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Structural Analysis of Aircraft Wing Using Finite Element Analysis

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***Abstract*—**Wings are structural components of an aeroplane that are used to produce lift while the aircraft is in flight. The initial assault angle of the wing is definite. Due to the pressure difference at the top and bottom surfaces of the wing, lift force is produced when the flow passes over it. This paper explains the fundamental concept of the structural behaviour of a wing threatened by flowing loads during the voyage. The study comprises the use of concepts and analysis with the help of finite element analysis. Wing assembly is the first stage of wing model and design, which are determined by fascinating factual features. The basic gathering wing consists of a thin membrane, two poles, and several ribs. It has two spars, the major spar and the secondary spar. Here, NACA 23015 is selected as the standard model for all types of aerofoil structures since it is more akin to the custom aerofoil utilized in large aircraft, specifically the Airbus A320. Two rods mostly endure the twisting moment and trim strength, which is finished with titanium contamination to ensure enough inflexibility. The covering and wing spars are made of aluminium amalgam to lessen the structural heaviness. Following that, a static underlying examination is performed, and the general contortion, equivalent flexible strain, and comparing Von-Mises pressure are obtained to aid in investigations of the mechanical behaviour of the wing. Moreover, the modular examination is being upheld to decide the normal pace of repetition as well as the modular state of the three orders, which are obtained through the pre-stress modular investigation. The findings of the modular investigation assist engineers in reducing their excitement about regular events and turning away the wing from the whirlwind. Based on the findings of the study, planners can prioritise union and examination of the pressure mindfulness range and tremendous twisting region. All in all, the entertainment outcomes demonstrate that the game plan is feasible and further develop the data grade of the lifting surface.

***Keywords*—**FEM, Airbus, NACA, modulus of elasticity, aircraft wing.

I. INTRODUCTION

THE function of the wings can be altered by using different materials. Aircraft wings come in a variety of shapes, including conventional, delta, swept, tapered, two-sided, and flexible geometric wings [1]. The wing, which supports the aircraft's air-breathing engines and generates lift, is one of the main structural components during flight. Air is pulled into the compressor through the starter when the engine is turned on. The compressor's exit has an increasing pressure ratio near the inlet [2]. Air and gasoline are then combined within burned in a combustion chamber. When high-pressure and high-temperature gases are accelerated in the nozzle, thrust force is generated, propelling the plane forward. Air flows over the aerodynamically shaped wing as it moves. The flow velocity is lower at the bottom of the wing and higher at the top of the wing because of the aerodynamic form of the wing and Bernoulli's principle [3]. Because of this, there is a pressure difference between the top and bottom surfaces of the wing, which causes lift. Wings must have a high strength-to-weight ratio and a long fatigue life because they are subjected to alternating, repeated loadings during flight [4].

Each wing has unique wind protection, stability, and manoeuvrability properties. It is important to remember that the majority of commercial aircraft today fall into the fixed-wing category. Due to prolonged life and structural health, several commercial aircrafts, notably the Airbus A320, are getting close to the end of their original design lives. The wings are given special structural care because they are a crucial component of the aircraft [5]. A special Airbus A320 is designated as an emergency aircraft, and structural analysis is carried out using ANSYS. The analysis of wings in commercial A320 aircraft is crucial for determining the mechanical behaviour and stability. The most popular form of jet fuel, Jet-A, which is manufactured from kerosene and resembles diesel fuel, is stored in the wings. There are inner and outer tanks on the wings. Each wing has a vent surge tank that is located outside the outer tank [6]. The simplest design consists of a frame with spars covering it that is fastened to the fuselage while leaving the leading string free. Spars and ribs make up the wing's most basic structure. Airplane wings are an example of a simple cantilever beam. So, before performing a dynamic assessment, we first perform a modal evaluation.

When creating and manufacturing aircraft wings, there are a number of special design considerations to take into account. High strength and light weight are two primary functional needs to take into account while developing material for aircraft wings. Metals like aluminium alloys have traditionally been used in the construction of aircraft. Modern aeroplanes are lighter because of silicon carbide metal matrix composites, which take the place of conventional metals and have the additional benefits of low workload, extreme fatigue, and excellent durability. fuel economy [7]. When comparing weight to stiffness, these composite materials are substantially stronger. A linear static analysis of the aircraft wing and its stresses is carried out in [8] to investigate the behaviour of the wing structure. Authors have also Investigated moment reaction on aircraft wing. This study's goals include finite element modelling with ANSYS and structural idealisation [8]. The structural stability and integrity of the structures used in aerospace or aerospace structures must be maintained through research. A form of vibration known as a buffet is

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typically brought on by aerodynamic excitement.

