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Design, Development and Analysis of Ornithopters

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Abstract -Ornithopters, biomimetic systems that utilize flapping wing flight to generate lift, are a growing field of robotics. Large scale ornithopters have several real world applications, including payload carrying and transport. Although these bio-inspired robots are of particular interest, there are currently no successful large scale hovering ornithopters in existence over 2 kilograms. This project developed a prediction and validation system that can effectively guide, examine, and validate ornithopters prototype designs. The development of flapping wing utilizes a combination of two things, biologically inspired design and incorporation of composite material. The ornithopter has imitated the wing structure as a basic concept of aerodynamics and kinematics. Hence, study and analysis of aerodynamics of bird and insect has been carried out. The main objectives of this project are, to create an ornithopter with best available flapping using kinematic arrangement and to attain crash resistance power by building the ornithopter with suitable material. In particular, by using customizable input variables of angle of attack, crank speed, and wing size, the projected lift force, flapping frequency, and power requirements of the prototype could be determined. A Two-Dimensional Computational Fluid Dynamic study is administered on an oscillating flat plate at various flow situations so as to realize insight on the flow field and forces acting on a generic flapping wing in a viscous flow within a certain flying conditions and static structural analysis on frame of ornithopters for various forces acting on it.

Index terms- aerofoil, Ansys fluent, bird drone, flapping mechanism, ornithopter,solidworks.

1 Introduction

An ornithopter is an aircraft that flies by flapping its wings. Designers seek to imitate the flapping-wing flight of birds, bats, and insects. Though machines may differ in form, they're usually built on an equivalent scale as these flying creatures. [1] eximines the history of ornithopters and their design, and investigates developments and future trends of this uniquely inspired aircraft. Since the earliest recorded history, humans have shared a nearly universal desire for the freedom of flight. Though science eventually shifted its focus to balloons, and then to fixed-wing flight, as a means of sustaining flight, the freedom and effortless grace of birds is as captivating now as it ever was. From the earliest days of man's dreams of launching himself skyward to today's advanced designs, flapping-wing craft, known generally as ornithopters, have held a constant place in the quest to achieve the flowing elegance of flight so easily mastered by nature's own aeronauts. [2] Studied versatile mechanisms which are developed for 20 cm wing span flapping MAV with VTOL provision. Kinematic and aerodynamic performance of Stephenson and Evans mechanisms are studied in detail. [3] studied traditional ornithopters use a complete membrane wing which flaps its wing with a single degree of freedom and [4] examines that the feasibility of using various RP techniques for fabricating light weight flapping wing mechanisms for subsequent use in bird mimicking micro aerial vehicles. [5] studied an ornithopter prototype that mimics the flapping motion of bird flight is developed, and the lift and thrust generation characteristics of different wing designs are evaluated. [6] Studied the dynamics of the robotic bird in terms of time response and robustness. It is analyzed the wing angle of attack and the velocity of the bird, the tail influence, the gliding flight and the flapping flight. The results are positive for the construction of flying robots. The development of computational simulation based on the dynamic of the robotic bird should allow testing strategies and different algorithms of control such as integer and fractional controllers. [7] he developed which flaps its wings in fixed amplitude with variable frequencies. CFD is a simulation tool used to predict what will happen, quantitatively when fluids flow, often with the complication of simultaneous flow of heat, mass transfer, phase change, chemical reaction, mechanical movement, stresses in and displacement of immersed or surrounding solids. [8]Computational Fluid Dynamics on aircraft model which has come to complement the experimental studying, reducing the cost in tests and time for the generation of prototypes. The study of the aerodynamic design has played an important role in the airplanes optimization. He Analyzed delta wing conceptual aircraft model on the parameters of speed at sub sonic speed, angle of attack, drag force, lift force generated, stall angle and turbulences. [9] Performed in order to understand the effects of the flow field and forces acting on an oscillating flat plate, as a generic flapping wing, in viscous flow at certain conditions. A bird strike or bird aircraft strike hazard could also be a collision between an airborne and a manmade vehicle, especially an aircraft.The term is additionally used for bird deaths resulting from collisions with structures like power lines, towers and wind turbines. It caused a number of accidents with human casualties.Most accidents occur when a bird collides with the windscreen or is sucked into the engine of jet aircraft.During landing and takeoff of the flight or aeroplane, the birds try to follow the aeroplane and losses their life. This is also results in accidents for small aircrafts to overcome the problem we are going to develop an ornithopter which is operated by human to guide the birds away from the plane.

