Simulation Studies of Ornithopter and Development

Submitted in Partial Fulfilment of The Requirements
of The Degree of

Bachelor of Mechanical Engineering

by

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2021-2022

Certificate

This is to certify that the project entitled **"Simulation Studies of Ornithopter and Development"** is a bonafide work of "**Deshpande Pratik (MEA721), Ghatge Harshwardhan (MEA728), Gopale Sanket (MEA730), Joshi Ameya (MEA738)"** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of **"Bachelor"** in **"Mechanical Engineering"**.

Prof. Miriyala Durga Rao
Guide

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Approval

This project report entitled **Simulation Studies of Ornithopter and Development** by **Deshpande Pratik (MEA721), Ghatge Harshwardhan (MEA728), Gopale Sanket (MEA730), Joshi Ameya (MEA738)** is approved for the degree of **Bachelor** in **Mechanical Engineering**.

Examiners

1.---

2.---

Date:

Place:

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

The objective for this project is to design and implement an ornithopter capable of short-distance flight. An ornithopter is a robot that flies in a manner similar to a bird by generating flapping wing motion. Ornithopters can be more efficient, cost effective and environmentally friendly in comparison to fixed-wing aircrafts. This ornithopter has been developed by observation of both natural and man-made fliers, as well as previous academic projects. Goals for this project include being capable of maneuvering around and over obstacles by adjusting pitch, yaw, and roll, able to glide for five seconds under its own power, skillful at alternating between flapping and gliding with minimal disruption of flight pattern and being durable enough to withstand impacts with minimal to no damage.

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List of Symbols

Symbol	**Description**
S	Total wingspan
A_t	Total Wing Area
c	Chord Length
AR	Aspect Ratio
ϕ	Flapping Amplitude Angle
m	Mass of Component
C_d	Coefficient of Drag
C_l	Coefficient of Lift
F_d	Drag Force
F_l	Lift Force
ω	Angular Momentum
T	Torque
ρ	Air Density

Chapter 1: Introduction

Natural fliers like birds and insects have captivated the minds of human inventors through history. The ease and grace with which they take to the air vastly surpasses the state of the art in aircraft and their control systems. This is not to say that modern aircraft designs are ineffective, they are excellent in many respects. Propellers and turbines are very efficient methods of producing thrust and aerofoils efficiently produce lift. A Boeing 747 achieves a dimensionless cost of transport (energy used divided by weight times distance) of 0.1, equivalent to a soaring albatross, and does it with amazing reliability, but it will never match the manoeuvrability of the albatross. Birds also have a natural advantage of being able to generate lift and drag with same wings which turns out to be very efficient as compared to standard planes and also their ability to take off and land with minimum runway length is appreciable. However, that being said the science behind bird flight is still not evolved enough to use it at large scale applications.

The robo-bird (or an Ornithopter) is a mechanical replica of birds that can be used for various applications like protecting aircrafts from sudden hit of bird flocks during take off and landing, military operations like spying, survey, signaling; agricultural uses, etc.

1.1 History and background

It is no surprise that humanity's first attempts at flight were in the form of birdlike, human-powered ornithopters. The great artist and engineer Leonardo Da Vinci is often credited as the first to propose a reasonable flying machine in 1490: a giant bat-shaped craft that uses both the pilot's arms and legs to power the wings. Though the aircraft was never built, and we now know that it would not have flown, it was a remarkable achievement considering the knowledge of the day. At the turn of the 20th century, focus shifted both in the method of thrust production, from flapping wings to the propeller, and the method of power generation, from the human body to the internal combustion engine. With the aerodynamic problem greatly simplified, the impossibility of human flight was disproved by the Wright brother's flight in 1903 and the stage was set for the boom of aircraft developments in the decades to come. Though work on human-powered aircraft was still carried on from time to time by several groups in various countries, it would be three-quarters of a century before anyone mastered the art of human-powered flight.

The first truly successful HPA came in 1977 when Paul MacCready's Gossamer Condor flew a one-mile figure-of-eight course in 7 ½ minutes to capture the £50,000 Kremer Prize. What followed was breakneck development in the field, and a mere two years later the Gossamer Albatross flew 36 km across the English Channel, earning the team the second Kremer Prize. To date, the greatest HPA accomplishment was by M.I.T.'s Daedalus, which in 1988 flew 119 km from Crete to Santorini, an incredible feat worthy of the aircraft's mythological name. These and many other HPA projects have pioneered methods of lightweight composite construction, power transmission, and multi-disciplinary aero-structural optimization, much of which has been published and made available to those eager to pursue the field.

1.2 Motivation

The idea of human flight has been present throughout history. Recreating flight has proven successful to varying levels incorporating the use of artificial flapping wings. These attempts have lead research towards the idea of an Ornithopter, a bio-inspired robot utilizing a flapping mechanism to achieve flight. While the development of the airplane and the jet engine have changed history and have led to the evolution of air travel, the ability to achieve flight with flapping wings like a bird has still remained elusive. A large-scale ornithopter can become more efficient than a normal airplane by gliding and flapping, and could become a new mode of transportation if its feasibility was developed further.

Chapter 2: Literature Survey

2.1 Can Scalable Design of Wings for Flapping Wing Micro Air Vehicle Be Inspired by Natural Flyers? Published: 21 October 2018

The comprehensive scaling laws are subsequently analysed and achieved from a morphometric perspective by collecting extensive data of natural flyers. The wing performances of the existing flapping wing MAVs are also studied, which follows the obtained scaling laws

2.2 Optimization of Simple and Complex Pitching Motions for Flapping Wings in Hover. Published: 12 March 2018

This study aims to identify whether a flapping wing with more complex pitching motion achieves superior aerodynamic performance as compared to a wing undergoing a simple harmonic pitching motion. The kinematics of insect like flapping wings are optimized for efficient hover and maximum lift generation. Two pitching motion profiles are considered: namely, the simple harmonic motion, which is a generic simplified motion; and the insect-imitating motion, which is able to approximate the actual pitching motion of common insects.

2.3 Ornithopter Type Flapping Wings for Autonomous Micro Air Vehicles. Published: 13 May 2015

In this paper, authors did the experiment on thrust measurement and material selection. They constructed a flapping wing model along with multiple experiments on the cross section of airfoil.

2.4 Insect like Flapping Wings in the Hover Part 2: Effect of Wing Geometry. Published: 6 December 2008

The effects of wing geometry on the aerodynamic performance of such flapping wings are investigated by comparing the influence on a number of synthetic planform shapes while varying only one parameter at a time.

Chapter 3: Problem Statement

Identification of problems:
To create a solution for special purpose uses like military operations, airport surveillance and biomimicry.

Aim : To perform various simulations studies for optimal design, to compare various flapping mechanisms, to identify suitable components, to develop an economical ornithopter model

Objectives:

1. To compare various mechanisms and develop one for flapping
2. To perform various 2D analysis over wing structure
3. To design a CAD model
4. To develop a prototype of ornithopter

Chapter 4: Methodology

Step 1: Selection of Bird To Replicate Features And Selection of Relevant Data

Step 2: Technical Details

Step 3: Components

Step 4: Aerodynamic analysis

Step 5: Comparison of various mechanisms and their analysis

Step 6: Theoretical Calculations

Step 7: Gearbox Calculation

Chapter 5: Study

5.1 Selection of bird to replicate features and selection of relevant data

For the design reported in this paper, we took inspiration from the Raven bird and developed requirements for wings of our platform based on this inspiration. Our design process began by tracing bird wing dimensions. We concurrently optimized wing design and flapping frequency to generate the highest possible lift and operate near the maximum power operating point for the selected motors.

