Structural Analysis of a Transport Aircraft Wing

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Abstract: *In this study the procedures of structural analysis of a typical transport aircraft wing has been followed. The wing model has been drawn using CATIA® V5; this model consists of several structural components such as spars, ribs and skin. The model has been exported into structural analysis software ANSYS® 2016. Stresses, strains, deformations and safety factors were obtained for the model. It is found that the obtained stresses caused by the aerodynamic loads on the wing are within the design structural limits where the failure by yield or buckling has not been occurred.*

Key Words: *Wing, Structural analysis, Stresses, Strain, Deformation*

1. INTRODUCTION

The three most important structural components of aircraft, namely; wing, fuselage and empennage are considered from the point of view of stressing as beams or cantilevers with variable loading along their lengths. The wing is a complicated structure of the aircraft due to its complex behavior towards different loads and maneuvers. The design of wings may vary according to the type of the aircraft and its purpose. The aircraft wings are the primary lift producing devices for an aircraft and are designed aerodynamically to generate a lift force which is required for flying. Besides generating the necessary lift force, the aircraft wings are used to carry the fuel for the mission of the aircraft, to mount engines or to carry extra fuel tanks or other armaments. The basic goal of the wing is to generate lift and minimize drag [1].

The wing structures support some of the heaviest loads to which the aircraft structure is subjected. The particular design of a wing depends on many factors, such as size, weight, speed, and rate of climb. Wing is mainly used as a lift producing component in an aircraft [2]. Ramesh Kumar, Balakrishnan and Balaji [3] predicted the fatigue life for crack initiation at maximum stress location. Then stress analysis of the wing structure is carried out to compute the stresses at wing structure. The stresses are estimated by using the finite element approach with the help of ANSYS®2016 to find out the safety factor of the structure. In their project, the detailed design of the trainer aircraft wing structure was made using CATIA V5 R20.

Ghassan M. Atmel et al [4], created in their work a three-dimensional layout of an aircraft using the RDS software based on conic lofting, then placed it in a simulation environment in

MATLAB which proved the design adherence to the design goals. In addition, static stress analysis was also performed for wing design purposes. Shabbier KP et al [5] developed an accurate model for optimal design. Structural modeling was completed with the help of CATIA V5 R20, using workbench of ANSYS/ FEM. The distribution of Von-Misses stress in the case of wing is less towards the wings leading and trailing edges and decreases towards the wing tip. Maximum values of Von-Misses stress were observed at the support position of the combined wing. The largest magnitude of displacement was obtained at the free end of the combined wing. In this work, the response of the wing structure to the applied aerodynamic loads has to be evaluated by considering the following objectives:

a. Analyzing the existing structure layout of the wing.
b. Developing an accurate finite element model that predicts the wing response.
c. Find the stresses and strains that act on the wing structures.
d. Obtaining the safety factor of the structure.

2. PROBLEM STATEMENT

The wing of a transport jet airliner is subjected to various loading such as pressure differences between the upper and lower surface, concentrated loads from engine mounting, distribution of fuel by the internal fuel tanks and structural weight of the wing itself. These loading may be changed through the flight phases. Due to these loading, stresses may be resulted and the wing may deform accordingly; these stresses should be determined and compared with the material ultimate strength and then it must be checked whether the wing structure failure will occur or not.

The wing geometric is as follows:

a. The airfoil used in aircraft wing is supercritical airfoil NACA 64A215 at root and NACA 64A210 at tip.
b. The material used for the whole structural and modal analysis purpose is Aluminum alloy 2024-T3 for spars and ribs and Aluminum alloy 7068 for skin.

Table 1. Material mechanical properties

Material	Density (kg/m^3)	Young modulus (MPa)	Poison's ratio	Yield strength (MPa)	Ultimate tensile strength (MPa)
AL 2024-T3	2780	7310	0.33	385	483
AL 7068	2770	7100	0.33	590	641

The wing geometrical data are shown in table (2) below:

Table 2. Wing geometrical data

Parameter	Value
Aspect ratio (AR)	9.3
Taper ratio (λ)	0.24
Area (S)	111.63 m^2
Span(b)	32.22 m
Root chord $(C_r$	5.59 m
Tip chord (C_t)	1.34 m
Dihedral angle (Γ)	5^0
Airfoil (root)	NACA 64A215
Airfoil (tip)	NACA 64A210
Front spar (I – section)	18 - 25% of chord

Rear spar (C- section)	65 - 70% of chord
Quarter chord sweep angle	27.7^0
Twist angle	3^0
Incidence angle	1^0

3. METHODOLOGY

The wing model was drawn using CATIA® V5 R20 program and then exported to ANSYS®2016 for the analysis; the wing was supported from root chord. Loads acting on the wing were found from CFD (FLUENT). Finally the load was applied to the ANSYS®2016 and static structural (FEM) was used for analysis and display of the results.