1.1. Concept of Ornithopters

These bird-inspired robots are called ornithopters which fly by flapping their wings, over the years there has been a growing interest in ornithopters by universities, which has led to a variety of novel and innovative ornithopter designs. The principle of operation of the ornithopter is same because the airplane; the progress through the air allows the wings to deflect air downward, producing lift. The flapping motion of the wings takes the place of rotating propeller. During the wing upstroke the air flow hits the wing rather from above and within the down stroke rather from bottom. These modifications are small within the area of the wing root and gets bigger towards the wing tip.
Ornithopters are often made to resemble birds or insects; they could be used for military applications like aerial reconnaissance without alerting the enemies that they are under surveillance. Several ornithopters are flown with video cameras on board, a number of which may hover and maneuver in small spaces. The radio-controlled robot bird is used to scare away birds that could damage the engines of airplanes used for forestry and wild life survey. Some ornithopter used for traffic monitoring. Ornithopters are often more efficient, cost effective and environmentally friendly as compared to fixed-wing aircrafts.

1.2. Aerofoil Shape Selection

We studied and analyze different types of aerofoil shapes. After that we selected the optimum shape for the aerofoil as Drela AG17 airfoil for our operation. The specifications of the selected aerofoil are as follows.

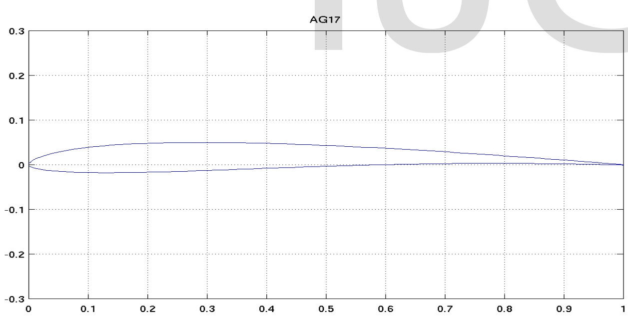

Fig. 1.1 aerofoil shape

2 DESIGN

2.1. Calculation for power requirement

2.1.1. Forces on wings

Assume,
Length of wing = 0.4 m
Width of wing = 0.15 m
The total length was divided into three sections with lengths 0.30 m, 0.10 m, 0.05 m.
Wing loading equation,

$\frac{W}{S} = 0.38 \times V^2$ [3]

Weight acting on wings is the total weight of the ornithopter = 1.2 kg x 9.81 = 11.772 N
Surface area of the wings =0.15 x 0.8 =0.12 m^2

Wing loading = $\frac{W}{S} = \frac{11.772}{0.12} = 98.1$ N/m2
$98.1 = 0.38 \times V^2$
V= 16.067 m/s
Lift produced by each section for an aerofoil,
$F_L = \frac{1}{2} \times C_L \times \rho \times v^2 \times S$ [3]
From α vs. C_L graph, at α =6 degree, C_L = 1.2
Wing aspect ratio $= \frac{0.4}{0.15} = 2.667$
Velocity of flight (level flight) =16.067 m/s (approximated from 18 m/s for designing)
Density of air = 1.225 kg/m3
Air speed = 5 m/s
Section 1, Tertiary section area = 0.05 x 0.15 = 0.0075 m^2
$F_L = 0.5 \times 1.2 \times 1.225 \times 5^2 \times 0.0075 = 0.1378$ N
Section 2, Secondary section area = 0.1× 0.15= 0.015m^2
$F_L = 0.5 \times 1.2 \times 1.225 \times 5^2 \times 0.015 = 0.2756$ N
Primary section area = 0.40 x 0.15 = 0.06 m^2
$F_L = 0.5 \times 2.667 \times 0.06 \times 1.225 \times 18^2 \times \frac{\pi}{180} \times 6 = 3.325$ N
Total lift = lift produced by aerofoil + (lift produced by membrane x flapping frequency) [3]

$$Total\ lift = 0.1378 + 0.2756 + (3.325 \times 5) = 17.0384 \text{ N}$$

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

2.1.2. Total Torque

Torque = Force x Perpendicular distance [3]

$$\text{Torque} = 3.325 \times \left(\frac{1}{3} \times 0.25\right) + (0.15) + (0.2756 \times 0.05) + 0.1378 \times \left(0.1 + \frac{0.05}{2}\right)$$

