composite materials, simulation, CAx systems

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MODELLING OF UAV'S COMPOSITE STRUCTURES AND PREDICTION OF SAFETY FACTOR

Abstract

The paper presents possibilities of composite materials modeling using SolidWorks enviroment on example of Unmanned Aerial Vehicle wing structure. Mechanical properties of composite materials used in UAV's and process of modeling such structures in SolidWorks are described. The research problem is CFD and strenght analysis of considered structure in SolidWorks Flow Simulation. Different displacement, stresses and safety factors values were obtained for analysed types of loads. The presented approach was used to develop aircraft wing for Air Challenge 2015 competition.

1. INTRODUCTION

Unmanned Aerial Vehicles (UAV) gained high popularity in the civil applications. They are widely used in varius fields of life like: polar region monitoring, research, studying atmospheric pollution, counting animal populations etc.

Today's engineers task relies on design and manufacture products at reasonable prices and short time. It is possible due to the development of computer systems and wide availability of modern composite materials. Polymer matrix composites are commonly used in today's industry due to low fabrication cost and satisfactory mechanical properties. They mostly occur in form of symmetrical and asymmetrical laminates. Low weight, high strength, high stiffness, corrosion resistance and vibration damping ability features polymer

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matrix composites reinforced with continues fibre. Thanks to high strength-to-weight and stiffness-to-weight ratios they are used for lightweight structures in automotive, sport industries and aviation (as parts of airframes) [1].

Nowadays technical universities become serious competitors against specialized companies in developing UAV designs. It is possible due to dynamic progress in computer technology and electronics. Modern computer-aided design tools are widely available and used by both industry and universities for engineers education [2]. Using the CAx tools meaningfully decreases price of the new product introduction. Results obtained from numerical analysis for safety reasons need to be compared with experimental data. CAx environment gives the possibility of designing 3D model (CAD), then performing series of numerical simulations like strength and flow analysis (CAE), technology development (CAM) and finally creation of 2D documentation. Computer aided design however, is only a tool in the hands of engineers, therefore it is important to choose or elaborate suitable strategies for creation a virtual model of real objects [3]. We can distinguish types of 3D modelling such as solid, surface, hybrid (surface-solid) and multibody. Usage of these techniques depends on the complexity and purpose of project. Computer systems like SolidWorks provide tools for modelling structure of composite materials and analysis of their mechanical properties. The software allows to define new types of material by describing their material properties (izo-, orthotropic materials).

2. MODELLING OF COMPOSITE MATERIALS IN SOLIDWORKS

SolidWorks Simulation provides tools for modelling and analysing structures based on composite materials (the mentioned module requires surface model of designed component). Software environment allows to create surface model (3D CAD module) and use designed geometry in Simulation for modelling the composite structure. Another solution relies on creating preliminary solid model (3D CAD module) and then generating shell elements in SolidWorks Simulation module based on given geometry. This function gain importance in further analysis (strength) based on CFD resultant loads (Flow simulation requires 3D solid model for analysis).

Abovementioned environment gave possibilities to analyse composite laminates up to 50 different layers. SolidWorks assumes perfect bond between plies. Most common types of composites are (Fig. 1):

- Symmetric laminates defined by symmetric arrangement of ply materials, orientations, thicknesses, fibre orientation about the mid plane.
- Asymmetric laminate characterized by no symmetry layers, orientations and properties in reference to the mid plane.

– Sandwich composites represents case of symmetric laminates with mid plane layer defined by greater thickness and lower mechanical properties compared to other plies. Structure suitable when higher resistance to bending load is required.

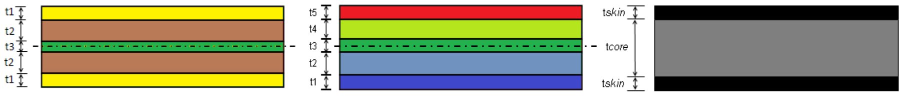
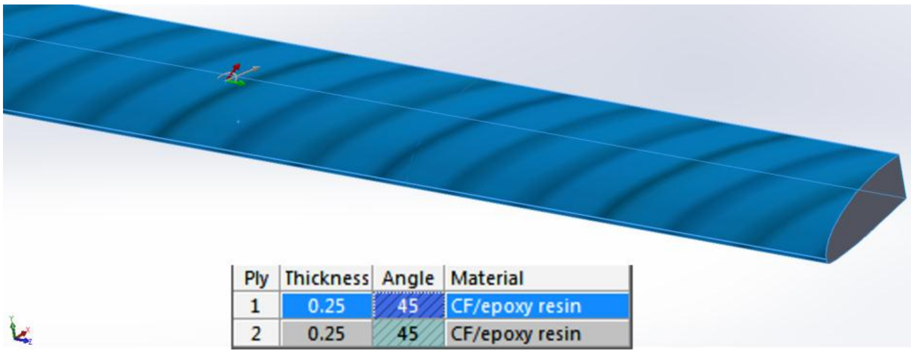


