DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY ROPAR

RUPNAGAR-140001, INDIA

IIT Ropar

MACHINE DESIGN (ME205) LABORATORY REPORT ON
ORNITHOPTER

SUBMITTED BY

- Sumit Yadav:2022meb1352
- Sunny Bharti:2022meb1353
- Tanish GoyaL:2022meb1356
- Tarini magotra:2022meb1358
- Tejasva jindal:2022meb1359

GROUP -C/11 FRIDAY

SECOND SEMESTER, 2023-2024

REPORT SUBMITTED ON: 08-05-24

PROBLEM STATEMENT

Designing and constructing a functional ornithopter mechanism involving multiple four bar mechanisms and to understand the velocity analysis of multiple parts. Our aim was to build such favorable mechanism along with understanding flapping-wing flight. The project aims to address these challenges by developing a prototype ornithopter mechanism using solidworks.

Key objectives include optimizing airfoil design for efficient lift and thrust generation, designing a lightweight yet robust structure, implementing a reliable propulsion system.

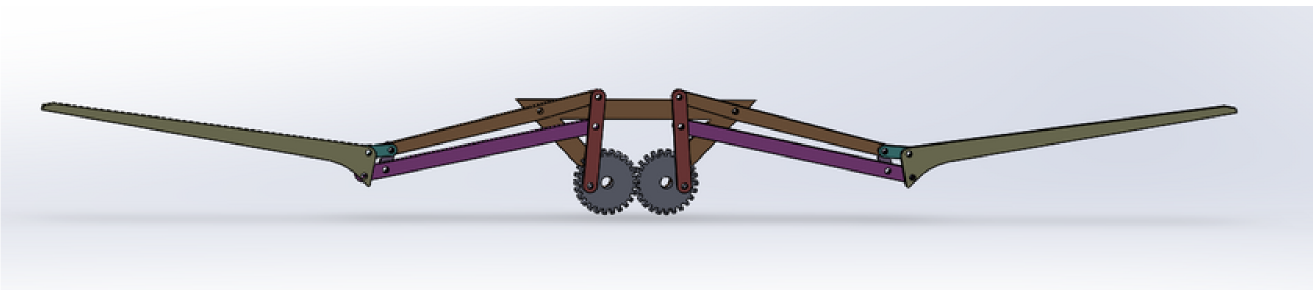
WORK DONE:

Week 1: Studying ornithopter and designing its links on solidworks to obtain a mechanism corresponding to flapping wing mechanism.

Week 2: 1)Studying different type of airfoils and their analysis to understand wing mechanism better.
2)Gear designing using module, addendum and dedendum values.

Week 3: 1)Rescaling of the prototype
2)velocity analysis

Week 4: 1)Assembling the components



CONTRIBUTION OF EACH MEMBER:

Tarini Magotra :
1)Preparing Solidworks model
2)Airfoil Analysis
3) Rescaling and Prototyping
4)Final report and video submission

Sunny Bharti
1) Coordinating to get 3d printed
2) Assembling of Materials
3) Designing Connectors (Screws) and Shaft on Solidworks
4)Base Designing

Tejasva Jindal
1) Gears Designing
2)Writing Code for motor
3)Assembling of Materials

Tanish Goyal
1)Velocity Analysis

Sumit Yadav
1)Velocity Analysis

ORNITHOPTER

Definition: An ornithopter is a type of aircraft that achieves flight by flapping its wings, mimicking the motion of birds and insects. Unlike fixed-wing aircraft, which generate lift through forward motion and the shape of their wings, ornithopters generate lift by moving their wings in a flapping motion. This motion creates both lift and propulsion, allowing ornithopters to fly in a manner similar to birds**.**
This was the motivation behind choosing ornithopter

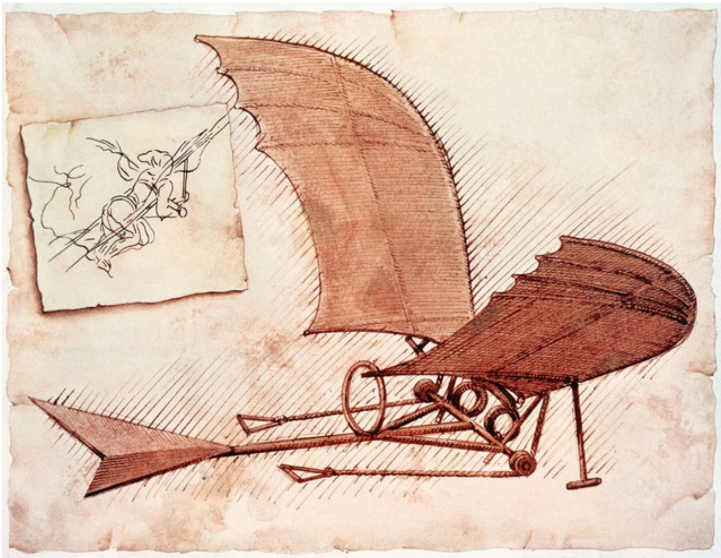


fig 1: ornithopter design

Drawback: While ornithopters have been experimented with for centuries, they are not commonly used for practical purposes such as transportation or commercial aviation. This is primarily due to the technical challenges associated with designing and operating efficient and reliable flapping-wing aircraft compared to fixed-wing or rotary-wing aircraft.

HOW TO MEASURE THE FLAPPING RATE?

The stroboscope is an electronic device consisting of a flashing strobe light and equipment for precisely controlling the flashing rate of the light. You can measure the flapping rate of your ornithopter by synchronizing the strobe rate with the flapping rate of the ornithopter, and then reading the strobe rate from the device. The stroboscope (or even a cheap party strobe light) is also useful as a way to observe what the wings are doing as they move through the flapping cycle under load. When the strobe is synchronized with the wings, the wings appear to stand still, and you can also watch the wings flap in slow motion. Stroboscopes require fairly dark conditions in order to be useful.