Torque = 0.8068 N-m

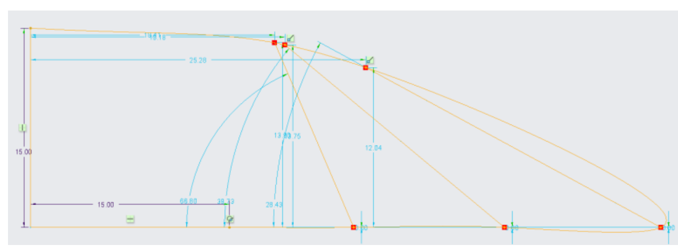

Fig.2.1 Wing Design

2.1.3. Selection of motor

Robodo 600 RPM 12v DC Johnson Gear Motor - High Torque

2.1.4. Gear selection

The motor has a maximum speed of 600 rpm at 12v. So to get a maximum flapping frequency of 5 flaps per second, the gear reduction should be
5 fps = 5x60 = 300 rpm.
600/300 = 2
All the gears have same module which means the all engage correctly and the teeth are same.

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TABLE 2.1
GEARDIMENSIONS

Gear no	Pitch diameter (mm)	No of teeth	Module (mm)	quantity
1	30	30	1	2
2	60	60	1	2

The equation of gear ratio

$$\mathrm{GR} = \frac{\text{number of teeth on gear 2}}{\text{number of teeth on gear 1}}$$

$$\mathrm{GR}_1 = \frac{30}{30} = 1$$

$$\mathrm{GR}_2 = \frac{60}{30} = 2$$

Total gear reduction $\mathrm{GR} = \mathrm{GR}_1 \times \mathrm{GR}_2$

$$\mathrm{GR} = 1 \times 2 = 2$$

Force at gear periphery $= \frac{\text{torque}}{\text{link length}} = \frac{0.8068}{0.04} = 20.17$ N

Torque required = force x gear radius = 20.17 x 0.02 = 0.40034 N-m

The motor used have design torque of 0.5 Nm

So the torque available at gear = design torque of motor x gear ratio of final set of gears

Torque = 0.5 x 2 = 1 Nm

This is higher than the required torque.

2.1.5.Power Required

$$\text{power} = \frac{2\pi NT}{60}$$

$$\text{power} = \frac{2 \times \pi \times 300 \times 0.40034}{60}$$

$$\text{power} = 12.57 \text{ watt}$$

2.1.6.Selection of battery

Super Power DC 12V Portable 6800mAh Li-ion Rechargeable Battery Pack

This Rechargeable battery is a 12 V 6800mah Li-ion Battery. Specially designed for powering the system device which uses 12V DC power.

2.2.Tail design

The tail section of the ornithopter is liable for both of the controllable degrees of freedom apart from the power to throttle the drive motor. The tail is set up with one servo directly connected to the tail at an angle and another further up the body which rocks it via a linkage. Mounting the rudder servo at an angle is vital because with one airfoil the elevator and rudder are naturally coupled, moving the rudder servo makes the tail also move within the vertical direction unless it's at zero angle where it doesn't have any control authority anyway. With the tail at an angle to the rudder servo it allows the servo to held into the zero angle position with reference to the ornithopter body and while the tail stays near the trimmed position for horizontal flight. This causes the tail to maneuver during a bowl shaped trajectory decoupled from the elevator action and is far easier to regulate by a person's pilot. It doesn't solve the matter when the elevator servo moves the tail out of the trimmed horizontal position, but having the ability to take advantage of that's an enormous advantage where it applies.

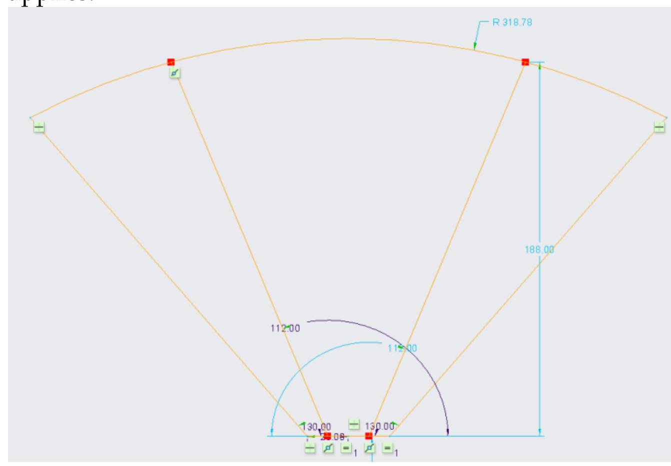

Fig.2.2 Tail Design

2.2.1.Selection of Servos

MG995 metal gear servo 180 degree rotation

Two servos are mounted on body frame to move rudders attached to the tail, which are used to change the direction and pitch of ornithopter.