4. WING STRUCTURE AND LOADS

In this paper two types of analyzes are conducted mainly, normal mode and linear static analyzes. The wing geometry is imported from CATIA® V5 R20, figure (1), into ANSYS®2016 by extracting each points and curves for geometrical accuracy of the model. In the wing model structure there are eight ribs and two spars. The types of mesh, figure (1), used for the spars, ribs and skin ($3mm$) are as in table (3).

Table 3. Structure mesh types

Structure	**Element**
Spars	3D Tetrahedral
Ribs	3D Tetrahedral
Skin	2D Quad lateral

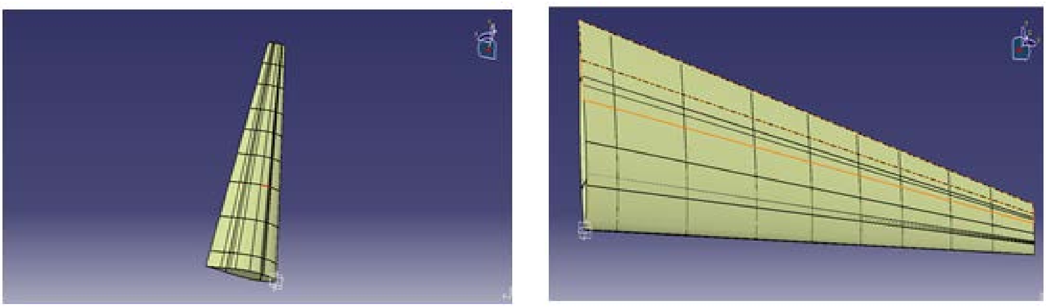

Figure 1: Wing Model (CATIA)

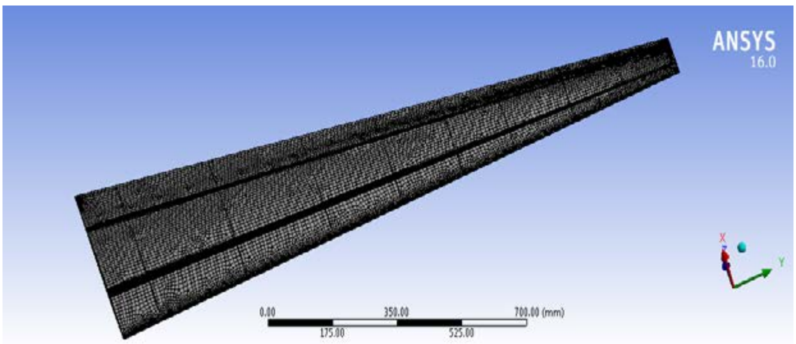

Figure 2: Wing mesh

Figure (3-a) shows the distribution and the location of the ribs (8 ribs) along the wing span located at different distances. The wing structure has two spars, the front spar is the I section located at 21% of the root chord, and the rear spar is the C section located at 70% of root chord, as seen in figure (3-b). The wing skin is modeled as in figure (3-c), the material is aluminum alloy 7068 and the thickness is 3 mm.

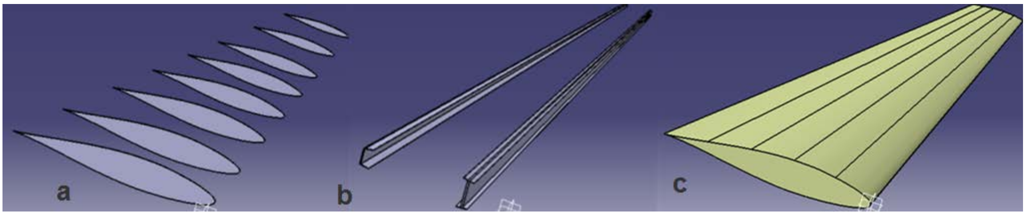

Figure 3: Wing: a- Ribs, b- Spars, c- skin

Figure (4) shows the imported load from FLUENT; as shown, the maximum pressure in the leading edge is $5 * 10^{-3}\ Mpa$, and the minimum at the trailing edge is $6.385 * 10^{-6}\ Mpa$.

