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Numerical Analysis of the Influence of Fibre Orientations in a two-layered Biomimetic Flapping Wing

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Abstract. A numerical study was carried out to investigate the effects of fibre orientation angles in an adopted biomimetic flapping wing having two-layered Carbon/Epoxy Composite T300/5208. The purpose of this paper is to understand how different orientation angles with different combinations affect the stresses of a flapping-wing. One flapping cycle was divided into twelve segments and both maximum stress and deformation were calculated for all the segments. The results revealed that, the maximum stress was produced in [0/-45] combination, where the least was found for [45/0]. For all the simulated wings, deformation was found less than 1.8 mm. ANSYS DesignModeler and Static Structural was used to design and perform structural analysis. The findings are helpful in answering why insect wings are so impeccable, thus providing a possibility of improving the design of flapping-wing aerial vehicles.

1 Introduction

Significant amount of researches in the design of micro-sized air vehicles (MAVs) have been carried out over the past 15 years [1–6]. Alternatively, tremendous progress was done in the field of aerodynamics and Kinematics [7-16]. Vincent [17] found that the material of insect wing was similar to composite materials, many other researchers also believed that the wing of natural insects are composite structures [18-20]. Composite materials are currently used for UAVs [21,22].

Unfortunately, most of the works mentioned above have been generally limited to CFD and CSD. Still research in deformation and stress analysis continues to lag, especially for composite models. In this paper, total sixteen different orientations and layer combinations were analysed for maximum aerodynamics force and inertial force. Because the structure of insect wings is very complex and their elastic Module and thickness in irregular, at present we can only simulate it to manufacture flapping-wing aerial vehicle.

2 Analytical Model

2.1 Aerodynamics Force and Inertial Force

Three-dimension unsteady vortex lattice method (UVLM) [23] is used to calculate the aerodynamics. The aerodynamics of flapping-wing aerial vehicle

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$$\Delta F_{ij} = (\Delta P \cdot \Delta S)_{ij} \tag{1}$$

where ΔP is pressure of element & ΔS is area of element.

The flapping motion of the present model wing is simplified to a cosine rotation around a fixed axis located at the root.

$$\beta(t) = \beta_{max} cos\ (\omega t) \tag{2}$$

The periodic inertia force generated from the acceleration and deceleration of flapping wing, is the main acting load on it during every cycle. Its specific load distribution can be predicted as

$$F_i(t) = -m_i \frac{d^2\beta(t)}{dt^2} = \omega^2 \rho m_j r_j \beta_{max}\ cos(\omega t) \tag{3}$$

where $F_i(t)$ is the inertial force of element i, m_i is the mass of element i, r_i is rotational radius of element i, ω is angle velocity, t is time, β_{max} is amplitude of flapping angle.

Because the units of aerodynamic force is N/m^2, the calculation formula of inertial force can express as

$$F_i(t) = \omega^2 \rho_s A_i t_i r_i \beta_{max}\ cos(\omega t) \tag{4}$$

$$f_i(t) = \frac{F_i(t)}{A_i} = \omega^2 \rho_s t_i r_i \beta_{max}\ cos(\omega t) \tag{5}$$

where A_i is area of element i, ρ is material density.

2.2 Composite Material Model

The carbon/epoxy composite T300/5208 is used for the membrane of the flapping wing; its material properties are shown in Table 1. For this analysis, it exhibits viscoelastic behavior, and all the insect wings have the viscoelastic behavior.

Table 1. T300/5208 material characteristics

E_{11}(GPa)	E_{22}(GPa	E_{33}(GPa)	$_{12}\upsilon$	$_{23}\upsilon$	$_{31}\upsilon$	G_{12}(GPa)	G_{23}(GPa)	G_{13}(GPa)
181	10.3	10.3	0.28	0.3	0.28	7.17	3.78	7.17

3 Results analysis

We designed a membrane flapping-wing model, which is shown in Figure 1. A mesh convergence study was performed to obtain the accurate results, which is shown in Figure 2. The parameters used in this model are shown in Table 2.

Table 2. Parameters used in the flapping-wing aerial vehicle model

Semi-span length (mm)	320
Maximum chord length (m)	100
Flapping frequency (Hz)	8
Flapping angle	45°
Flight velocity (m/s)	11
Angle of attack	5°
Outer radius of beam (mm)	3
Inner radius of beam (m)	2
Elastic module of beam (GPa)	40
Poisson’s ratio of beam	0.3

Thickness of membrane (mm)	1

The boundary condition of the fixed support in the body-fixed coordinate system is adopted. During the flapping flight, the flapping-wing must withstand not only aerodynamic force but also inertial force. Aerodynamic force of every shell element is calculated from Equation (1), and the inertial force of every element is calculated from Equation (5).