When an important component of a plane is lost, it can cause great harm to both the plane and its lifetime. Examining the plane wing's hidden lead can help identify any problems with transporter structures, which will help prevent additional occurrences. Fatal incidents in the aviation sector are not a novel topic, as there have been many occasions throughout plane history that have had tragic and horrible outcomes. When everything is taken into account, the vast majority of the major disasters examined have involved metal components, showing the durability of metal structures in planes. A growing number of plane manufacturers have been using fibre-built-up polymer combinations for fundamental components since the mid-1980s. Thus, fundamental complaints about metallic plane plans can be reduced [9]. As a result, in order to respond to failures and destructive disasters caused by an aeroplane wing, it is necessary to assess the essential direction and success of a three-layered wing. However, to aid in the analysis of aircraft accidents, here are several examples of wing region catastrophes and problems that were resolved before a problem could arise.

II. METHODOLOGY

Every material has a specific chemical composition. In this paper, two materials, aluminium alloy and titanium alloy have been studied, both of which have properties that make them ideal for wing design [10]. Aluminium alloy: It has good strength and a high degree of hardness, and it can be machined easily in some tempers. This material is mostly used in the aerospace sector. Titanium Alloy: They are utilised to prevent galvanic corrosion issues and are more compatible with carbon fibres. A design reaction to the mechanical and thermal demands associated with high mobility and supersonic cruise speed is what motivates the increased exploit [11]. The material properties used in this investigation are shown in Table I.

TABLE I
MATERIAL PROPERTIES

	Aluminium Alloy	Titanium Alloy
Young's Modulus (GPa)	73	120
Poisson's Ratio	0.3	0.342

A. Structural Analysis by Using FEM

The Finite Element Analysis (FEA) is the numerical method known as the Finite Element Method that simulates any given physical occurrence. Engineers utilise FEA software to speed up the development of better goods while cutting costs by reducing the number of physical prototypes and experiments and optimising components throughout the design process. Any physical phenomenon, such as the behaviour of structures or fluids, heat transfer, wave propagation, the formation of biological cells, etc., must be fully understood and quantified using mathematics [12]. Partial Differential Equations (PDEs) are used to describe the majority of these processes. However, numerical methods have been developed over the past few decades in order for a computer to solve these PDEs, and one of the most well-known is FEA [13]. In addition to describing natural events, differential equations can also describe the physical phenomena found in engineering mechanics. In order to compute pertinent structural quantities (such as stresses, strains, etc.) and estimate the structural behaviour under a given load, PDEs must be solved. It is crucial to understand that FEA only provides a rough solution to the issue and is a numerical method to determine the true outcome of these PDEs. To put it simply, FEA is a numerical method for predicting how a part or assembly will react under specific circumstances. It serves as the foundation for contemporary simulation software and aids engineers in identifying design flaws, tension points, etc. The outcomes of a FEA-based simulation are typically represented by a colour scale that, for instance, displays the pressure distribution over the object.

The aero plane wing is treated as a cantilever beam in this article and is subjected to elliptical loading. Because it is difficult to theoretically solve the equation with three unknowns due to the nonlinear nature of wings, structural analysis for wings is theoretically performed by deriving a generalized equation with one unknown termed the potential function (r,z). The fundamental controlling equation as shown in (1) is calculated as for any type of beam [14].

$$\frac{\partial^4\varphi}{\partial r^4}+\frac{1}{r^4}\frac{\partial^4\varphi}{\partial\theta^4}+\frac{\partial^4\varphi}{\partial z^4}+\frac{2}{r^2}\frac{\partial^4\varphi}{\partial r^2\partial\theta^2}+\frac{2}{r^2}\frac{\partial^4\varphi}{\partial z^2\partial\theta^2}+2\frac{\partial^4\varphi}{\partial r^2\partial z^2}-\frac{2}{r^3}\frac{\partial^3\varphi}{\partial r\partial\theta^2}+\frac{2}{r}\frac{\partial^3\varphi}{\partial r\partial z^2}+\frac{2}{r}\frac{\partial^3\varphi}{\partial r^3}-\frac{1}{r^2}\frac{\partial^2\varphi}{\partial r^2}+\frac{4}{r^4}\frac{\partial^2\varphi}{\partial\theta^2}+\frac{1}{r^3}\frac{\partial\varphi}{\partial r}=0 \tag{1}$$

