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Design and Analysis of Composite Structure for Development of A Flapping Wing Micro Air Vehicle

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Abstract: **This paper presents the application of composite material utilized for the development of a Flapping Wing Micro Air Vehicle [1] (MAV). Design and Analysis of structural components made of Carbon Fiber Reinforced Composite (CFRP) material is presented using Finite Element Analysis (FEA) method. MAV is a class of Unmanned Aerial Vehicle that has a size restriction with their largest dimension not exceeding 300mm.These vehicles are meant to address a large number of civilian and military applications including search and rescue, disaster management, traffic monitoring and management, remote sensing and terrain mapping.**

Flapping flight has the potential to revolutionize MAVs due to increased aerodynamic performance, improved maneuverability and hovering capabilities. Structural configuration of possesses a challenging task for the development of strategic MAV's. As weight become stringent design parameter, a highly optimized and validated approach is followed for light weight material selection.

The design procedure entailed the overall system design, component selection and placement in Autodesk Inventor CAD software package. The fuselage and outer body is designed and fabricated using Carbon Fiber Reinforced Composite through proper structural analysis [2] using Abaqus CAE Software while retaining the aerodynamic configuration. The effective engineering properties were calculated for various orientations and composite stress analysis [3] was performed on a single CFRP lamina. Finally the aerodynamic analysis [4] was performed for the fuselage and outer body. Qualitative flight testing confirmed and validated the overall optimized design and analysis procedure.

1. INTRODUCTION

An Unmanned Aerial Vehicle (UAV) is an aircraft without a human pilot on board having flight controlled either autonomously by computers in the vehicle, or under the remote control of a pilot on the ground or in another vehicle. Micro Air Vehicle [1] (MAV) is a class of UAV that has a size restriction with their largest dimension not exceeding 300mm.

These vehicles involve a large number of civilian and military applications in the field of Intelligence, Surveillance and Reconnaissance. The present design of MAV is an ultra-light weight flapping wing micro air vehicle as shown in Fig. 1. It is inspired by nature and came into picture through bio-mimicry. The raptor bird Falcon is the main inspiration behind this design. The MAV is designed to have the capability of bomb dropping and surveillance through modern sensing capabilities. It consist of a micro camera as the design is based on FPV, a vision based navigation. The system uses a microprocessor, a trans-receiver and other essential circuit elements for controlling the system through computer on the ground control centre.

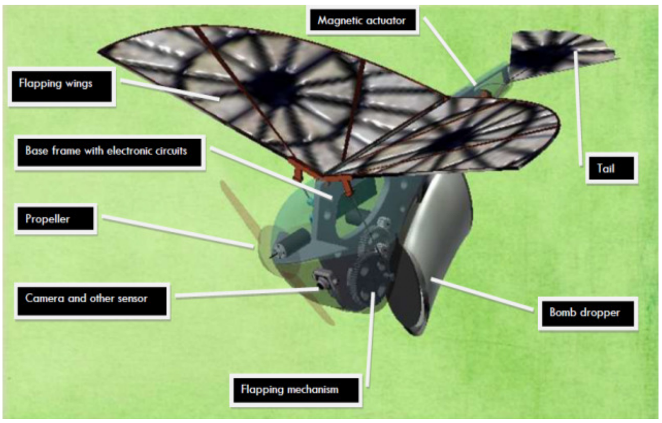
The performance, capabilities and maneuverability of MAV is associated with an optimized and validated material selection procedure. As the weight of a flying vehicle is the major concern, thus an optimized procedure for material selection is required. The growing demand of light-weight structures in the aerospace industry has made composites highly desirable. The use of composite materials in this field has made it increasingly important to predict the service life and the mechanical responses of structures involving these materials. The complexity of modeling the process-induced effects requires the use of modern software engineering techniques with multi physics coupled models.

2. SYSTEM DESIGN

As a result of Bio –inspiration, Flapping wing MAVs are latest research hotspot. The study of flapping flight from an experimental standpoint brought insight into the lift-generating mechanisms produced during flapping. For designing this MAV as shown in Fig. 1, the inspiration was taken from birds which creates lift by flapping its wing and navigates through its tail. For this, intensive study of Falcon bird was done for design and aerodynamics. Weight reduction was done for optimized flight with strength to fulfill the surveillance requirement.