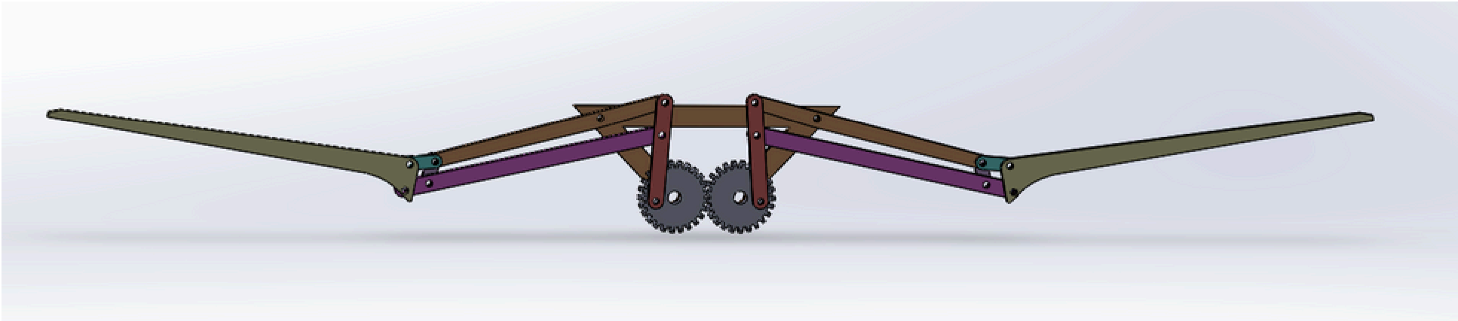
1.GEARS TO BE USED:

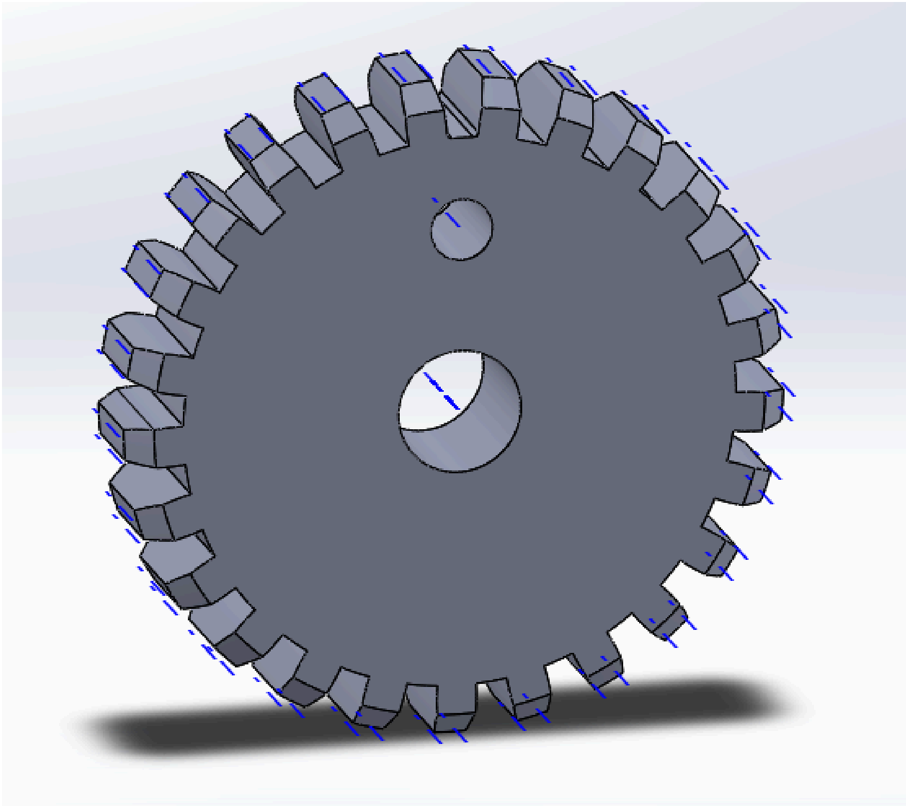
Spur gears, as shown, are the best choice for ornithopters because of their low friction. The vast majority of successful ornithopters have used spur gears. Planetary gears, harmonic drives, timing belts, chain-and-sprocket systems, and ball screws are other low-friction candidates.

These gears mesh together to transmit motion and power between parallel shafts. Spur gears are commonly used in machinery and mechanical systems for various applications, such as speed reduction, torque amplification, and direction change. They provide efficient power transmission with minimal noise and are relatively easy to manufacture, making them widely used in gear trains found in automobiles, industrial machinery, and other mechanical devices.

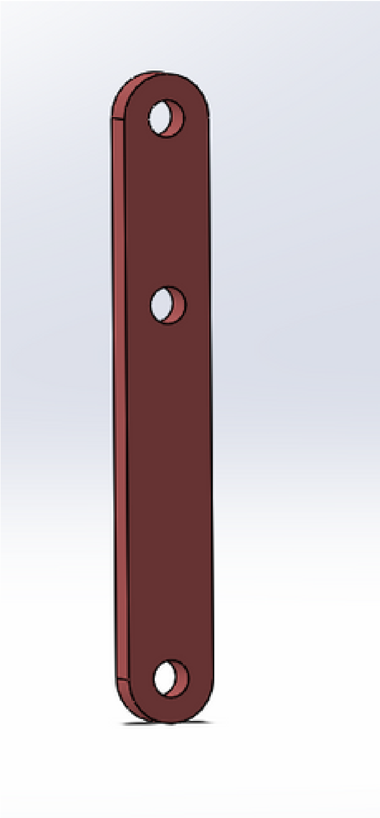
THE GEAR DESIGNED BY US HAD THE FOLLOWING DIMENSIONS:
Number of teeth = 25
Angle between two tooth of a gear = 14.4 degrees = 360/number of teeth
Module= 2mm
Pressure angle = 20 degrees Pitch circle radius = 50mm = Module * Number of Teeth

