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Optimization of Ply Orientation of Different Composite Materials for Aircraft Wing

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***Abstract*— *The target of this paper is to build up an exact model for ideal plan through outline the structure of wing that consolidate the composite (Skins) and isotropic materials (every single other structure) and contrast this and a similar wing made by changing the materials and the orientation of composite ply in skin.The ideal plan for each wing with various materials and different ply orientation can be obtained by comparing the displacement and stress on the wing. The structural design of the wing is finished with the assistance of CATIA V5, every parts modelled independently and collected in the IGS file. By using the IGS file as geometry, the Finite element modeling is completed in ANSYS and the Static analysis was done using ANSYS. In this analysis, the boundary conditions of inertia force of 1Kg and the lift force is used to simulate the wing loading on the wings. From this study, the Optimum design of the wing was found from the comparisons of stress and displacement of each material and ply combination.*

Keywords*— Composite Wing, Modeling in CATIA V5, Finite element Analysis in ANSYS, Optimum ply orientation and material.

I. INTRODUCTION

The basic component of airplane is the outline of the wings. A few components impact the choice of material of which quality associated to llightness is the most critical. Composite materials are notable for their superb blend of high structural stiffness and low weight.. In light of higher stiffness-to-weight or strength-to-weight ratios contrasted with isotropic materials, composite laminates are winding up noticeably better known. Composite structures ordinarily comprise of laminates stacked from layers with various fiber orientation angles. The layer thickness is typically settled, and fiber orientation angles are frequently restricted to a discrete set, for example, 0°, ±30°, ±45°, ±75°, and 90°. This prompts different combinations of ply orientation and among that one will gives the better outcomes, that is the optimized design for composite structures.A unidirectional laminate is a laminate in which all filaments are arranged in a similar direction, cross-ply laminate is a laminate in which the layers of unidirectional lamina are situated at right angles to each other and quasi-isotropic laminate carries on correspondingly to an isotropic material; that is, the flexible properties are same toward all paths. Unidirectional composite structures are worthy just to carry basic loads, for example, uniaxial tension or pure bending. In structures with complex prerequisites of loading and stiffness, composite structures including angle plies will be necessary. Since each laminate in the composite material can have distinct fiber orientations which may vary from the adjoining laminates, the optimum material and ply orientation is also obtained as a result of the parametric study conducted using ANSYS software by varying the material and orientation sequence in the composite.

II. GEOMETRICAL CONFIGURATIONS

The wing configuration is an iterative procedure and the selections or calculations are typically repeated several times. An extraordinary tools and software packages have been created in the previous decade, which is based on aerodynamics and numerical methods, there by a decrease in the number of iterations is observed. In normal transport aircraft wing design, which is composed of two spar constructions. Aircraft wing consist of leading edge and trailing edge so the spar at the leading edge portion is called front spar and the spar at the trailing edge portion is called rear spar of the wing. Generally the aircraft wing which is connected to the fuselage of the airplane, so that the free end of the wing is tip of the wing and other end is fixed to the fuselage which is name as root of the wing. This design is fundamentally the same as the cantilever beam arrangement in any engineering structure. . Spars and Ribs are associated utilizing L angle fittings. Fig.1 and Fig.2 underneath demonstrates the Area of spar and Ribs from root of wing and Fig.3 demonstrates the entire wing structure modeled in CATIA V5.

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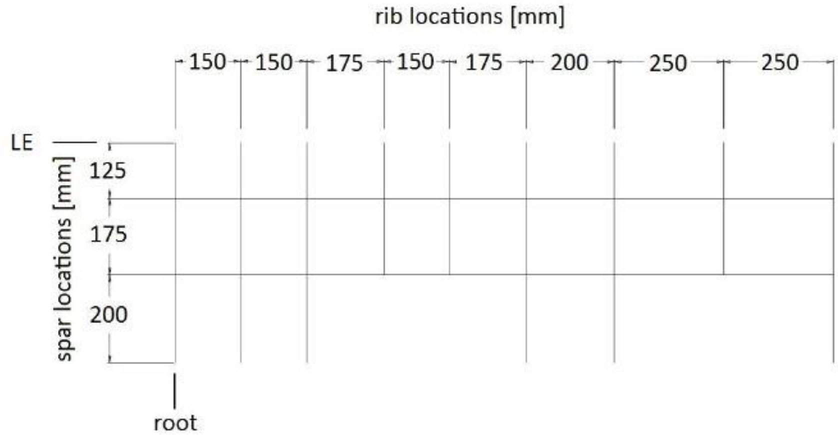

Fig.1: Area of Spar and Ribs from root of wing [mm] [1].

