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Design and Analysis of Flying Insect Robot

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***Abstract* - This project is meant to design and analyze a bio-inspired flying butterfly robot. The butterfly robot designed in this project is based on aerodynamics, especially for designing a flapping mechanism due to its complexity. The flapping mechanism was designed by using two separate servo motors because of its flexibility and performance. This mechanism enables the robot's motion without an extra actuator. A butterfly wing structure was designed by considering aerodynamic forces based on assumptions. Aerodynamic equations were used to obtain lift and drag forces that acted on small wing section. Carbon fibre rods were used as an internal support structure for wing frames, as it achieved the wing's rigidity and was considered as a thin aerofoil. Finite Element Method is used to carry out the analysis. Static Structural Analysis is carried out, to find out stresses on the wings. Modal Analysis is also performed to find out natural frequencies.**

Keywords: Bio-inspired, Aerodynamics, Flapping Mechanism, Lift and Drag Force, Aerofoil, Finite Element Method, Static Structural, Modal.

I. INTRODUCTION

Flying robots always amaze human because they can mimic flying ability of the insects or birds. This kind of robot has several aerodynamic properties benefits for designing a micro stair vehicles or MAV's. This is demonstrated by the development of unmanned air vehicles (UAVs) in the last two decades, where the miniaturization challenge has gone from 'mini' to 'micro' then to 'nano' and now to 'pico'. Whilst there is no clear definition of the boundaries between these classes, the naming progress is obviously encouraging smaller and smaller platforms. This passion towards smaller air vehicles is not only because of being a new frontier to human scientific knowledge but also because of our rapidly progressing life demands that involve missions in geometrically constrained areas. The first concept that will approach one's mind when considering tiny sized air vehicles is 'insects'. This does not necessitate that they are the best solution, but they are definitely a proven solution that is copious in nature. Indeed Insect-like flapping flight is nowadays a very interesting research topic lying at the interface between biology and engineering.

In recent years, flying robots such as multi-rotor helicopters have been actively developed for practical applications. Although, the size of these common flying robots ranges from several tens of centimeters to a few meters, it is desirable that the size of the robots decreases so as to let it pass through narrow spaces. From this viewpoint, flapping robots modeled after small bird such as humming-birds or insect such as flies have been developed. However, these robots have not achieved practical flight because it is difficult to implement a battery, complex link mechanisms, and actuators that drive wings and control postures within such a small body.

The last four years, in particular, witnessed the presentation of breath taking designs that can be considered important milestones within the development history of these vehicles, In 2011, the 'Nano-Hummingbird' was introduced, representing a successful palm-size flapping wing vehicle capable of controlled hovering flight. In 2013, the pneumatic and electric automation company Festo presented its 'Bionic-Insect'. Whilst having a relatively large size (wing span of 63 cm), the dragonfly-like vehicle was able to demonstrate full active control of wing pitch, flapping amplitude and frequency.

II. METHODOLOGY

Solid modeling is a consistent set of principles for mathematical and computer modeling of three-dimensional solids. Solid modeling is distinguished from related areas of geometric modeling and computer graphics by its emphasis on physical fidelity. Together, the principles of geometric and solid modeling from the foundation of 3D-computer-aided design and in general support the creation, exchange, visualization, animation, interrogation, and annotation of digital models of physical objects. The use of solid modeling techniques allows for the automation of several difficult engineering calculations that are carried out as part of the design process. Simulation, planning, and verification of processes such as machining and assembly were one of the main catalyst for the development of solid modeling. More recently, the range of supported manufacturing applications has been greatly expanded to include sheet metal manufacturing, injection molding, welding, pipe routing etc.

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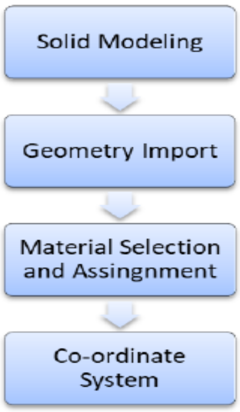

Figure 1: System Analysis

FORCE CALCULATION

Drag Force (F_D):

Force component in the opposite direction to flight. This can exists between two fluid layers or between a fluid and a solid surface.

$F_D = 0.5*\rho*v^2*C_D*A$

F_D = Drag Force (N)

ρ = Density of Fluid (1.225 kg/m^3)

v = Speed (m/s)

C_D= Drag Coefficient (0.01981 at $\alpha = 6°$)

A = Area of object facing fluid (0.011 m^2)

Drag force is calculated by assuming extreme and lowest environmental conditions.

Force calculation using extreme condition i.e (v_1 = 15 m/s)

$F_{D1} = 0.5*1.225*15^2*0.01981*0.011$

F_{D1} = 0.03003 N

Force calculation using lowest condition i.e (v_2 = 3 m/s)

$F_{D2} = 0.5*1.225*3^2*0.01981*0.011$

F_{D2} = 0.001201 N

Average Drag Force i.e (F_D)

$F_D = (F_{D1} + F_{D2})/2$

$F_D = (0.03003 + 0.001201)/2$

F_D = 0.015615 N

Therefore the average drag force acting on wings is 0.015615 N.

Lift Force (F_L):

A fluid flowing around an object exerts a force on it. Lift force is the component of this force that is perpendicular to the oncoming flow direction.