Fig. 1. Types of composites (right-symmetrical, asymmetrical, sandwich composite)

SolidWorks composite property manager allows to define required thicknesses, orientations, numbers of layers and ply materials for designed structure. Graphic window of this tool shows laminate and global coordinate system with direction of each individual layers. It is very important to notice that coordinate system of composite is not the same as model or assembly. Defined composite structures position can be controlled relative to its surface. Composite property manager allows to position designed stack of plies middle surface, top surface, bottom surface and at specific ratio (position defined by offset value that is fraction from total thickness of structure, measured from the mid-surface to the reference surface). Fig. 2 presents symmetrical laminate consisting of 2 plies of 0.25 mm thicknesses, rotated with respect to material coordinate system by 45° based on carbon-fabric/epoxy material and surface mapping (software provide also planar mapping used to project a common 0º reference to a group of surfaces).

Important step in the modelling of composite structures is defining materials properties. SolidWorks environment for complete characterization of the orthotropic materials (composites used in analysis) requires describing properties such as elastic modulus *E*, Poisson ratio *v*, shear modulus *G*, shear strength, tensile strength and compressive strength in specific directions [4].



Ply	Thickness	Angle	Material
1	0.25	45	CF/epoxy resin
2	0.25	45	CF/epoxy resin

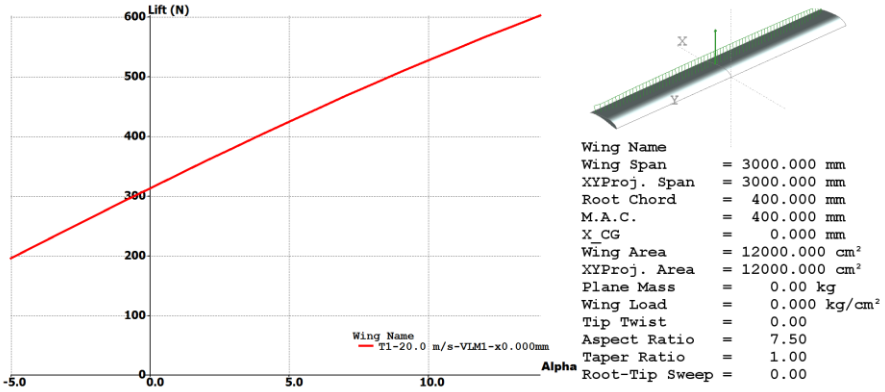
Fig. 2. Orientation, thickness, layer, material and coordinate system of composite

Results obtained from composite materials strength analysis apart from the standard strength analysis plots are: maximum stress across all plies, stress along the ply orientation direction and transverse direction to ply angle, stress on top or bottom face of each ply, interlaminar shear stress at the contact between two different plies. It should be noticed that strain fields and displacements are continuous through thickness of considered composite, while stress fields are discontinuous due to different orientations and material properties across plies.

SolidWorks contains three theories available for calculating laminate failure criteria: Tsai-Hill Failure Criterion, Tsai-Wu Failure Criterion, Maximum Stress Criterion. Based on one of these criteria we can generate safety factor plots (FOS) for our designed structure. Failure of composites occurs in several steps. When stress in the first ply or group of plies is high enough, it fails. This point of failure is called the first ply failure (FPF) beyond which considered laminate still carry the load. For safety reasons laminates should not experience stress high enough to cause FPF [5].

3. DESIGN AND NUMERICAL ANALYSIS OF COMPOSITE WING STRUCTURE

Design of unmanned aerial vehicles wing structure is multistage task that requires: defining UAV's purpose, aerofoil selection, geometrical calculations, structural design, materials selection, numerical analysis and elaboration of technology. Preliminary research of UAV wing structure concerns calculation of geometrical main dimensions (wing span, root and tip chords, twists, dihedrals and aerofoil distribution) based on the project assumptions and selected aerofoils [6,7]. Figure 1 presents results of initial study performed in XFLR5 environment - designed geometry (aerofoil cord 400mm, wing span 3000 mm) characterize by 310 N lifting force obtained at air velocity equal to 20 m/s (Fig. 3).



