Structural Analysis of an Aircraft Wing with Aluminium Alloy and Carbon Fibre Reinforced Polymer using Finite Element Analysis

S Siva Sai Krishna[1], Nutakki Priyatham[2]

[1,2]Student, Department of Aerospace Engineering, Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India, 603103

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Abstract - *This paper deals with the modelling of a commercial aircraft wing and analysing its structural behaviour when subjected to an external pressure load. The design process starts with the modelling of the internal framework of the wing whose dimensions are similar to an actual commercial aircraft like the Airbus A350. The result of this simulation produced the stress, strain and displacement values and also determined the factor of safety (FoS) of this wing which was around 1.5 on an average. The wing structure consists of 16 ribs with 3 spars, the front and rear spars are made of rectangular cross section beams while the mid spar is made of an I-section beam. Two types of materials – Aluminium Alloy 7075-T6 (SN) and carbon fibre reinforced polymer composite Hexcel AS4C (3000 Filaments) have been used for comparison and identification of the most suitable material. The airfoil shape used for the ribs is NACA 23015. The software used for modelling and finite element analysis is SOLIDWORKS 2020.*

Key Words: Aircraft wing, stress, strain, displacement, SOLIDWORKS.

1. INTRODUCTION

Wing is the main component of aircraft that is responsible for the generation of lift. During the forward motion of the aircraft, the air flows over the wing and produces a pressure difference between the top and bottom surface of the wing and generates the lift to the aircraft. The pressure difference is caused due to the aerodynamic shape of the cross section of wing and is known as aerofoil. Other components of the aircraft like fuselage and empennage are also aerodynamically shaped to reduce the amount of drag produced [1].

The main objective of this research is to identify the most suitable alternative for the conventional aluminium used in aircraft wings. Therefore composites are taken into consideration and their physical properties are being compared with the aluminium alloy.

2. Problem statement

Aircraft wings are built to withstand the extreme weather conditions that occur during flight and the turbulence that is created should not affect the performance of the wing. Hence material selection is an important parameter to be considered when designing an aircraft wing. Composites made of carbon fibre has the capacity to serve this purpose due to its high stiffness, high strength and less weight.

3. WING MODEL

The wing structure modelled in this study has an aerofoil cross section NACA 23015. The internal structure of the wing consists of 16 ribs and 3 spars, the front and rear spars are made of rectangular cross section beams while the mid spar is made of an I-section beam [3].

Table -1: Dimensions

Root chord length	13m
Tip chord length	3.5m
Thickness of rib	0.2m
Length of front spar	31m
Length of mid spar	30.6m
Length of rear spar	30.2m

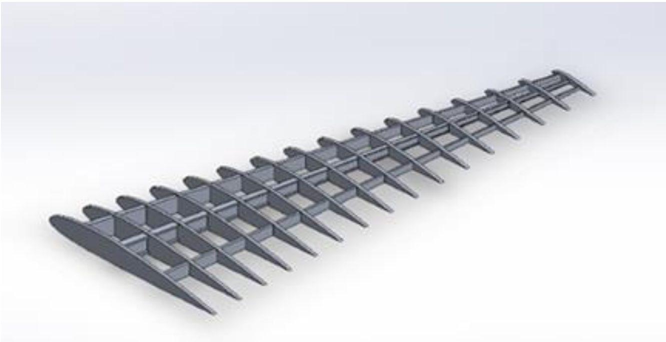

Figure 1 Isometric view of wing

The above Figure 1 shows the isometric view of the internal structure of the wing. 3 spars have been connected from wing root to wing tip.

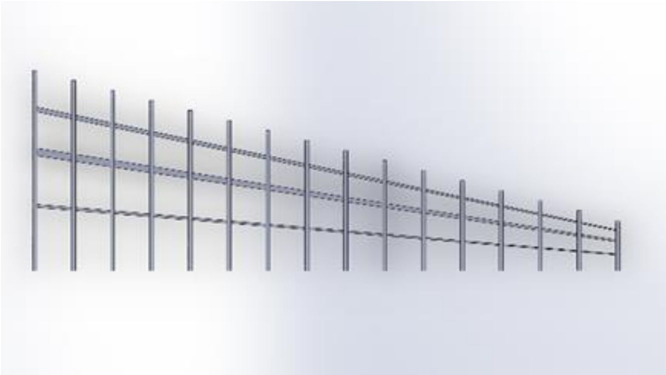

Figure 2 Top view of wing

The above Figure 2 shows the top view of the wing. The tapered wing increases aspect ratio, reduces drag and improves the lift.