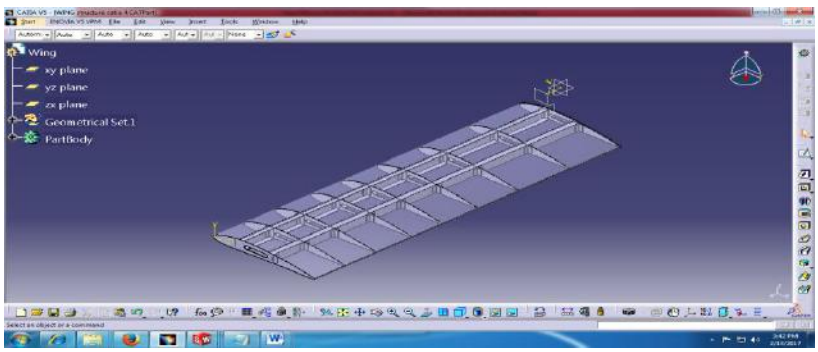

Fig.2: Area of Spar and Ribs from root of wing modeled in CATIA V5.

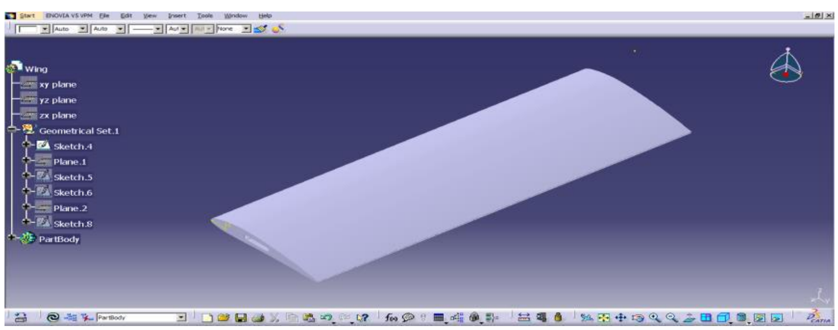

Fig.3:The entire wing structure modeled in CATIA V5.

Table.1: Physical and Mechanical Properties of Aluminium 2024-T3

Density	2780[kg/m^3]
Young's modulus	73.1[GPa]
Shear modulus	28[GPa]
Poison's ratio	0.33
Ultimate strength	483[MPa]
Yield strength	385[MPa]
Shear strength	283[MPa]

Table.2: Physical and Mechanical Properties of Aluminium 7075-T651

Density	2810[kg/m^3]
Young's modulus	71.7[GPa]
Shear modulus	26.9[GPa]
Poison's ratio	0.33
Ultimate strength	572[MPa]
Yield strength	503[MPa]
Shear strength	331[MPa]

Table.3: 7781 E-Glass Fabric–Araldite LY5052 Resin–Aradur HY5052 Hardener

Density	1772 [kg/m3]
Young's modulus	22.1 [GPa]
Shear Modulus	3.79 [GPa]
Poison's ratio	0.33
Ultimate Compression Strength	249 [MPa]
Ultimate Tensile Strength	369 [MPa]

Table.4: Physical and Mechanical Properties of Graphite Epoxy

Density	1580 [kg/m^3]
Young's modulus	145 [GPa]
Shear Modulus	4.8 [GPa]
Poison's ratio	0.33
Ultimate Compression Strength	373 [MPa]
Ultimate Tensile Strength	373 [MPa]

Table.5: Physical and Mechanical Properties of CFRP (M55j/914prepreg)

Density	1760 kg/m^3
Young's modulus	270 GPa
Shear Modulus	3.870 GPa
Poison's ratio	0.365
Ultimate Compression Strength	1.8 GPa
Ultimate Tensile Strength	0.6GPa

Table.6: Physical and Mechanical Properties of Models, Elements And Its Materials