3 MATERIAL PROPERTIES

3.1.Wing Skeleton –

The material should be chosen such it's high stiffness, high lastingness, low weight, high chemical resistance, heat tolerance and low thermal expansion. To realize all such needs, Carbon Fiber was chosen as the material for wing frame over steel and aluminium. Carbon fiber may be a polymer and is usually referred to as graphite fiber. Carbon fiber is formed of thin, strong crystalline filaments of carbon that's wont to strengthen material.The properties such as high stiffness and high lastingness, low weight, high chemical resistance, heat tolerances, and low thermal expansion made carbon fiber very fashionable in aerospace, engineering, military, and motorsports.

- High Strength to weight ratio.
- Carbon fiber has high Rigidity.
- Electrical Conductivity.
- Good Fatigue Resistance.
- Good tensile strength.
- They are high Fire Resistance.
- Low coefficient of thermal expansion.
- Corrosion resistant and chemically stable.

3.2.Frame –

Frame must have good strength to support all the components and must fulfill its deliberate purpose. In designing an aerial vehicle, initial calculations for calculating the lift of the vehicle are directly associated with the gross weight of the vehicle. So the frame must be designed for low weight possible without compromising on strength. By designing an ornithopter what we are necessarily doing is imitating the flight of birds. Most applications of an ornithopter require an appearance resembling a bird. Therefore while designing the frame, it's almost mandatory to fabricate it within the shape of a bird.

Acrylic is light weight thermoplastic is an effective glass alternative with thermal insulation properties. It is known for its attractive glossy surface that's available in clear or nearly any color and in transparent, translucent and opaque options. Acrylic can withstand incorrosive atmospheres without losing its transparency, gloss or dimensional shape. They are easily sawed, drilled, milled, engraved, and finished with sharp carbide-tipped tools. Cut surfaces may be readily sanded and polished.

TABLE 3.1
PROPERTIES OF ACRYLIC

Sr. No.	Property		Unit
1	Density	0.043- 1.18	(lb/in^3) (g/cm^3)
2	Water Absorption,	0.3	24 hrs (%)
3	Tensile Strength	8,000 - 11,000	(psi)
4	Compressive Strength	11,000 -19,000	(psi)
5	Coefficient of Linear Thermal Expansion	5 – 9	(x 10-5 in./in./°F)
6	Dielectric Strength short time, 1/8" thick	400	V/mil
7	Hardness, Rockwell	M80 - M100	

3.3.Plastic gears-

Molded plastic gears in lightly loaded drives. They transmit power quietly and often without lubrication in applications such as food processors, windshield wiper drives, and even watches. They also reduce the amount of parts and resist chemicals in many applications. They respond to environmental conditions such as moisture, temperature, and chemicals.

- They are usually ready to use as-molded and require no finishing.
- Plastics gears are light weight
- Plastic gears run much quieter.
- A low coefficient of friction means less horsepower wasted in heat.
- No lubrication required.
- They are lower in cost.

3.4. Wing Membrane –

The wing membrane material should be lightweight, flexible and at an equivalent time high shear strength. The material used was polyester 85% by weight of an ester and a diol and a terephthalic acid. It has high strength and resistance against tearing. It is light weight with a density of 1.3g/cc. It is long lasting, chemically stable and abrasion resistant. It is easily washable. Most importantly it is very cheap and readily available.

3.5. Shafts and Pushrods-

The material used for construction of shafts and push rods is aluminium for following reasons:

- High strength to weight ratio.
- Corrosion resistant.
- It can be easily bored, milled or turned.
- High longitudinal stability and specific rigidity.

