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Structural Analysis on an Aircraft Wing Model Using Finite Element Method: A Review

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Abstract- In this work, a commercial aircraft wing is modeled, and its structural behavior under an external pressure load is examined. Beginning with the interior wing framework, which has proportions close to those of a real commercial aircraft, such as the Airbus A350, the design process may begin. The stress, strain, and displacement figures as well as the wing's factor of safety (FoS), which was around 1.5 on average, were obtained from the simulation's output. The three spars that make up the wing structure's sixteen ribs are separated by an I-section beam in the middle, while rectangular cross section beams make up the front and rear spars. For the purpose of comparison and material selection, two different types of materials have been used: carbon fibre reinforced polymer composite Hexcel AS4C (3000 Filaments) and aluminum alloy 7075-T6 (SN).

Keywords— Aircraft Wing, Stress, Strain, Displacement, SOLIDWORKS, Computational Fluid Dynamics, AMTAS, ANSYS, Factor of Safety.

INTRODUCTION

The main structural element of aircrafts (air breathing engines) that generates lift force during flight is the wing. Air is drawn into the compressor through the intake when the engine is started, raising the pressure ratio at the compressor's output. Next, the fuel and air are combined inside the combustion chamber and burned. Thrust force is created when high temperature, high pressure gases are forced into the nozzle, propelling the aircraft forward. The forward velocity causes air to flow across the aerodynamically shaped wing. The wing's aerodynamic form and Bernoulli's principle cause the flow velocity to be higher at the top of the wing and less at the bottom. The primary part of an aeroplane that generates lift is the wing. The airflow over the wing creates a pressure differential between the wing's top and bottom surfaces as the aircraft moves forward, providing lift. The term "aerofoil" refers to the pressure differential that results from the aerodynamic form of the wing cross section. The aerodynamic form of the aircraft's fuselage and empennage reduces drag. A fixed-wing aircraft is an aircraft, such as an aero plane, which is capable of flight using wings that generate lift caused by the vehicle's forward airspeed and the shape of the wings. Fixed-wing aircraft are distinct from rotary-wing aircraft, in which the wings form a rotor mounted on a spinning shaft, in which the wings flap in similar manner to a bird. Glider fixed-wing aircraft, including free-flying gliders of various kinds and tethered kites, can use moving air to gain height. Powered fixed-wing aircraft that gain forward thrust from an engine (aero planes) include powered par gliders, powered hang gliders and some ground effect vehicles. The wings of a fixed-wing aircraft are not necessarily rigid; kites, hang-gliders, variable- sweep wing aircraft and aero planes using wing-warping are all fixed-wing aircraft. Most fixed-wing aircraft are flown by a pilot on board the aircraft, but some are designed to be remotely or computer controlled. Wings The wings of a fixed-wing aircraft are static planes extending either side of the aircraft. When the aircraft travels forwards, air flows over the wings which are shaped to create lift. An attempt is made to design wing using different configuration to determine maximum stress and deformation it can withstand. The design of a replacement wing requires stress analysis. In engineering, stress analysis is a tool rather than a goal; the aim is to determine the stress and to predict the failure in materials subjected to forces or to increase the strength of the wing without increasing the weight. Stress analysis can be performed

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using conventional and analytical mathematical techniques, an experimental testing or computational simulation. Aluminum alloy Titanium alloy is considered as materials to do static structural analysis. Aircraft are built to meet certain specified requirements. These have to be chosen in a way that allows them to be integrated into a single aircraft. No one aircraft can have every attribute, just as no single aircraft can be both a comfortable passenger carrier and a fighter with equal maneuverability. How sturdy an aeroplane must be built depends on its type and class. A Navy fighter has to be quick, agile, and capable of both attack and defence. The aeroplane has an extremely sturdy construction and a high power output to suit these criteria.