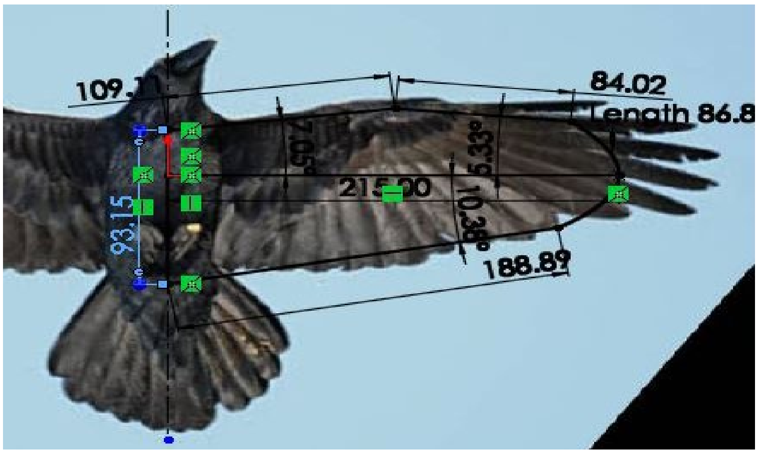


Figure 5.1: Tracing of natural features of raven bird

5.2 Technical Details

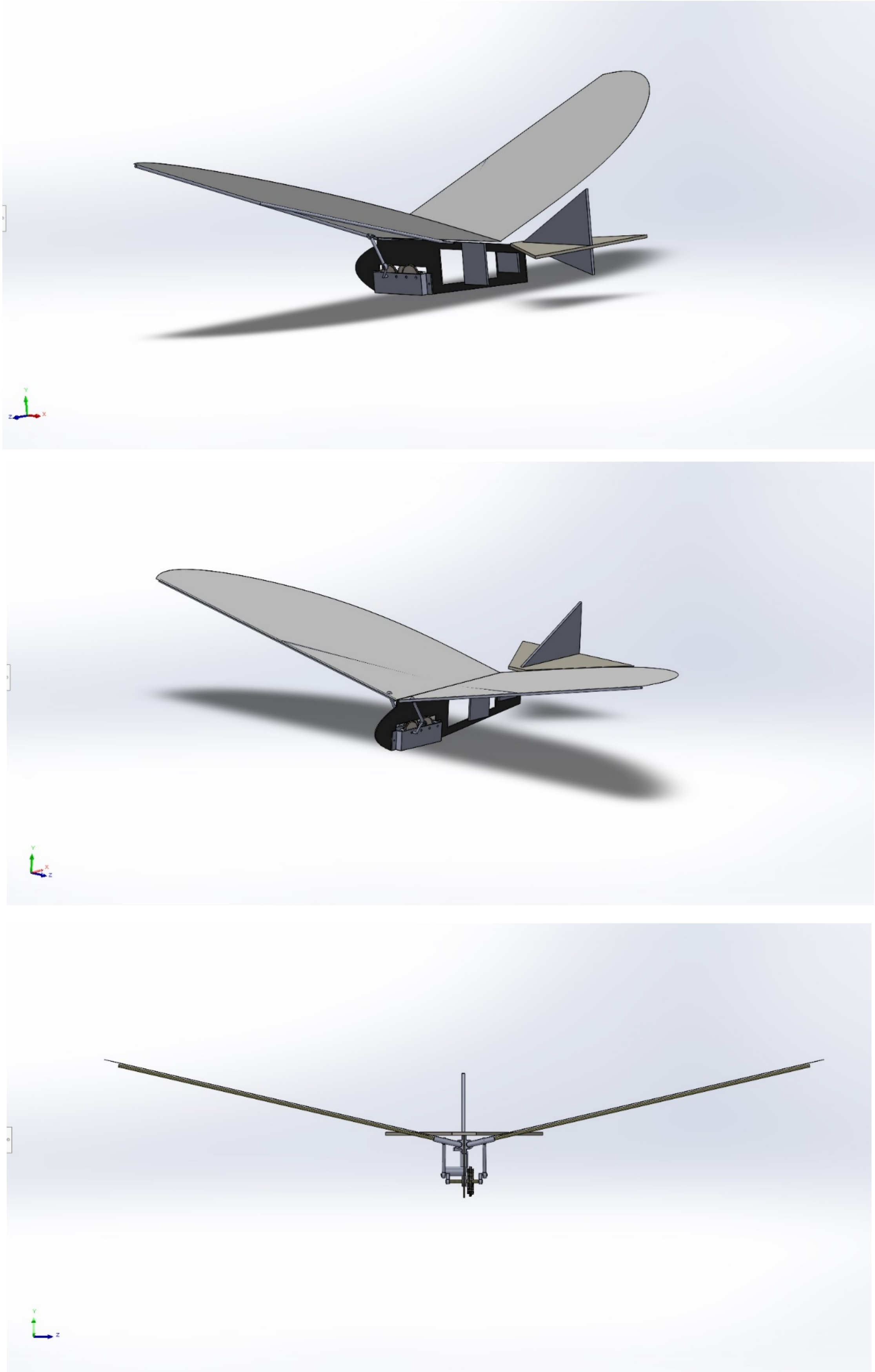


Figure 5.2: CAD Model

Specifications:

Weight	135 g
Span	683.5 mm
Chord	155.32 mm
Air Speed	5 m/s
Wing Area	106164.82 mm^2
Aspect Ratio	4.4
Coefficient of Lift (Cl)	0.0275
Coefficient of Drag (Cd)	0.0350

Table 5.1

5.3 Components

The main component of the ornithopter include wings & tail, flapping mechanism, motor, battery and receiver

- **Wing and Tail**
  Material: Polythene, Styrofoam
  Combined weight: 22 g

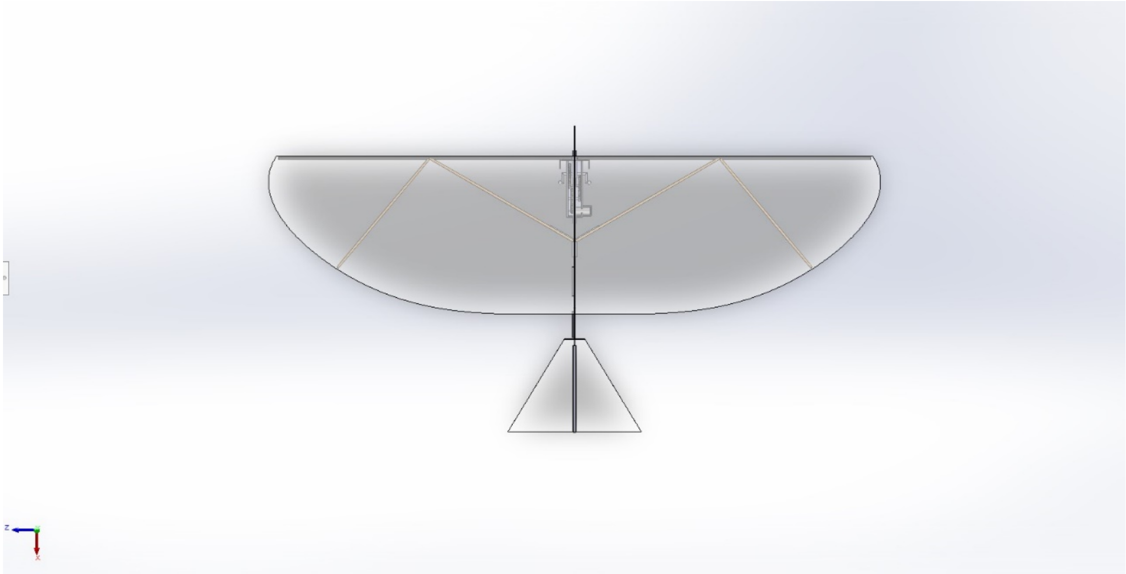


Figure 5.3 Wing and Shape geometry

- **Flapping Mechanism**
  Material:
  For gears: Nylon
  For shaft: Aluminium
  Combined weight: 50 g

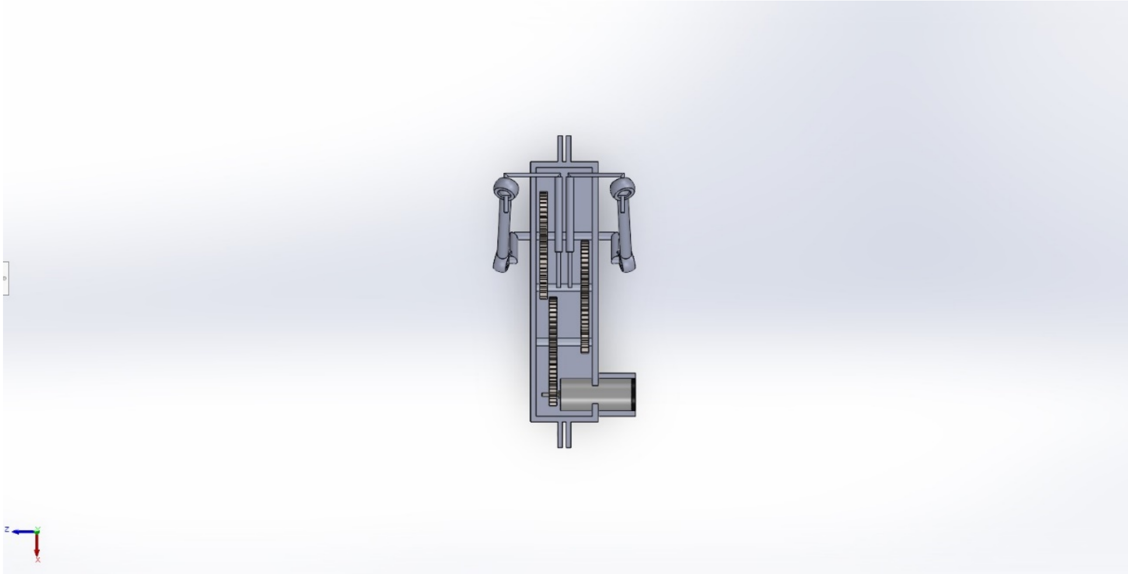


Figure 5.4 Flapping Mechanism

- **Motor**
  Name: 8520 coreless motor
  Rated rpm: 30500
  Volt: 3.7 V
  Combined weight: 20 g

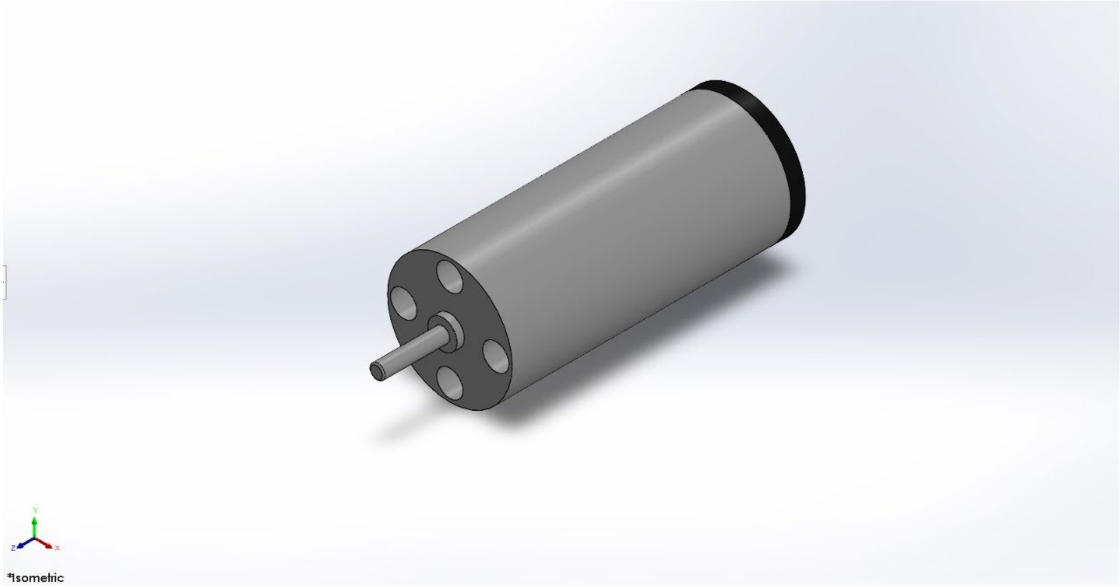


Figure 5.5 8520 Motor

- **Frame**
  Material: Carbo Fiber
  Weight: 6 g

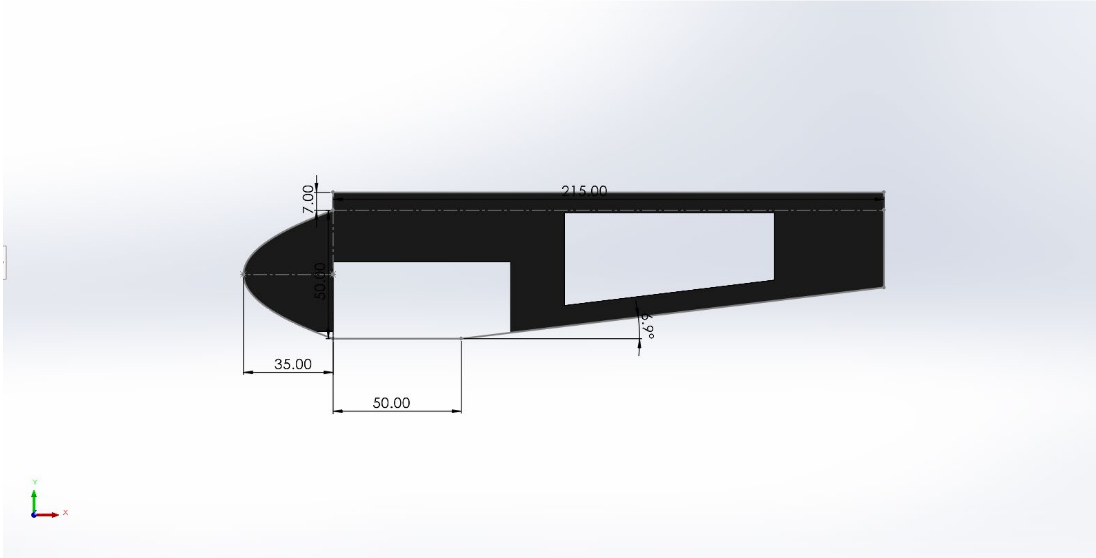


Figure 5.6 Carbon Fibre Frame

- **Battery**
  Name: 3.7v 180mAh li-po battery
  Weight: 10 g

- **Receiver**
  Name: 2.5 D
  Weight: 10 g

5.4 Aerodynamic analysis

In experimental measurement to get the values of constant like coefficient of drag and coefficient of lift to proceed for manual calculation, proceeding with Ansys Fluent.

