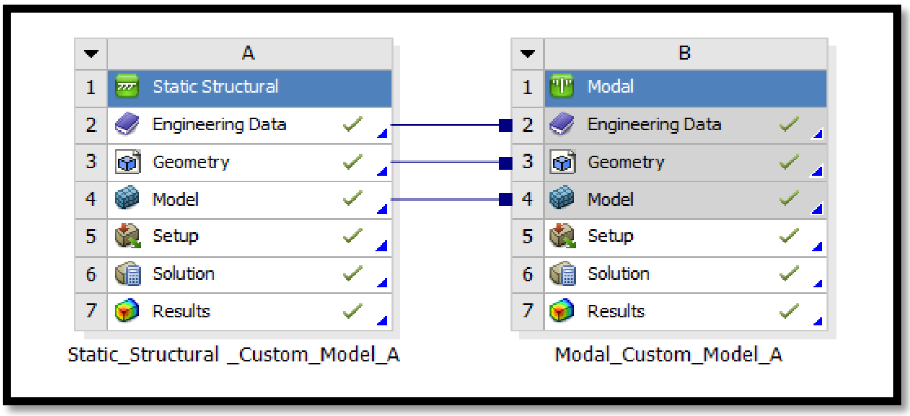

Fig.1.6 Project Schematic illustration

Data values retrieved from static structural were harmonically linked to path flow to modal analysis. The workspace from ANSYS APDL were schematically arranged and recorded formally. This aided us to visually view the changes in behavior of the system.

VI. RESULTS AND DISCUSSION

Initially a trainer aircraft wings airfoil is taken into consideration. Where the coordinates of the airfoil co-ordinates were taken from NACA official website by preferring the required specifications. The same were modelled in CAD formats and were discretized finely to perform a FEA test. Under vigorous static analysis and dynamic test, the results were retrieved under tabulated form. Tabulating and enumerating in charts aid us in briefing out more in-depth behavior of the system which is subjected applied boundary conditions. Following tabular columns illustrated below represents the post analysis data retrieved from FEA tools analysis. It is ensured that the debut values are obtained under prompt observations.

Ideal Model Results:

Table. 1.5 Data of Ideal models retrieved after post analysis

Character	Magnitude	Ideal Model A	Ideal Model B	Ideal Model C	Ideal Model D
		(Al 2024 T3)	(Epoxy E Glass)	(Epoxy Carbon Woven)	(Epoxy S Glass)
Static Structural Analysis					
Total Deformation (mm)	max	0.41	3.07	4.49	3.84
	min	0	0	0	0
Equivalent Elastic Strain	max	3.90E-05	3.60E-04	4.3-4	4.40E-04
	min	6.17e-9	5.3e-8	2.6e-5	7.2e-8
Equivalent stress (N/mm^2)	max	2.895	2.853	2.785	2.82
	min	0.0004	0.000389	0.0008	0.0007
Fatigue Test					
Life	max	3.00E+05	1.00E+07	1.00E+06	1.00E+07
	min	3.00E+05	1.00E+07	1.00E+06	1.00E+07
Damage	max	3333.3	100	1000	100

	min	3333.3	100	1000	100
Factor of Safety	max	15	15	15	15
	min	15	15	15	15
Dynamic Modal Analysis					
Total Deformation (mm)	max	26.36	30.89	36.6	30.9
	min	0	0	0	0

Custom Model Results

Table.1.6 Data of Custom models retrieved after post analysis

Character	**Magnitude**	**Ideal Model A**	**Ideal Model B**
		(Al 2055 T85)	(Al 7475 T7351)
Static Structural Analysis			
Total Deformation (mm)	max	0.39	0.42
	min	0	0
Equivalent Elastic Strain	max	3.80E-05	4.01e-5
	min	6.17e-9	5.3e-8
Equivalent stress (N/mm^2)	max	2.89	2.8
	min	0.0004	0.000389
Fatigue Test			
Life	max	1.00E+06	1.00E+08
	min	3.00E+05	1.00E+07
Damage	max	100	100
	min	3333.3	100
Factor of Safety	max	15	15
	min	15	15
Dynamic Modal Analysis			
Total Deformation (mm)	max		
	min	0	0

Systems behavioral characters like total deformation, equivalent elastic strain, equivalent stress, fatigue data and modal analysis are obtained, which portrays the wings along static and dynamic analysis system. Some isometric pictures from post analysis are displayed below for reference purposes, the rest data obtained are displayed in tabulated form represented in above tables.