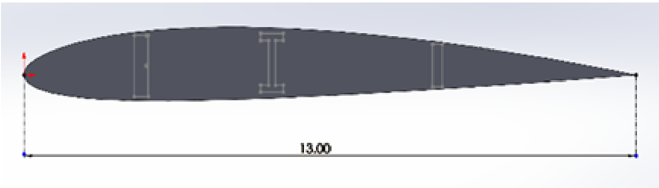

Figure 3 Wing root

The above Figure 3 shows the cross section of wing root depicting the cross sections of the 3 spars that are connected to the rib.

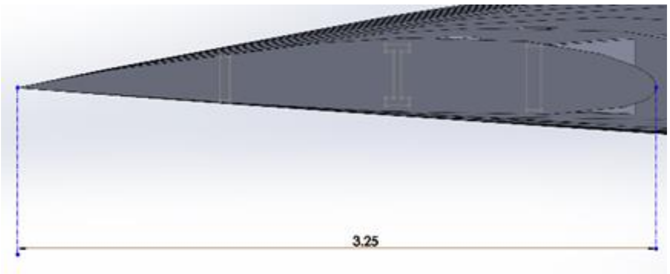

Figure 4 Wing tip

The above Figure 4 shows the cross section of wing tip depicting the cross sections of the 3 spars that are connected to the rib.

4. FINITE ELEMENT ANALYSIS

The numerical method adapted for solving the boundary value problem in this study is Finite Element Method (FEM). It is the numerical technique that is used to perform Finite Element Analysis (FEA) on the wing structure. Engineers use this type of analysis to run virtual simulation experiments of the modelled part or assembly.

This analysis describes how a part or assembly behaves under certain given conditions. The result of the simulations based on FEA method are depicted in a colour scale where each colour mentions the range of magnitude of the physical properties like stress, strain, displacement. Etc.

5. INTRODUCTION TO COMPUTER-AIDED DESIGN (CAD)

Computer-aided design (CAD) is the use of a computer software for modelling, analysis and optimization of a design. Frequently used by engineers and students to create 2D drawings and 3D models.

Advantages of CAD modelling:

- High quality designs.
- Less cost compared to the production of prototypes.
- High accuracy and less errors.
- Ability to analyse the model by simulating it in required conditions.

SOLIDWORKS 2020 is a powerful CAD design tool developed by Dassault Systèmes. It has been used in this research to handle both modelling and simulation required for this wing analysis.

6. BOUNDARY CONDITIONS

6.1 Fixtures

The wing is a stiff cantilever structure that is supported at one end. It lies in the lateral axis of the aircraft and resists large amount of shear stress generated. As a result, the wing must consist of strong spars that run along the span of the wing.

Therefore the model is fixed at one end to represent a cantilever structure.

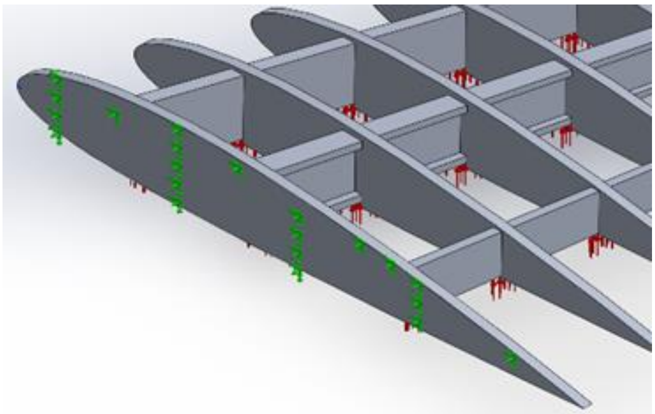

Figure 5 Fixed end (green arrows)

The above Figure 5 shows the fixed end of the wing which is attached to the wingbox near the fuselage.

6.1 Load conditions

An aircraft wing experiences pressure load. It is a distributed load that is applied on a surface where the resultant of the load is in normal direction to the surface.

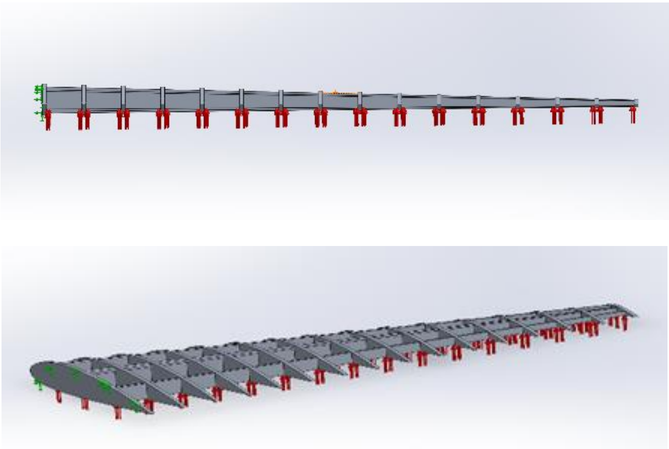

Figure 6 Direction of pressure load

The above Figure 6 shows the direction of pressure load applied on the bottom of the wing surface.