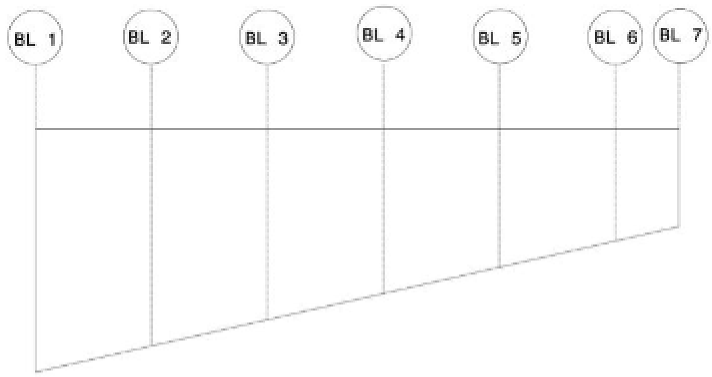

Figure 1- Wing station lines

LITERATURE REVIEW

The purpose of the literature survey is to study the works of different researchers concerned with the detailed study of the air craft wing design. Also to find out the scope for any new methods of design by which the design process is made simple, robust, less time consuming and cost effective. The literature survey is entirely based on the previous research methods. It is desired to explore the application of the fundamental properties such as vibration which plays an important role in the failure of the structure. Hence the literature survey is carried out emphasizing the structural design of the aircraft wing subjected to vibration The airfoil design is a time consuming and a complex process. The knowledge of aerodynamics is the requisite of expertise. Airfoil aerodynamic properties can be verified by wind tunnel test, which is most expensive. Huge aircraft production firms, viz., Boeing and Airbus, have sufficient budget and experts to design their own airfoil. Designing their own airfoil is not economical for small aircraft manufacturing companies, investigational aircraft producers and homebuilt manufacturers. Best method for small aircraft manufacturing firms is to select airfoils from the standard data available in several books or websites. Two standard airfoil resources are NACA and Eppler. Maximum aircraft designers select airfoil sections from NACA standards. Since 1930's some families of airfoil sections and camber lines were arrived by the NACA was a U.S. federal agency. General and military aircraft, as well as propellers and helicopter blades were using many of these airfoil shapes at wing and tail sections. The ordinates for number of particular airfoils of these series at rough stations of data points were published in a series of NACA reports. When carrying out parametric studies on results of variables such as thickness, location of maximum thickness, leading edge radius, location of maximum camber and others, it is difficult to obtain the ordinates of the required shapes correctly and quickly. To overcome these difficulties the NASA Langley Research Centre developed computer programs for standard airfoil generation. The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties. The contributions of different researchers, who worked on the design of aircraft wing, using NACA standards, have been discussed in the following paragraphs.

Nguyen Minh Triet et.al in their paper they expressed their view regarding difficulty in solving analytically the aerodynamic problems. Huge experimental expenses are involved in solving aerodynamic problems. Hence they preferred numerical methods. They modeled aircraft wing using standard NACA 2412 airfoil and carried out computational fluid dynamic (CFD) simulation using ANSYS Fluent and analyzed the pressure and velocity distribution on the surface of wing. Using ANSYS Structural module they calculated drag and lift forces. Additionally, the coefficients of drag and lift forces can be calculated through the data obtained when the relative velocity inlet between the airflow and airfoil changes from 0 to 50 m/s.

Kakumani Sureka and R Satya Meher in their paper they modelled A300 aircraft wing using standard NACA 64215 airfoil with spars and ribs was done using the CAD software, CATIA V5 R20, and later using ANSYS WORKBENCH (the finite element analysis (FEA) software) structural analysis on wing skeleton was carried out. It was observed that difference between the values of equivalent stress, deformation; max principle stress, stress intensity and shear stress of Aluminium alloy and Aluminium alloy7068 are minimal. The results obtained were validated and the differences between the two result values were negligible. They arrived to the conclusion that Aluminium alloy 7068 is preferred over Aluminium alloy in order to give the more strength to the structure.