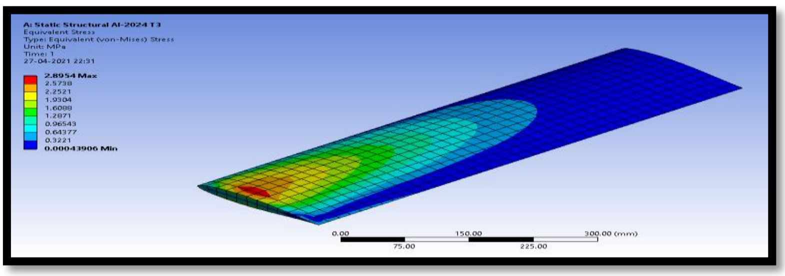

Fig.1.7 Equivalent (Von-Moises) stress of Ideal Model A (Al 2024 T3)

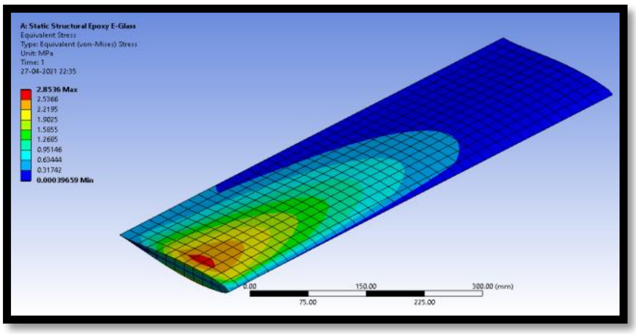

Fig.1.8 Equivalent (Von-Moises) stress of Ideal Model B (Epoxy E Glass)

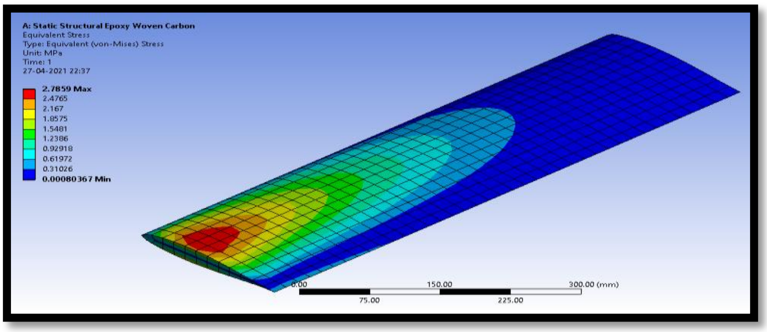

Fig. 1.9 Equivalent (Von-Moises) stress of Ideal Model C (Epoxy Woven Carbon)

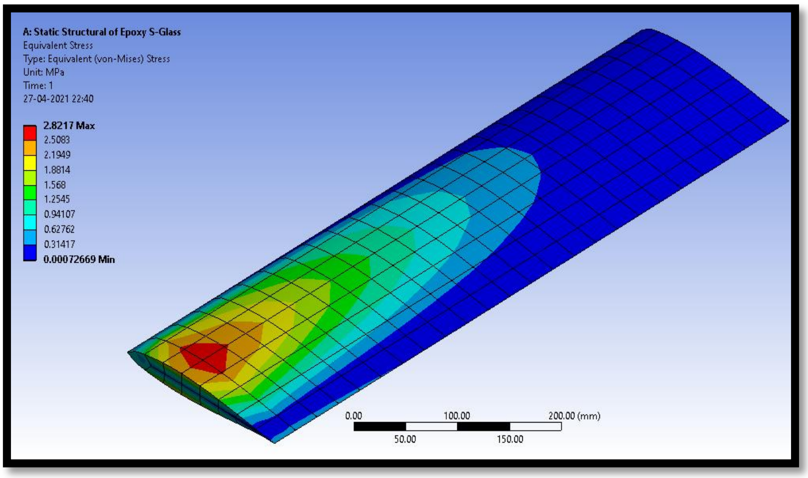

Fig. 1.10 Equivalent (Von-Moises) stress of Ideal Model D (Epoxy S-Glass)