Therefore a pressure load of magnitude 400,000 Pa is applied on the bottom surface of the wing and the simulation computes the results of stress, strain and displacement of the wing.

7. MATERIAL SELECTION

Wings are a vital part of an aircraft, hence the materials used play a key role in the performance of the wings.

The desired properties for wing materials are lightweight, high strength and stiffness, resistance to fatigue, resistance to stress. Therefore material selection is one of the most important step in aircraft wing design. Aluminium is the most widely used material for aircraft structures. However, composite materials are slowly emerging as the best alternative to aluminium and steel due to its high strength, stiffness and less weight.

Therefore two materials (Aluminium alloy and carbon fibre epoxy composite) have been considered for this study to compare the simulation results and identify the most suitable material for the wing.

1. Aluminium alloy 7075-T6 (SN).
2. Hexcel AS4C (3000 Filaments).

7.1 Material Properties

7.1.1 Aluminium alloy 7075-T6 (SN)

Table -2: Physical properties of 7075-T6

Yield strength:	5.05 x 10^8 N/m^2
Tensile strength:	5.7 x 10^8 N/m^2
Elastic modulus:	7.2 x 10^10 N/m^2
Poisson's ratio:	0.33
Mass density:	2,810 kg/m^3
Shear modulus:	2.69 x 10^10 N/m^2
Thermal expansion coefficient:	2.36e-05 /Kelvin

7.1.2 Hexcel AS4C (3000 Filaments)

Table -3: Physical properties of Hexcel AS4C

Tensile strength:	4.41 x 10^9 N/m^2
Elastic modulus:	2.31 x 10^11 N/m^2
Poisson's ratio:	0.3
Mass density:	1,780 kg/m^3

8. MESH

Meshing is the process of breaking down the geometric shape of an object into numerous elements which properly defines the overall physical shape of the object. The conditions are applied to these elements and the solution is calculated and interpolated across the entire domain.

Generating a high quality mesh is one of the most critical factor that should be considered to ensure accuracy in simulation [4].

Table -4: Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard
Jacobian points for High quality mesh	16 Points
Element Size	0.200148 m
Tolerance	0.0100074 m
Mesh Quality	High

Total Nodes	79207
Total Elements	40913
Maximum Aspect Ratio	32.944
% of elements with Aspect Ratio < 3	90.7
% of elements with Aspect Ratio > 10	0.186
% of distorted elements(Jacobian)	0

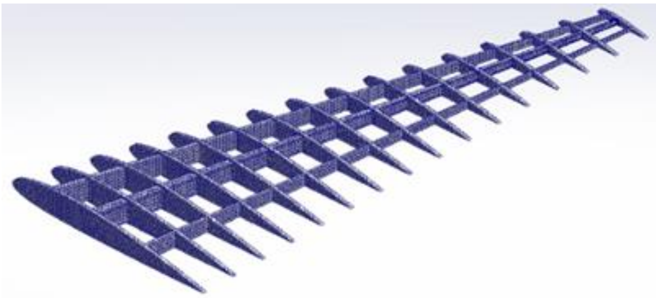

Figure 7 Meshed surface

The above Figure 7 shows the meshed surface of the wing model.