Nguyen Minh Triet et.al	2015	computational fluid dynamic (CFD) simulation using ANSYS Fluent and analyzed the pressure and velocity distribution on the surface of wing
Kakumani Sureka and R Satya Meher	2015	modelled A300 aircraft wing using standard NACA 64215 airfoil with spars and ribs was done using the CAD software, CATIA V5 R20, and later using ANSYS WORKBENCH (the finite element analysis (FEA) software) structural analysis on wing skeleton
Sudhir Reddy Konayapalli and Y Sujatha	2015	modeled using standard NACA 4412 airfoil in CAD software
Guguloth Kavya et.al	2015	Design and Finite Element Analysis of Aircraft Wing using Ribs and Spars

Sudhir Reddy Konayapalli and Y Sujatha discussed the aircraft wing design. It was modeled using standard NACA 4412 airfoil in CAD software, CATIA V5 R20. They imported CATIA V5 model to ANSYS 14.5 software. They observed from the fluent analysis that the dynamic pressure on leading edge was decreasing with increasing the angle of attack. Static pressure on lower surface was increasing with increase in angle of attack. They concluded that static pressure was increased with increase in the angle of attack. Dynamic pressure on the lower surface was decreasing with increasing angle of attack whereas static pressure was increasing on lower surface. They concluded that dynamic pressure was increased with increasing the angle of attack.

Guguloth Kavya et.al in their study, an aircraft wing was designed and modeled in CAD software, Pro/Engineer. They have not mentioned the type of NACA profile used. They modified the wing by adding ribs and spars. Static analysis was done on the wing by applying air pressure for three materials like S-Glass, Kevlar 49 and Boron fiber because of their high strength to weight ratio. Using ANSYS Workbench Structural analysis on wing skeleton was carried out. After analyzing the results, they concluded that deformation and stresses were less for wing with ribs and spars than compared with that of original wing. Modal analysis was done on the aircraft wing to determine the frequencies. They observed that frequencies were more for wing with spars and ribs but deformations are less. After conducting random vibration analysis, they arrived to the conclusion that the shear stress was less for modified model than original model. They concluded that the wing strength could be increased by adding ribs and spars.

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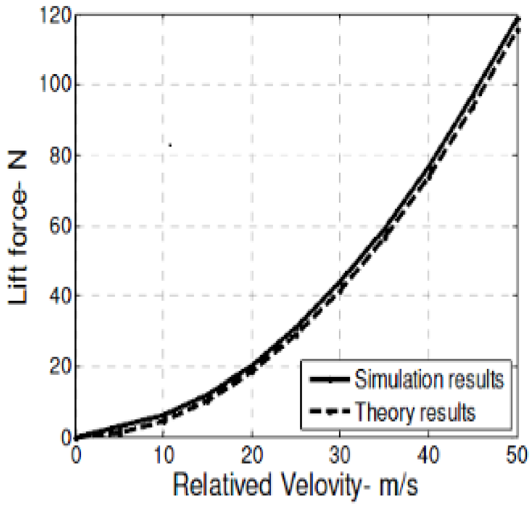

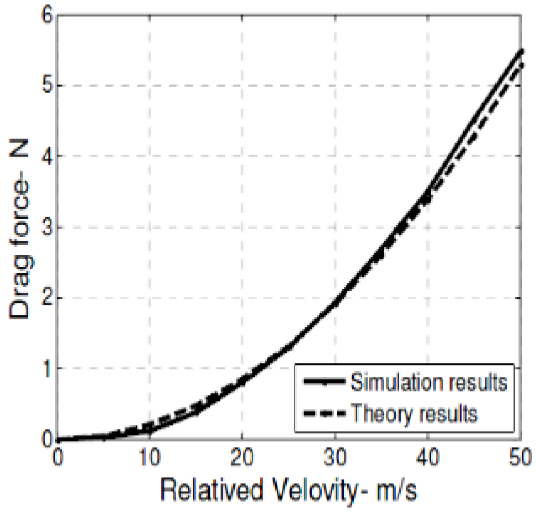

Figure 2- Relative velocity versus Lift **Figure 3-**Relative velocity versus Drag