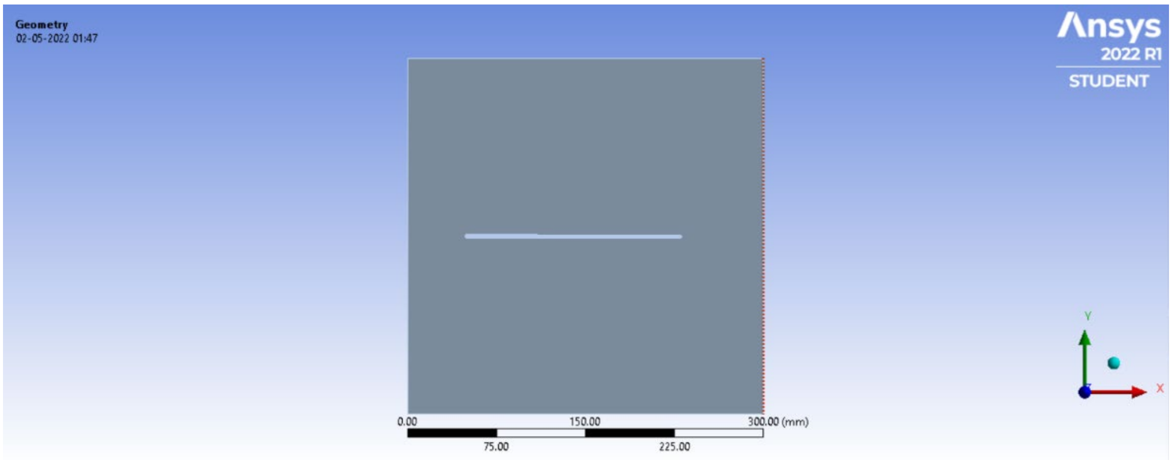


Figure 5.7: Creation of enclosed area for 0 degree flapping angle

Enclosed area is created for thin wing cross section with 3mm contour at the left.

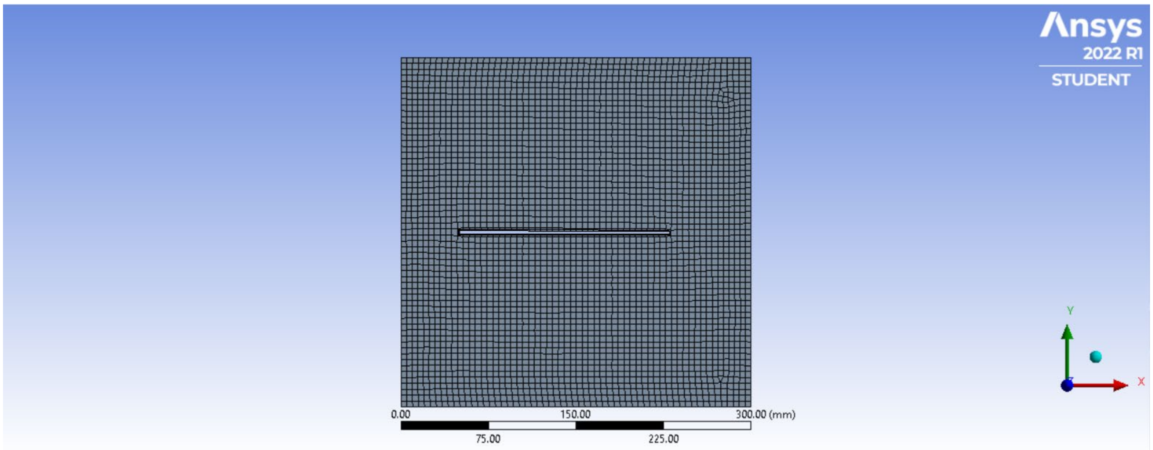


Figure 5.8: Meshed area (for 0° flapping angle)

Standard meshing is applied given control volume.

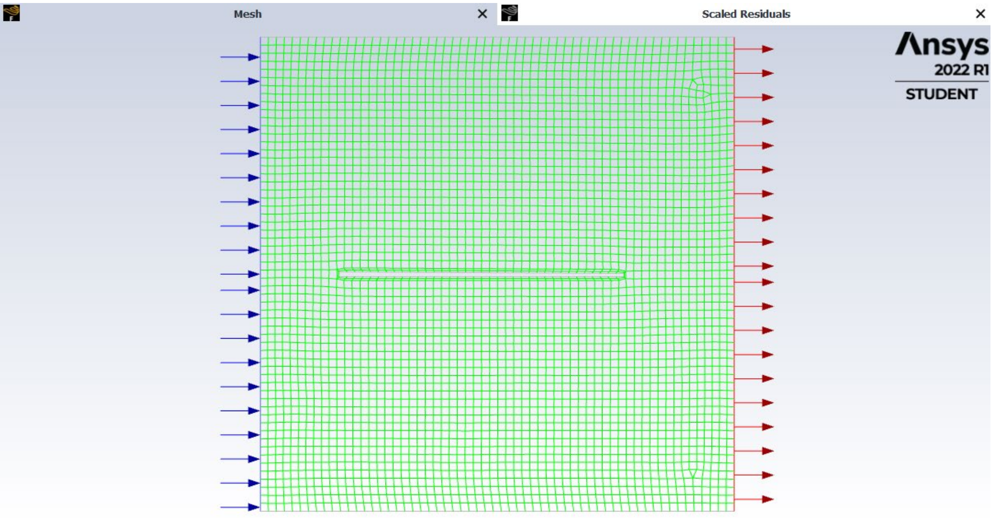
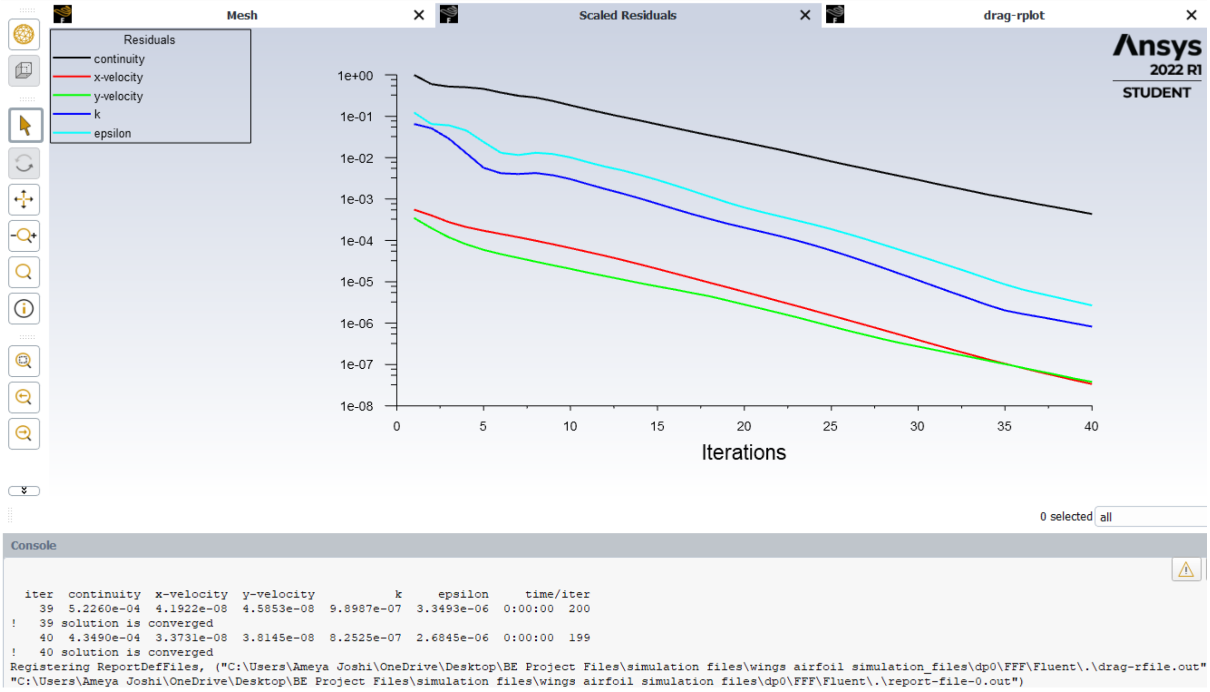


Figure 5.9: Setup Conditions (for 0° flapping angle)

Fluid used is air throughout the domain. Inlet and outlet boundary conditions are defined. Inlet velocity is taken as 5m/s and outlet at atmospheric condition.



```
  iter  continuity  x-velocity  y-velocity           k     epsilon     time/iter
    39  5.2260e-04  4.1922e-08  4.5853e-08  9.8987e-07  3.3493e-06  0:00:00  200
!   39 solution is converged
    40  4.3490e-04  3.3731e-08  3.8145e-08  8.2525e-07  2.6845e-06  0:00:00  199
!   40 solution is converged
Registering ReportDefFiles, ("C:\Users\Ameya Joshi\OneDrive\Desktop\BE Project Files\simulation files\wings airfoil simulation_files\dp0\FFF\Fluent\.\drag-rfile.out"
"C:\Users\Ameya Joshi\OneDrive\Desktop\BE Project Files\simulation files\wings airfoil simulation files\dp0\FFF\Fluent\.\report-file-0.out")
```

Figure 5.10: Iteration (for 0° flapping angle)

Solution is converged!