The design resembles bottom- up approach. It is modeled as a collection of three rigid bodies (a central body, two wings and a tail). The wings and tail have prescribed motions relative to the central body, i.e., they are kinematically driven. The numerical integration of all the governing equations, which are differential-algebraic, is performed simultaneously and interactively in the time domain. For designing this MAV, Frequency selection and fluid flow velocity are calculated using Reynolds and Strouhal number scaling.

$$f_{scale} = \left(\frac{v_{scale}}{v_{animal}}\right)\left(\frac{L_{animal}}{L_{scale}}\right)^2 f_{animal} \,,$$

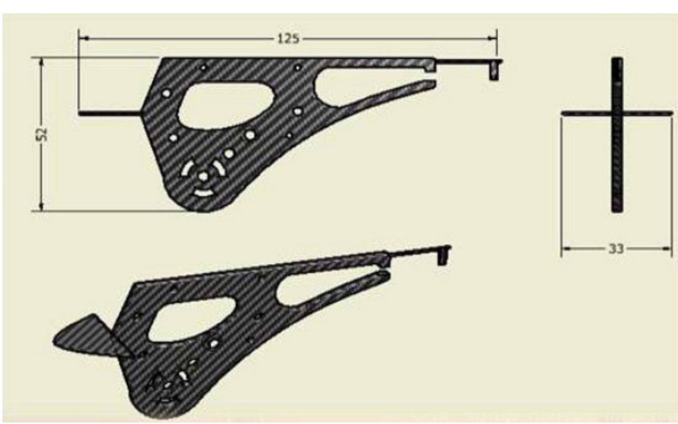


Φιγυρε 1. Φαλχον ΜΑς δεσιγν

For a bird like falcon, the values in the above equations were put and the scaling was done to fit with size of a MAV.

2.1 Fuselage Design

The Fuselage as shown in Fig. 2 is the base frame which supports other parts. It is made of carbon fiber reinforced plastic. The flapping mechanism gears and motors are mounted on the bottom side. Wings are hinged on the top side. In the front, camera and other sensors and the propeller motor is attached. Slots are cut in the frame to reduce the weight from unwanted area.



Φιγυρε 2. Φυσελαγε

The fuselage is designed to use carbon fiber having the properties as shown in Table 1.

Table 1: Carbon fiber properties

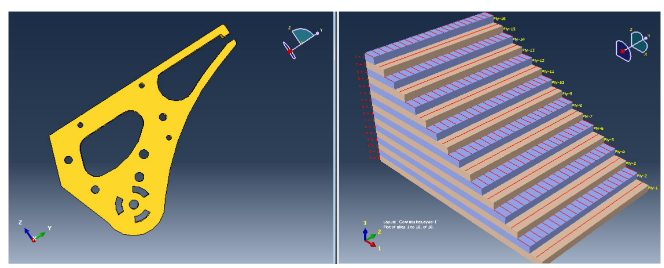
Property	Young's Modulus	Ultimate Tensile Strength	Ultimate Compressive Strength	Density
Value	70 GPa	600 MPa	570 MPa	1.6 g/cc

2.1.1 Composite Layup The frame is supposed to be a constant layup [2] and thickness throughout the entire area to simplify manufacture. The modeling of frame as shown in Fig. 2 is done in Autodesk Inventor software. For analyzing the composite frame, the Composite Layup Manager Tool of Abaqus Software is used. As shown in Table 2, different frame layups and thickness were chosen for analysis.

Table 2: Layup composition

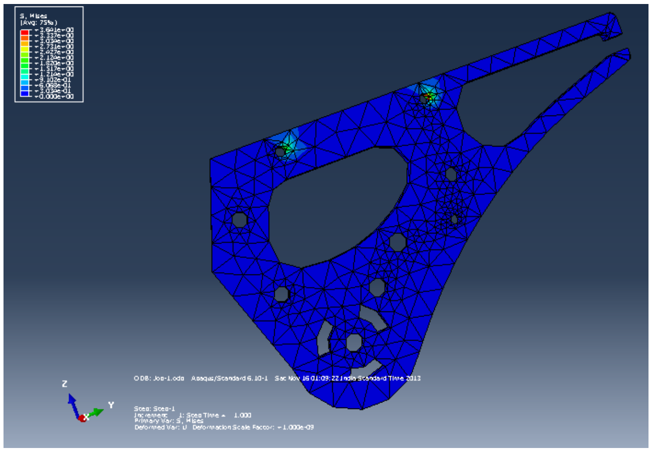
Case	Layup	Plies	Thickness (mm)
1	[±452]s	8	1
2	[±453]s	12	1.5
3	[±454]s	16	2
4	[0/90]s	16	2

Mechanical properties of CFRP were applied by giving elements material and layup definition as shown in Fig. 3