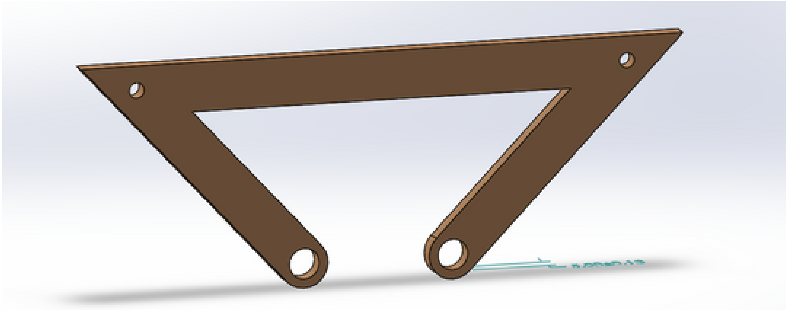
GEAR REDUCTION : Electric motors typically spin at very high speeds, measured in thousands of RPM (revolutions per minute). However, bird wings, which ornithopters replicate, beat at a much slower rate. Gear reduction bridges this gap, slowing down the motor's rotation to a speed that effectively flaps the wings and generates lift for flight. The gear reduction allows the motor to operate at a more efficient and cooler RPM, maximizing its lifespan and flight time for the ornithopter. The best gear ratio would be the one that flaps the wings fastest. That is our maximum power output, For us the gear reduction ratio is driver/driven = 8/25 .

