6. ANKARA INTERNATIONAL AEROSPACE CONFERENCE
14-16 September 2011 - METU, Ankara TURKEY

AIAC-2011-056

MULTIPLE ASPECT DESIGN OF AN UNMANNED AERIAL VEHICLE WING

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ABSTRACT

The design of aircraft structures is a critical issue, because the structure has to provide enough strength while keeping the weight minimum. In order to achieve a successful design, the aircraft structures must meet all design requirements in addition to satisfying the optimal weight criteria. Materials selection affects the structural design, weight and strength. The material also has a direct impact on production technique and the overall cost. In this study, three different candidate materials were studied in the structural design of an unmanned aerial vehicle wing and their structural characteristics were compared.

INTRODUCTION

An unmanned aerial vehicle wing which was studied in a previously conducted TUBITAK (Turkish Scientific and Technological Research Council) project was chosen as the starting point for overall sizing [1-3]. The general geometry and configuration of the selected wing is given in the Figure 1. The wing consists of torque box, flap and aileron. The torque box has 2 spars and 5 ribs. The wing dimensions are given in Table 1.

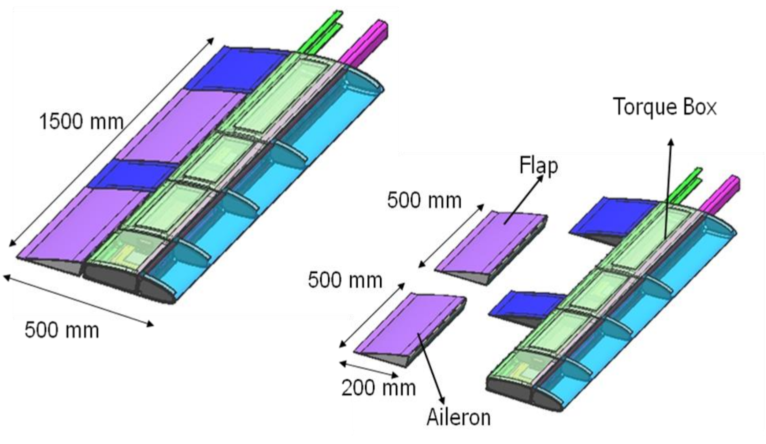

Figure 1: General Configuration of the Wing

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Table 1: The Dimensions of the Wing

Geometry	Dimension [mm]
Wing span (b_{wing})	1500
Wing chord (c_{wing})	500
Flap span (b_{flap})	500
Flap chord (c_{flap})	200
Aileron span ($b_{aileron}$)	500
Aileron chord (c_{flap})	200

The motion of each control surface (flap or aileron) was intended to be controlled by a single servo motor. In order to integrate the servo motor on the ribs of the structure, some cut-outs were provided in the lower skin. Since these cutouts inevitably weakened the overall strength of the structure, the lower skin was further strengthened by using doublers. Doublers, which are shown in Figure 2, also provided the lapping surface for the removable fasteners; like nutplates, in order to connect covers. The control surfaces were connected to the rear spar with piano type hinges. Figure 3 shows the details of the piano type hinge concept.

