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Linear Static Analysis of CFRP Aircraft Wing

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ABSTRACT
In the present day scenario, use of carbon fibre composites has been extended to a large number of aircraft components which includes structural and non-structural components. These composite materials can provide a much higher strength to weight ratio and stiffness-to-weight ratio than metals. Wing of the aircraft is one of the crucial components which determine the performance of the aircraft. The systematic and proper analysis of the aircraft wing is of prime importance due to its contribution towards the efficiency of the whole aircraft. In the present study, linear static analysis of the preliminary model of selected CFRP aircraft wing is done to find out the stresses and displacements. Based on the results, a refined model is prepared and analysed. The stresses and displacements of the refined model are found to be within the permissible limits. Also it is found that various components of an aircraft wing can be safely made using CFRP.
Keywords - Ansys 12, CFRP, finite element modelling, linear static analysis, von Mises stress

I. Introduction

The design and manufacture of aircraft wings require attention to several unique structural demands. High strength and light weight are the two primary functional requirements to be considered in selecting materials for the construction of aircraft wing. Traditionally aero planes have been made out of metal like alloys of aluminium [1]. Now a days the carbon fibre composites have replaced the traditional metals. Use of CFRP makes the aircraft lighter with added benefits of less maintenance, super fatigue resistance and high fuel efficiency. These composite materials can provide a much higher strength to weight ratio and stiffness-to-weight ratio than metals. In order to study the structural behaviour of a CFRP aircraft wing the linear static analysis is carried out on a subsonic aircraft wing and the stresses and displacements are analysed. In linear static analysis [2], the dynamic loads acting on the structure is idealized to equivalent uniformly applied static loads by multiplying with a suitable factor of safety and the stress strain relationship of CFRP is also considered linear. The objective of this study includes structural idealization, Finite element modelling using ANSYS 12, linear static analysis and study and interpretation of analysis results

II. Literature Review

Daniel P Raymer [3] has described the various aerodynamic considerations in the design of aircrafts. According to him the key geometric parameters of wing are span, reference wing area, aspect ratio and taper ratio.

Dr. M. Neubauer, G. Günther [4] gave description regarding various loads to be considered in the analysis and design of air frame structures .He also discussed the Conversion of "external loads" into structural airframe loads. He conducted aircraft analysis using static loads and fatigue loads.

Sanya Maria Gomez [5] has analysed wing components like ribs, spars and panels of hypersonic aircraft using FEM considering both isotropic and composite materials. The optimum ply orientation was obtained by conducting parametric study using ANSYS FEM package by varying the orientation sequence in the composites.

Dr.R.Rajappan, V.Pugazhenti [6] in their thesis deals with bending Finite Element Analysis of monocoque laminated composite aircraft (subsonic and supersonic) wing using commercial software ANSYS.

III. Structural Components of the Wing

The various structural components of a conventional aircraft wing structure considered for the design are [7]:

3.1 Wing panel

The primary function of the wing skin is to form an impermeable surface for supporting the aerodynamic pressure distribution from which the lifting capability of the wing is derived. These aerodynamic forces are transmitted in turn to the ribs by the skin through plate and membrane action.

3.2 Ribs

The wing ribs are the forming and shaping structural member of an aircraft wing. The ribs provide the necessary aerodynamic shape which is required for generation of lift by the aircraft. They are attached to the wing spars and thus provide structural stiffness. Ribs also act as a member for transfer or distribution of loads from wing panel to spars.

3.3 Spars

The wing spars are the main load carrying structural member of the aircraft wing. The wing spars are used to carry the loads that occur during the flight (flight loads) as well as carry the weight of the aircraft wing while on the ground (ground loads). The spars are the longitudinal load carrying members which are connected to the ribs.

IV. Material Used

The entire wing is considered to be made up of CFRP composites. The properties of the carbon fibre reinforced polymer used in the present study are given in TABLE 1 below:

Table 1: Properties of CFRP (M55j/914prepreg)

Young's Modulus (longitudinal)	270 GPa
Young's Modulus (transverse)	5.535 GPa
Inplane shear Modulus	3.870 GPa
Mass Density	1760 kg/m^3
Major Poisson's Ratio	0.365

V. Aircraft Loads

The aircraft wings are subjected to a wide variety of aerodynamic, structural, wind, and flight and ground loads [4]. The major forces and loads acting on the wing are:

1. Pressure force: For an aircraft wing higher pressure exists on the bottom surface while a lower pressure exists on the top surface which results in generation of an upward force known as the lift.
2. Drag force: Drag is a consequence of flight in a medium such as air or any other fluid having density. It should also be resisted by wings.
3. Gravity: Self weight of the wing which acts in the downward direction.

After a number of studies the load on the aircraft wing is assumed as a uniformly distributed pressure of magnitude 56 kN/m^2 acting on the top panel.

VI. Structural Idealization

Wing components such as ribs and spars are idealized as general plate elements [8]. The wing is idealized to consist of four equally spaced ribs and two spars at leading and trailing edges [5]. The wing is idealized as a cantilever beam with fixity at the fuselage end. The connection between various components is assumed as rigid. All the structural components are designed to have a thickness of 2 mm.