We may derive a number of other structural parameters, including deformation and stresses, from (1). Once we discovered the φ and its different derivative w.r.t (r,z), (2)-(4) can be used to determine displacement:

$$u_r=\frac{\partial^2\varphi}{\partial r\partial z} \tag{2}$$

$$u_\theta=\frac{1}{r}\frac{\partial^2\varphi}{\partial\theta\partial z} \tag{3}$$

$$u_z=2(v-1)\left\{\frac{\partial^2\varphi}{\partial r^2}+\frac{1}{r^2}\frac{\partial^2\varphi}{\partial\theta^2}+\frac{1}{r}\frac{\partial\varphi}{\partial r}\right\}+(2v-1)\frac{\partial^2\varphi}{\partial z^2} \tag{4}$$

With the aid of the potential function equation, we obtain shear stress for all types of beams now. By using the requisite boundary conditions for the respective sections, we can then find shear stress at any location on an aircraft wing in cylindrical coordinates.

$$\tau_{r\theta}=\frac{E}{r(1+v)}\left\{\frac{\partial^3\varphi}{\partial r\partial\theta\partial z}-\frac{1}{r}\frac{\partial^2\varphi}{\partial\theta\partial z}\right\} \tag{5}$$

$$\tau_{\theta z}=\frac{E}{(1+v)}\left\{\frac{v}{r}\frac{\partial^3\varphi}{\partial\theta\partial z^2}+\frac{(v-1)}{r}\left(\frac{\partial^3\varphi}{\partial\theta\partial r^2}+\frac{1}{r}\frac{\partial^2\varphi}{\partial\theta\partial r}+\frac{1}{r^2}\frac{\partial^3\varphi}{\partial\theta^3}\right)\right\} \tag{6}$$

$$\tau_{zr}=\frac{E}{(1+v)}\left[v\frac{\partial^3\varphi}{\partial r\partial z^2}+\frac{(v-1)}{r}\left\{\frac{1}{r}\frac{\partial^3\varphi}{\partial r\partial\theta^2}+\frac{\partial^2\varphi}{\partial r^2}-\frac{1}{r}\frac{\partial\varphi}{\partial r}-\frac{2}{r^2}\frac{\partial^2\varphi}{\partial\theta^2}+r\frac{\partial^3\varphi}{\partial r^2}\right\}\right] \tag{7}$$

Fig. 1 shows the Assembled CAD model of aircraft. The main step in setting up a model for any numerical simulation is meshing, and ANSYS Workbench's Setup component is used to mesh the wing model shown in Fig. 2. These are the statistics for this specific mesh:

A. There are 683366 nodes in total.
B. There are 163415 elements

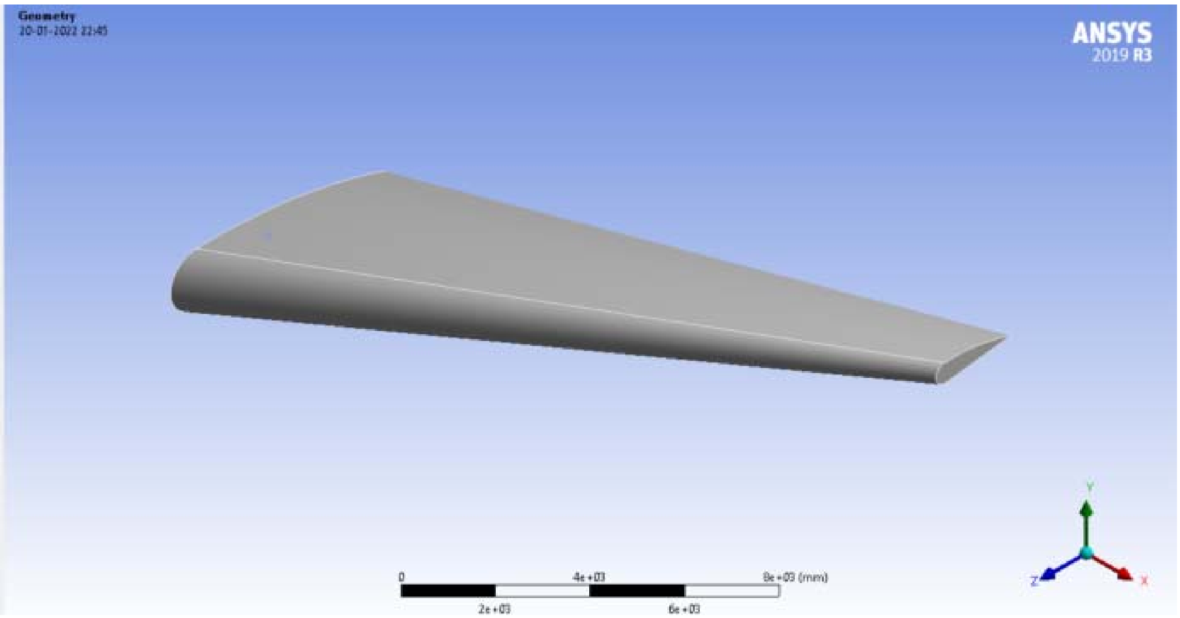

Fig. 1 Assembled CAD model of aircraft

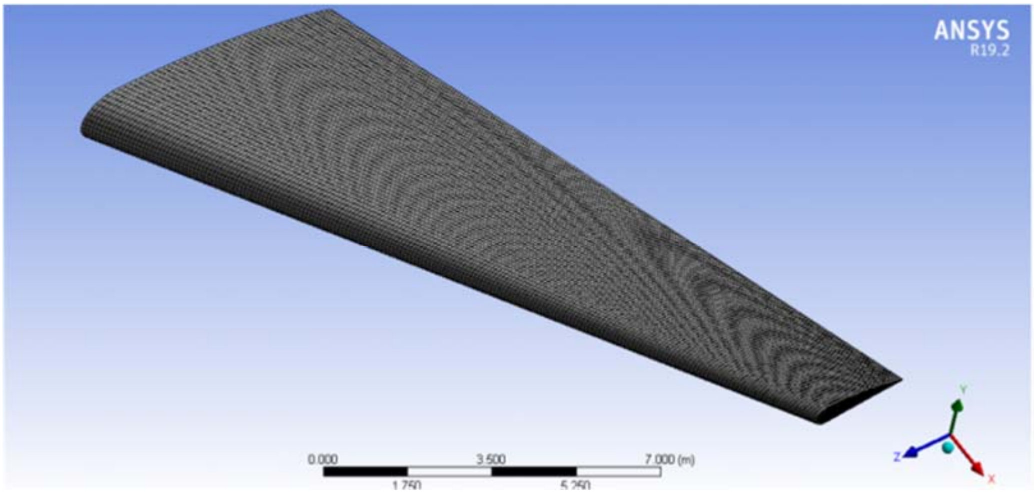

Fig. 2 Meshing of Airfoil Wing

III. Results and Discussion

Static structural examination is useful for analysing the wing because it does not rely on time motion. The goal of this research is to conduct an analysis and structural trend of a three-dimensional wing with no time motion. Thus, to observe the structural behaviour of the wing, static structural analysis is the best pick.

Total Deformation: The maximum total distortion calculated is 0.10126 m, while zero deformation is the minimum for the second case shown in Fig. 3.

It is evident from elastic strain, as shown in Fig. 4, and von-Mises stress, as shown in Fig. 5, that the majority of top and bottom surfaces have the lowest von-Mises stresses, while the centre of the lifting surface is experiencing the highest von-Mises stresses.

A. Force Reaction

Static structural analysis of wing force reaction showing Max. and Min Value over time in X, Y and Z Direction is shown in Fig. 6. And force reaction is mentioned in Table II.

Coordinates of Fig. 6 are represented as:

- X- Thrust Force
- Y- Reaction Due to Load/ Weight
- Z- Drag Forcep

B. Moment Reaction

Static structural analysis of wing showing moment reaction of Max. and Min Value over time is shown in Fig. 7. And Moment reaction values are mentioned in Table III.