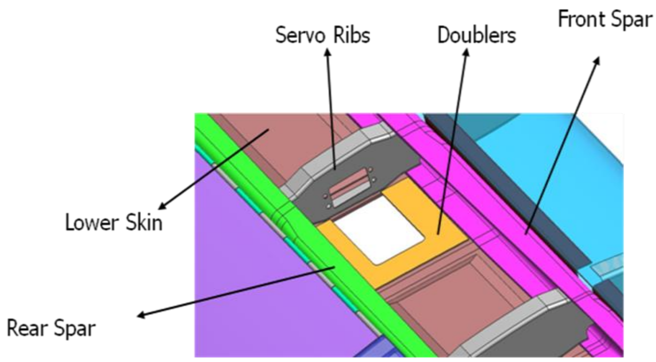

Figure 2: Doublers, Servo Ribs Used in the Study

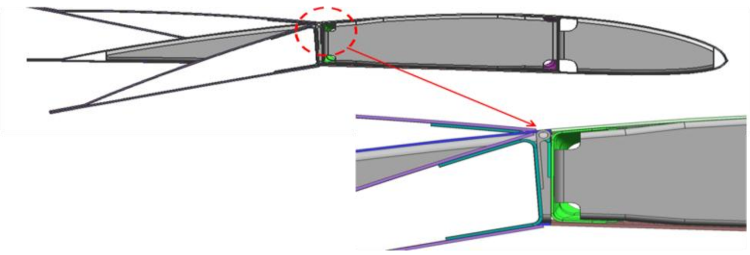

Figure 3: Piano Type Hinge Concept Used in the Study

STRUCTURAL MODELING OF THE WING

The structural design of the wing was conducted by using three different material and production techniques. Structural design was conducted using Unigraphics NX. The first model was designed using prepreg composite materials, while second model was designed by using wet lay-up composite materials in order to see the difference in the design of structural members due to composite manufacture processes [4, 8]. The third model was designed using aluminum material in order to highlight the differences between composites and aluminum. Each structural member was designed according to the design constraints of relevant material used.

The general detailed views of the torque box for the prepreg composite design, wet lay-up design and aluminum design are given in Figure 4, 5 and 6 respectively.