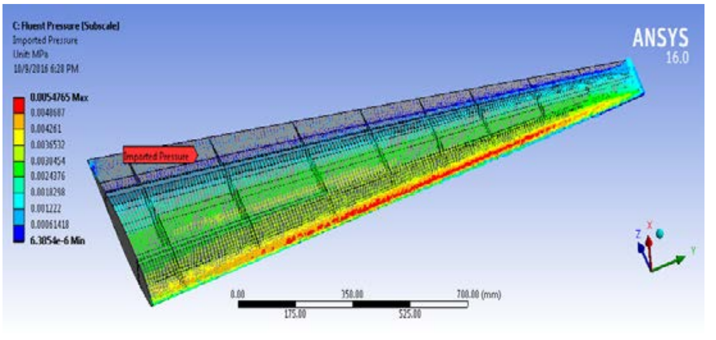

Figure 4: Loads acting on the wing model

5. RESULTS AND DISCUSSIONS

a. Normal mode analysis:

Finite element analysis (FEA) approach was used in term of normal mode analysis in order to obtain both modal properties of the wing structure which are the natural frequencies and the mode shape. Figure (5) shows the wing model bending modes; a- 1st bending mode with frequency$33.007\ Hz$, b- 2nd bending mode with frequency $114.59\ Hz$, c- 3rd bending mode with frequency$250.31\ Hz$. Figure (6) shows the twisting and combined bending and twisting mode with frequency$421.78\ Hz$.

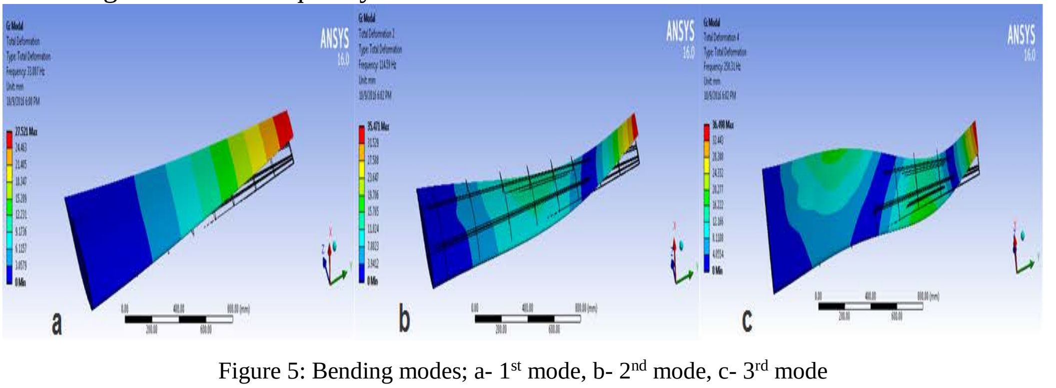

Figure 5: Bending modes; a- 1st mode, b- 2nd mode, c- 3rd mode

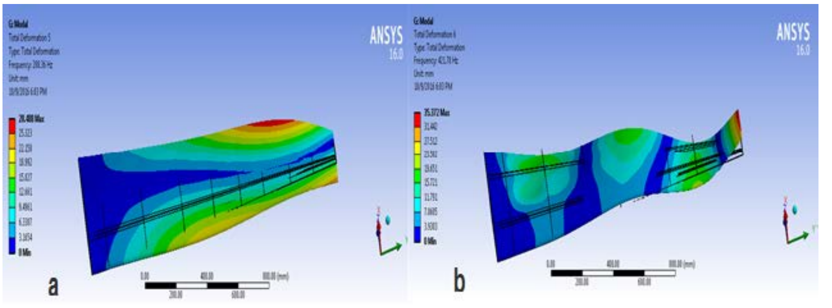

Figure 6: Modes; a- twisting mode, b- combined bending and twisting mode

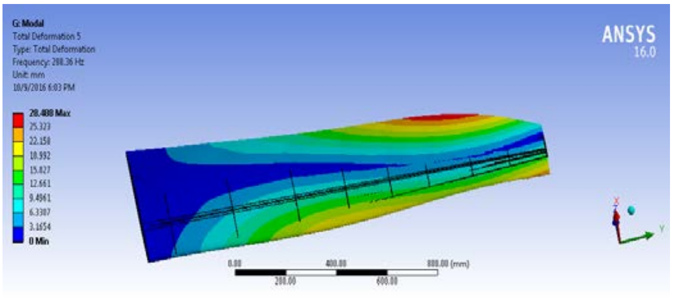

Figure 7: Twisting mode

Table 4: Modes type and frequencies

No	Mode	Frequency (Hz)
1	First bending	33.007
2	Second bending	114.59
3	Third bending	250.31
4	Twisting	288.36
5	Combined bending and twitting	421.78

b. Linear static structure:

The purpose of linear static structure is to find stresses, strains, deformation and safety factor of the wing at effected loads. As shown in figure (8) the maximum total deformation in tip is 26.922 mm, and there is no deformation at wing root, because the wing is acting as a cantilever beam fixed at the root and free on its tip.