Sr. No.	Model	Spar	Ribs & Fittings	Skin	Weight
1	Model 1	Al 7075-T651	Al 2024-T3	E Glass Fabric	13950.46grams
2	Model 2	Graphite Epoxy	Graphite Epoxy	E-Glass Fabric	12433.10grams
3	Model 3	Graphite Epoxy	Graphite Epoxy	CFRP (M55j/914prepreg)	8617.96grams

III. FINITE ELEMENT MODELING STRUCTURAL ANALYSIS OF WING STRUCTURE

The material properties are assigned for all the three models individually as per the Table 6 and the boundary conditions are carried out. The boundary conditions consists of the wing structure of an aircraft is connected to the fuselage through keel beam. So the wing structure is act as a cantilever beam connected with fuselage. One end of the wing structure can be fixed and taken as the boundary conditions of the model. This was satisfied by fixing all six

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degrees of freedom on the nodes corresponding to the fixing point.

Wing Structure under Aerodynamic Loading

The steady straight and level flight conditions of the aircraft the aerodynamic loading can just be characterized as L = W. The unmanned aerial vehicle, all-up weight of the aircraft is 500NThis 500N is depends on the performance parameters considered for the aircraft, which is calculated by the aerodynamic load calculation. During the steady straight level flight conditions the load factor (n) is equal to one. If the aircraft is flying with the conditions of 1g the load acting on the aircraft will be equivalent to the weight of the structure. In the aircraft, wing structure is known as lifting component. Greater part of the lift load will acting on the wing. In generally 80% percent of the lift load is uniformly distributed over the wing structure of the aircraft and the remaining 20% which is acting on the fuselage. From this considerations the total 80% of the load acting on the wing, which is equivalent to 500 X 0.8 =400N.Therefore the each wing will carry200N load. From the boundary conditions of the model, one end of the wing structure can be fixed and other end is free. A lift load of 200N is applies on center of pressure of the entire wing model (1-3) for simulating the results. The Ply sequences selected for this study are [0/90/+0/-0/90/0], [0/90/+45/-45/90/0], [0/90/+15/-15/90/0] and [0/90/+30/-30/90/0].

Analysis of Model 1

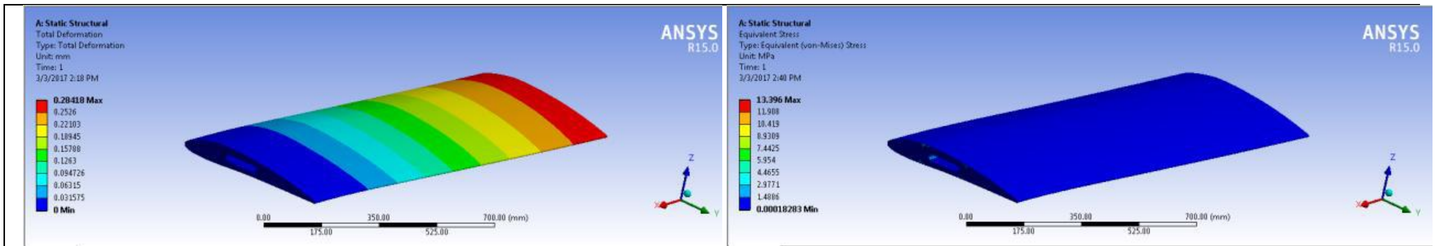

Fig.4: Displacement and stress field of the Model 1 wing structure for ply sequence[0/90/+0/-0/90/0]

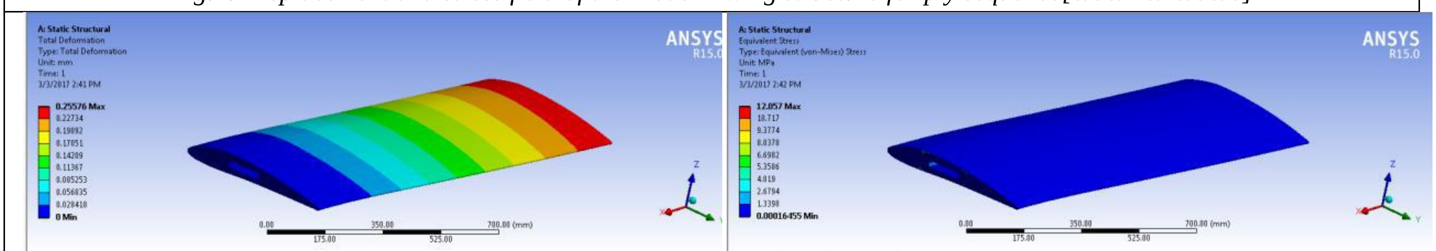

Fig.5: Displacement and stress field of the Model 1 wing structure for ply sequence [0/90/+15/-15/90/0]