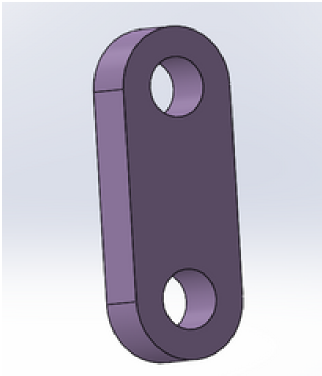


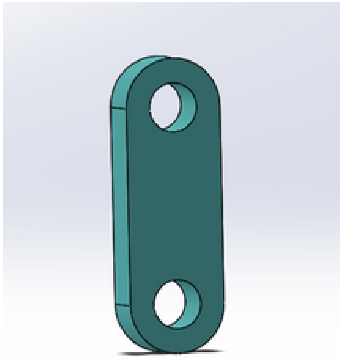


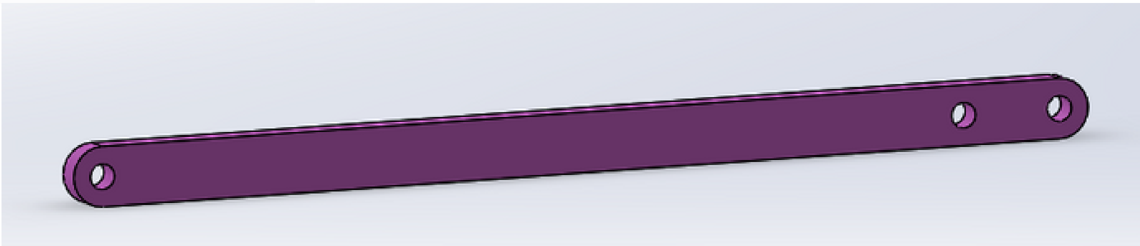
2.LINK DESIGNING

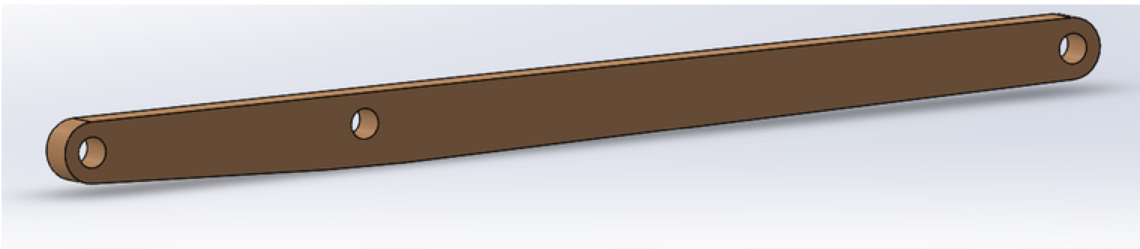


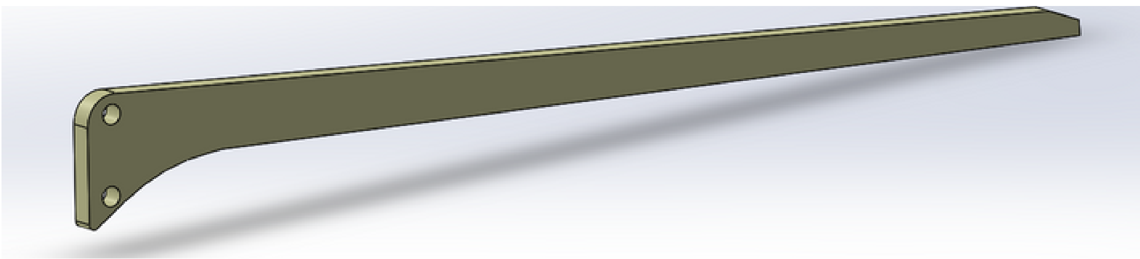


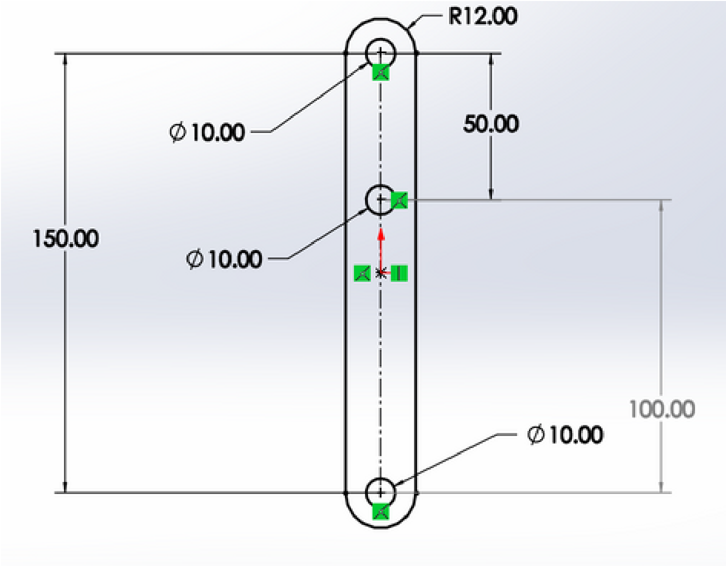


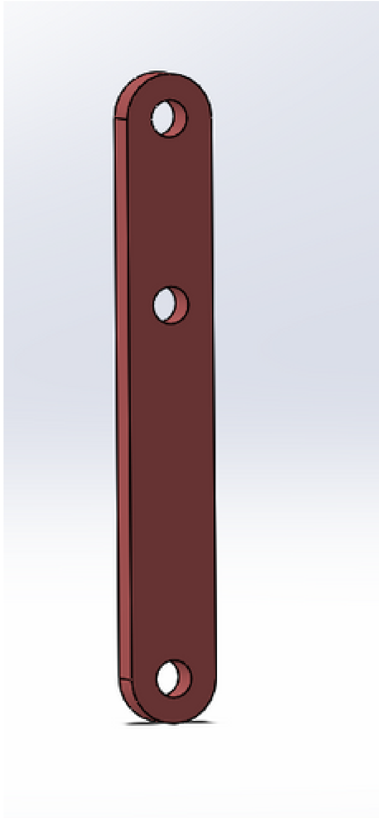


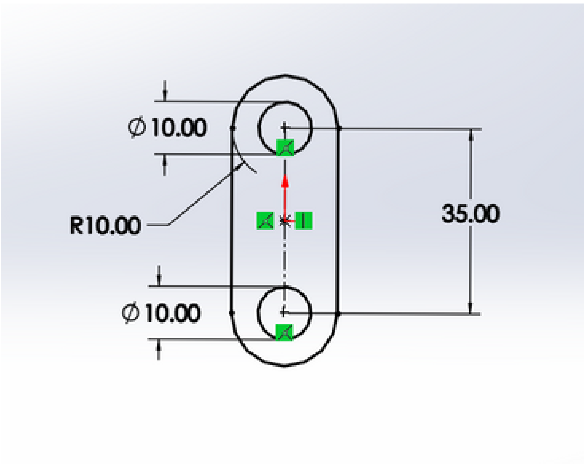


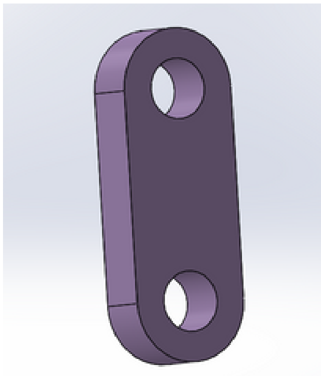


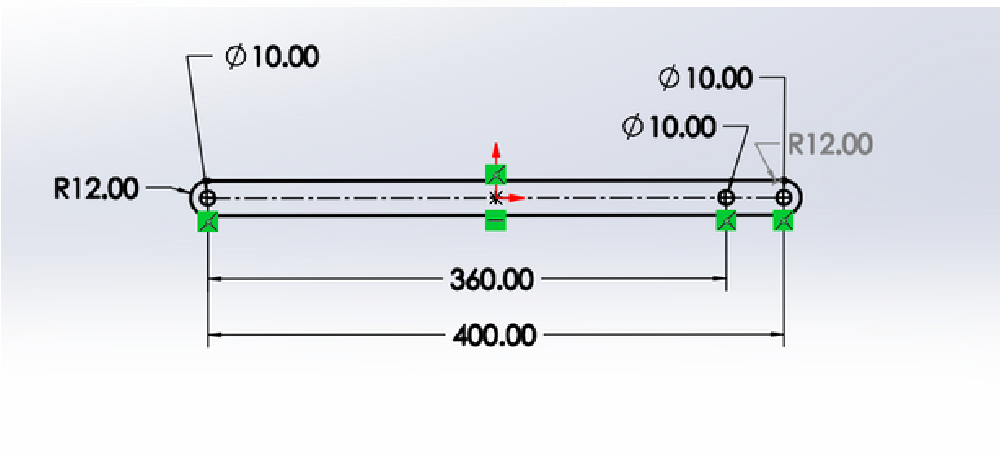