4 ANALYSIS

4.1. Introduction of CFD Analysis

Flying animal generates lift, thrust, and performing astonishing manoeuvres by flapping its wings. By studying the flight characteristics of natural flyers such as birds and bats, the motion of a two-dimensional model can be identified, and the associated unsteady aerodynamics can be modeled and simulated using CFD.CFD uses a computer to unravel the relevant science based mathematical equation, using information about the circumstances in question. There are three laws that have to be satisfied for the control volume, the conservation laws. CFD is applied to a broad range of research and engineering problems in many fields of study and industries, including aerodynamics, weather simulation, natural science and environmental engineering.

4.2.Steps in Analysis –

4.2.1.Developing CAD Model

CAD model is first prepared in solid works 2018 and is converted in .iges format to export it to ANSYS FLUENT.The solid modeling tool used here allows us to easily import the standard format files with an amazing compatibility to other software.

4.2.2.Ansys Simulation

The CAD model is imported in ANSYS FLUENT and enclosure is created. Using binary operation continuum is generated the acceptable size and shape of the computational domain, also mentioned as control volume, and therefore the best placement of the model in the domain, needs to be determined. A domain overlarge will make the simulation unnecessarily large and waste computational resources, however a website too small will lower the accuracy of the results. The properties of the domain like temperature, pressure and fluid properties got to be chosen.

4.2.3.Boundary Conditions

The conditions at the boundary of the domain require to be set such as inlet velocities, outlets and wall attributes. For the case of forward flapping flight, the inflow and outflow of the domain boundaries are defined. At the inflow boundary the velocity is defined as fixed-value and the pressure as zero-gradient. On the other hand, at the outflow boundary, the pressure has to be fixed-value and the velocity zero-gradient.

5 RESULTS

The results were obtained during the analysis of ornithopter on Drela AG17 airfoil. Following figure shows different types of graphs and contour plots. Cross section of the wing is aerofoil shape (Drela AG17) having length 400mm and width 150mm. Two no of wings are attached to the frame and this setup is used as a model for the analysis. The model was placed with its center coinciding with the origin of the workplace co-ordinate system.

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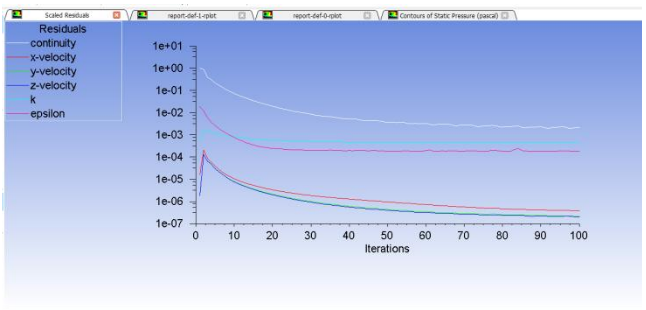

Fig.5.1. Graph of Velocity Vs Iterations

The above graph shows the velocities along the different axis over the period of the 100 iterations. Firstly the velocity for all axes is maximum after some iterations is gets constant.

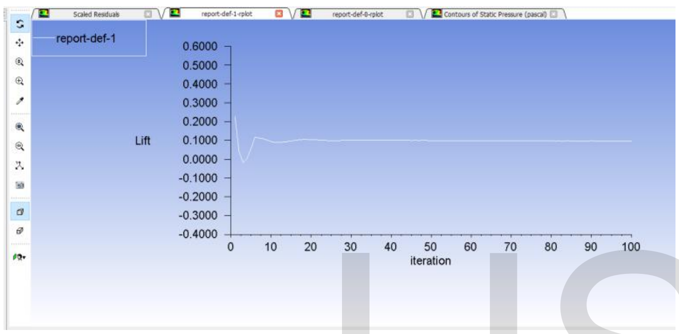

Fig. 5.2 Graph of Lift Vs Iterations

The graph shows the variation of lift over the number of iterations. Firstly the lift force is maximum for the first 5 iterations it drops and after that it increases up to iteration no 10, and then it becomes steady for further iterations.

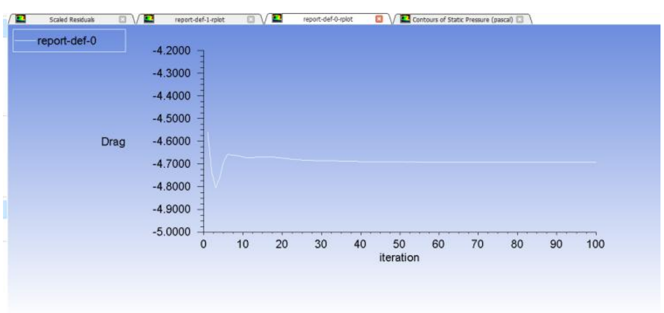

Fig.5.3 Graph of Drag Vs Iterations

The graph shows the variation of drag over the number of iterations. Firstly the lift force is maximum for the first 3 iterations it drops and after that it increases up to iteration no 7, and then it becomes steady for further iterations.