VII. Wing Model Using ANSYS Software

ANSYS is a general purpose finite element modelling package for numerically solving a wide variety of mechanical problems. These problems include static/dynamic structural analysis (both linear and non linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. Wing was modelled in ANSYS SOFTWARE using shell element, SHELL99 [9].This element can be used for layered applications of a structural shell model. The element has six degrees of freedom at each node, translations in the nodal x, y and z directions and rotations about the nodal x, y and z axes.

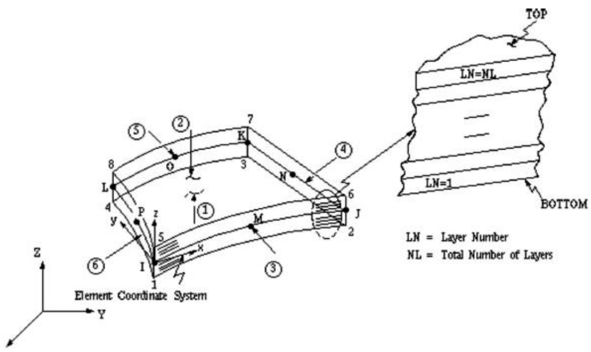

Figure 1: SHELL99 Geometry

Fig 1 above shows the geometry of the shell 99 element where, LN=Layer Number and NL=Total Number of Layers.

VIII. Analysis of Preliminary Wing Model

The analysis results of the preliminary model are shown in the following figures. Fig 2 shows the meshed model of the aircraft wing. Fig 3 shows finite element model of CFRP aircraft wing with load and boundary condition and Fig 4 shows the deformed configuration.

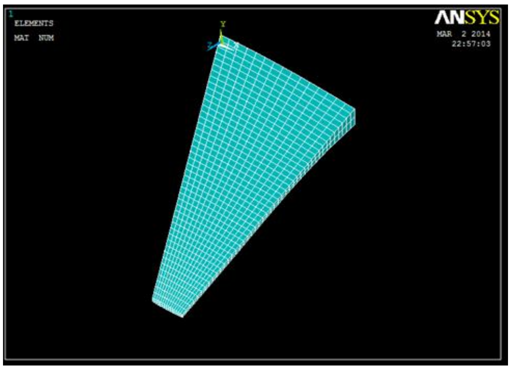

Figure 2: finite element model of CFRP aircraft wing

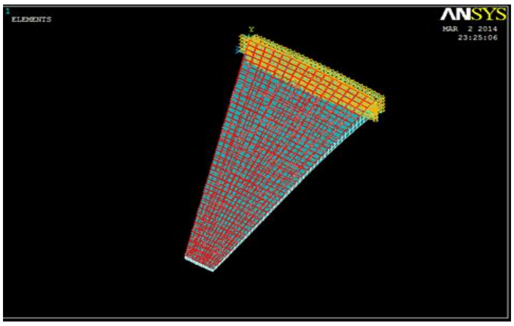

Figure 3: finite element model of CFRP aircraft wing with load and boundary condition

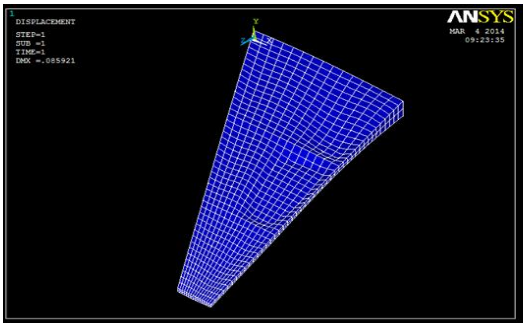

Figure 4: Deformed configuration of finite element model

The maximum deflection occurs at top mid panel near to the rear spar and its magnitude is 85.921mm. The increased deflection in the mid panel than in the end panel is due to the larger distance between the supporting spars at the middle portion.

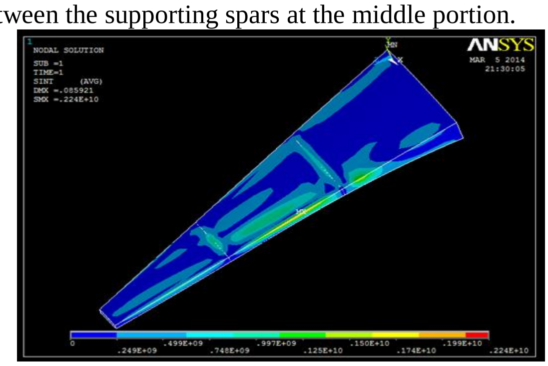

Figure 5: nodal solution for von Mises stress

The nodal solution for von Mises stresses are shown in Fig 5.The figure shows that maximum stress intensity of magnitude 2240N/mm^2 occurs at the middle portion of rear spar which is more than the permissible stress in CFRP (1800N/mm^2)[10]. Also there is stress concentration at ribs and spars. This stress concentration occurs as these are designed as simple plate elements.