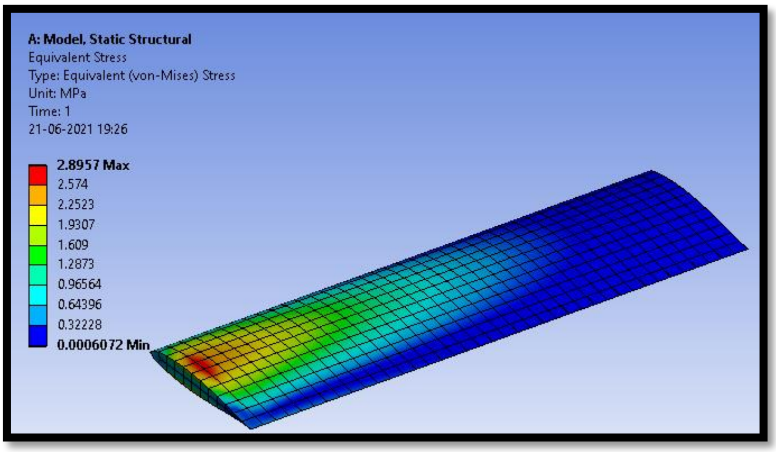

Fig. 1.11 Equivalent (Von-Moises) stress of Ideal Model D (Epoxy S-Glass)

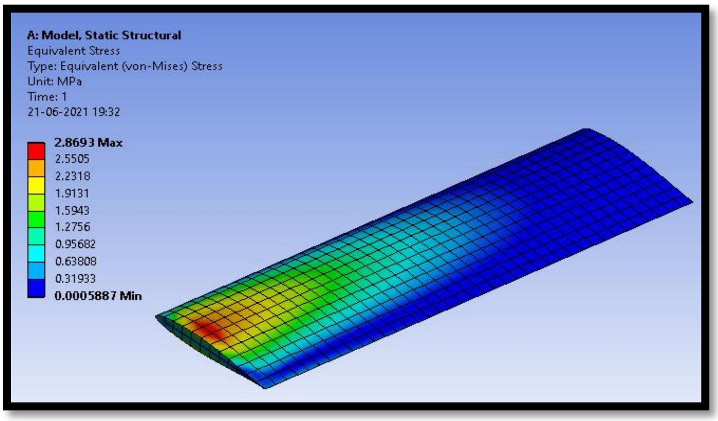

Fig. 1.12 Equivalent (Von-Moises) stress of Ideal Model D (Epoxy S-Glass)

Results for dynamic behavior of the wing under analysis report:

Under modal analysis, the primary factor to be observed is that resonance frequencies do not exist i.e., natural frequency of that particular material model do not coincide with the mode frequencies. Below figures represents the dynamic behavior taken from post results data from ANSYS Workbench. These aids us in analysis report of all the models by visualizing the changes in behavior of the system.

Table.1.7 Modal analysis results of all the models

Ideal Model A

Mode	Frequency [Hz]
1	33.982
2	210.61
3	246.89
4	301.61
5	580.1
6	906.69

Ideal Model B

Mode	Frequency [Hz]
1	14.613
2	91.018
3	107.72
4	149.81
5	252.35
6	451.69

Ideal Model C

Mode	Frequency [Hz]
1	14.371
2	89.517
3	105.5
4	131.83
5	248.32
6	399.33

Ideal Model D

Mode	Frequency [Hz]
1	13.075
2	81.511
3	96.454
4	149.69
5	226.32
6	437.83

Custom Model A

Mode	Frequency [Hz]
1	2.4E-06
2	3.1E-05
3	3.52E-05
4	6.57E-05
5	7.95E-04
6	1.11E-03

Custom Model B

Mode	Frequency [Hz]
1	1.22E-05
2	3.52E-04
3	6.15E-04
4	8.18E-04
5	8.76E-04
6	1.64E-03