$\mathbf{F_L = 0.5*\rho*v^2*C_L*A}$

F_L = Lift Force

ρ = Density of Fluid (1.225 kg/m3)

v = Speed (m/s)

C_L = Lift Coefficient (0.8706 at $\alpha = 6°$)

A = Surface Area

Calculation of Lift Force on Following Assumptions:

Length of wing = 0.2 m

Width of wing = 0.15 m

Wing Loading equation,

$W/S = 0.38*V^2$

Weight acting on wings is the total weight of the robot = 0.5*9.81 = 4.905 N

Surface area of wing = 0.15*0.4 = 0.06 m^2

Wing loading = W/S = 4.905/0.06 = 81.75 N/m^2

$81.75 = 0.38*V^2$

V= 14.66 m/s

Lift produced by each section for an aerofoil,

$\mathbf{F_L = 0.5*\rho*v^2*C_L*A}$

Wing aspect ratio = 0.2/0.15 = 1.333

Velocity of flight (level flight) =14.667 m/s (approximated 16 m/s for designing)

Density of air = 1.225 kg/m3

Air speed = 9 m/s

Section 1, Tertiary section area = 0.05*0.15 = 0.0075 m^2

$F_L = 0.5*0.06*1.225*9^2*0.0075 = 0.3237$ N

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Section 2, Secondary section area = 0.1*0.15= 0.015m^2

F_L = 0.5*0.06*1.225*9^2*0.015 = 0.6475 N

Primary section area = 0.40*0.15 = 0.06 m^2

F_L = 0.5*1.333*0.06*1.225*16^2*π/180*6 = 1.3132 N

Total lift = lift produced by aerofoil + (lift produced by membrane x flapping frequency)

Total Lift = 12.79 N (approximated 13 N)

Since the Total Lift (i.e 13N) is greater than the Self Weight of the robot (i.e 5N).

So there is net upward force acting on the robot. This force lifts the robot into the air.

Total Torque

Torque = Force*Perpendicular Distance

Torque = 0.33277 N-m

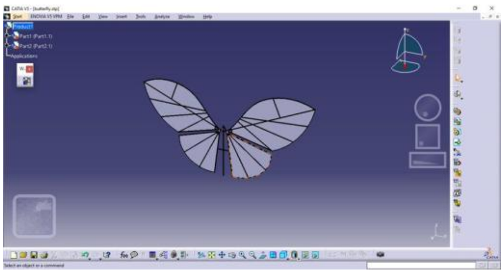
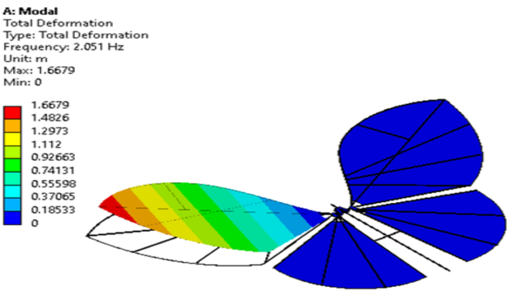


Figure 2: CAD Model



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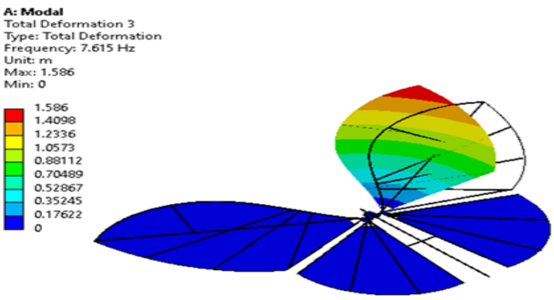

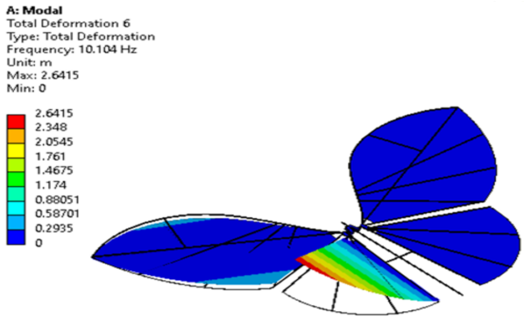

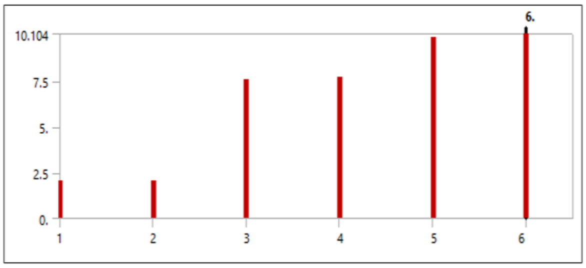

Figure 3: Frequency Graph of Full Body

It is found that the wing skeleton is most stressed and complicated section of the robot. It is due to the varying thickness which leads to stress concentration and complexity in manufacturing. In this project it has been observed that the tip of the wing is the most complex and most stressed part of the robot, which also leads to complexity in manufacturing due to its varying thickness. Hence analysis is performed after changing the thickness of the wing skeleton. Originally, the thickness of the wing was varying (i.e. 1 to 2mm), hence analysis is done for uniform thickness of 1.5 mm.

III. RESULTS AND CONCLUSION

We studied the various designs and structures of wings, aerodynamics of wings, flapping mechanism and different types of motors. We selected high lift, low aspect ratio shape for wing surface and aerofoil shape for thickness of the wing. The various forces acting on the body, such as lift force and drag force were calculated and depending on the force required motor was selected.

The accuracy of finite element analysis is highly depending on the type of mesh employed. It is observed that tetra mesh generally produces a better and more precise mesh as compared to hex mesh. The Static Structural Analysis was done by considering various load conditions, such as gravitational force, self weight and drag force.

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