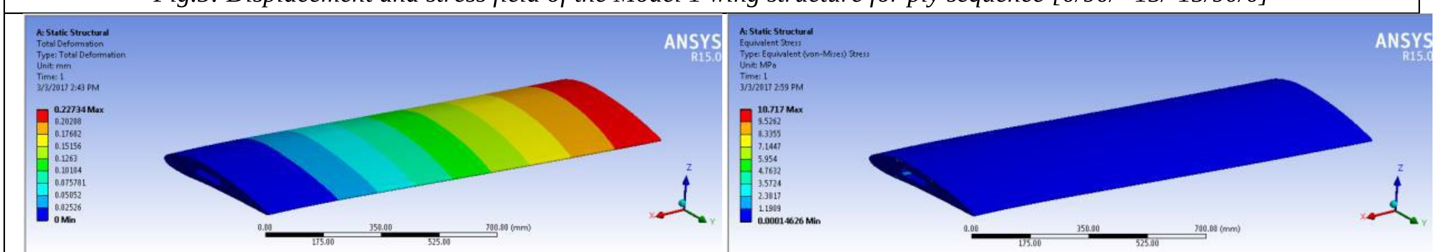

Fig.6: Displacement and stress field of the Model 1 wing structure for ply sequence[0/90/+30/-30/90/0]

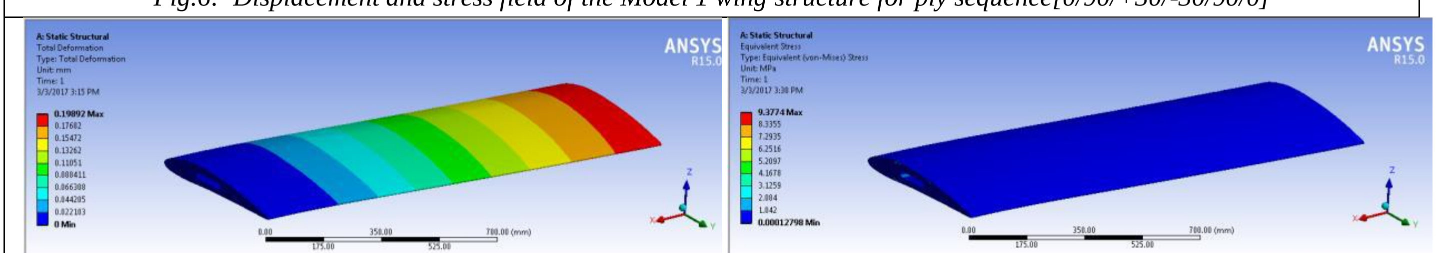

Fig.7: Displacement and stress field of the Model 1 wing structure for ply sequence [0/90/+45/-45/90/0]

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The Displacements and Von-Mises stresses results obtained for the model 1 with various ply layout sequences whish is tabulated in the table 7.

Table.7: Displacement and von-mises stresses obtained for Model 1 at various ply orientations.

Ply sequence	Displacement [mm]	Stress [MPa]
[0/90/+0/-0/90/0]	0.28418	13.396
[0/90/+15/-15/90/0]	0.25576	12.057
[0/90/+30/-30/90/0]	0.22734	10.717
[0/90/+45/-45/90/0]	0.19892	9.3774