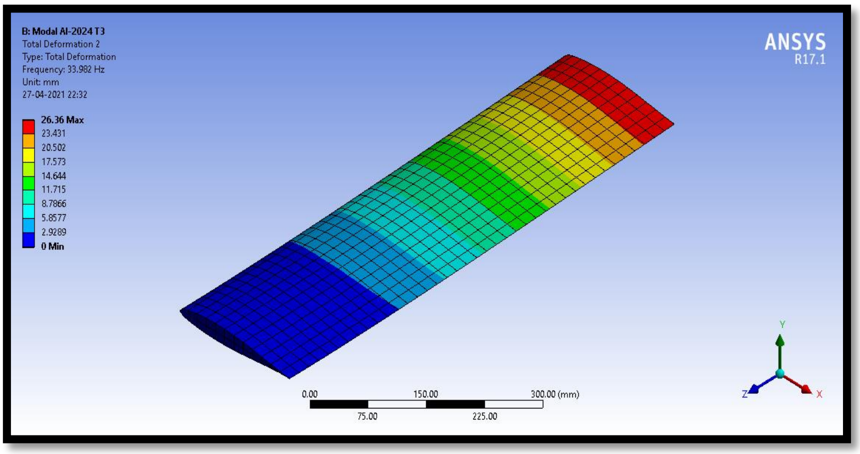

Fig. 1.13 Modal analysis for Al 2024 T3

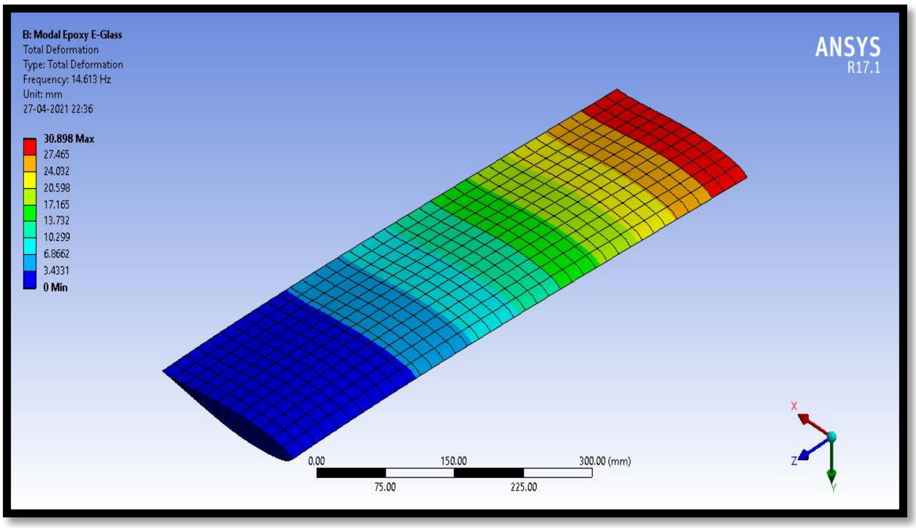

Fig.1.14 Modal analysis for Epoxy E Glass

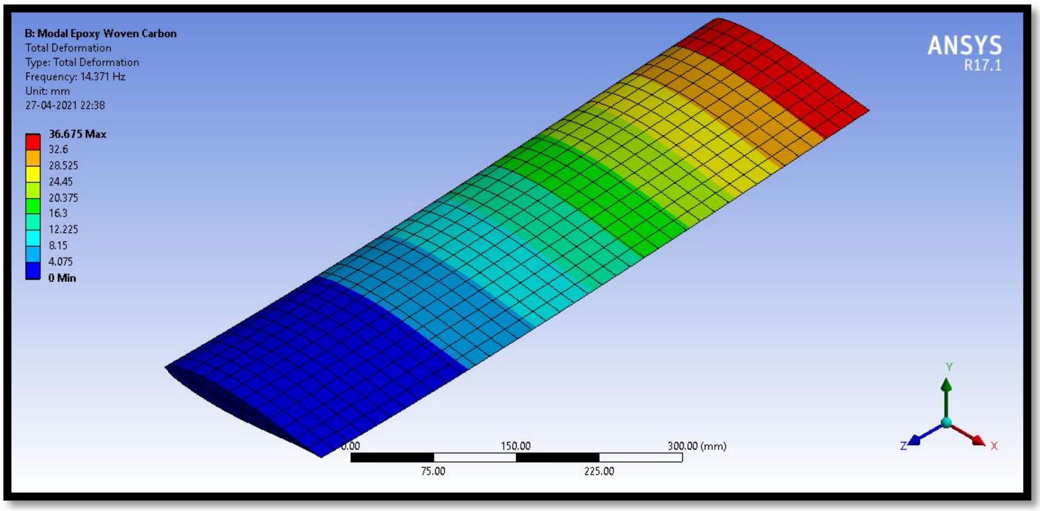

Fig. 1.15 Modal analysis for Epoxy Woven Carbon

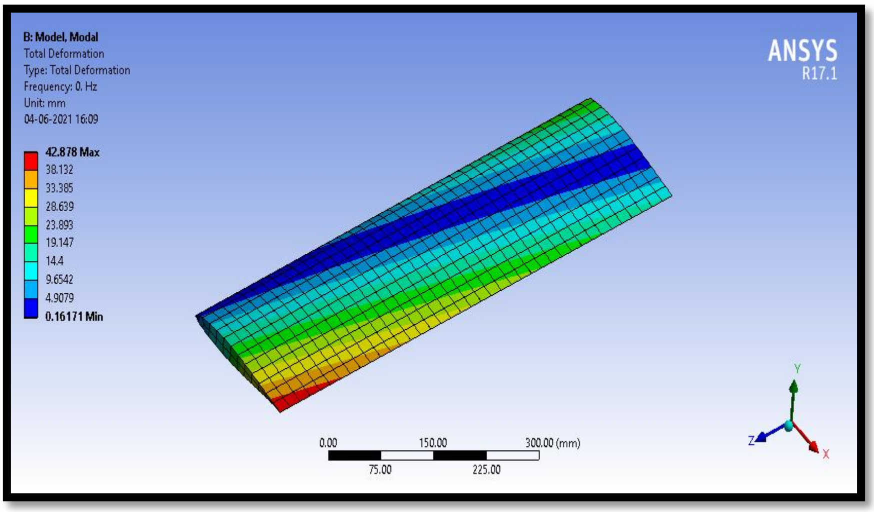

Fig. 1.16 Modal analysis for 7475 T7351

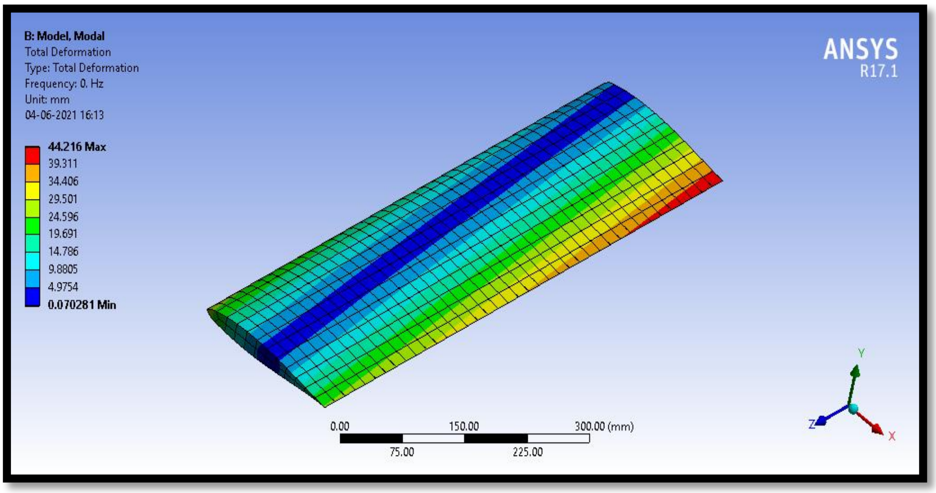

Fig.1.17 Modal analysis for 2055 T85

VII. CONCLUSION

Under complete analysis and discussion, the data prevails more value from the ideal models and custom models. Thus, on comparing the aforementioned data the following points are concluded and put forth in accordance to the verified data:

- On commensurate with all the materials utilized for ideal models, the Aluminum 2055 T85 material performs substantially the least total deformation values. Such least deformable material is encouraged for aircraft wing structure, as it provides better stiffness compared to the rest models.
- When an aircraft is subjected to interact with real-time environment under dynamic load condition, fatigue test data plays vital role. Similarly on scrutinizing the retrieved values from fatigue test, the Aluminum 7475 T7351 yields highest life span, prior to failure amongst the ideally chosen data.
- Aluminum 2055 T85 and Aluminum 7475 T7351 are substantially low in cost to manufacture and readily available across various manufacturers across globe. On the other hand, the orthotropic materials indicated as ideal models are treacherous to manufacture and costs exponentially high simultaneously, due to its complexity involved.
- Finally, the aforementioned points can summarize and concluded as, the Aluminum 2055 T85 and Aluminum 7475 T7351 are extremely reliable and stands as a best alternative material compared to the ideal model materials.

FUTURE SCOPE

Since this research study was extensively focused on static analysis and dynamic modal analysis, the path for improvements and studies are enormous. Some of the key aspect, where there are future opportunities with regard to this research study are:

- A different boundary conditions may be incorporated to the wing structure i.e., the weight of propeller engine unit or turbo engine unit. As these loading members also aid in the dynamic behaviour of the wing structure.
- A complete heat transfer study under varying temperature flow, across the aerofoil structure can be performed. Since the aircraft predominantly operates in a extremely low temperatures at higher altitudes. Thereby a CFD analysis of heat transfer may be extended with reference to aforementioned listed material.
- An acoustic test under standard static and dynamic test may be conducted while considering the with boundary conditions taken from vibrational specifications of aircrafts turbo or propeller engine. Since these vibrations act towards the wings structure and may results in acoustic discomforts to cabins where passengers accommodate.

ACKNOWLEDGEMENTS

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