RESEARCH ARTICLE OPEN ACCESS

Ply Orientation of Carbon Fiber Reinforced Aircraft Wing - A Parametric Study

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ABSTRACT
In the present day scenario, use of carbon fiber composites has been extended to a large number of aircraft components which includes structural and non-structural components. Carbon fiber reinforced polymer (CFRP) is a composite material which consists of laminates having reinforcing fibers (carbon) of significant strength embedded in a matrix material. Each lamina can have distinct fiber orientations which may vary from the adjoining lamina. The present study focuses on the effect of the ply orientation on the strength of the panels. The wing of a subsonic aircraft was modeled in the ANSYS software. The performance of wing under the application of loads was studied by varying the orientation of fiber layers. From the study, it was observed that the variation in stress occurs with variation in orientation of fiber layers of CFRP composites.
***Key Words*: Ply orientation, CFRP, Finite Element Modeling, ANSYS**

I. INTRODUCTION

The first generation of conventional powered aircraft was constructed of wood and canvas. Then aluminium alloy was the used in aircraft construction [1]. The increased wing loadings and complex structural forms of present day aircrafts cause high stress concentrations for which the conventional material is not well adapted. Now a days, the carbon fiber composites have replaced the traditional metals. FRPs are commonly used in the aerospace, automotive, marine, and construction industries [2]. Carbon fiber reinforced polymer or carbon fiber reinforced plastic or carbon fiber reinforced thermoplastic (CRP, CFRP or often simply carbon fiber), is an extremely strong and light fiber reinforced polymer which contains carbon fibers. Use of CFRP makes the aircraft lighter with added benefit 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, sometimes as much as 20% better. These CFRP composites are made up of fiber layers or laminates of different ply orientation. The objective is to conduct parametric study on composite aircraft wing by varying the ply orientation to find the corresponding variation in stress and displacement.

II. LITERATURE REVIEW

Daniel P Raymer [2] 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. COMPOSITE MATERIALS

Composite materials consist of strong fibers such as glass or carbon set in a matrix of plastic or epoxy resin, which is mechanically and chemically protective. The fibers may be continuous or discontinuous but possess strength very much greater than that of the same bulk materials. For example, carbon fibers have a tensile strength of the order of 2400 N/mm^2 and a modulus of elasticity of 300000 N/mm^2.

IV. LAMINATE

A laminate is a material which can be constructed by uniting two or more layers of material together that is by stacking together several laminas.

This is the most common form of fiber reinforced composites. In structural form of composites two or more sheets are sandwiched together to form a lay-up so that the fiber directions match those of the major loads. Each layer of sheet is orthotropic and when they combine becomes anisotropic. The fibres in the laminate are arranged in a particular orientation known as ply orientation with respect to the reference axis as shown in Fig.1. The composite is stronger along the direction of orientation of the fibers and weaker in a direction perpendicular to the fiber.

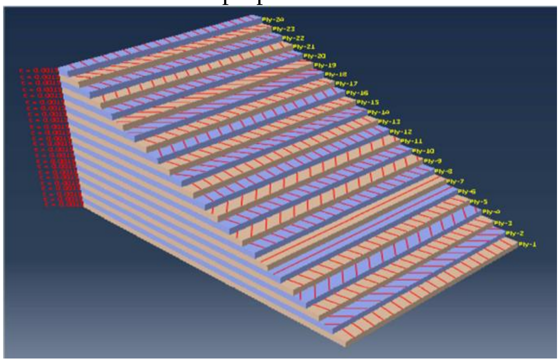

Fig.1: Ply stack plot of a laminate

V. MODELING OF WING

The aircraft wing is modeled in ANSYS software [7]. In this study the aircraft wing is modeled as CFRP (M55j/914prepreg) consisting of 20 plies each. The thickness of each ply was taken as 0.1mm. The properties of CFRP material used are given in TABLE1.