Analysis of Model 2

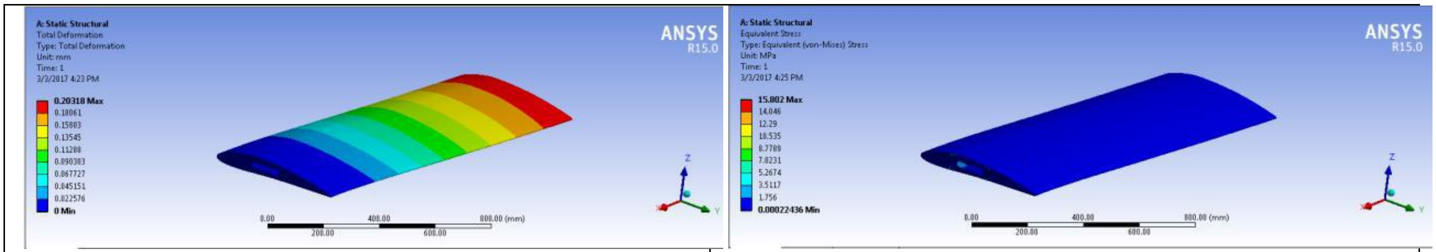

Fig.8: Displacement and stress field of the wing structure for ply sequence[0/90/+0/-0/90/0]

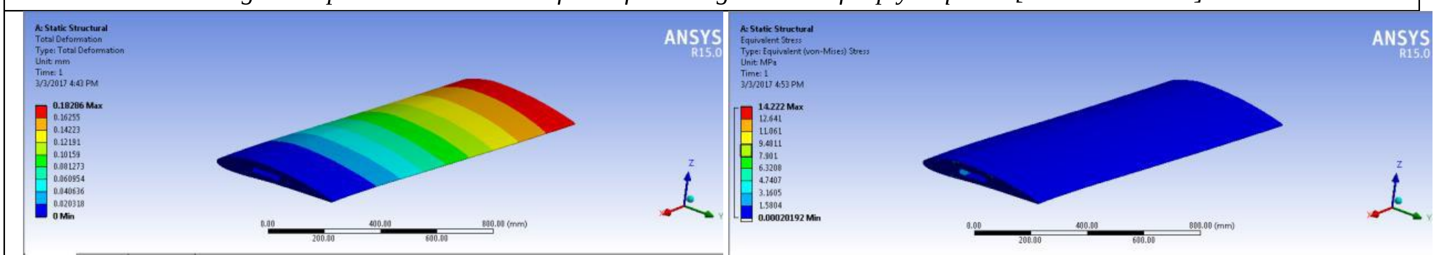

Fig.9: Displacement and stress field of the wing structure for ply sequence [0/90/+15/-15/90/0]

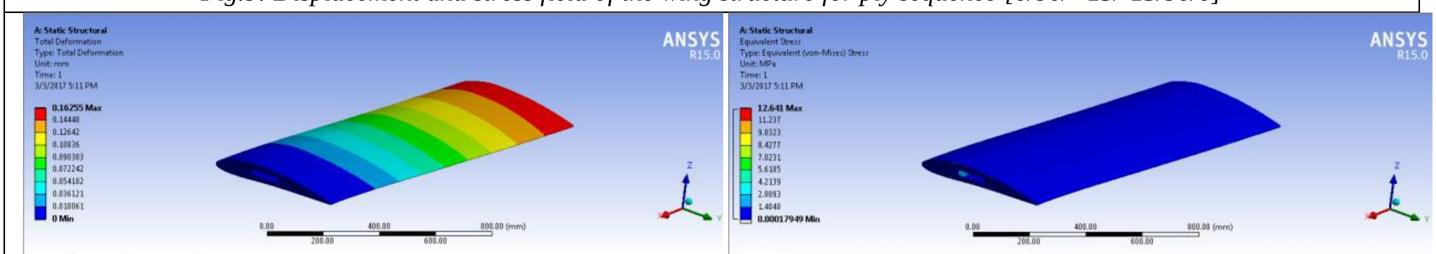

Fig.10: Displacement and stress field of the wing structure for ply sequence [0/90/+30/-30/90/0]