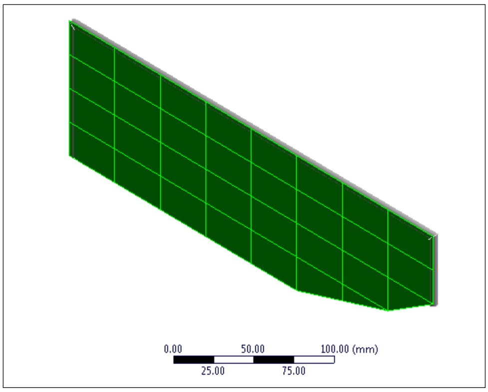

Figure 1. Flapping wing model

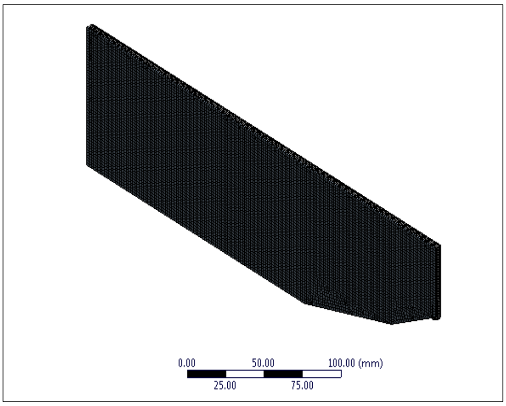

Figure 2. Meshed Body (Element Size=1,5)

For the simulation part, all sixteen possible combinations were calculated for the twelve flapping periods, totaling 192 simulations to find the impact of fiber orientations. The curves of Von-Mises Stress in one flapping cycle are shown in Figure 3. And the curves of maximum deformation are shown in Figure 4. From the figures [3,4] it is clearly understood that [0/-45] will occur maximum stress during a flap, on the other hand, [45/0] will produce the least while deformations are very small, less than 1.8 mm, for all the variants we simulated.