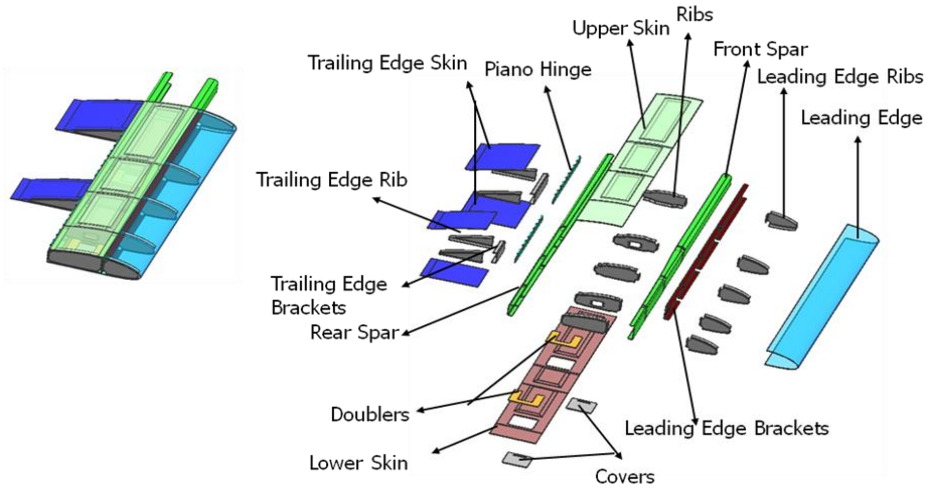

Figure 4: Prepreg Torque Box Design

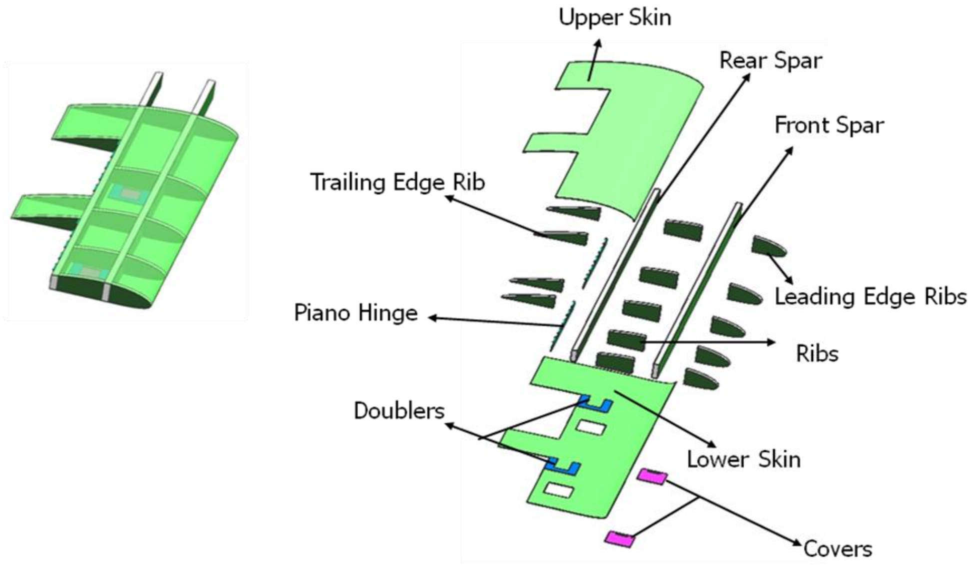

Figure 5: Wet Lay-up Torque Box Design

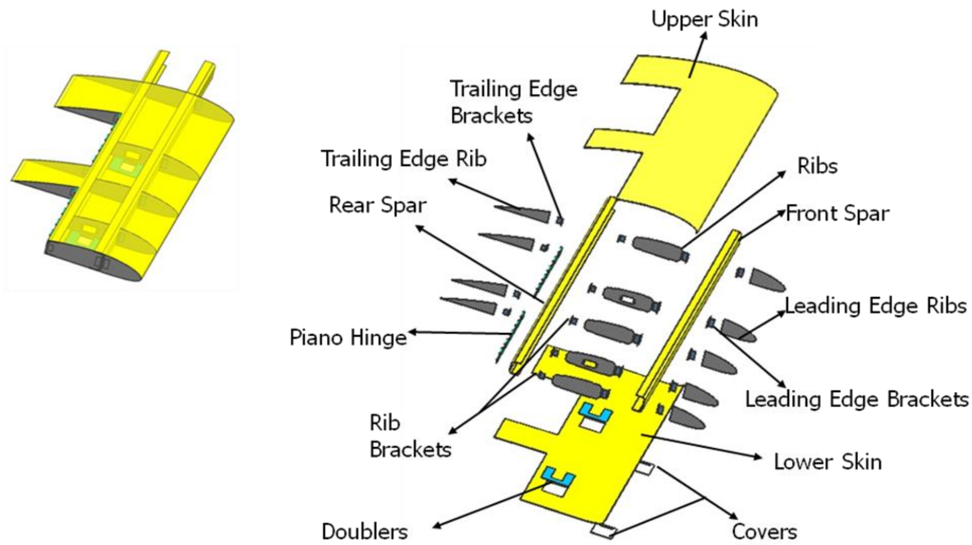

Figure 6: Aluminum Torque Box Design

Prepreg wing model was designed by using HexPly 8552 AS4 UD Carbon Prepregs and HexPly 8552 AGP 280-5H Woven Carbon Prepreg. The wet lay-up model was designed by using 7781 E-Glass Fabric, Araldite LY5052 Resin, Aradur HY5052 Hardener and Rohacell 71 A Foam. Material properties for prepreg and wet lay-up composites are given in Table 2 and Table 3, respectively. Table 4 shows the material properties used in the design of aluminum wing.

Table 2: Material Properties for Prepreg Design [7]

	HexPly 8552 AS4	**HexPly 8552 AGP 280-5H**
Density	1580 [kg/m3]	1570 [kg/m3]
Young's Modulus, E11	141 [GPa]	67 [GPa]
Young's Modulus, E22	8 [GPa]	66 [GPa]
Shear Modulus, G12	3.3 [GPa]	3.6 [GPa]
Shear Modulus, G23	2.6 [GPa]	2.8 [GPa]
Shear Modulus, G13	2.6 [GPa]	2.8 [GPa]
Ultimate Compression Strength	1531 [MPa]	924 [MPa]
Ultimate Tensile Strength	2207 [MPa]	876 [MPa]
Inter-laminar Shear Strength	128 [MPa]	79 [MPa]

Table 3: Material Properties for Wet Lay-up Design [1,10]

	7781 E-Glass Fabric, Araldite LY5052 Resin, Aradur HY5052 Hardener	**Rohacell 71 A**
Density	1772 [kg/m3]	75 [kg/m3]
Young's Modulus, E11	22.1 [GPa]	92 [MPa]
Young's Modulus, E22	22.4 [GPa]	92 [MPa]
Shear Modulus, G12	3.79 [GPa]	29 [MPa]
Shear Modulus, G23	2.96 [GPa]	29 [MPa]
Shear Modulus, G13	2.96 [GPa]	29 [MPa]]
Ultimate Compression Strength	249 [MPa]	1.5 [MPa]
Ultimate Tensile Strength	369 [MPa]	2.8 [MPa]
Inter-laminar Shear Strength	33.21 [MPa]	-