TERMINOLOGY FOR AIRCRAFT

(i) Airfoil- The forward point in the airfoil shape is referred to as the leading edge, and the backward point as the trailing edge. The chord line of an airfoil is the straight line that joins the leading and trailing edges. A chord (c) is the length measured along the chord line between the leading and trailing edges. The point located halfway between the upper and lower surfaces when measured normal to the mean camber line is known as the mean camber line. The greatest distance, measured normal to the chord line, between the chord line and the mean camber line is known as the camber. The thickness is determined by measuring the distance normal to the chord line between the upper and lower surfaces. At the leading edge, the airfoil typically has a circular form with a leading-edge radius of 0.02c, where c is the chord length. Suction and pressure surfaces, respectively, are other names for the upper and lower surfaces.

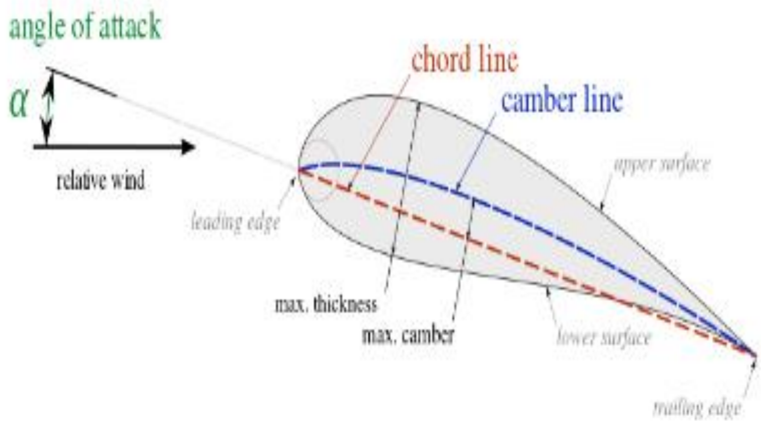

Figure 4- Airfoil Shape

(ii) Airfoil Classification- The 4-, 5-, and updated 4-/5-digit airfoil series, as well as the section's thickness distribution along its length, were all described by the curvature of the airfoil's mean-line, or geometric centerline, through the use of analytical equations and analogies developed for the Network of Aquaculture Centers in Asia-Pacific. Furthermore, the families among which the 6-Series was one were more intricate forms that were produced by theoretical techniques.

(iii) NACA Four-Digit Series- the NACA Four-Digit Series is the name of the airfoil family that was assembled using this method. Here, the first digit provides the maximum camber in the chord's % (airfoil length); the second shows the maximum camber's position; and the last two digits offer the maximum airfoil thickness in the chord's percentage. For example, the NACA 2415 airfoil has a maximum thickness of 15% with a camber of 2% located at 40% chord from the airfoil leading edge (or 0.4c). Using these values, one can compute the coordinates of the entire airfoil using specific equations.

(iv) NACA Five-Digit Series- Although the mean camber line is specified differently and the naming procedure is a little more complicated, the NACA Five-Digit Series and the Four-Digit Series are very comparable since they employ the same thickness forms. The first digit, multiplied by 3/2, gives the design lift coefficient (cL), which is expressed in tenths. The greatest camber in tenths of the chord is indicated by the following two figures when divided by two. The last two numbers once more represent the maximum thickness as a chord percentage. As an illustration, the NACA 24013 has a maximum camber that is 20% behind the leading edge, a peak thickness of 13%, and a design lift coefficient of 0.3. Currently, the computational tools accessible to designers enable them to create and optimise airfoils that are uniquely suited for a certain purpose.

AIRCRAFT WING MODEL USING FINITE ELEMENT ANALYSIS

The Finite Element Method (FEM) is the numerical approach that was used in this work to solve the boundary value issue. The wing structure is subjected to Finite Element Analysis (FEA) using this numerical method. This kind of analysis is used by engineers to do virtual simulation tests on the component or assembly that they have modeled.

(i) Computer-Aided Design- The use of computer software for modeling, analysis, and optimization of a design is known as computer-aided design (CAD). Often utilized by students and engineers to produce 2D and 3D models.

(ii) 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.