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Wing Name
Wing Span       = 3000.000 mm
XYProj. Span    = 3000.000 mm
Root Chord      =  400.000 mm
M.A.C.          =  400.000 mm
X_CG            =    0.000 mm
Wing Area       = 12000.000 cm²
XYProj. Area    = 12000.000 cm²
Plane Mass      =    0.00 kg
Wing Load       =    0.000 kg/cm²
Tip Twist       =    0.00
Aspect Ratio    =    7.50
Taper Ratio     =    1.00
Root-Tip Sweep  =    0.00
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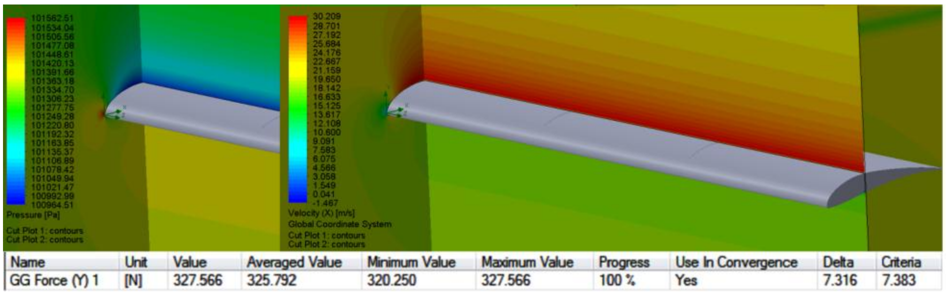
Fig. 3. Designed wing geometry in XFLR 5

XFLR 5 is a free software that allows numerical analysis of aerofoils, wings and airframes. In simulation this software uses a non-linear lifting line method, vortex Lattice Method (VLM) and 3D panel method. The results are lift and drag coefficients in case of aerofoils and lift and drag forces in case of wings and airframe according to defined geometry. Abovementioned software operates at Reynolds numbers [8].

The knowledge about types of loads acting on aircraft wing is essential during design process of new construction. In case of UAV wing structures most important are bending loads and torsion loads derived from acting lift force. Based on CFD simulation we are able to determine their types and values. Figure 4 shows flow simulation analysis of considered wing along with resultant lift force. On the basis of CFD simulation types and values of loads were obtained: average pressure acting on wing 275 Pa, concentrated force placed in geometric centre of wing equal to maximum lift 327 N.

Differences between values of lift force from XFLR 5 environment (315 N) and SW Simulation (327 N) results from type of research. In order to improve Flow simulation calculation time, analysis was simplified to 2D issue which does not take into account the decrease in lift force on the ends of the wings resulting from mixing of air masses with a high and low pressure.



Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress	Use In Convergence	Delta	Criteria
GG Force (Y) 1	[N]	327.566	325.792	320.250	327.566	100 %	Yes	7.316	7.383

Fig. 4. CFD analysis of considered wing geometry (2D), results – lift force

Designed wing geometry (3D solid model) analysed in Flow simulation in order to achieve values and types of loads for further studies (modelling composite structure, strength analysis) requires geometry type change to surface model. Main bearing element of considering wing construction is caisson (part of an aircraft wing design to transferring bending and torsional loads, resulting from the impact of aerodynamic forces. Located on the front portion of the aerofoil, taking form of a closed thin-walled section). Design of composite structure (Simulation module) for further study is based on surface model of wing caisson filled with carbon fibre ribs. Created wing structure represented by symmetrical laminate consisting of 2 plies of 0.25 mm thicknesses, rotated with respect to material coordinate system by 45° based on carbon-fibre/epoxy material is shown at Figure 2.

Strength analysis of designed wing (SW Simulation) will be carried out for two cases of boundary conditions resulting from different types of loads: average pressure acting on wing (763 Pa) derived from acting lift force and concentrated force (315 N) placed in centre of wing simulating conditions of 2,5g overload (safety reasons) (Fig. 5). For analysis it was necessary to create finite element mesh equally distributed for the whole model (global size of the element 3.9 mm, tolerance 0.18). Figure 5 presents discussed boundary conditions.

For the numerical analysis iterative solver FFE Plus were applied. This method uses approximate techniques to calculate the solution and repeat the process until the difference between two consecutive solutions is significantly small or does not exceed set error limits.