Table 4: Materials Used in Aluminum Wing Design

Component	**Material**
Skin, Spar, Ribs, Doublers, Covers, Control Surface Skin, Control Surface Ribs	Aluminum Clad Sheet 2024 T3
Brackets, Control Surface Brackets	Aluminum 7075-T651
Control Surface Spar	Aluminum 7075-T651

Differences in the Structural Model

There were major differences between the wet lay-up model and prepreg model due to the producibilty constraints. In the prepreg model, leading edge skin, upper skin, lower skin and trailing edge skins were taken as manufactured separately. In the wet lay-up model, the upper and lower skin were assumed to be manufactured as one piece by using female tools in order to obtain smooth aerodynamic surface as shown in Figure 7.

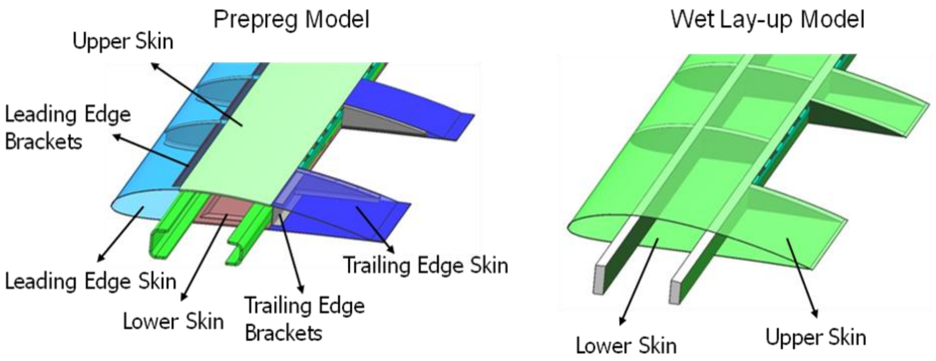

Figure 7: Comparison of the Skins of the Composite Wing Models

The composite structural members with U profiles, such as spars and ribs, can be manufactured with prepreg material. The wet lay-up approach cannot be used for this type of members because of the possibility that excess resin build-up in corners. Thus, in order to account for the loss of inertia provided by spar and rib caps, core materials were used to generate thickness to increase inertia. Figure 8 shows these differences in a close-up view of spars and ribs for these wing models.

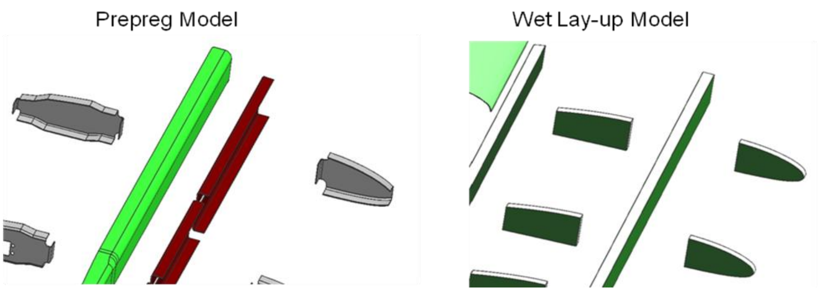

Figure 8: Comparison of the Spars and Ribs of Composite Wing Models, Close-up View

Table 5 gives total mass of each wing model according to the results of initial sizing. Since the aluminum model was the heaviest, it was eliminated from the analysis and further analysis was concentrated only on composite models.

Table 5: The Total Mass of Different Wing Models after the Initial Sizing

	Mass (kg)
Prepreg	6.7
Aluminum	8.9
Wet Lay-up	5-5.5

STRUCTURAL ANALYSIS OF THE WING

Finite Element Modeling and Analysis of the wing was conducted using MSC Patran and NASTRAN [5, 6]. The Finite Element Model of the wing is shown in Figure 9. The structural meshes were created for 2D Shell elements having orthotropic properties. The control surface hinges were modeled with multi point constraint (MPC) connectors. Element properties were defined for each material selection and whenever necessary the spar caps were modeled as beam elements.