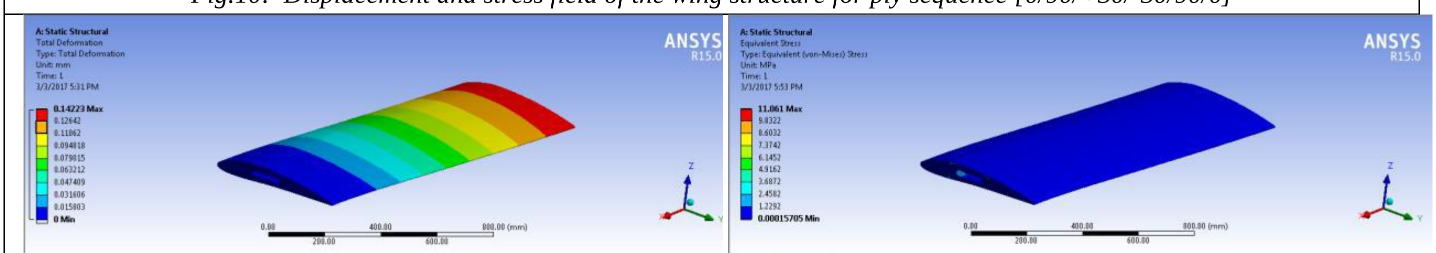

Fig.11: Displacement and stress field of the wing structure for ply sequence [0/90/+45/-45/90/0]

The Displacements and Von-Mises stresses results obtained for the model 2 with various ply layout sequences whish is tabulated in the table 8.

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Table.8: Displacement and von-mises stresses obtained for various ply orientations.

Ply sequence	Displacement [mm]	Stress [MPa]
[0/90/+0/-0/90/0]	0.20318	15.802
[0/90/+15/-15/90/0]	0.18286	14.222
[0/90/+30/-30/90/0]	0.16255	12.641
[0/90/+45/-45/90/0]	0.14223	11.061

Analysis of Model 3

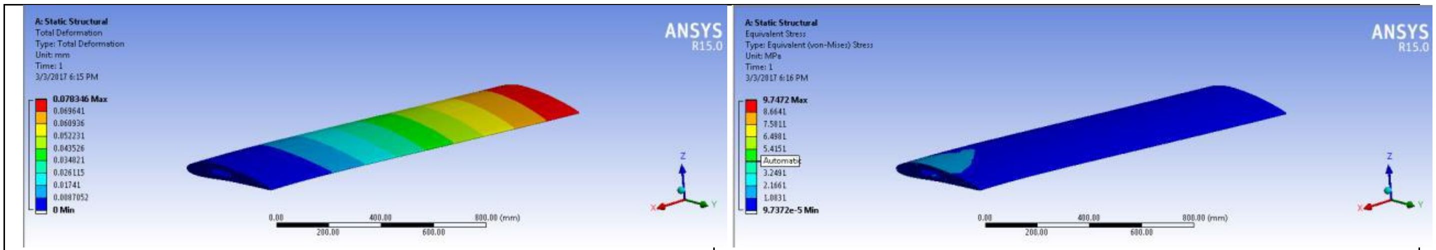

Fig.12: Displacement and stress field of the wing structure for ply sequence[0/90/+0/-0/90/0]

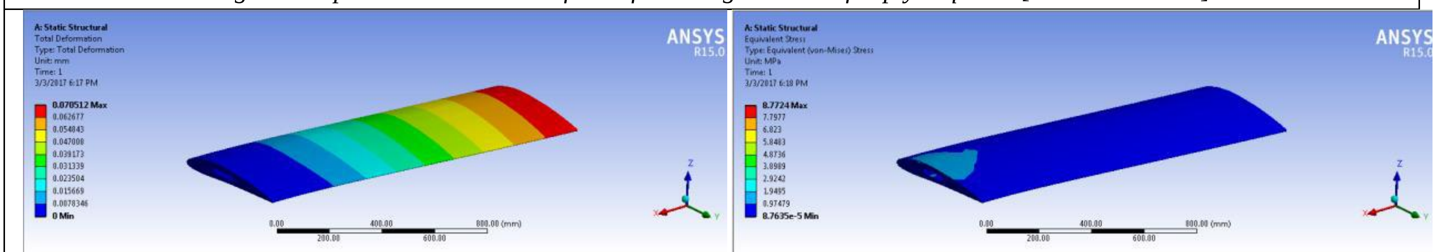

Fig.13: Displacement and stress field of the wing structure for ply sequence [0/90/+15/-15/90/0]