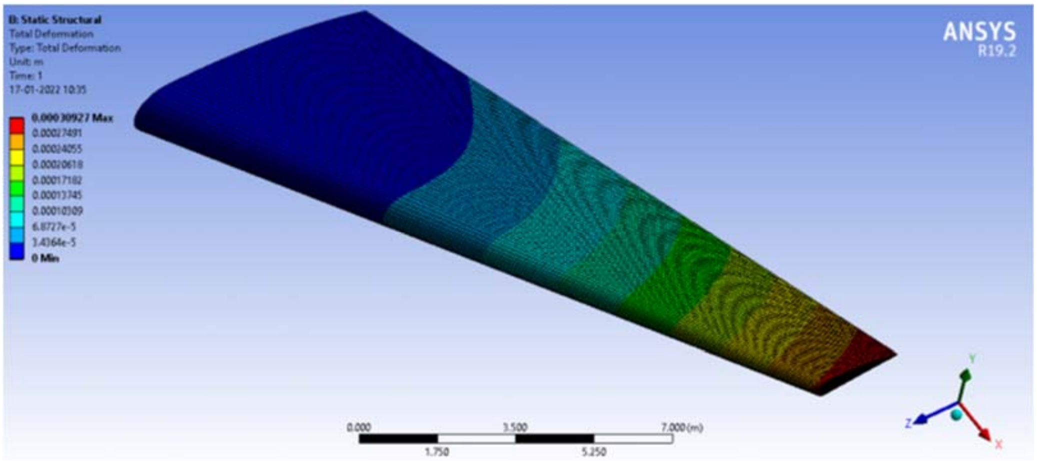

Fig. 3 Total Deformation contour

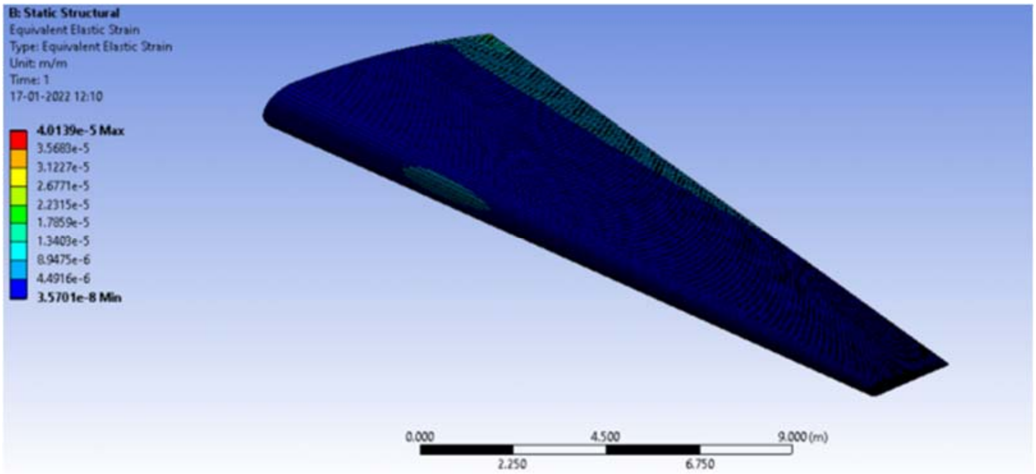

Fig. 4 Equivalent Elastic Strain contour

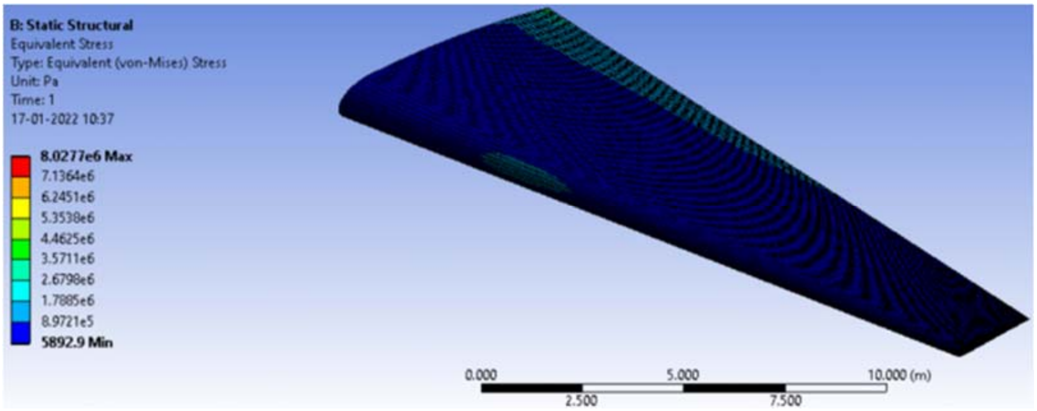

Fig. 5 Equivalent Von-Misses stress contour

TABLE II
CALCULATION OF FORCE REACTION

Sr. no.	Value over time	Time [Sec.]	Force Reaction X [N]	Force Reaction Y [N]	Force Reaction Z [N]	Total [N]
1	Max.	0.5	-1710.4	-0.77889	-3.19e05	6.38e05
2	Min.	1.0	-3416	-31154	-6.38e05	3.19e05