9. RESULT

9.1 Aluminium alloy 7075-T6 (SN)

9.1.1 Von mises stress

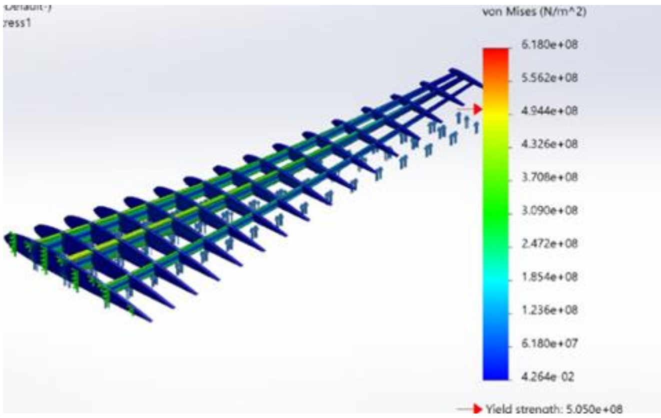

Figure 8 Von mises stress

- Minimum : 4.264 x 10^2 N/m^2
- Maximum : 6.180 x 10^8 N/m^2

9.1.2 Resultant displacement

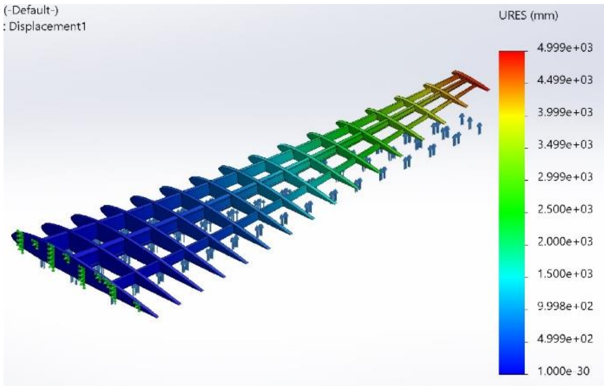

Figure 9 Resultant displacement

- Minimum : 0 mm
- Maximum : 4.999 x 10^3 mm (~5 m)

9.1.3 Equivalent strain

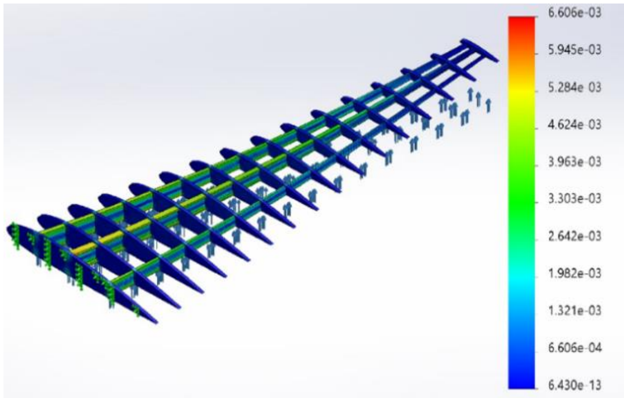

Figure 10 Equivalent strain

- Minimum : 6.43 x 10^-13
- Maximum : 6.606 x 10^-3

9.1.4 Factor of safety (FoS)

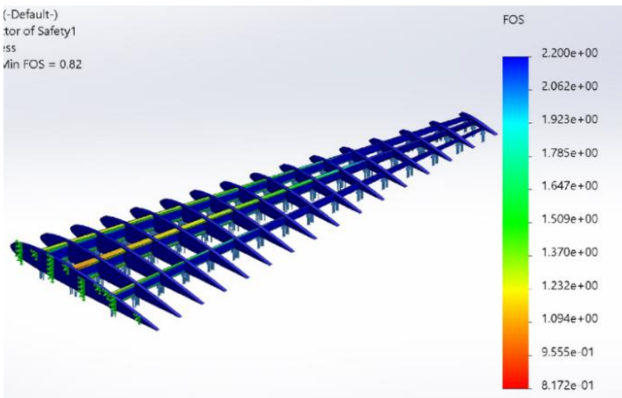

Figure 11 Factor of safety

- Minimum : 0.8172
- Maximum : 2.2

Factor of safety is the ratio of ultimate load (strength) to the allowable load (stress).

The average value of Factor of safety is the average of maximum and minimum values which was around 1.5.

The Factor of safety of aircrafts generally lie in the range of 1.5 – 2.5. Therefore the design lies in the acceptable range.