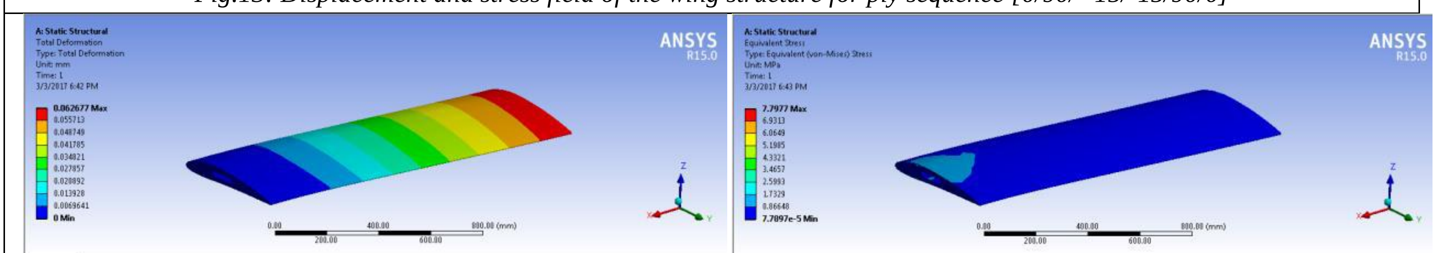

Fig.14: Displacement and stress field of the wing structure for ply sequence [0/90/+30/-30/90/0]

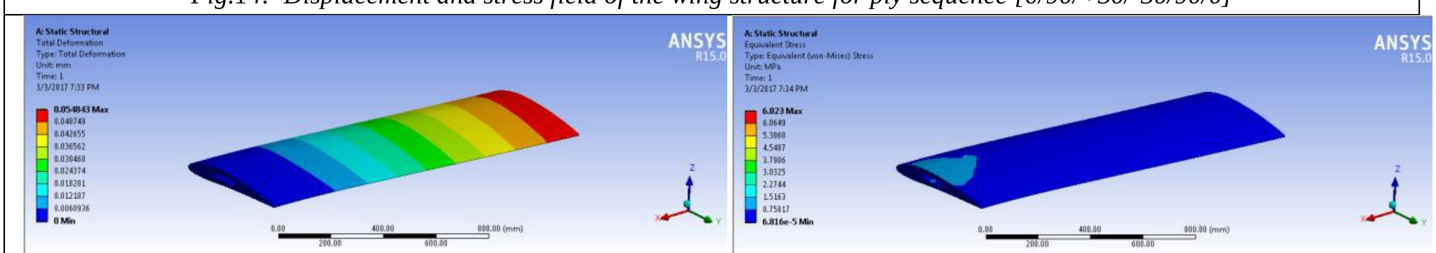

Fig.15: Displacement and stress field of the wing structure for ply sequence [0/90/+45/-45/90/0]

The Displacements and Von-Mises stresses results obtained for the model 3 with various ply layout sequences whish is tabulated in the table 9.

Table.9: Displacement and von-mises stresses obtained for various ply orientations.

Ply sequence	Displacement [mm]	Stress [MPa]
[0/90/+45/-45/90/0]	0.078346	9.7472
[0/90/+15/-15/90/0]	0.070512	8.7724
[0/90/+30/-30/90/0]	0.062677	7.7977
[0/90/+45/-45/90/0]	0.054843	6.823

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IV. CONCLUSION

After the successful completion of design and analysis of the three wing models with various materials and ply, sequences under static conditions, the following conclusions can be drawn from this study.

1. Using of CFRP (M55j/914prepreg) instead of E-Glass can reduce weight may lead to improve performance. Even though Gr /Epoxy can reduce weight of wing while comparing with aluminium alloy, the replacement of CFRP (M55j/914prepreg) used in skin with Gr/Epoxy can reduce 38% of weight than E-Glass used in skin with Gr /Epoxy in ribs and spars can reduce 11% of weight.
2. Wing structure with the same thickness, the variation in fiber orientation will produce variation in von Mises stress and displacement (increase or decrease).
3. By comparing Table 7, Table 8, Table 9 it is concluded that the ply sequence [0/90/+45/-45/90/0] is shown to be the better performance for all the three models, which is attractive to receive the arrangement [0/90/+45/ - 45/90/0] for aircraft composite wing in correlation with the other ply sequence considered in the present study.

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