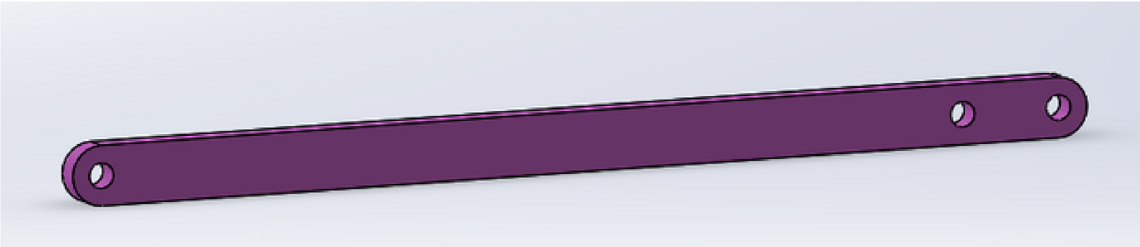

R12.00
Ø 10.00
50.00
150.00
Ø 10.00
100.00
Ø 10.00

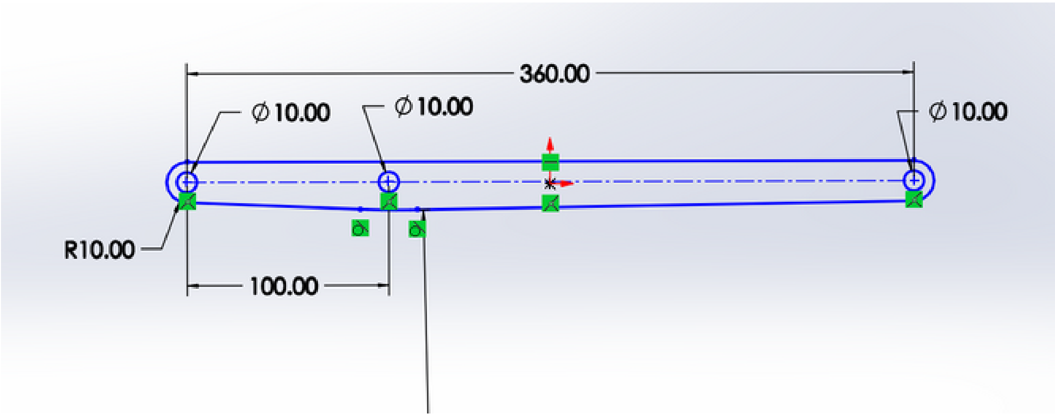



Ø 10.00
R10.00
35.00
Ø 10.00

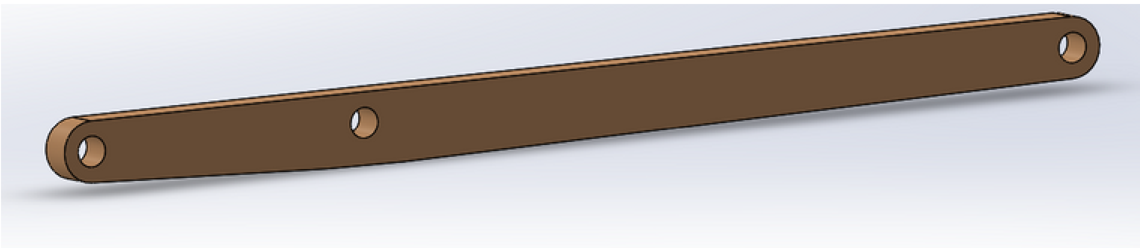


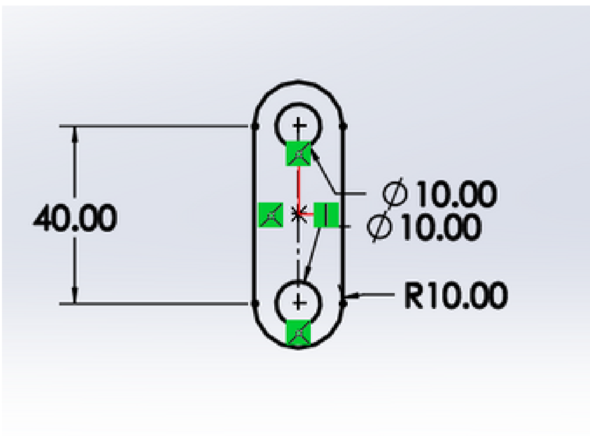

Ø 10.00
Ø 10.00
Ø 10.00
R12.00
R12.00
360.00
400.00



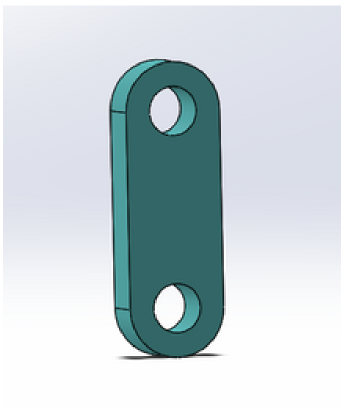


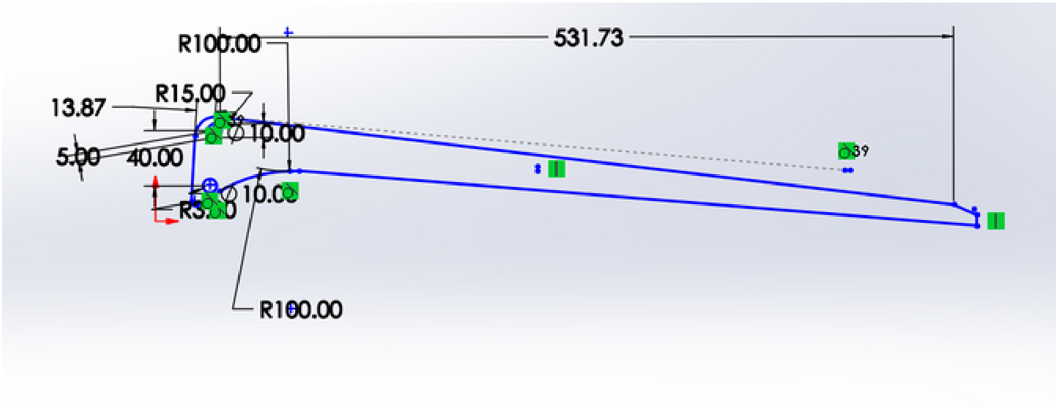
360.00
Ø10.00
Ø10.00
Ø10.00
R10.00
100.00