TABLE III
CALCULATION OF MOMENT REACTION

Sr. no.	Value over time	Time [Sec.]	Moment Reaction X [N]	Moment Reaction Y [N]	Moment Reaction Z [N]
1	Max.	0.5	25018	2.39e06	-1.94e04
2	Min.	1.0	50022	4.79e06	-3.88e04

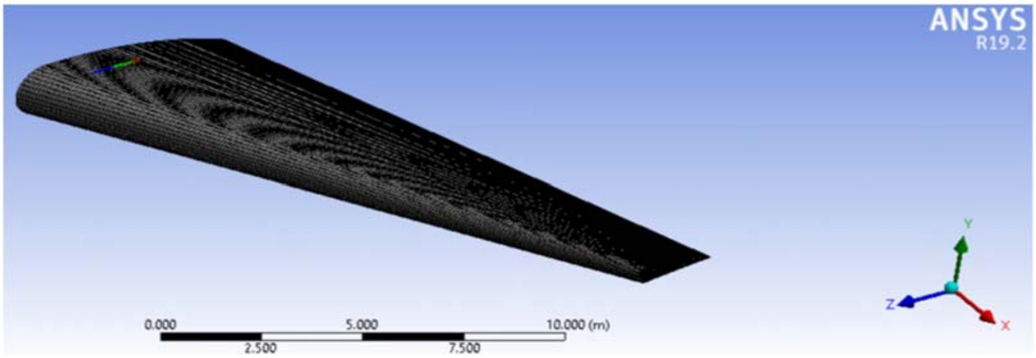

Fig. 6 Force Reaction contour

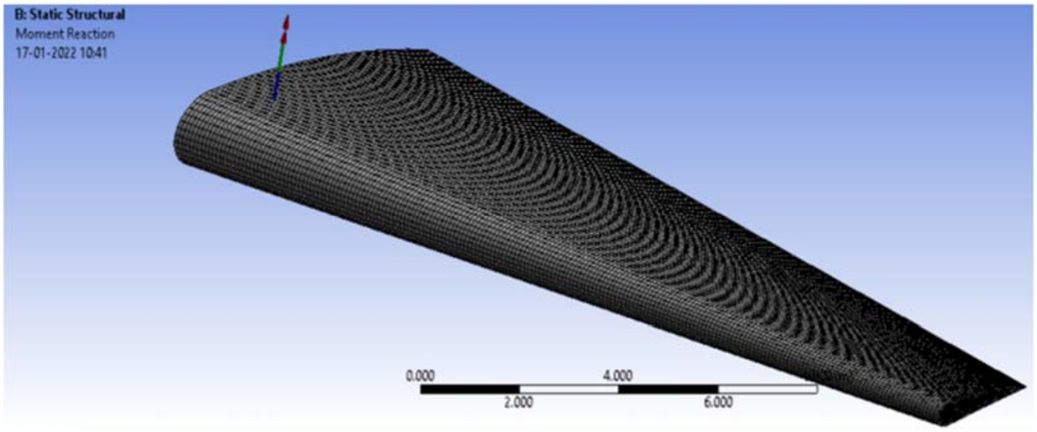

Fig. 7 Moment Reaction contour

IV. CONCLUSION

The conclusions drawn from this research are summarized as follows since it is focused on identifying the structural stress and the deformation introduced in the wing:

1. The structural behaviour of a three-dimensional wing has been modelled, and the deflection of the wing structure is also being studied.
2. In addition, since the % error is acceptable, the validation of results from prior studies using ANSYS is regarded as successful and reliable.
3. The lifting surface structure's static structural deformation has also been noticed.
4. The wing deformation, such as stress, strain, and total deformation, is acquired.
5. The calculated maximum total distortion is 0.10126 m, while the calculated minimum deformation in the second instance is zero.
6. The mode shapes for the bending modes of the given wing structure are determined using the ANSYS Workbench Modal analysis component. The natural frequencies for the 18 modes of the model are obtained.
7. The maximum natural frequencies obtained is 304.98 Hz.
8. Static structural analysis of wing shows Total Deformation with max. value of 0.00030927 m, Equivalent stress (Von-mises) with max. value of 8.0277e6 Pa and min. value of 5892.9 Pa, Equivalent Elastic Strain with max. value of 4.0139e-5m/m and min. value of 3.5701e-8m/m.

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