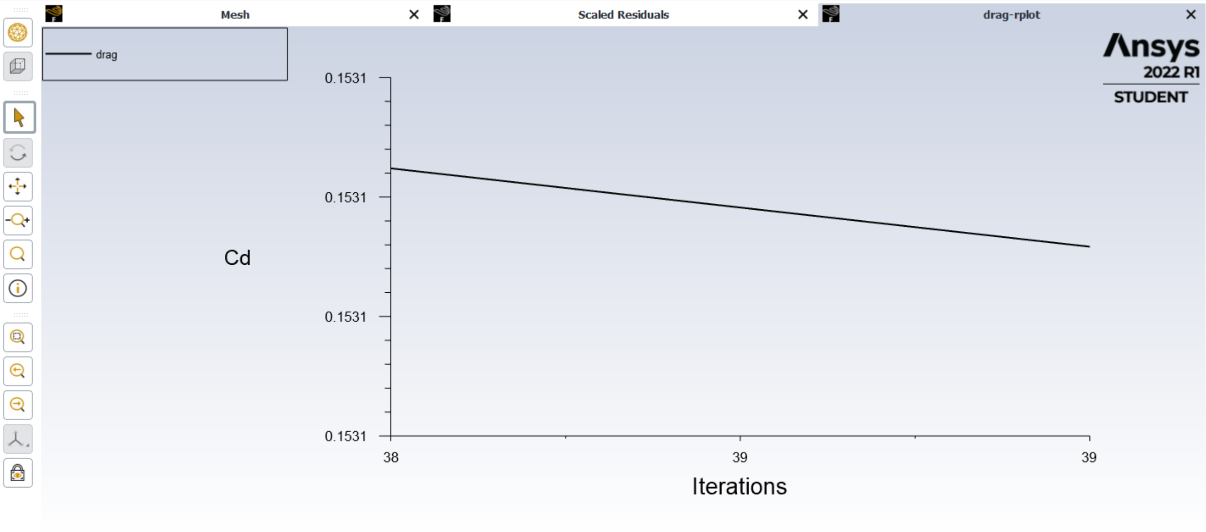


Figure 5.11: Coefficient of Drag (for 0° flapping angle)

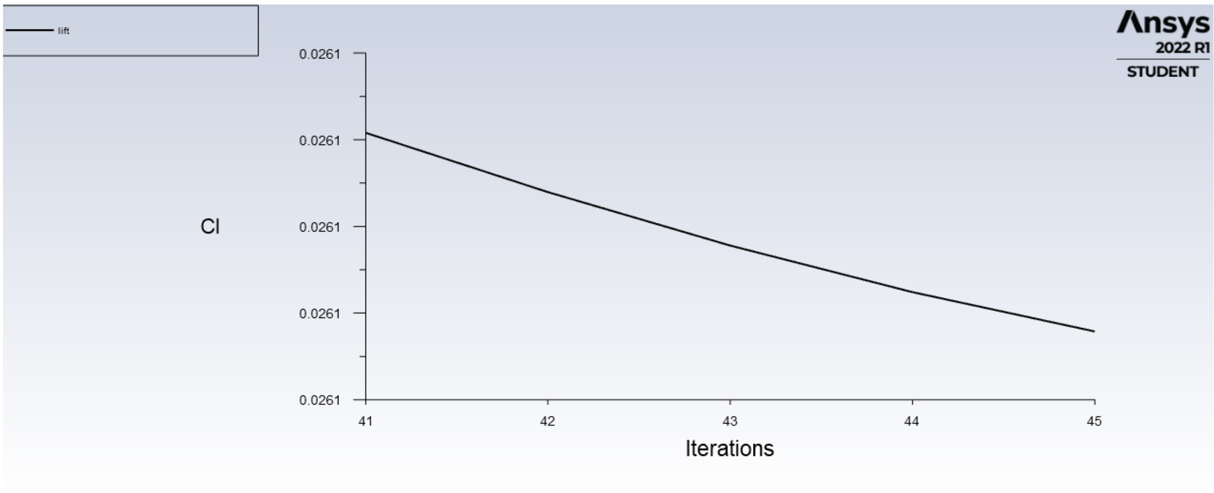


Figure 5.12: Coefficient of Lift (for 0° flapping angle)

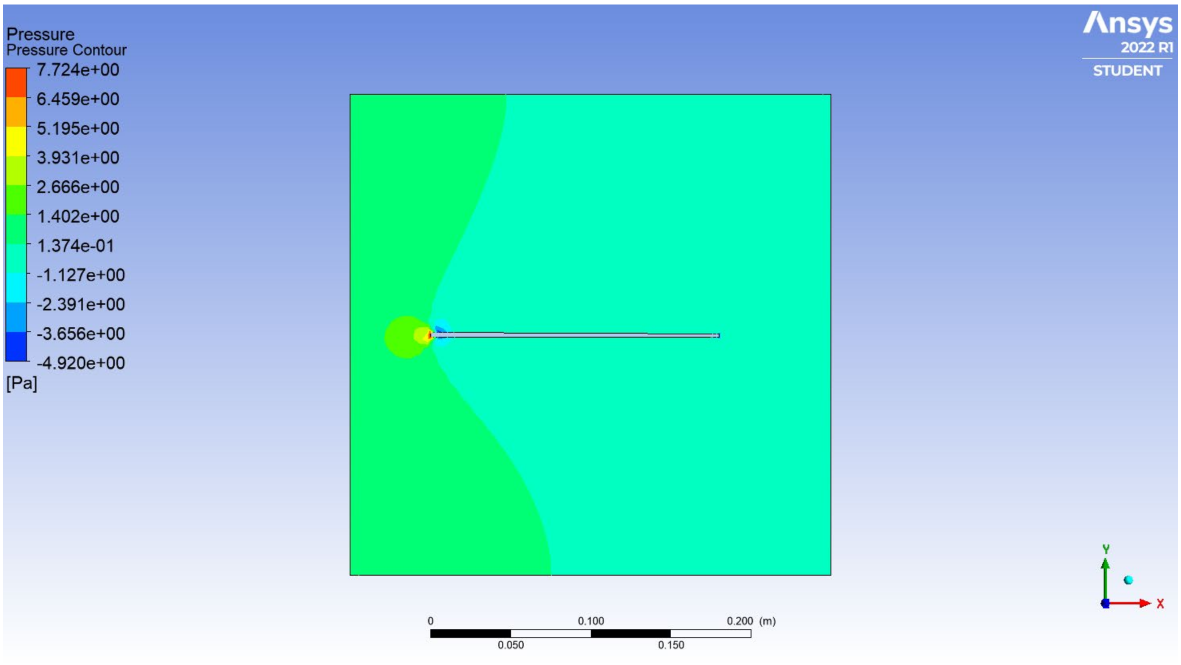


Figure 5.13: Pressure Contour (for 0° flapping angle)

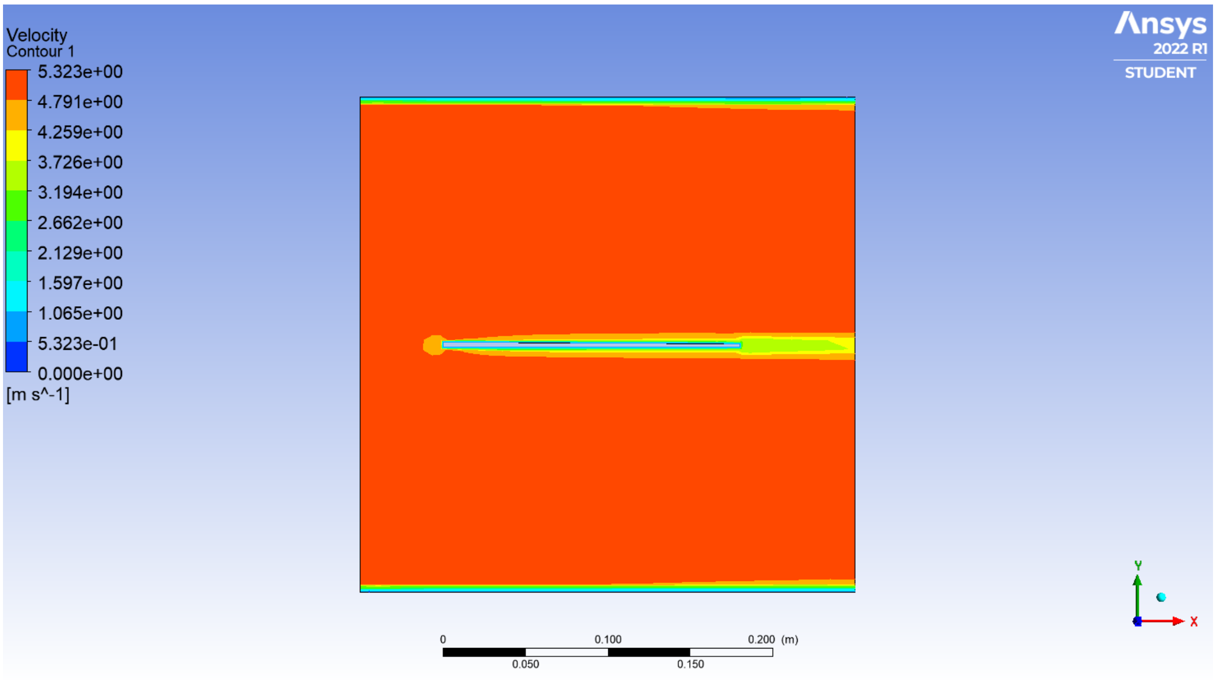


Figure 5.14: Velocity Contour (for 0° flapping angle)