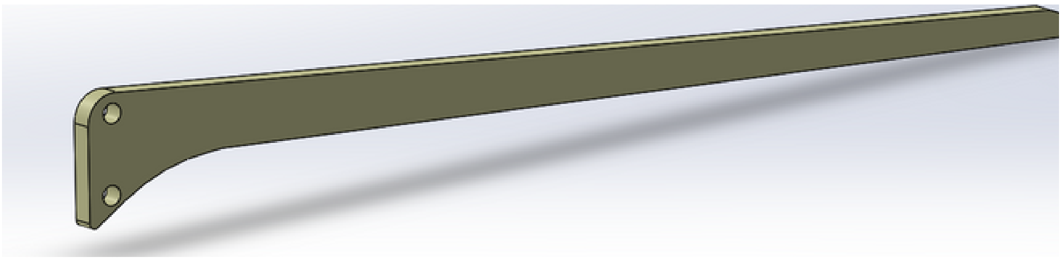


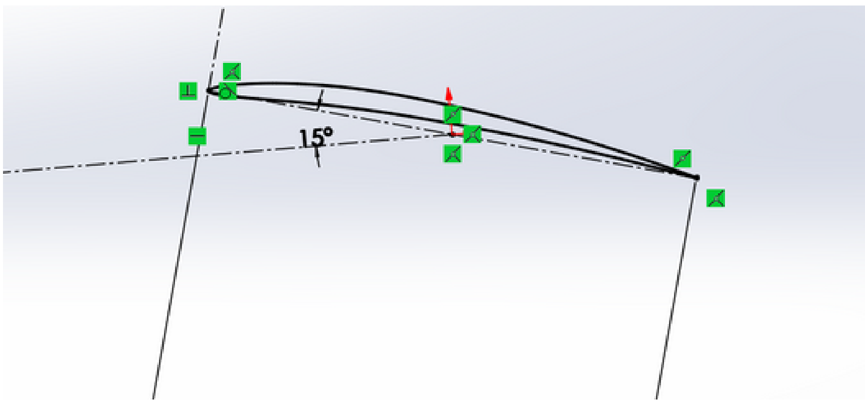
40.00
Ø10.00
Ø10.00
R10.00



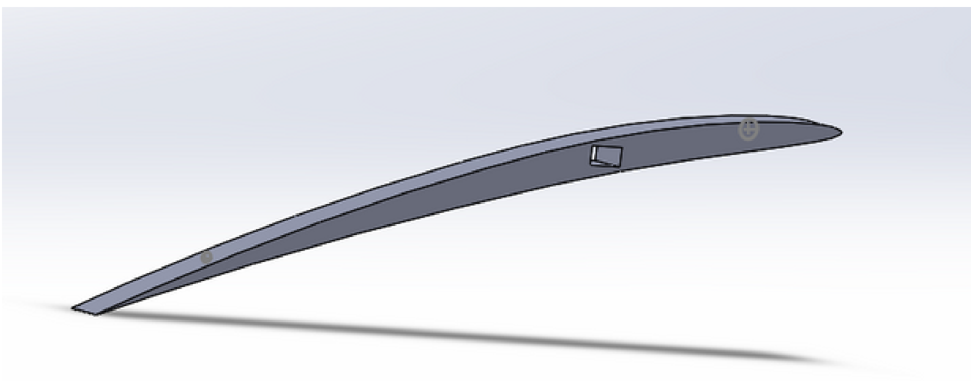


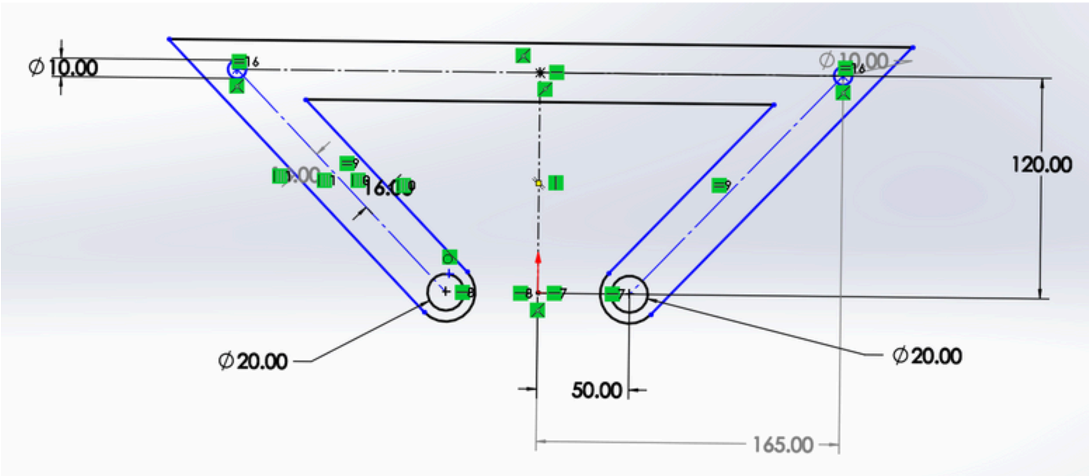
R100.00
531.73
R15.00
13.87
Ø10.00
5.00
40.00
Ø10.00
R100.00