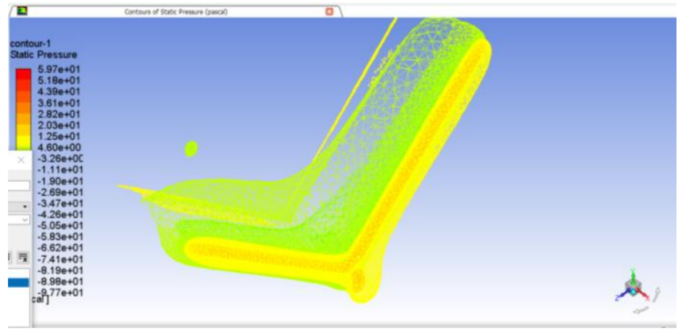

Fig.5.4 Contour Plot of Interior Surrounding For Static Pressure

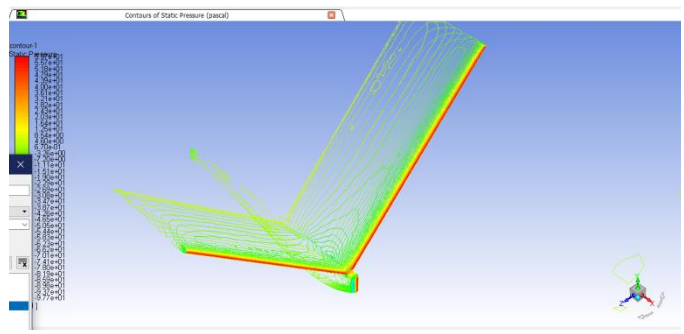

Fig.5.5 Contour Plot of Wall Surrounding For Static Pressure

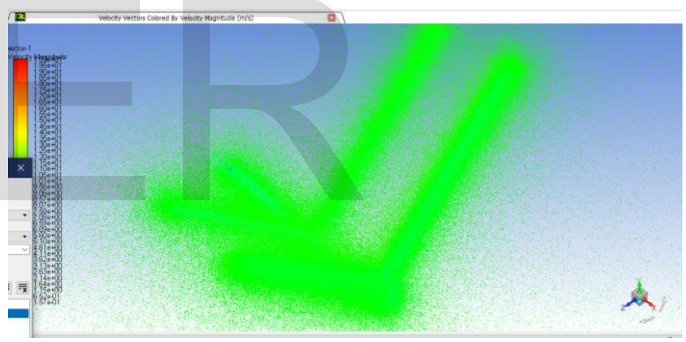

Fig.5.6 Contour Plot of Interior Surrounding For Velocity Magnitude

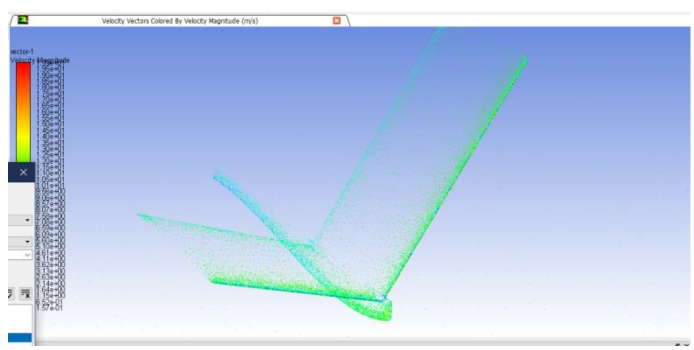

Fig.5.7 Contour Plot of Wall Surrounding For Velocity Magnitude

Contour Plots

In a post processing contour plots for the static pressure and the velocity magnitude are captured. Fig. 5.4 to 5.7 shows the different contour plots for static pressure and velocity magnitude. For static pressure there are two plots which are static pressure for wall surrounding (fig.5.5) and the static pressure for interior surrounding (fig.5.4).