Aerodynamic loading which was obtained by considering the cruise condition and gust condition, was applied to the wing as element uniform pressure [1, 2]. Figure 10 represents pressure distribution corresponding to the cruise condition.

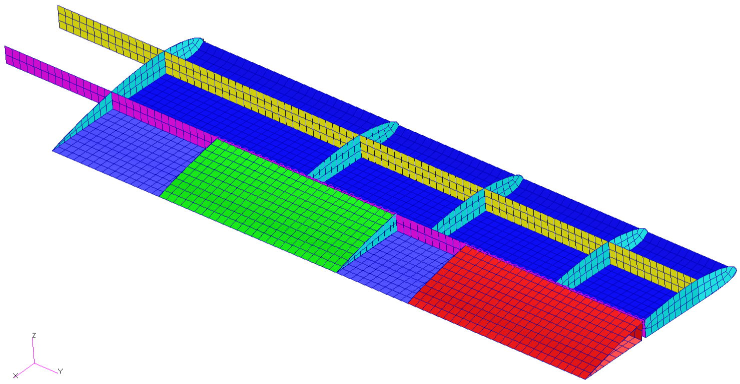

Figure 9: Finite Element Model of the Wing Studied (Upper Skin was Removed for Better Visibility)

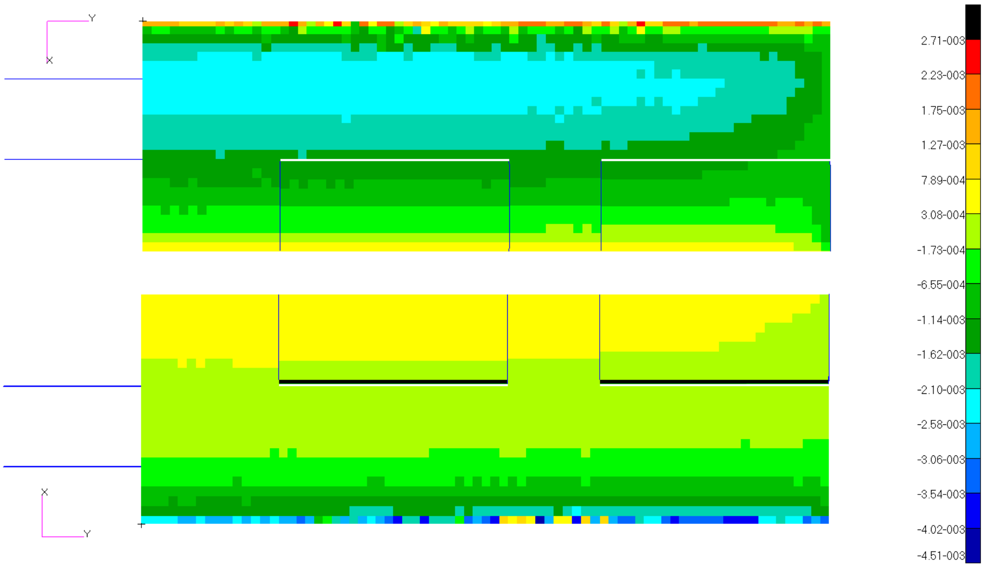

Figure 10: Cruise Condition Pressure Load Contours for Upper and Lower Skins

It was determined that the initially sized wet lay-up model failed in the stress check. Therefore, some parts of the relevant wing structure, mainly spars, were further strengthened by adding 4 fabric layers; thus leading to a heavier wing. On the other hand, in prepreg wing model a lighter wing model was obtained. Displacement results of final models for prepreg and wet lay-up configurations are shown in Figures 11 – 12. Stress results are shown for gust loading, since its stress results determine critical stress levels, Figure 13 – 14.