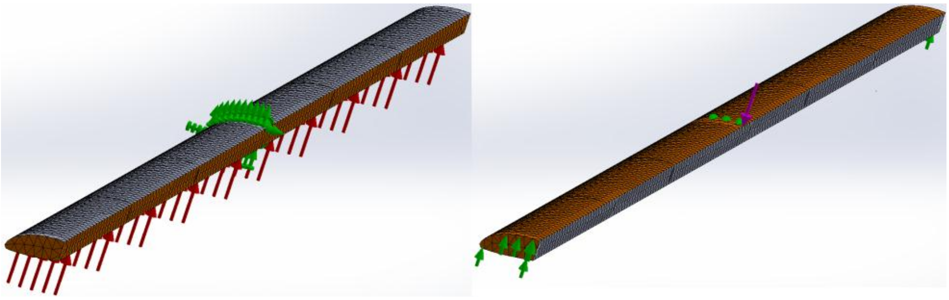


Fig. 5. Boundary conditions of two types of applied loads

Description of the research results will begin with displacement graph analysis (Fig. 6). It shows the resultant displacement (it is possible to check displacement in requested axis) of the analysed element under the influence of applied forces and geometrical restraints. Static test conditions caused three times larger wing deflection (124.2 mm) compared to load simulating flight conditions (40 mm). Higher structure stiffness (lower deflection) may be obtained by increasing thickness of the layers, adding number or changing rotation of plies.

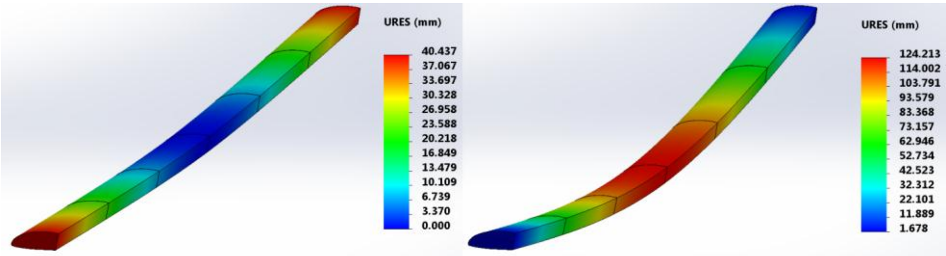


Fig. 6. Displacement of carbon fabric lamina (left-concentrated force load, right pressure load)

The following plot presents distribution of highest values and types of stress occurring in researched structure. Figure below (Fig. 7) shows values and distribution of tensile and compressive stresses appearing on carbon fibre layers of examined wing. It is possible to study stress values on each individual layer. Concentrated force placed in centre of the wing, simulating conditions of static test as predicted caused higher stress value equal to 260 MPa of tensile and 236 MPa of compressive stress compared to 104 MPa of tensile and 85 MPa of compressive stress in case of load simulated by pressure. Tensile stress appeared mostly on the lower part of construction while compressive stress occurred on the upper part of wing.

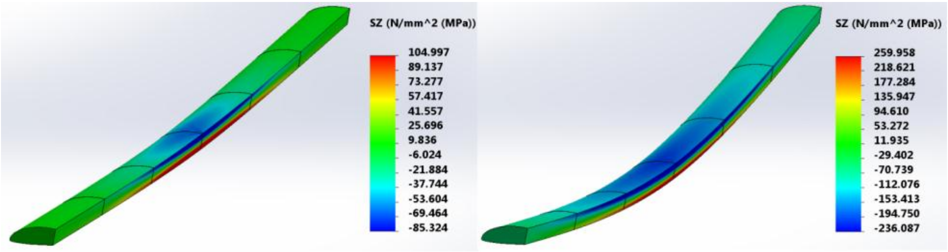


Fig. 7. Tensile and compressive stresses in considered structure

Last evaluated graph present distribution of factor of safety (FOS) over wing structure according to Tsai-Wu failure criteria (Fig. 8). This criterion considers the total strain energy (distortion and dilatation energy) for predicting failure. It is more conservative than the Tsai-Hill failure criterion because it distinguishes compressive and tensile failure strengths. The Tsai-Wu failure criterion cannot predict different failure modes such us fibre failure, matrix failure etc. Lowest FOS value across all plies equal to 1.6992 was obtained in case of study simulating static test. Factor of safety larger than 1.0 indicates that the laminate is safe from failure.