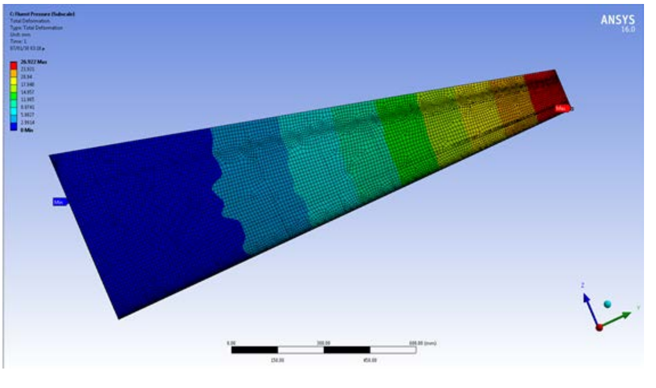

Figure 8: Total deformation

Figure (9) shows the Von-Mises stress; the maximum Von-Mises Stress is $724.74\ Mpa$, and the minimum is $0.057\ Mpa$.

Figure (10) shows that the Maximum shear stress in an interior component (spars &ribs) is $418.02\ Mpa$, and the minimum is $0.030\ Mpa$.

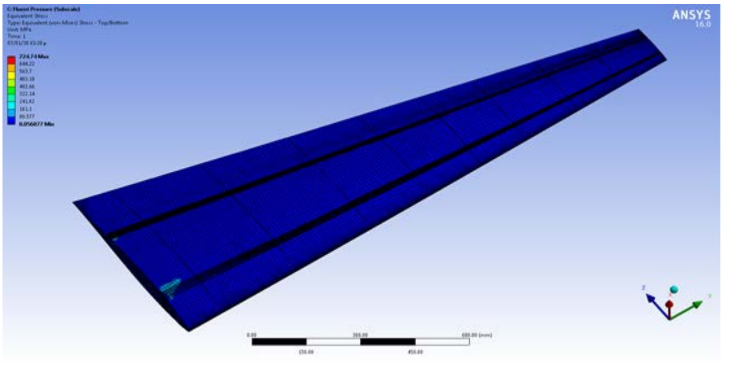

Figure 9: Von-Mises stress

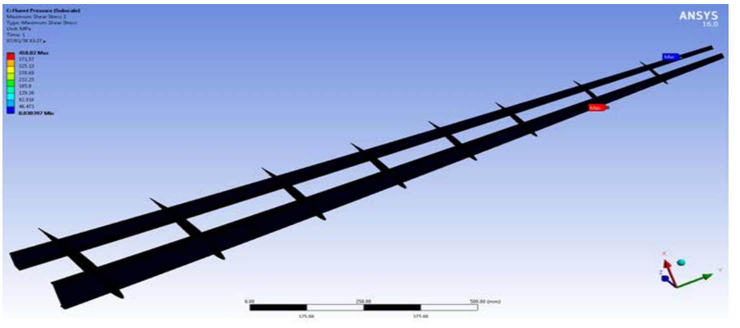

Figure 10: Shear stress in interior components

As shown in figure (11), the maximum equivalent elastic strain is $0.01\ mm/mm$, and the minimum is $1.461 * 10^{-6}\ mm/mm$.

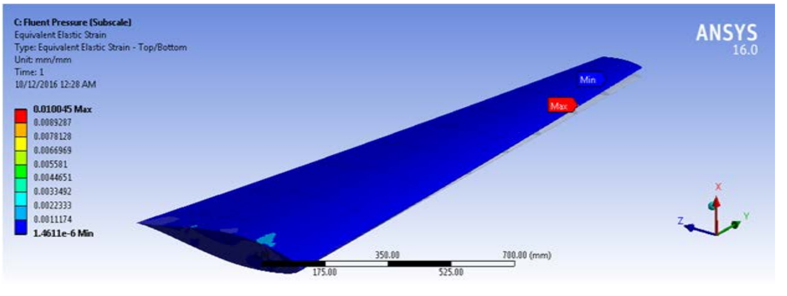

Figure 11: Equivalent Elastic Strain

6. CONCLUSIONS

An aircraft wing model is analyzed for to determine the normal mode analysis and the linear static structure. The finite element analysis (FEA) approach was used for obtaining the modal properties of the wing structure which are the natural frequencies and the mode shape. The linear static structure is conducted to find stresses, strains, deformation and safety factor of the wing at various loadings.

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