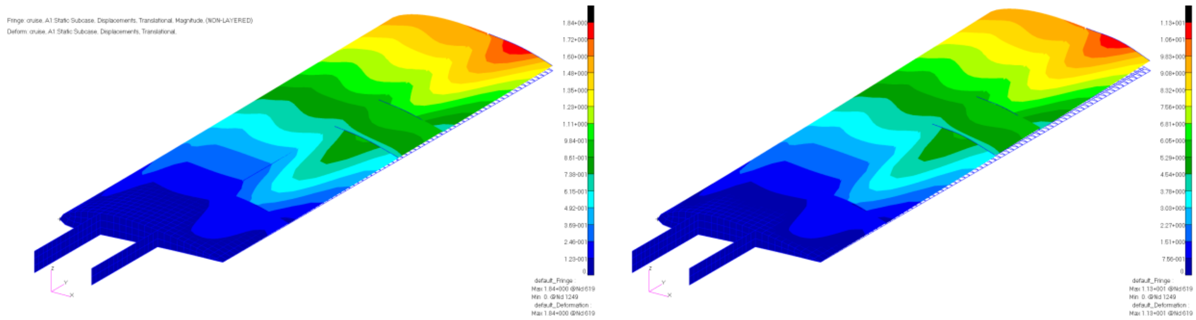

Figure 11: Displacements [mm] for Prepreg Wing Model (Cruise and Gust Loading, Final Model)

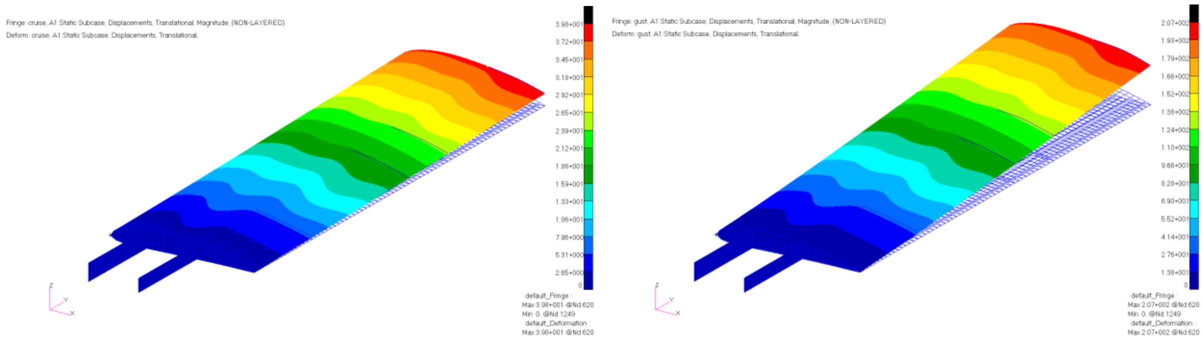

Figure 12: Displacements [mm] for Wet Lay-up Wing Model (Cruise and Gust Loading, Final Model)

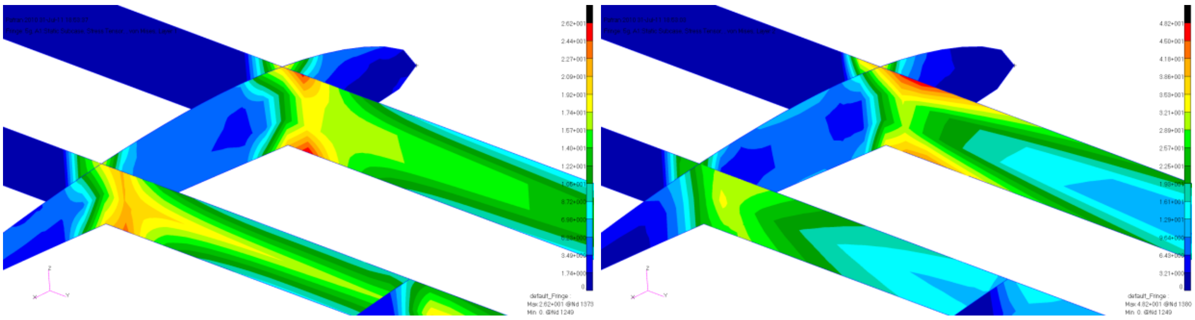

Figure 13: Stress [MPa] Critical Layers for Prepreg Wing Model (Gust Loading, Final Model)