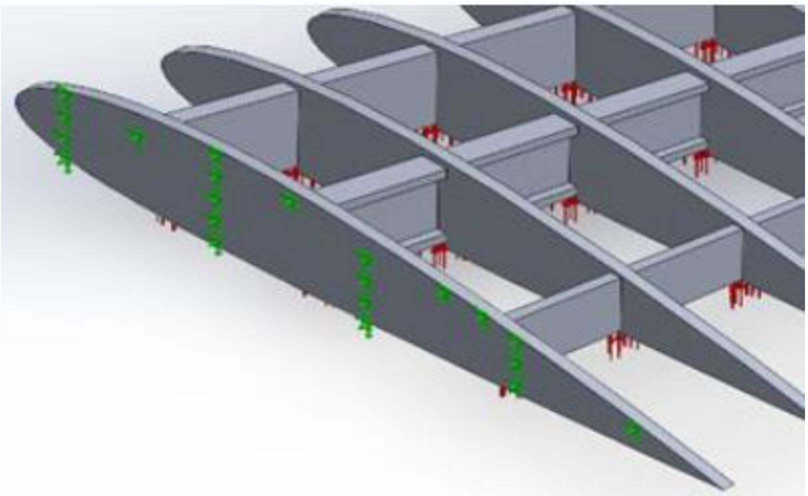

Figure 5 - Fixed end (green arrows)

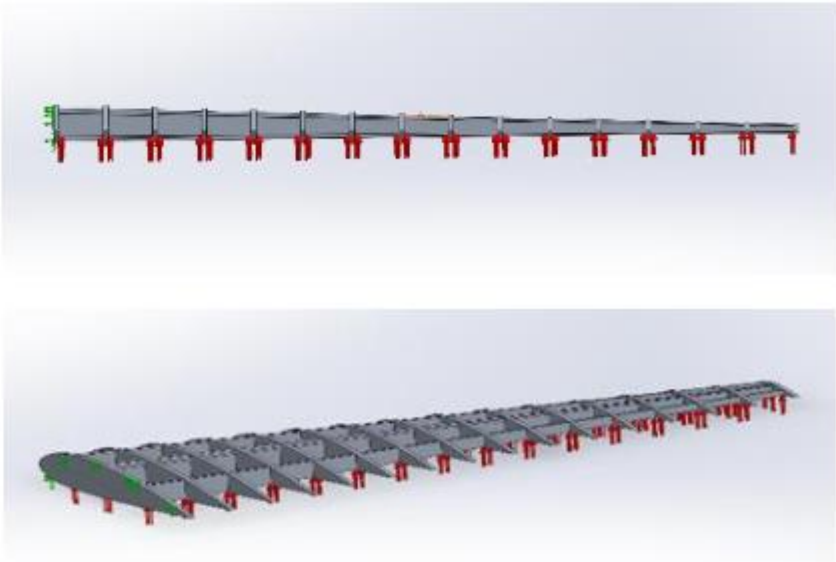

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Figure 6 - Direction of pressure load

(iii) 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. 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.

CONCLUSION

Finally, using two distinct wing construction cases one with titanium alloy and the other with aluminum alloy the structural behavior of a three-dimensional BOEING BACXXX airfoil wing has been simulated. Both fixed structural research and modal study reveal less distortion in the second example of the wing than in the first. Furthermore, because the percentage error is acceptable, the validation of the results from earlier investigations using ANSYS is regarded as reliable and successful. We may infer from the aforementioned findings that the Al alloy has negligible values for equivalent stress, total deformation, and equivalent strain.

To give the construction additional strength, we can employ titanium alloy rather than aluminum alloy. The strongest and lightest alloy, aluminum, also has a lower influence on stress during takeoff conditions while still reducing the weight of the wing. As a result, we can say that titanium is the greatest material to use while creating wings. Ultimately, the deformation of the lifting surface structure has also been seen and determined by the static structural examination. Future improvements might involve testing various materials under various boundary conditions to identify better materials with favorable structural and aerodynamic properties.

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