IX. Analysis Using Refined Model

The initial mathematical model is refined by designing the ribs as I sections and spars as channel sections. The top panel thickness is increased to 6mm for reducing the stress intensity and deflection. The refined model is analysed below. The Fig 6 shows finite element model of refined aircraft wing; figure 7 shows loads with boundary condition. Fig 8 is the deformed shape of the finite element model and Fig 9 shows the von Mises stress acting on the finite element model of the structure.

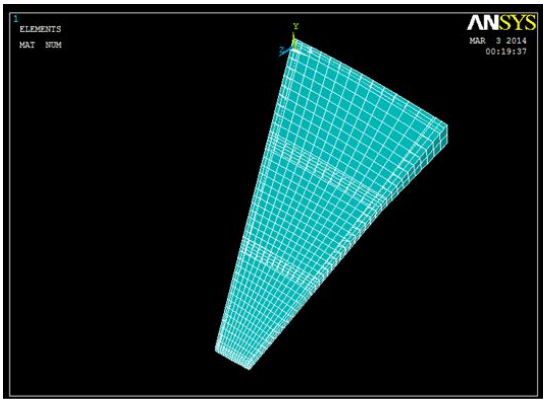

Figure 6: finite element model of refined aircraft wing

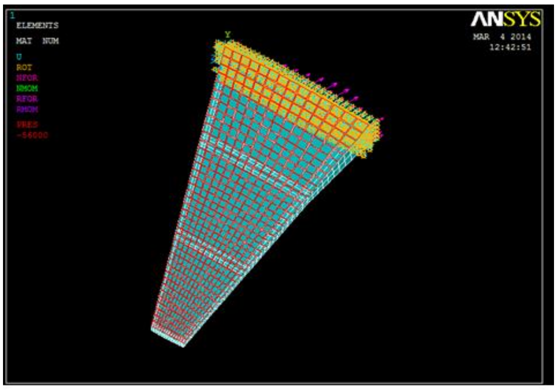

Figure 7: Loads with boundary condition

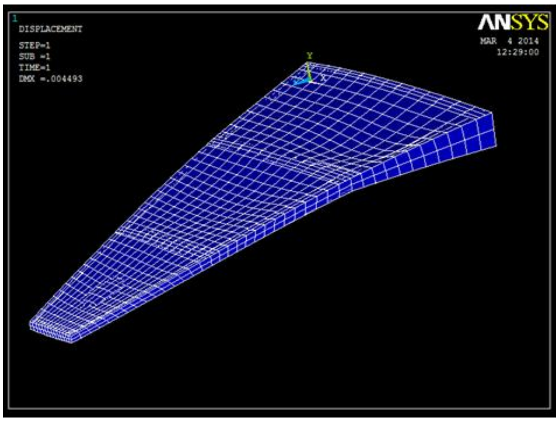

Figure 8: Deformed configuration of finite element model

The maximum deflection is reduced from 85.921mm to 4.493mm. The sagging of top mid panel is reduced by a large amount in this model and the deflection pattern is now similar to that of a cantilever beam with the maximum deflection occurring at the tip of wing.

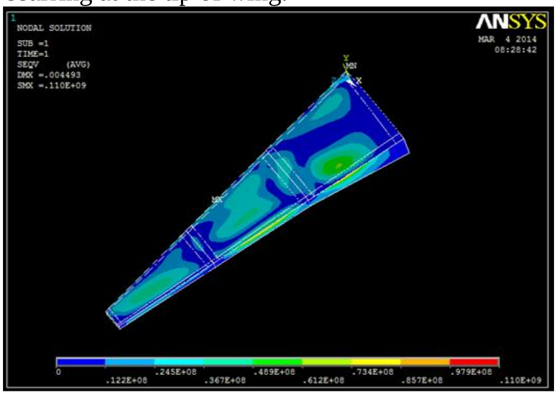

Figure 9: Nodal solution for von Mises stress

The maximum stress intensity obtained is 110 N/mm^2 at the middle portion of spar. The obtained value of maximum stress is well within the permissible limits of stress in CFRP. Also the stress distribution is nearly uniform throughout the wing in refined model.

X. Conclusions

The linear static analysis of CFRP aircraft wing was conducted. In the analysis the wing is idealized as a cantilever beam with fixity at the root rib. For a cantilever beam bending problem the maximum deflection is expected at free end. But in the linear static analysis of the preliminary model the maximum deflection occurred at top mid panel near to the rear spar and the maximum deflection in refined model is at the tip of wing.

Maximum stress intensity occurred at the middle portion of rear spar in preliminary model which was more than the permissible stress of CFRP and there was stress concentration at ribs and spars. This stress was reduced by providing flanges to ribs and spars in refined model. The obtained value of maximum stress in refined wing is well within the permissible limits of stress in CFRP. Also the stress distribution is nearly uniform throughout the wing in refined model. So the refined model is acceptable on the basis of the above obtained results and can be safely used for airplane wing. Also it is found that various components of an aircraft wing can be safely made using CFRP.

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