TABLE1: 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
Tensile strength (longitudinal)	1.8 GPa
Tensile strength (transverse)	0.022GPa
Compressive strength	0.6GPa
Shear Strength	0.092 GPa
Coefficient of thermal expansion	$1.2e5/^0K$

The finite element model of CFRP aircraft wing prepared in ANSYS 12 is given in Fig.2.

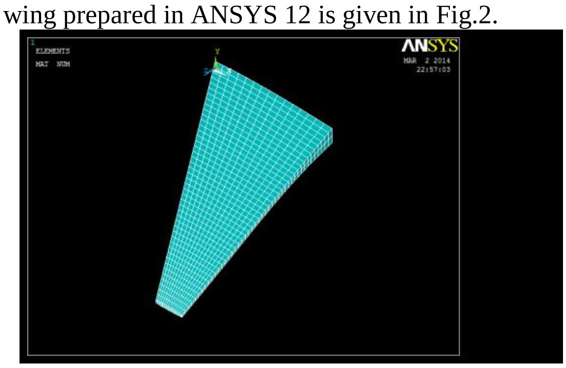

Fig.2: Finite element model of CFRP aircraft wing

The finite element model after applying the boundary conditions and a uniformly distributed load of 56kPa are given in Fig.3.

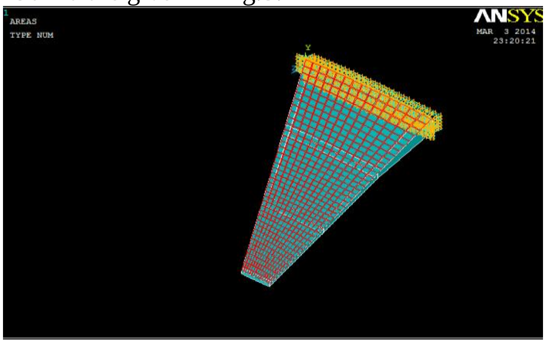

Fig.3: Finite element model of aircraft wing with loads and boundary condition

VI. PLY LAYOUT SEQUENCE

In order to study the effect of ply orientation, the following layup sequences were selected $[0_2/90_2/+\theta/-\theta/90_2/0_2]_{ns} = [0/0/90/90/+\theta/-\theta/90/90/0/0]_{ns}$. This sequence was selected since studies with regard to this sequence were already conducted on a CFRP material launch vehicle structure. The θ angle was varied from 0 degree to 90 degree at intervals of 15 degrees each [5]. The ply sequences selected for this study are given below in TABLE2.

TABLE2: Ply Layout Sequence

Ply Layout Sequence
$[0_2/90_2/+0/-0/90_2/0_2]_{ns}$
$[0_2/90_2/+15/-15/90_2/0_2]_{ns}$
$[0_2/90_2/+30/-30/90_2/0_2]_{ns}$
$[0_2/90_2/+45/-45/90_2/0_2]_{ns}$
$[0_2/90_2/+60/-60/90_2/0_2]_{ns}$
$[0_2/90_2/+75/-75/90_2/0_2]_{ns}$
$[0_2/90_2/+90/-90/90_2/0_2]_{ns}$

VII. RESULTS AND DISCUSSION

By varying the ply sequence of the composite layers, the von Mises stresses and the displacements obtained for each ply orientation was studied. The resultant von Mises stresses corresponding to the ply orientations $[0_2/90_2/+45/-45/90_2/0_2]_{ns}$ is as given below in Fig.4.

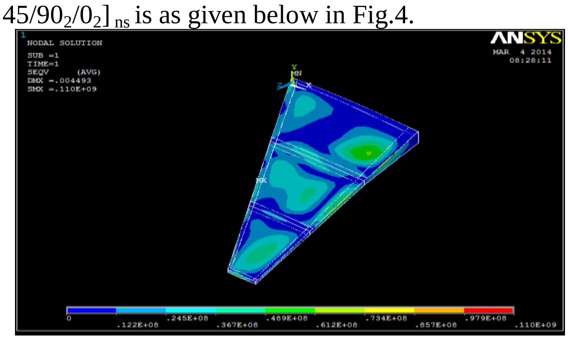

Fig.4: von Mises stress for ply layout sequence - $[0_2/90_2/+45/-45/90_2/0_2]_{ns}$

The ply layout sequence $[0_2/90_2/+45/-45/90_2/0_2]_{ns}$ are given in Fig.5.