9.2 Hexcel AS4C (3000 Filaments)

9.2.1 Von Mises stress

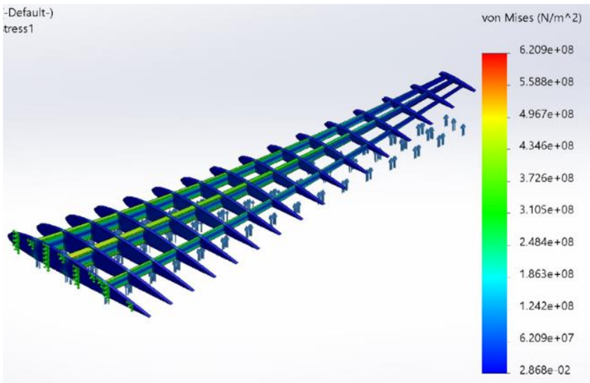

Figure 12 Von mises stress

- Minimum : 2.868 x 10^-2 N/m^2
- Maximum : 6.209 x 10^8 N/m^2

9.2.2 Resultant displacement

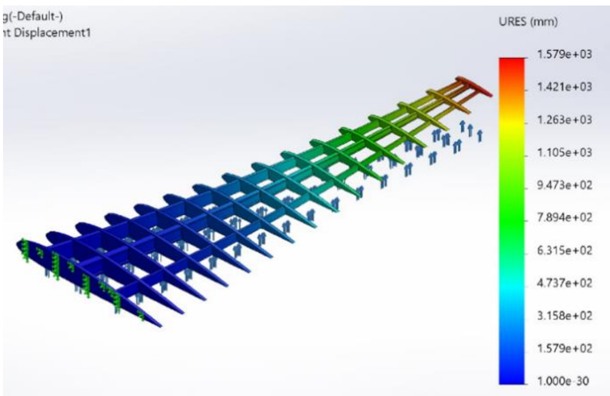

Figure 13 Resultant displacement

- Minimum : 0 mm
- Maximum : 1.579 x 10^3 mm

9.2.3 Equivalent strain

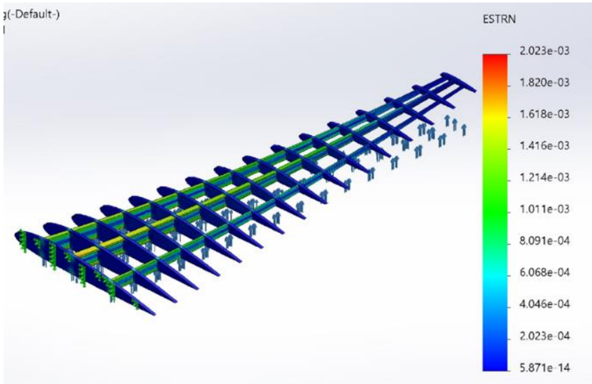

Figure 14 Equivalent strain

- Minimum : 5.871 x 10^-14
- Maximum : 2.023 x 10^-3

Table -5:. Comparison of results between aluminium alloy and hexcel carbon fibre

Property	Aluminium alloy 7075-T6 (SN)	Hexcel AS4C (3000 Filaments)
Von Mises Stress (N/m^2)	618000000	620900000
Resultant displacement (m)	5	1.579
Equivalent Strain	0.0066	0.0020
Factor of Safety	1.5	1.5

The above table depicts the magnitude of the physical properties experienced by the wing structure due to the applied external pressure load.

It can be seen that the Von mises stress is almost the same in both cases, but the displacement of the wing at the tip is 5 m for aluminium alloy and less than 2 m for the carbon fibre composite. Hexcel AS4C provides a clear advantage over aluminium alloy in terms of physical properties since the values of stress, strain and displacement is minimal.

CONCLUSIONS

Based on the simulation results it is evident that the displacement of the wing made of carbon fibre composite is less at the wing tip, indicating better strength. Hence composite materials provide better structural properties and the chances of catastrophic failures are less comparatively.

Due to the external pressure load the wing structure tends to deform. Extreme bending of wing is not desirable as it can lead to structural failure during flight. Therefore composite materials are the best choice due to its immense load bearing capacity, less weight and high thermal and corrosive resistance. These composites also provide a smooth surface finish to the whole aircraft external body which can provide good aerodynamic performance [5].

The light weight of carbon fibre composite also aids in fuel economy of the aircraft.

Composite materials are extensively used in many aircraft and automotive industries. The modern day aircraft Boeing 787 is made of 50% composites by weight and the percentage is bound to increase in the future.

REFERENCES

[1] Salu Kumar Das and Sandipan Roy 2018 IOP Conf. Ser.: Mater. Sci. Eng. 402 012077.M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[2] Sohel Rana, Raul Fangueiro, "Advanced Composite Materials for Aerospace Engineering". Woodhead Publishing, 2016. Elsevier Ltd., https://doi.org/10.1016/C2014-0-00846-5.

[3] Sivarama Prasad Peruru, Suman Babu Abbisetti, "DESIGN AND FINITE ELEMENT ANALYSIS OF AIRCRAFT WING USING RIBS AND SPARS". 2017, IRJET.

[4] Kathiravan.T, Mohammed Huda.A, Parthiban.K, "STRUCTURAL AND MODAL ANALYSIS OF SUBSONIC AIRCRAFT WING USING ANSYS WORKBENCH". 2018, IRJET.

[5] Rabbey, M. Fazlay, et al. "Structural Deformation and Stress Analysis of Aircraft Wing by Finite Element Method." Advanced Materials Research, vol. 906, Trans Tech Publications, Ltd., Apr. 2014, pp. 318–322. Crossref, doi:10.4028/www.scientific.net/amr.906.318. R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.