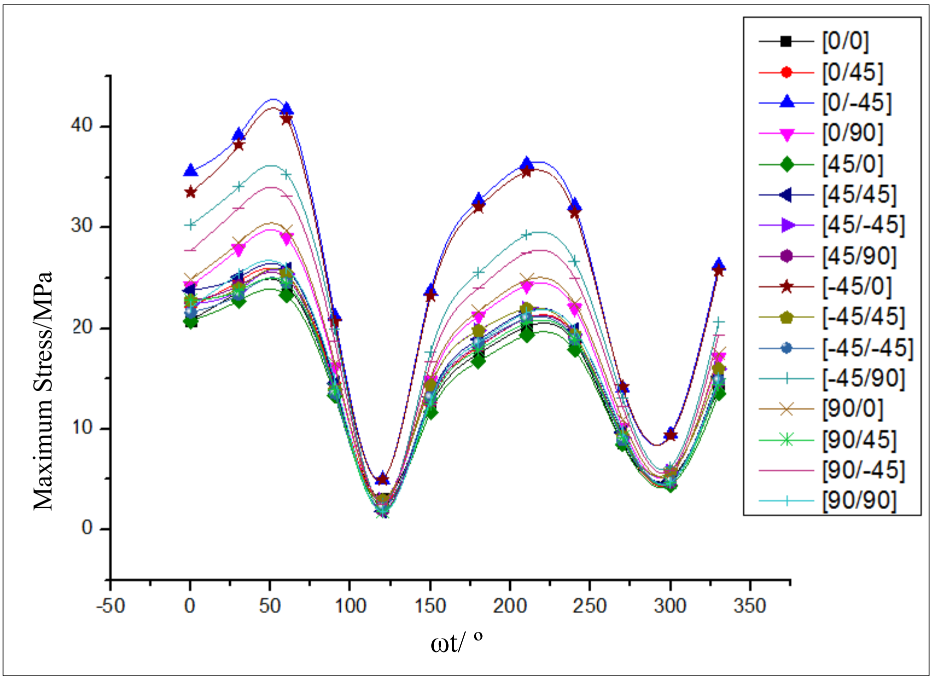

Figure 3. Maximum Stress Curves in one Flapping Cycle

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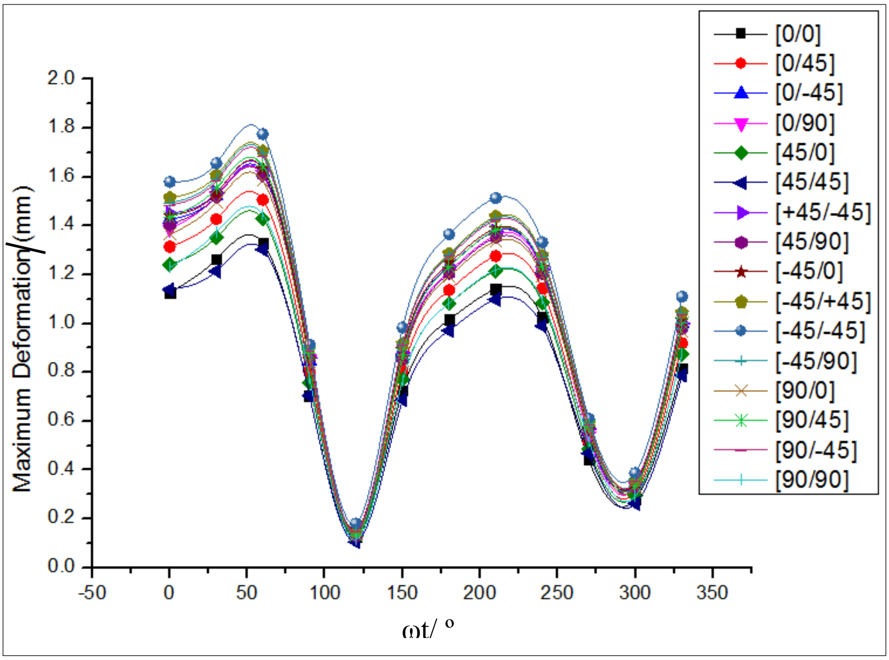

Figure 4. Maximum Deformation Curves in One Flapping Cycle

Figure 5 illustrates the maximum stress zone [45/0], at the root of the flapping wing, on the beam, which is produced during the third segment of the down stroke of a flapping cycle. Figure 6 illustrates the deformation contour [45/45] which is maximum at the tip of the wing.

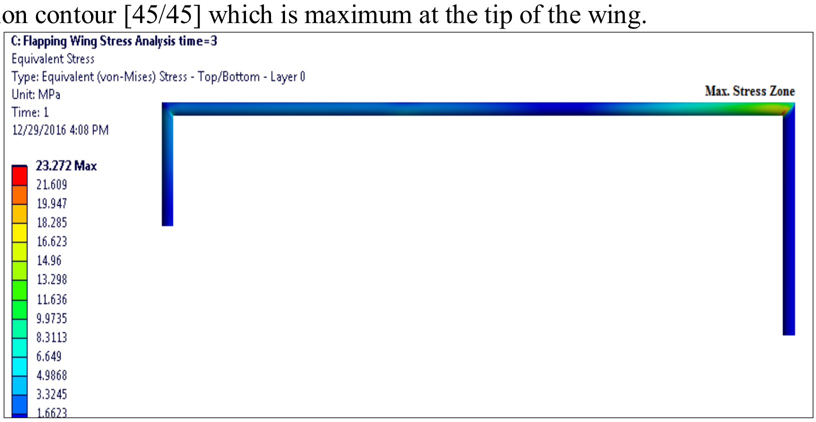

Figure 5. Maximum Stress Zone [45/0]

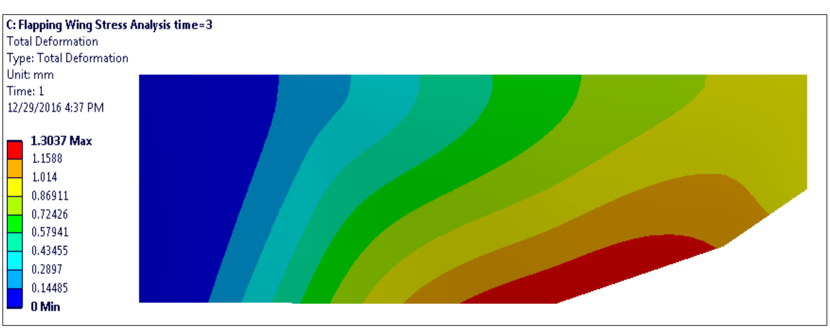

Figure 6. Maximum Deformation Profile [45/45]

Conclusion

Finite element analysis is performed to investigate the membrane stresses of a flapping wing made of Composite [T300/5208]. Our carried out research revealed the structural benefits of two layered flapping wing which experiences both least deformation and stress. In addition to that, we found the best combination of layers and fiber directions [45/0] which produces almost 41% less stress than [0/-45]. This work can contribute in progression of designing two layered flapping wings. In future, we will carry out a research on optimization to find the best performed flapping wing both structurally and aerodynamically.

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