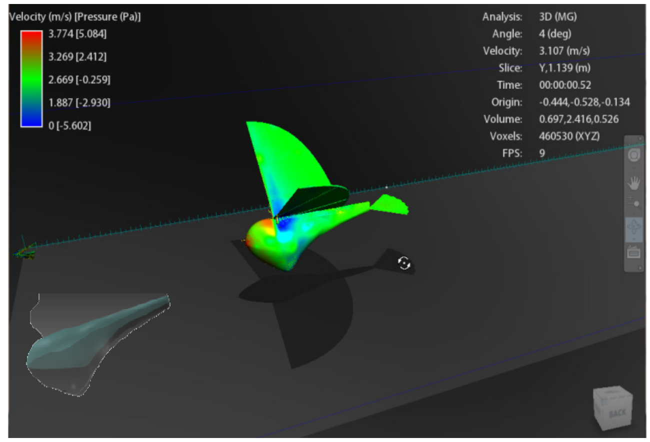


Φιγυρε 3. Πλψ σταχκ πλοτ φορ 0/90 λαψυπ

2.1.2 Structural Analysis The finite element model [3] is used to analyze the structure consisting of 3042 shell elements having Tet Element shape with free structure. The element type is C3D4, A 4-node linear tetrahedron. A global seed size of 5 is selected to control the element size. The upper surface of frame is constrained to be encastre. The loads applied are the force generated due to flapping of wings and aerodynamic forces. The principal direction of the fibers (i.e. the 0º orientation) is parallel to the long axis of the elements. The maximum von misses stress of value 450 Mpa is generated near the upper two hinge points where the wings are attached to the frame.



Φιγυρε 4. Στρεσσ αναλψσισ πλοτ



Φιγυρε 5. Αεροδψναμιχ αναλψσισ

To mimic slow-flight conditions, flow velocities between 2 m/s and 3 m/s are used for calculation. The force applied on the frame is a result of Gravity, Aerodynamic Force and Force due to Flapping. Thrust and lift forces [5] are approximated by the drag of the wing through the air, which are modelled as follows:

$$
\begin{aligned}
L &= \int f_D \cos(\theta) dA = \int C_D \rho v^2 \cos(\theta) dA \\
&= \int C_D \rho f^2 \cos(\theta) g^2(\theta_1) \cos(\theta_3) r^2 dA \\
T &= \int f_D \sin(\theta) dA = \int C_D \rho f^2 \sin(\theta) g^2(\theta_1) r^2 dA
\end{aligned}
\tag{1}
$$

where f_D is the drag force, C_D is the drag coefficient due to the shape of the wing that varies slightly with Reynolds's number, ρ is the density of air, v is the wing velocity, f is the flapping frequency in Hz, θ is the standard camber angle determined by the shape of the wing, θ_1 is the rotation angle of the crank mechanism that determines the wing velocity, θ_3 is the angle the primary spar makes with the horizontal plane during the flapping motion, r is the radial distance from the pivot point of the wing, and g is a function of θ_1 that relates the rotation angle of the crank mechanism to the angular velocity of the wing determined from the lengths of the shafts and the angles for the flapping mechanism.

2.2 Outer Body Design

The outer body is designed to protect overall system during operation. The outer body should have to be stiff and tough. For this, CFRP layer is designed having [±452] s layup with 8 plies and thickness of 1 mm. The body as shown in Fig. 4 is designed using surface modeling in Autodesk Inventor Software. The teardrop shape [4] is followed using aerofoil of different size in various cross sections. The overall design is analyzed for aerodynamic behavior as shown in Fig. 4, at an average velocity of 3 m/s, through which, the coefficient of drag is coming out to be 0.055. The maximum pressure generated due to aerodynamic forces is 5.084 Pa at the front.

3. RESULT

On the basis of analyzing the stress plot and availability, the [0/90] s layup with 10 plies are used having a thickness of 2mm for the manufacturing of base frame. The Maximum Stress generated is near the hinge of wing attachment on the base frame. The maximum Value of principle stress generated is 450Mpa which is less than the ultimate tensile strength of CFRP Fiber. Also the aerodynamic analysis of outer body and overall design shows 0.055 as the value of coefficient of drag with maximum pressure of 5.084 Pa generated at the front.

4. CONCLUSION

With a general overview on the design and analysis of composite structures used in base frame and outer body of a micro air vehicle, it can be concluded that CFRP is emerging as a material selection for design and development of Micro air vehicles due to its high strength to weight ratio. Also it can be concluded that, the analysis of various layup orientation for composite structure is an optimized and validated method of weight reduction and material selection for designing of aerial vehicles. Also the CFRP composite can be used as an alternative to other material to develop aerodynamic outer body having a very low coefficient of drag, minimized thickness and high strength.

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