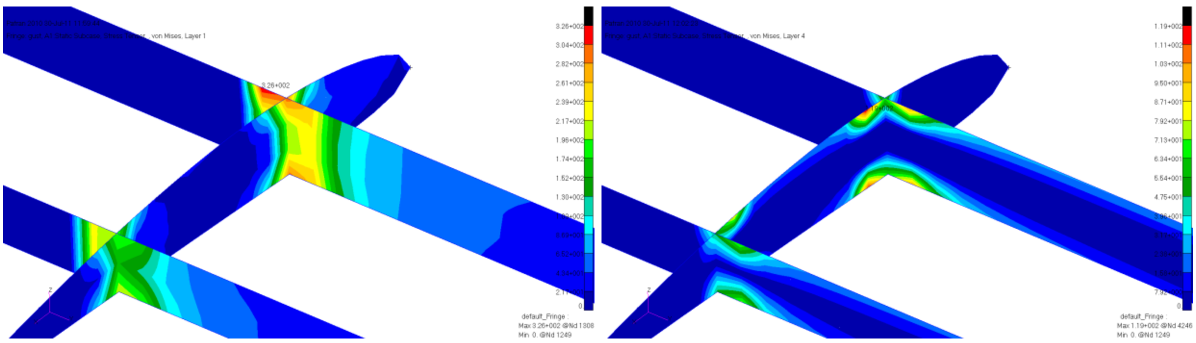

Figure 14: Stress [MPa]Critical Layers for Wet Lay-up Wing Model (Gust Loading, Final Model)

Table 6 shows overall results for each case, where final prepreg model is the lightest model with good wing tip deflection and acceptable for strength requirements.

Table 6: The Total Mass of Different Wing Structural Models after the Initial Sizing

	Aluminum	Wet Lay-up (Initial Model)	Wet Lay-up (Final Model)	Prepreg (Initial Model)	Prepreg (Final Model)
Mass [kg]	8.9	5.5	7.0	6.7	4.5
Wing Tip Deflection (Cruise) [mm]	N/A	92.8	39.8	1.04	1.84
Failure Index (Maximum Stress Criteria)	-	2.79	0.98	0.08	0.15
Stress Check	N/A	Fail	Pass	Pass	Pass

PRODUCIBILITY

Since the stress checks revealed the prepreg composite wing as the lightest and strong candidate; the required producibility analysis was conducted for the prepreg composite materials only. During the analysis FiberSIM program [9] was utilized. FiberSIM is an add-on for CAD programs. FiberSIM enables the correct design and manufacturing approach for the composite parts. It simulates laying up of the plies on tools in order to show whether the part is producible or not by using a given material. If a problem of producibility occurs on simulation due to the characteristic of the given material, the designer uses another method in order to make an acceptable design. Utilization of this program is believed to decrease the manufacturing time and cost for composite applications in industry.

The parts of upper skin, rear spar and rib in prepreg model was analyzed for producibility by using FiberSIM. The plies of each part were created and they were simulated that whether they can be laid on the tool or not.

Figure 15 shows one of the simulated 45° oriented ply of the upper skin and Figure 16 demonstrates another simulated 45° oriented ply of the upper skin.