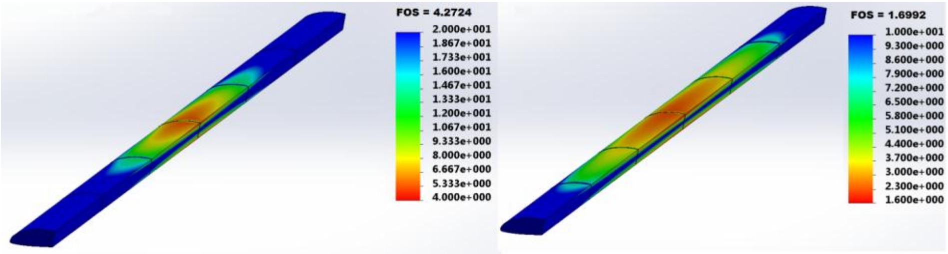


Fig. 8. Factor of safety (Tsai-Wu criterion) of carbon fibre lamina according to two type of load

4. CONCLUSION

Conducted analyses allowed to determine structure behaviour and stress occurring in respect to given geometry and used materials. Gathered information helps designer to create structure satisfying the requirements set out in the project. Results obtained from composite materials strength analysis gave possibility to evaluate additionally maximum stress across all plies, stress along the ply orientation and transverse direction to layer angle also stress on top or bottom face of each ply. For safety reasons laminates should not experience stress high enough to cause FPF (first ply failure). Higher structure strength (lower deflection) maintaining the same mass of the element may be obtained by changing rotation of composite layers. Analysed structure of the wings based on the carbon laminate satisfies Tsai-Wu failure criteria obtaining lowest FOS value across all plies equal to 1.6992. Using the CAx tools meaningfully decrease price of the new product introduction. Results obtained from numerical analysis for safety reasons should be compared with experimental data. Presented approach was used to develop aircraft wing structure based on carbon fabric epoxy resin laminate (Fig. 9).

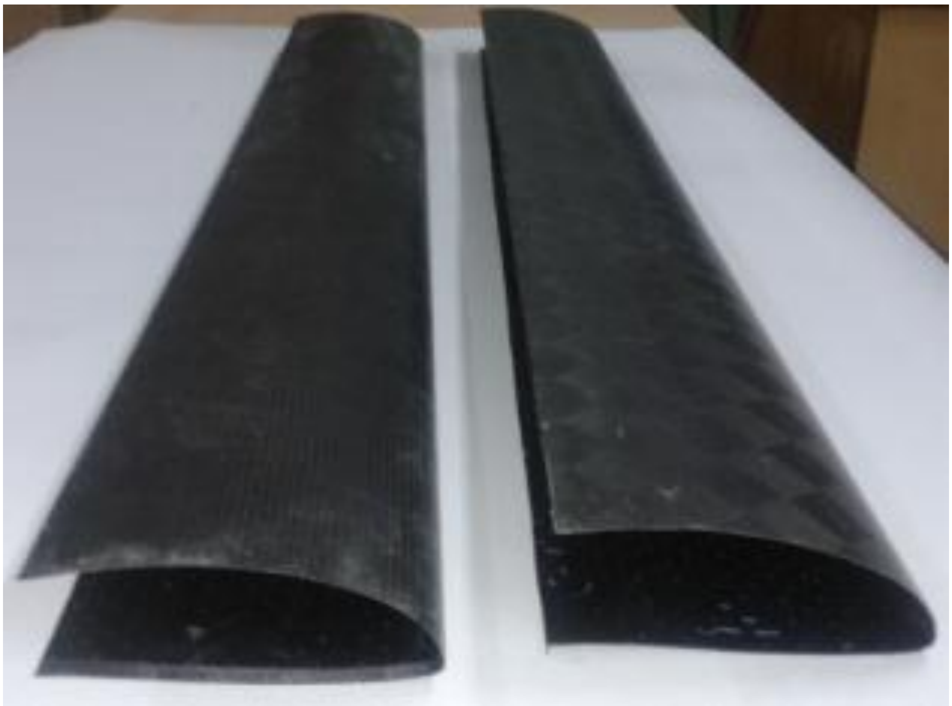


Fig. 9. Developed wing structure for ACC 2015 competition

ACKNOWLEDGEMENT

This paper was performed within a framework of project "Future Generation 2014" supported by the Polish Ministry of Science and Higher Education.

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