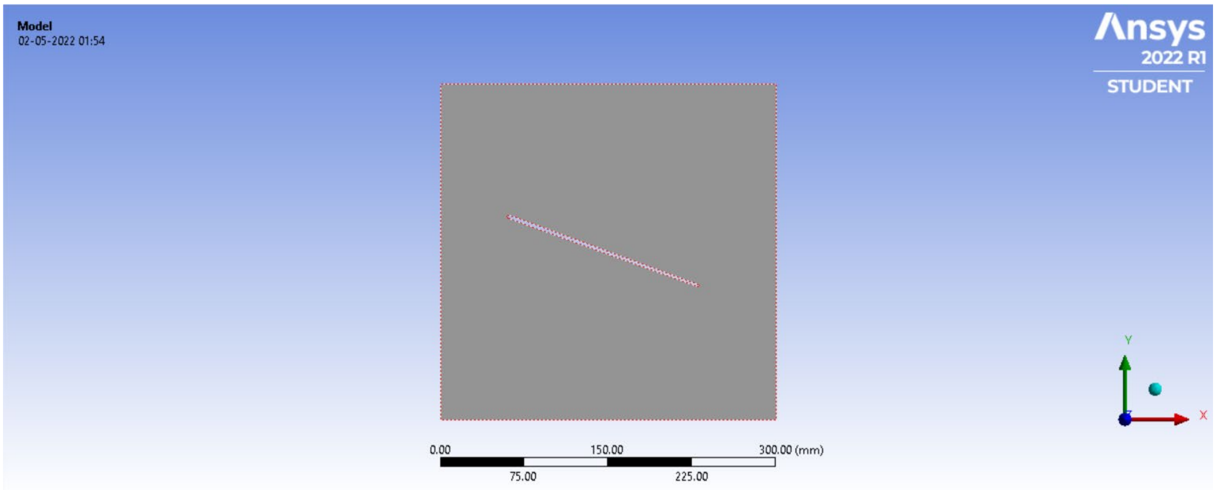


Figure 5.15: Geometry (for 20° flapping angle)

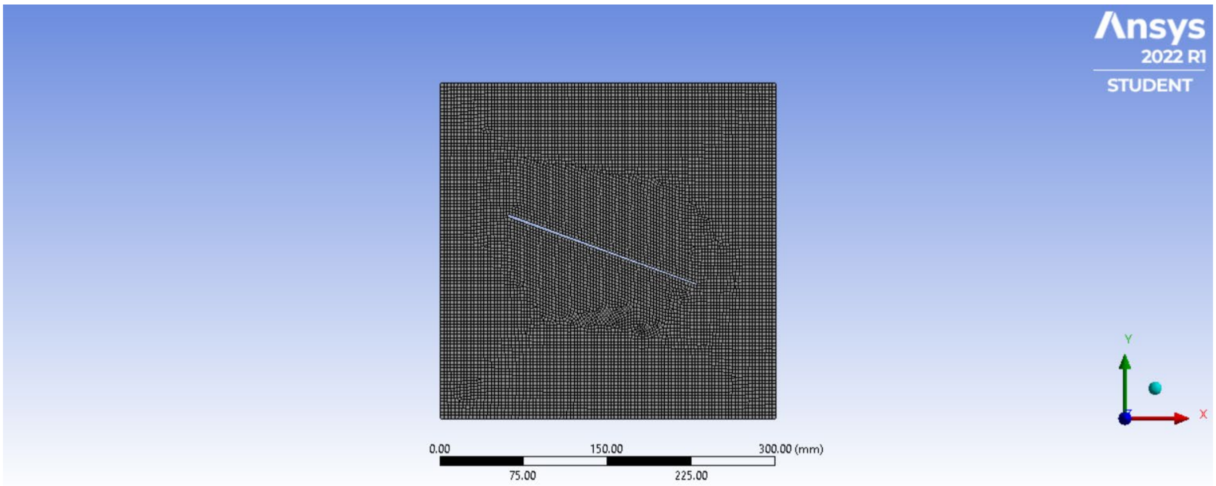


Figure 5.16: Mesh Area (for 20° flapping angle)

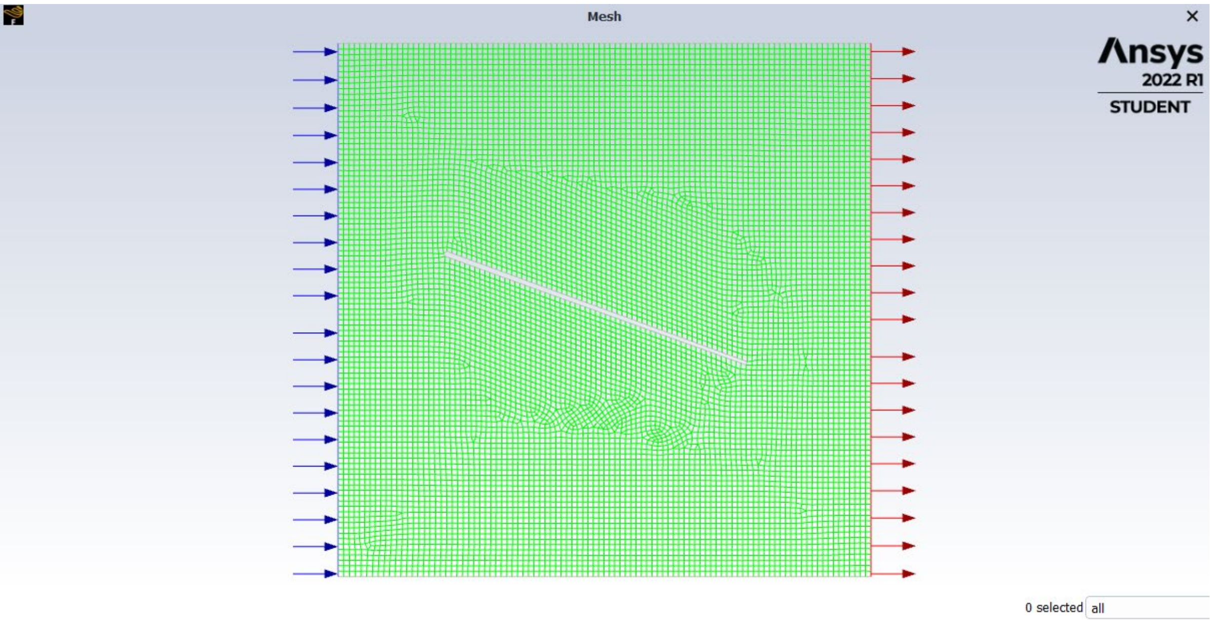
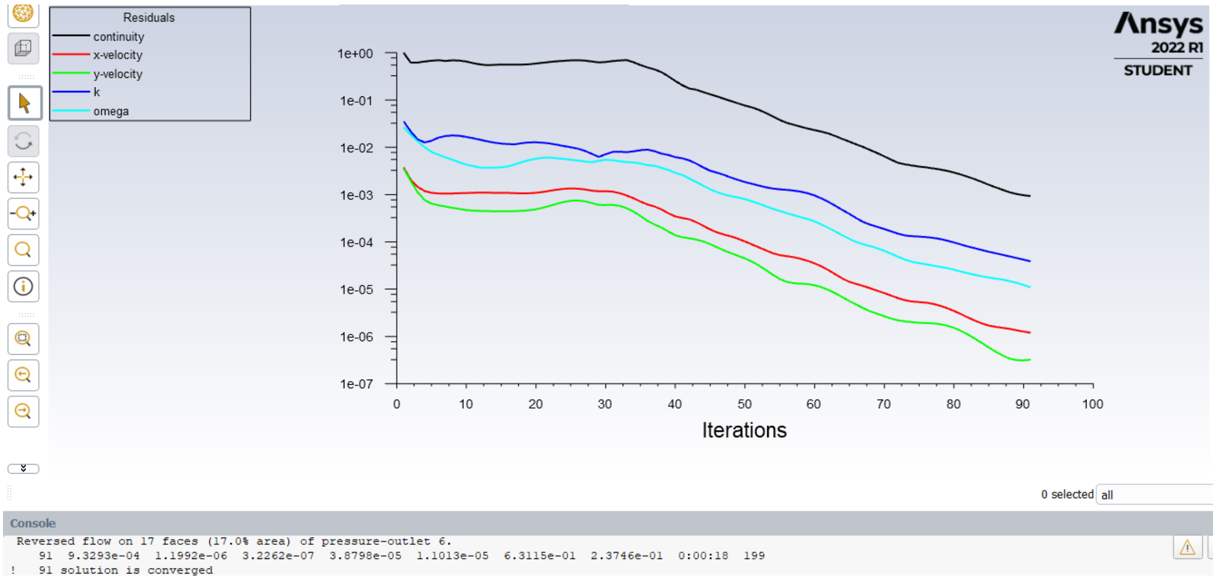


Figure 5.17: Setup Area (for 20° flapping angle)



```
 Reversed flow on 17 faces (17.0% area) of pressure-outlet 6.
    91  9.3293e-04  1.1992e-06  3.2262e-07  3.8798e-05  1.1013e-05  6.3115e-01  2.3746e-01  0:00:18  199
!   91 solution is converged
```

Figure 5.18: Iterations (for 20° flapping angle)

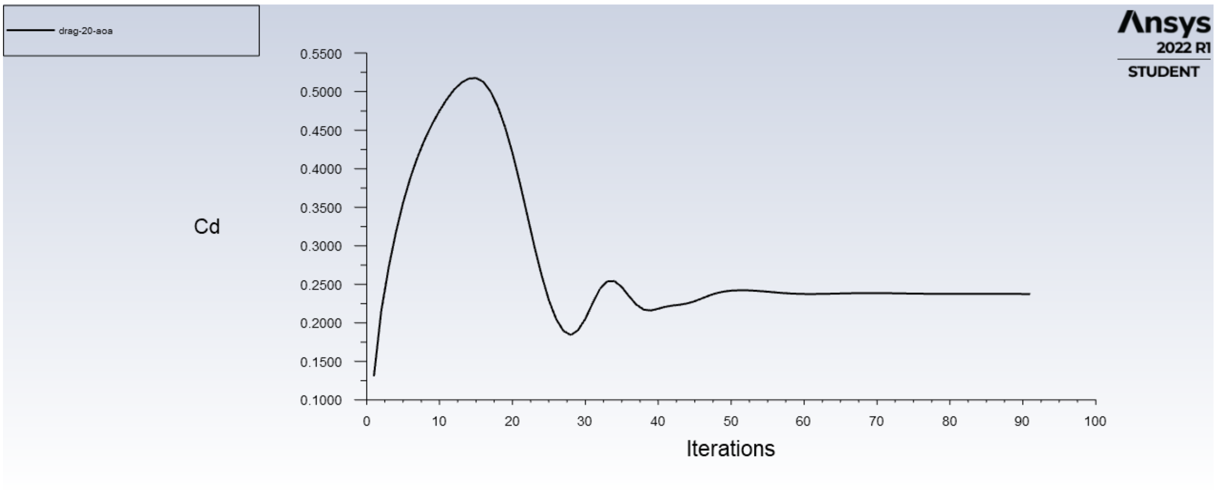


Figure 5.19: Drag Coefficient (for 20° flapping angle)