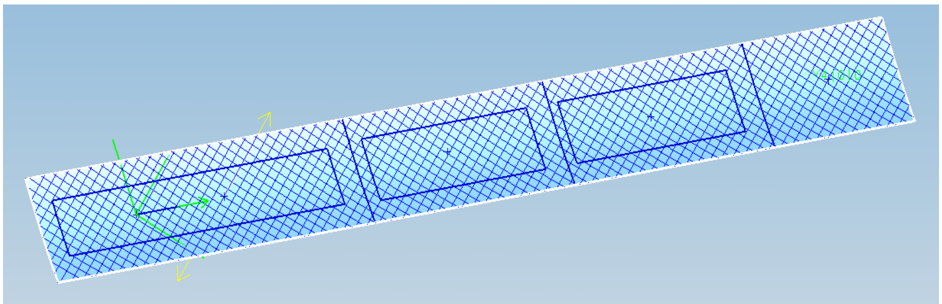

Figure 15: The Simulation Result of 45° Oriented Ply on the Upper Skin Tool

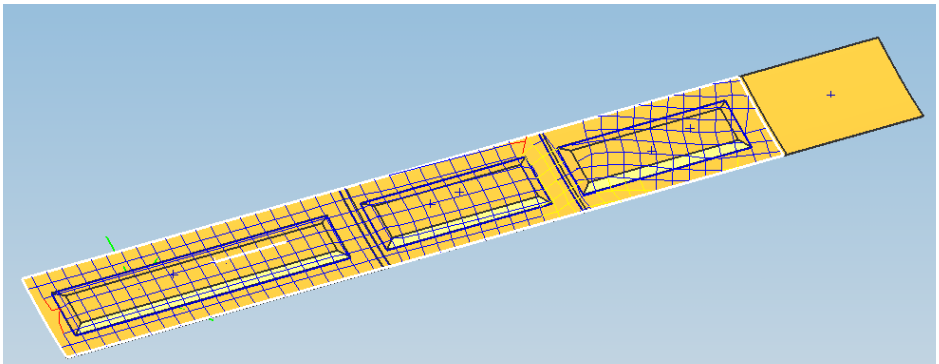

Figure 16: The Simulation Result of 45° Oriented Ply on the Upper Skin the Tool

As it can be seen, the ply in Figure 16 cannot be laid up on the tool easily. There are some wrinkles on some areas. Therefore, some modifications should be done in the ply as splicing the ply in two pieces.

The satisfactory simulation results of 0° oriented plies on the tools of the rear spar and rib are shown in Figure 17 and Figure 18 respectively.

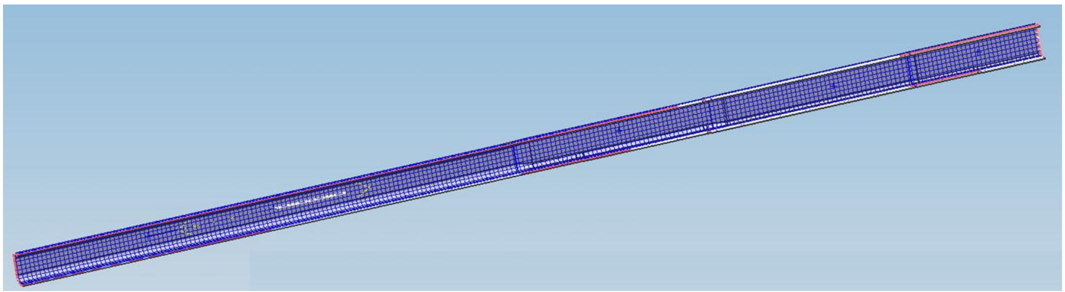

Figure 17: The Simulation Result of 0° Oriented Ply on the Rear Spar Tool

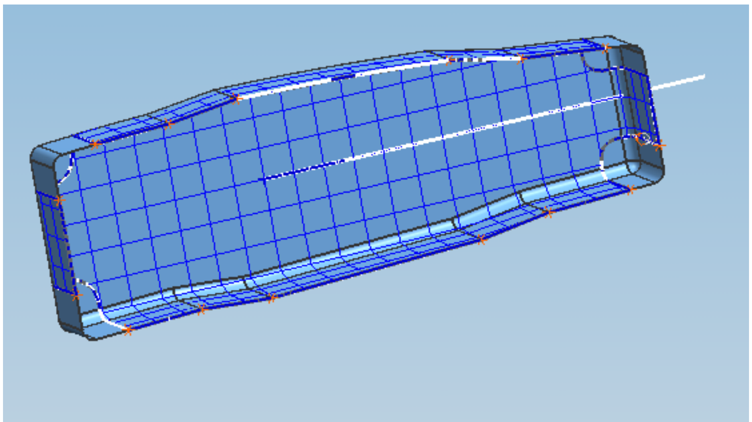

Figure 18: The Simulation Result of 0° Oriented Ply on the Rib Tool

The further analysis also indicated that the producibility of the prepreg composite wing was satisfactorily possible.

CONCLUSION

In this study, an unmanned aerial vehicle wing was modeled by using different materials and analyzed for wing tip deflection, overall weight, and stress critieria. The comparisons between models were presented. It was shown that the design techniques and model details differ according to the material chosen. Material selection also affected strength characteristics and the weight of the structure. The producibility analysis of some parts in prepreg model was done in order to see the possible manufacturing problems by simulating ply lay-ups on tools. Within the limitations of the study the prepreg composite model was proved to be the best design, hence meeting all the requirements.

References

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