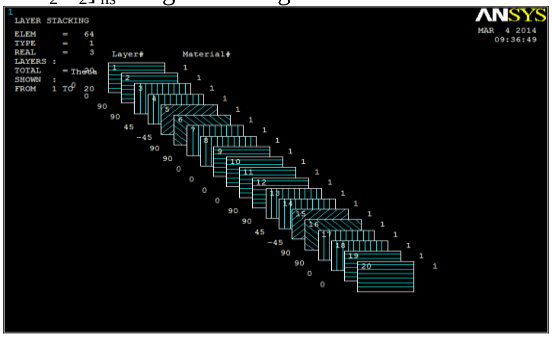

Fig.5: Ply layout sequence - $[0_2/90_2/+45/-45/90_2/0_2]$

The resultant von Mises Stresses and displacements for the ply orientations adopted are given below in TABLE3.

TABLE3: von Mises Stresses and displacements for the wing

Ply Layout Sequence	von Mises Stress(N/mm^2)	Displacement (mm)
$[0_2/90_2/+0/-0/90_2/0_2]_{ns}$	205	12.2
$[0_2/90_2/+15/-15/90_2/0_2]_{ns}$	141	8.01
$[0_2/90_2/+30/-30/90_2/0_2]_{ns}$	109	5.23
$[0_2/90_2/+45/-45/90_2/0_2]_{ns}$	110	4.49
$[0_2/90_2/+60/-60/90_2/0_2]_{ns}$	113	4.93
$[0_2/90_2/+75/-75/90_2/0_2]_{ns}$	146	7.49
$[0_2/90_2/+90/-90/90_2/0_2]_{ns}$	226	11.68

The graph of displacement values obtained for the various ply layout sequences varying from 0° to 90° at 15° intervals and the ply orientations are shown in Fig.6.

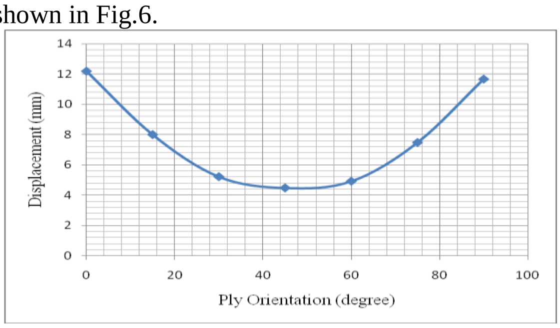

Fig.6: Displacements obtained for the various ply layout sequences

The von Mises stresses obtained for the various ply layout sequences varying from 0° to 90° at 15° intervals were tabulated and plotted on the graph shown in Fig.7.

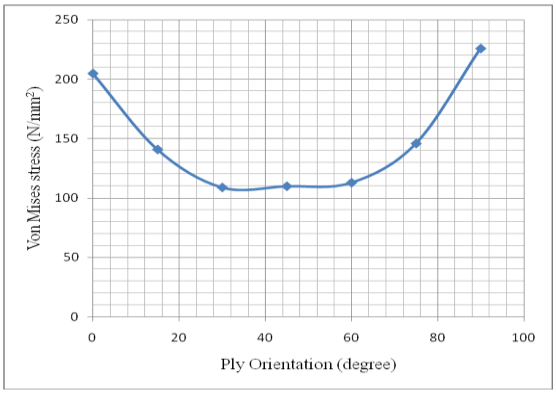

Fig.7: von Mises stresses obtained for the various ply layout sequences

VIII. CONCLUSIONS

From the parametric study of the wing it can be concluded that with the same skin thickness, variation in fiber orientation will produce variation in the von Mises stress and displacement. The scopes of future works are to conduct parametric study and optimization of structural components by taking thickness as variable. Also analysis can be performed by varying the rib spacing or by increasing the number of ribs. The analysis can be further extended by providing stiffeners.

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