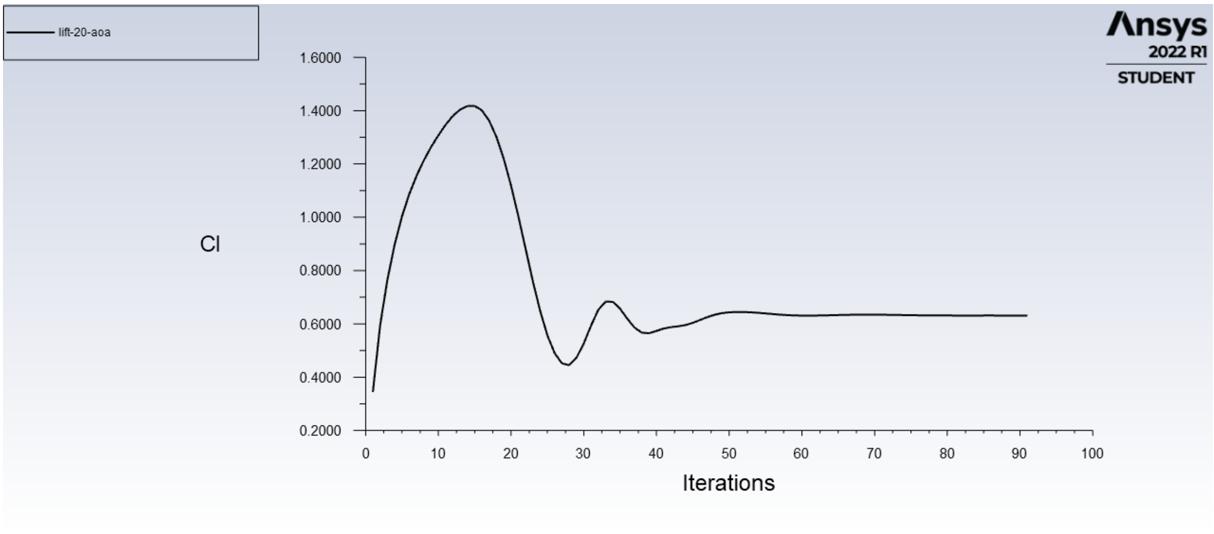


Figure 5.20: Lift Coefficient (for 20° flapping angle)

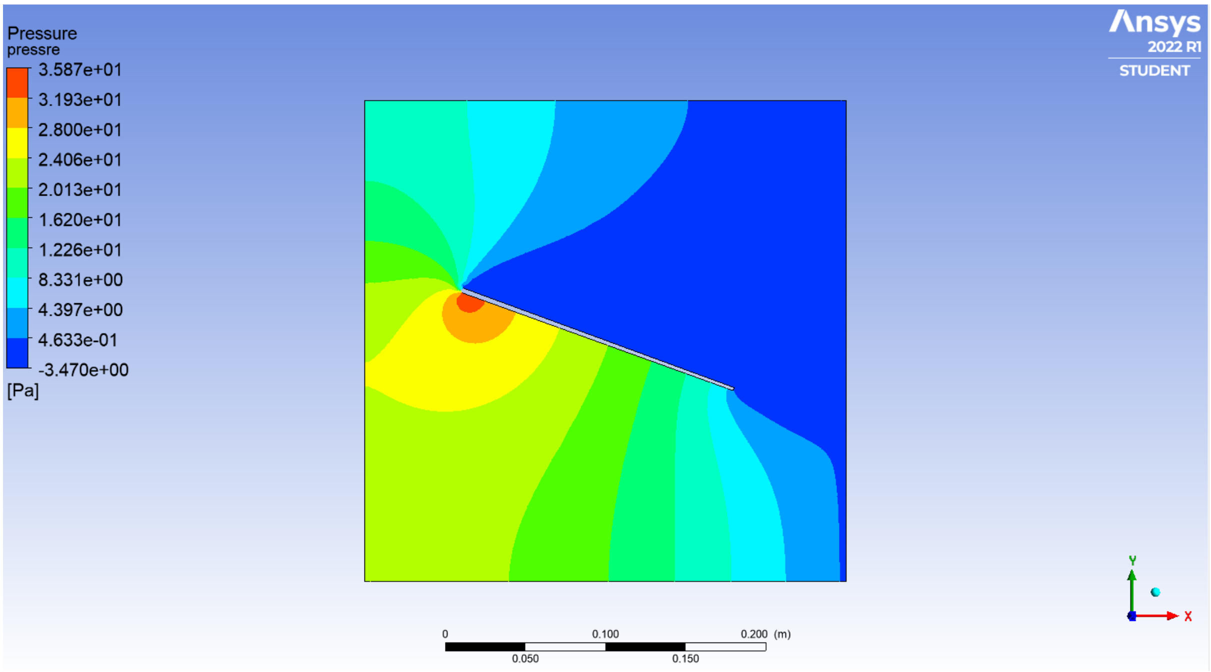


Figure 5.21: Pressure Contour (for 20° flapping angle)

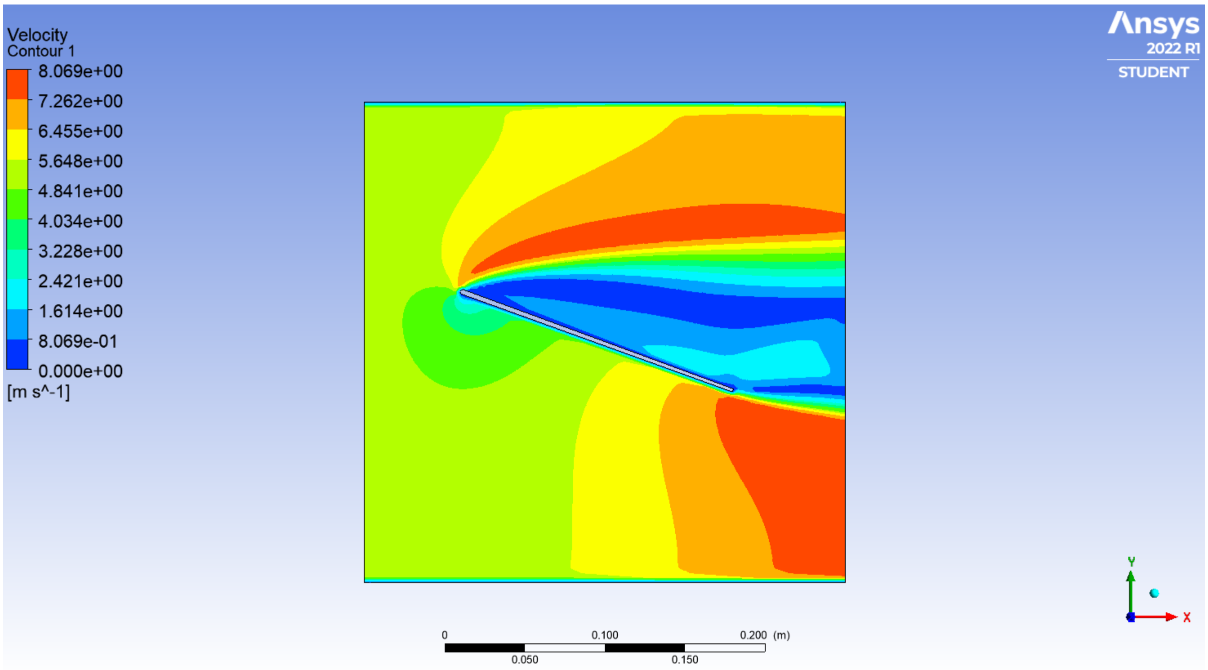
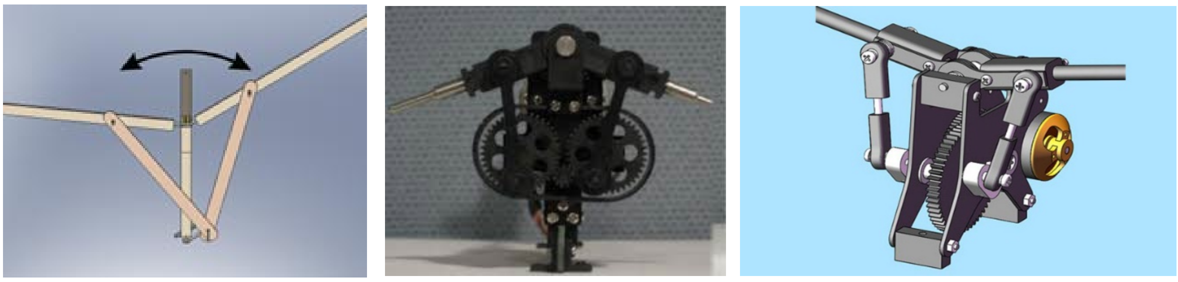


Figure 5.22: Velocity Contour (for 20° flapping angle)

5.5 Comparison of various mechanisms and their analysis

There are three widely studied mechanisms for an ornithopter namely Simple mechanism, Double crank mechanism and Transverse mechanism:

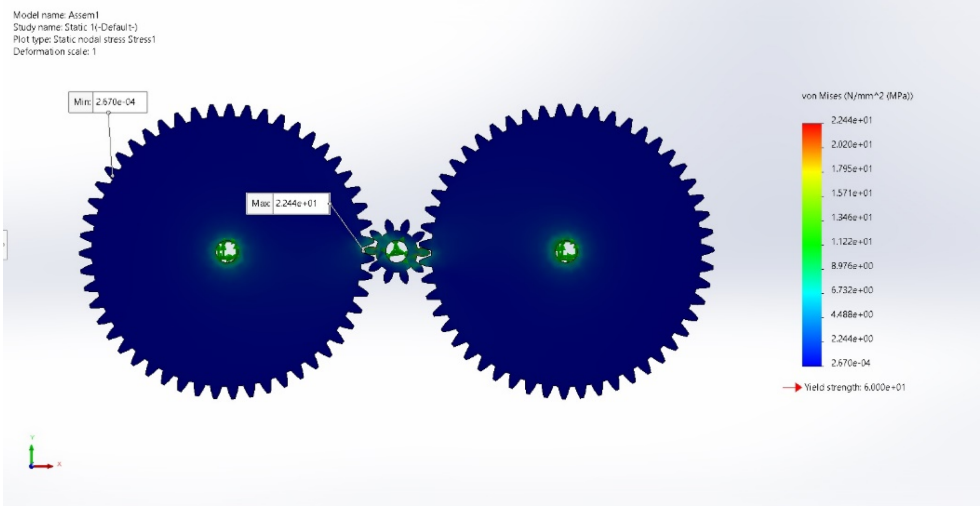


Simple Mechanism Double Crank Mechanism Transverse Mechanism

Figure 5.23: Different Mechanisms

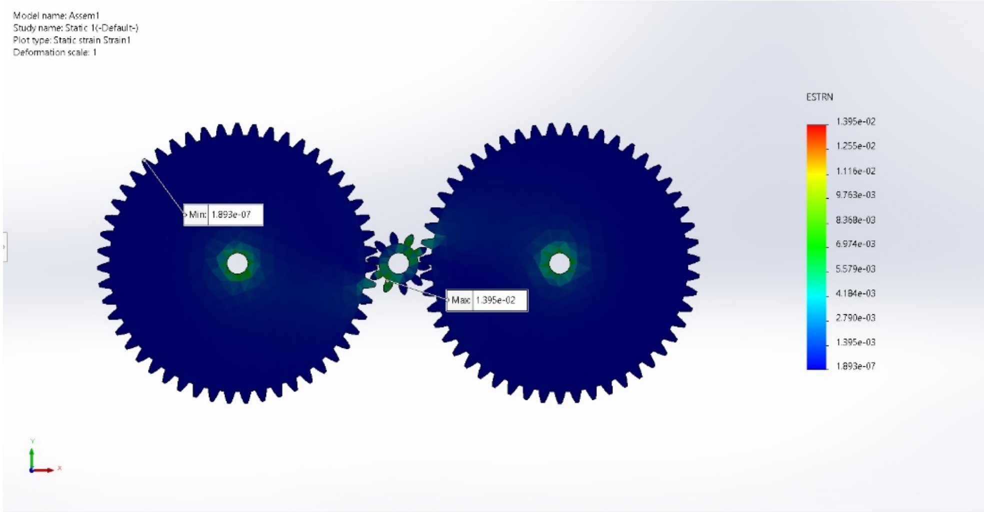
- **Mechanism 1: Simple Mechanism**
  This mechanism consists of a single shaft rotating about a circular hole or about a gear moving two connecting rods. This Mechanism is simple in operation but may produce asymmetric flaps, therefore rejected.

- **Mechanism 2: Double Crank Mechanism**
  This mechanism allows symmetric flap but may result in increased drag as it’s entire surface area is exposed.



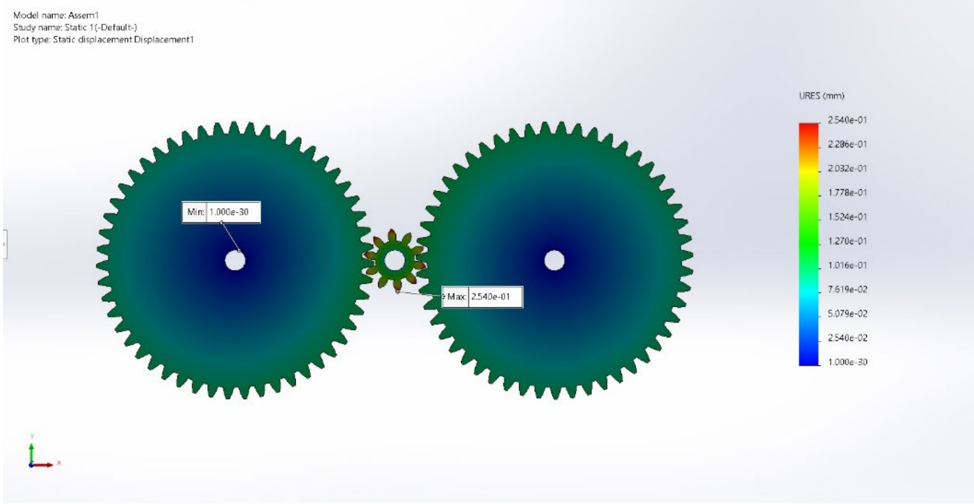
Model name: Assem1
Study name: Static 1(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 1

Figure 5.24: Von Mises



Model name: Assem1
Study name: Static 1(-Default-)
Plot type: Static strain Strain1
Deformation scale: 1

Figure 5.25: Strain



Model name: Assem1
Study name: Static 1(-Default-)
Plot type: Static displacement Displacement1

Figure 5.26: Static Displacement

- **Mechanism 3: Transverse Mechanism**
  This Mechanism is complex of all but it allows symmetric flaps and also does not expose major surface area, therefore selected.

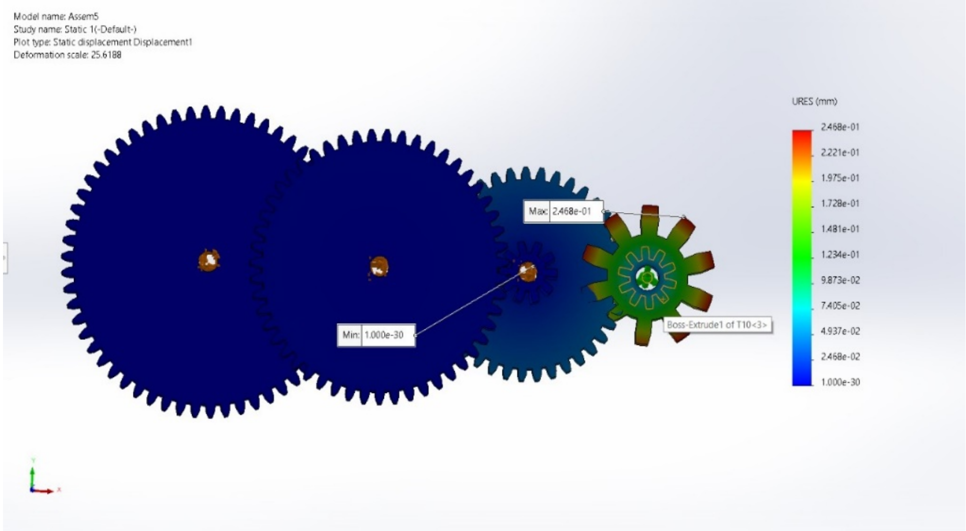


Figure 5.27: Static Displacement

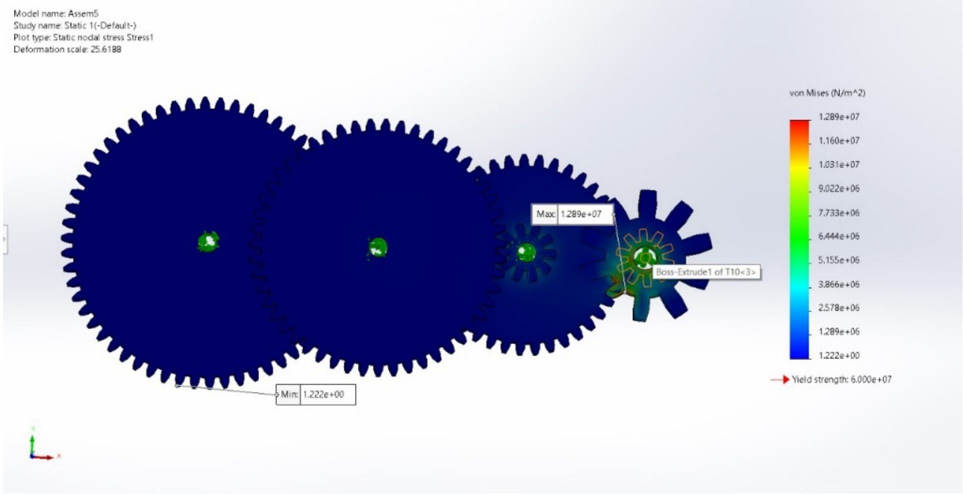


Figure 5.28: Von Mises

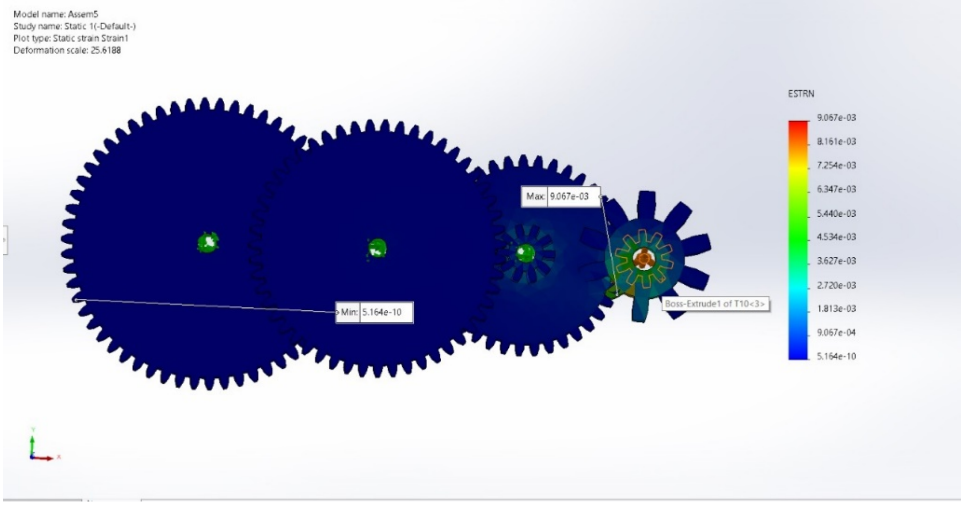


Figure 5.29: Strain

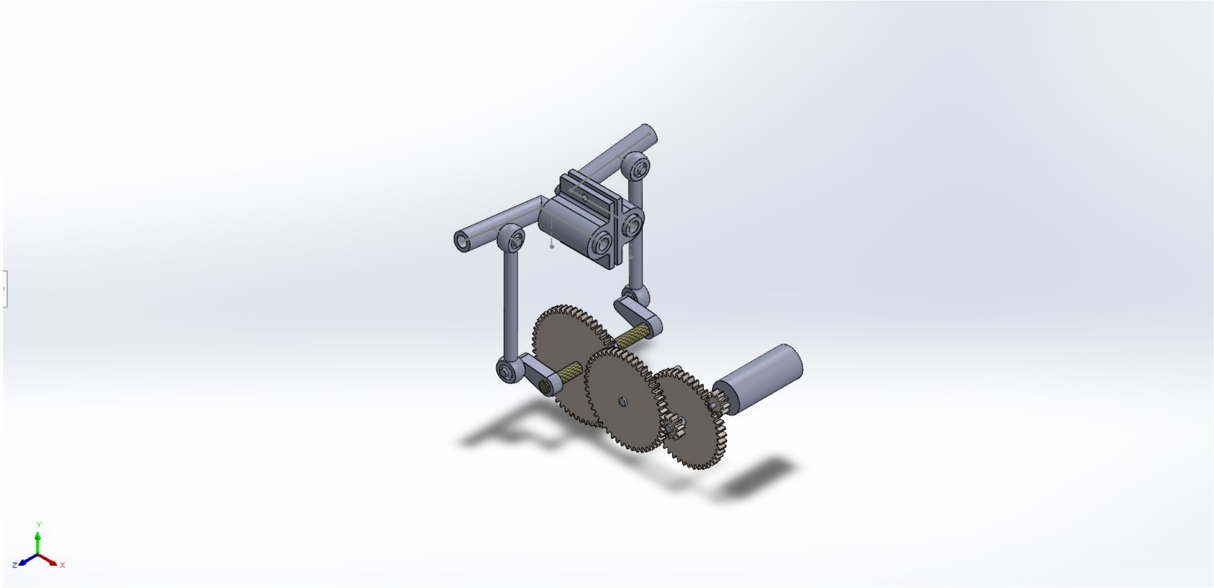


Figure 5.30: Transverse Mechanism

5.6 Theoretical Calculation

Data:

Coefficient of Drag (C_d) = 0.350
Density of air (ρ) = 1.225 kg/m³
Acceleration due of gravity (g) = 9.81 m/s²
Flapping Amplitude Angle (ϕ) = 0·536 rad
Wing span (S) = 0.6835 m
Chord length (C) = 0.15532 m
Initial weight of Bird (W) = 0.13245 kg

a) **Drag Force (Fd):**

$$F_d = \frac{\rho * C_d * C * b^3}{3}$$

$$= \frac{(1.225 * 1 * 0.35 * 0.15532 * 0.6835^3)}{3}$$

$$\boxed{F_d = 7.088 \times 10^{-3}\ \text{N}}$$

b) **Angular Momentum (ω):**

$$\omega = \sqrt{\frac{M * g}{F_d}}$$

$$= \sqrt{\frac{0.13245 * 9.81}{7.088 * 10^{-3}}}$$

$$\boxed{\omega = 13.53\ \text{rad/S}}$$

c) Torque of Wings (T):

$$T = \frac{\rho * \omega^2 * C_d * C * S^4}{8}$$

$$= \frac{(1.225 * 13.53^2 * 0.350 * 0.15532 * 0.6835^4)}{8}$$

$$\boxed{T \;=\; 0.110 \text{ N-m}}$$

d) Power (P) in watts

$$P = T * \omega$$

$$= 0.11 * 13.53$$

$$\boxed{P \;= 1.4685 \text{ watts}}$$

5.7 Gearbox Calculation

Gear	No. Of Teeth	G.R.	RPM	Torque (N-mm)
Gear 1	10	3.9	30500	0.93
Gear 2	39		32795.7	3.62
	10	5.1		
Gear3	51		9059.585	18.4977
	12	4.83		
Gear 4	58		489.7682	90.98

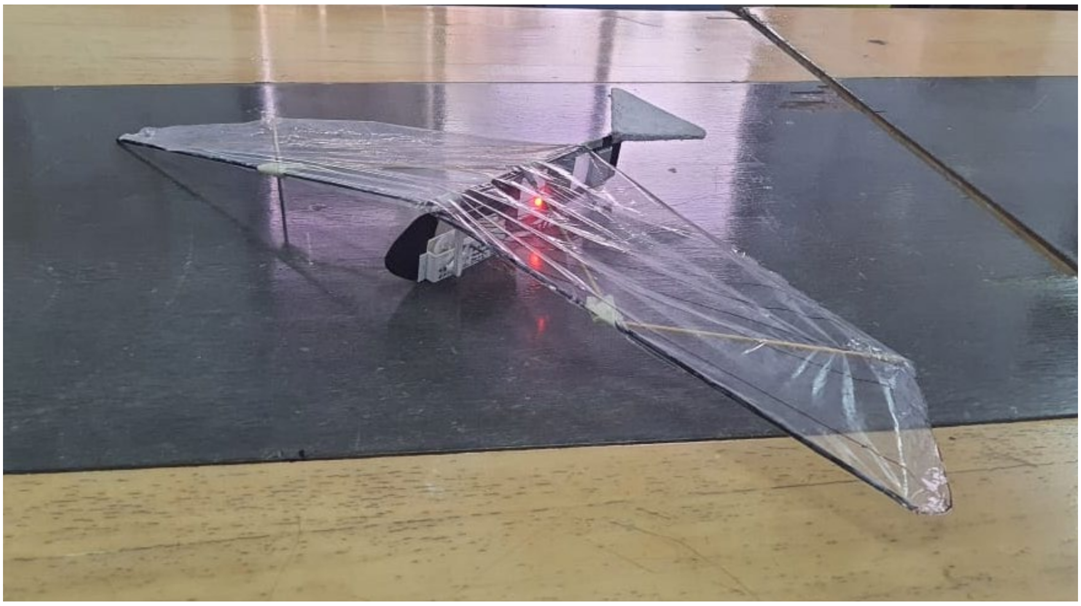
Table 5.2

Chapter 6: Manufacturing

6.1 Cost Estimation

Sr. No.	Part Name	Material	Qty.	Cost
1	8520 Brushless Motor	Steel	1	Rs. 150
2	Carbon Fiber Sheet Plate	Carbon Fiber	1	Rs. 699
3	Pultruded Carbon Fibre Rod	Carbon Fiber	1	Rs. 469
4	Gear Set	Nylon	1	Rs. 150
5	3D Pinted Parts	PLA	5	Rs. 700
6	2.5 GHz Transmitter And Receiver	NA	1	Rs. 1199
7	3.7v Li-Po Battery	NA	1	Rs. 80
8	AA Battery	NA	3	Rs. 39
9	Adhesive	NA	NA	Rs. 50
	Total Cost			**Rs. 3536**

6.2 Actual Model



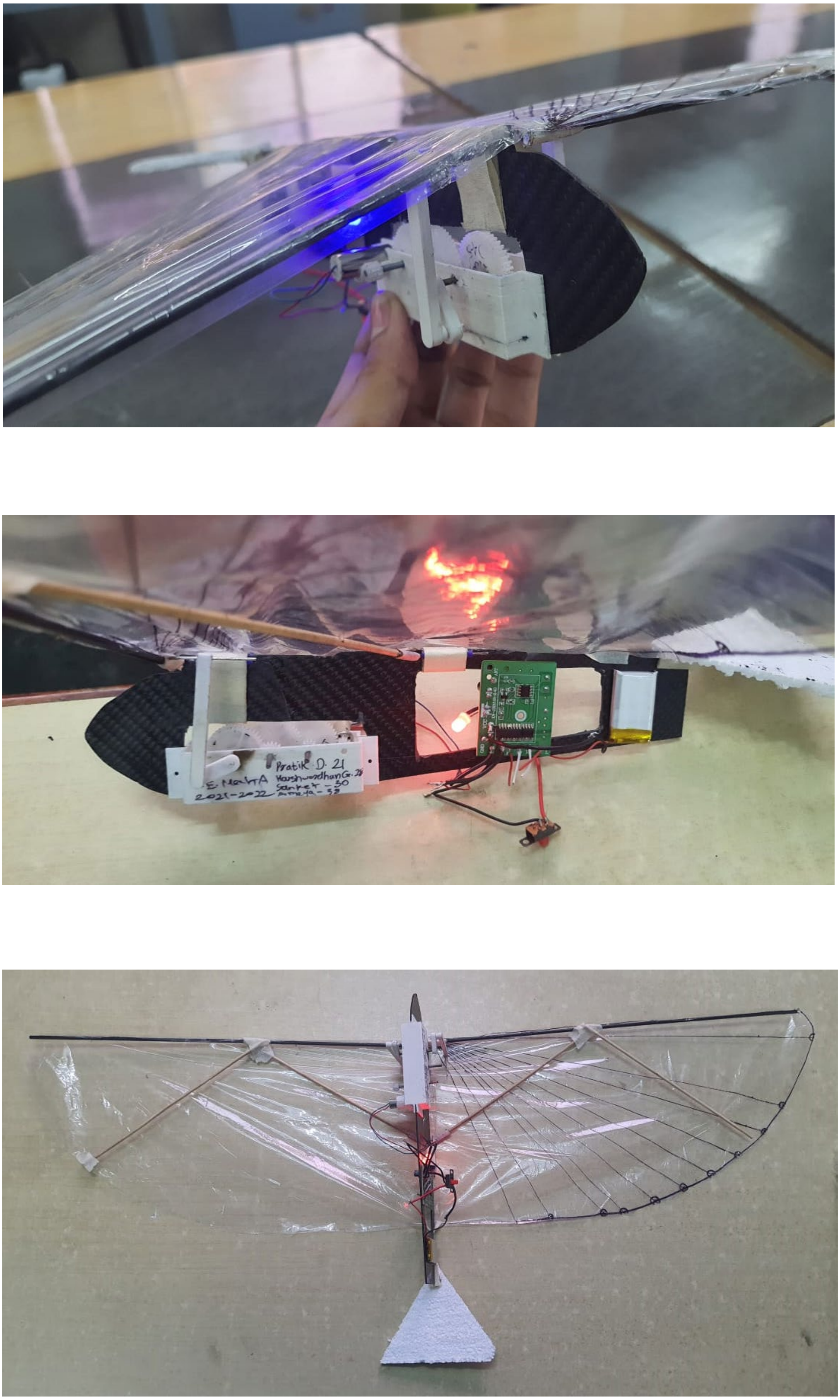


Figure 6.1: Actual Model

Chapter 7: Future Scope

Airports utilize pyrotechnics, long-range acoustic devices, and lasers in an attempt to ward off birds. But once the birds are in flight, these methods do little to encourage birds to move along. That’s where the robot bird takes over. It can be used at airports to move away birds.

For special military operations like spying, surveying.

For use in agriculture.

Chapter 8: Conclusion

- Theoretical results were analysed and respective model was developed.
- Transverse mechanism found to be a better choice as it helped reduce the asymmetric flapping and incidence of drag force.

Chapter 9: References

1. Leonardo da Vinci's Ornithopter design Jobert in 1871 used a rubber band to power a small model bird. Alphonse Pénaud, Abel Hureau deVilleneuve, and Victor Tatin, also made rubber-powered ornithopters.
2. WPI, Fluidic Muscle Ornithopter By Professor Marko Popovic and Professor Cagdas Onal, March 2015
3. Aerospace Research paper of Ornithopter, By Matthew, Ng Rongfa and Teppatat Pantuphag July 2016

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