Similarly for velocity magnitude two different contour plots are captured one for interior surrounding (fig.5.6) and the other for wall surrounding (fig.5.7).
From pressure contour plots we can determine the amount of pressure at a definite portion. And from the velocity contour plot the boundary layer separation of air flow over the wing is calculated.

6 FUTURE SCOPE

Through the comparative study of various ornithopters, Increased research, development and interest in this field. Hereby are the areas that can be focused upon fixed amplitude and variable frequency flapping motion of wings. Development of wing-twisting mechanism, progression in the technique to reduce negative lift generated during the upstroke of wing, provision of increased versatile maneuvering capabilities. Innovating techniques for independent successful take-off and landing techniques. Only a marginal number of the models developed today, possess autonomous, robust flight with onboard power source as well as a camera vision feed. Inventing techniques that allow backward-flying trends. It is equipped with atmega328p - MLF28 microcontroller, 3-axis accelerometers, gyros, magnetometers, and a barometer. With the co-ordination of all these it can autopilot and hence performing height control, disturbance rejection or more precise attitude control is done. Ornithopters provide with a wide range of application in the field of military surveillances, local inspection of a particular area, communication network links, local food deliveries, first-aid and medicines as well, in the remote or disaster-struck areas of the world. UAV applications were mainly due to rapid response or due to the harmful environment in the surveillance area.

7 CONCLUSION

We studied the various designs and structures of wings, aerodynamics of wings, different flapping mechanisms, different types of batteries and motors. We selected high lift low aspect ratio shape for wing surface and aerofoil shape for thickness of wing on the basis of their performance and efficiency. After that, the dual crank mechanism with some modification is used for ornithopter. For the required power and torque we selected the necessary battery and motor. After calculation of forces and torques we selected the proper gear which can gives us the proper gear reduction ratio. As per the calculations we develop a CAD model of mechanism which transmits the same motion as we required.

The work presented on the development of virtual model and analyzed that model in Ansys fluent that would give an accurate representation of aerodynamic forces, lift, drag and velocity acting on wings of ornithopter for complete steady flight study. CFD analysis done on steady wing .Result were study that gives the various counter plots, velocity vector and curve for lift and drag coefficient require for model. The study show that the value of coefficient of lift started with higher value at beginning but gradually convert to lower value, when the cycle are increased, it become steady. The velocity vector plot gives boundary layer separation of air flow over the wing. Static pressure counter gives actual pressure induced at point on wings. The red portion shows the higher concentration of pressure and green portion show the lower concentration of pressure at that section.

Hence, from the results we conclude that CFD analysis gives us the values and by comparing it with the theoretical values we can optimize the design for better performance.

8 ACKNOLEDGMENT

It is our privilege to acknowledge with deep sense of gratitude to our project guide, Prof. R. R. Chavan for their valuable suggestions and guidance throughout our study and timely help given to us in the completion of this project.
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9 REFERENCES

[1] B. J. Goodheart,"Tracing the History of the Ornithopter: Past, Present and Future", Journal of Aviation Education and Research, 2011.

[2] UdaygiriChandrashekhar, "Practical Flapping Mechanism for 20cm Span Micro Air Vehicle", International Journal of Micro Air Vehicles, 2015.

[3] Jithin M P, "Design of Ornithopter Flapping Wing Mechanism", International Research Journal of Engineering and Technology, 4 April 2018.

[4] SachinSalunkhe, "Rapid Prototyping of Flapping Mechanism for Monoplane and Biplane Ornithopter Configurations", International Journal of Modern Manufacturing Technologies, 2017.

[5] Woei-Leong Chan, "Ornithopter Type Flapping Wings for Autonomous Micro Air Vehicles", Aerospace, 13 May 2015.

[6] N.M. Fonseca Ferreira, "Application of Fractional Algorithms in The Control of A Robotic Bird",Sciencedirect, 3 May 2009.

[7] FuadHasanSabbir, "Design and Model Construction of a Flapping Wing UAV Ornithopter", International Conference on Mechanical, Industrial and Energy Engineering, 26 December 2016.

[8] Dr. AnkurGeete, "CFD Analysis of Conceptual Aircraft Body", International Research Journal of Engineering and Technology, 01 January 2017.

[9]HarijonoDjojodihardjo, "Two-Dimensional CFD Simulation For Visualization of Flapping Wing Ornithopter Studies", Arpn Journal Of Engineering and Applied Sciences, November 2015.