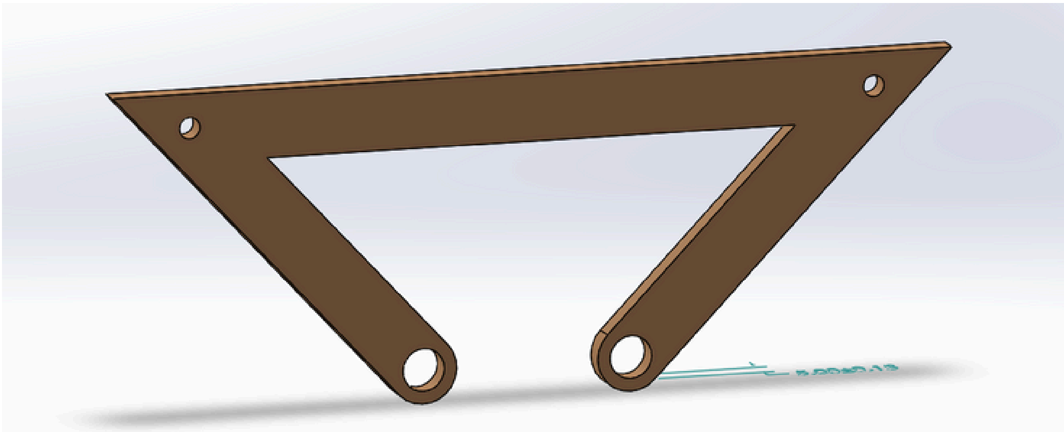




15°



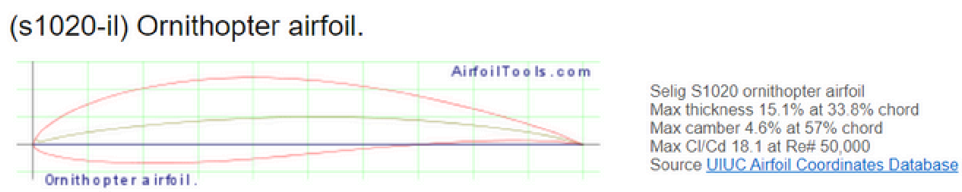

∅10.00
∅10.00
120.00
16.00
∅20.00
∅20.00
50.00
165.00

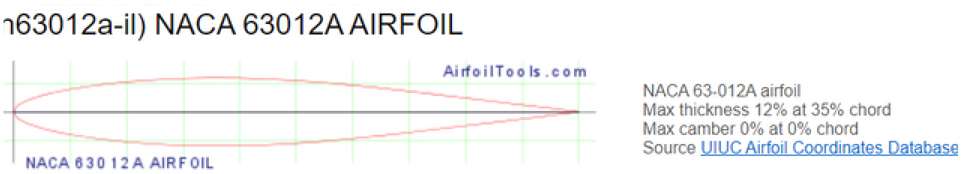


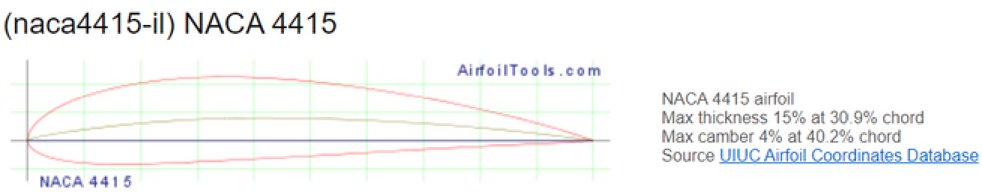
The week 2 report is based on airfoil designing and analysis of different type of airfoils and choosing the opt

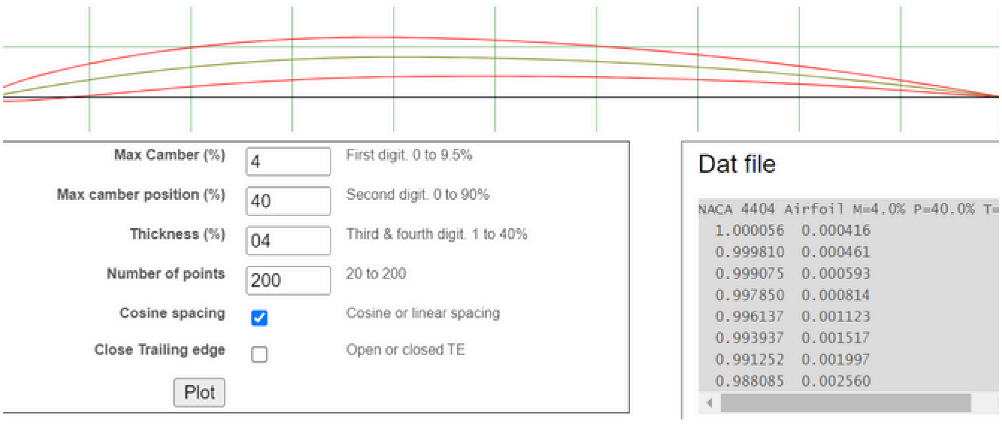
3. AIRFOIL ANALYSIS

An airfoil, also known as an aerofoil, is a streamlined shape designed to produce lift when air flows over it. It is a crucial component of wings, propeller blades, and other aerodynamic surfaces used in aircraft and vehicles. Airfoils are typically curved on the top surface and flatter on the bottom, creating a pressure difference that generates lift as air flows faster over the curved surface compared to the flat surface below. This lift force allows aircraft to overcome gravity and achieve flight. Additionally, airfoils are designed to minimize drag, which is resistance to the motion of the airfoil through the air, to improve the efficiency and performance of the vehicle.



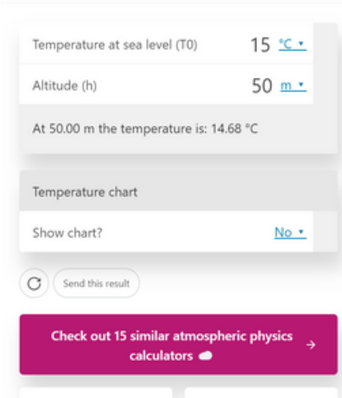


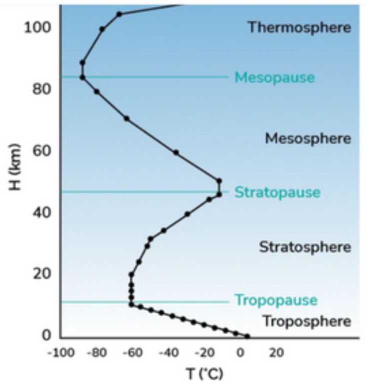




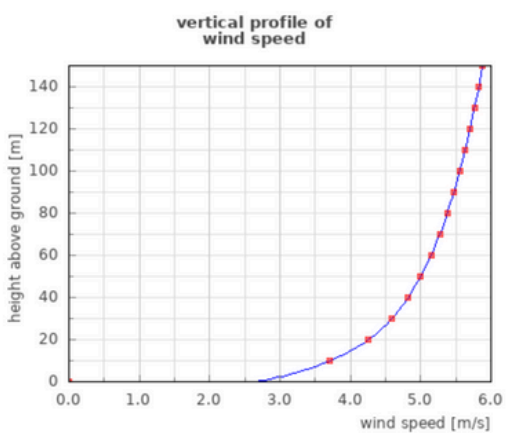
Stating Assumptions:

Flies till 50 meter, this is just an assumption to obtain reynolds number, this is required for calculation of kinematic viscoisty, this is just an estimate since the motor speed is less and hence it would fly at low at reynolds number which would more or less be same around lower heights.





height above ground	wind speed
150 m	5.88 m/s
140 m	5.83 m/s
130 m	5.77 m/s
120 m	5.70 m/s
110 m	5.63 m/s
100 m	5.56 m/s
90 m	5.47 m/s
80 m	5.38 m/s
70 m	5.27 m/s
60 m	5.15 m/s
50 m	5.00 m/s
40 m	4.82 m/s
30 m	4.59 m/s
20 m	4.26 m/s
10 m	3.71 m/s



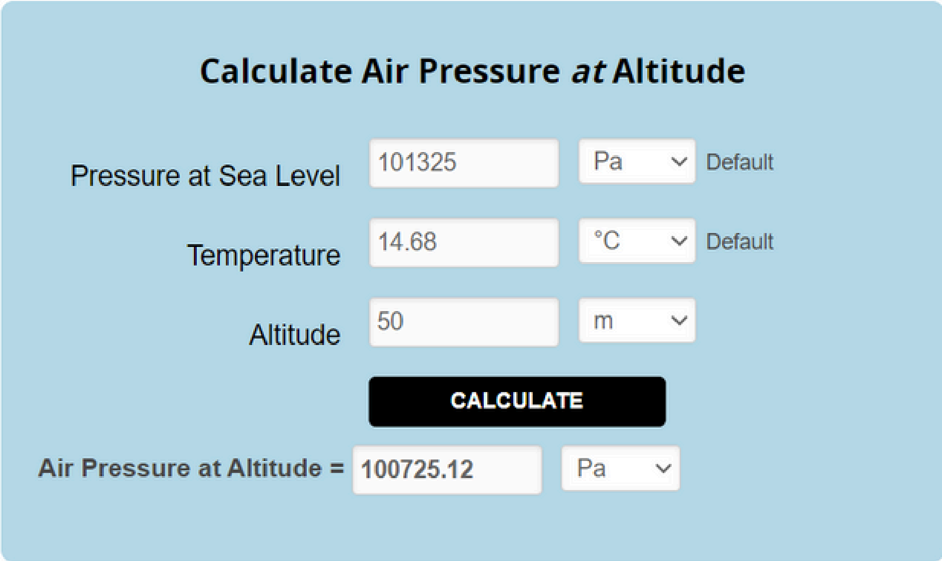
Roughness Classes and Lengths

In these calculations the roughness length factor is considered to be 0.1 , suiting our current needs

0.1 m

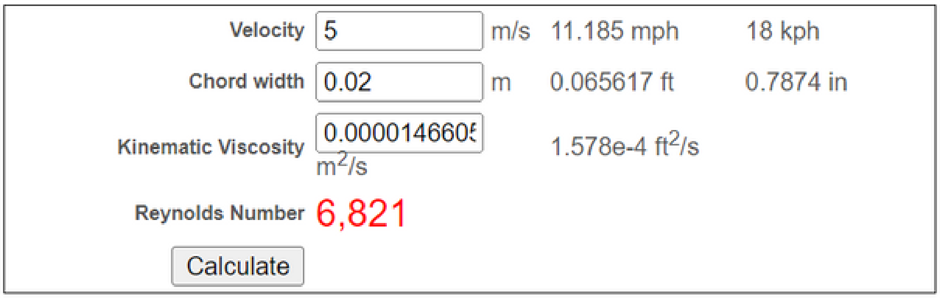
Agricultural land with a few buildings and 8 m high hedges seperated by approx. 500 m

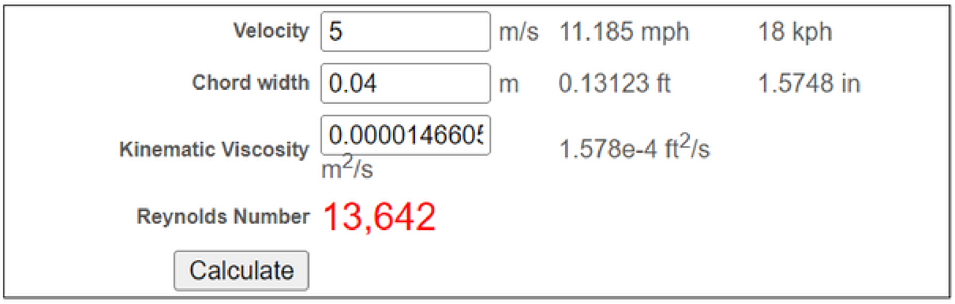
The roughness length factor represents the height above the ground or surface at which the wind speed profile transitions from being influenced by surface roughness to becoming more uniform or "neutral." In other words, it is a measure of how rough or smooth the surface is and how it affects the airflow near the surface.

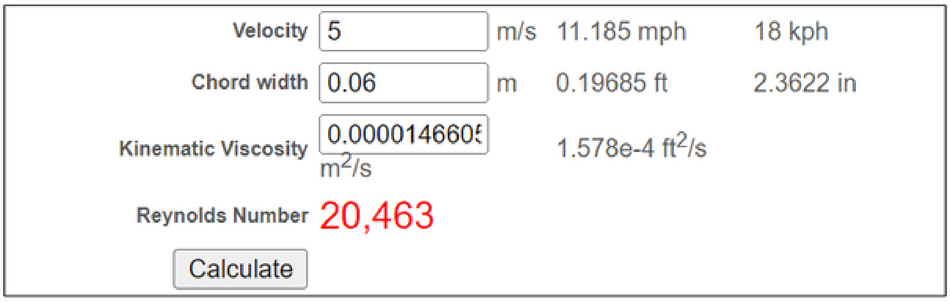


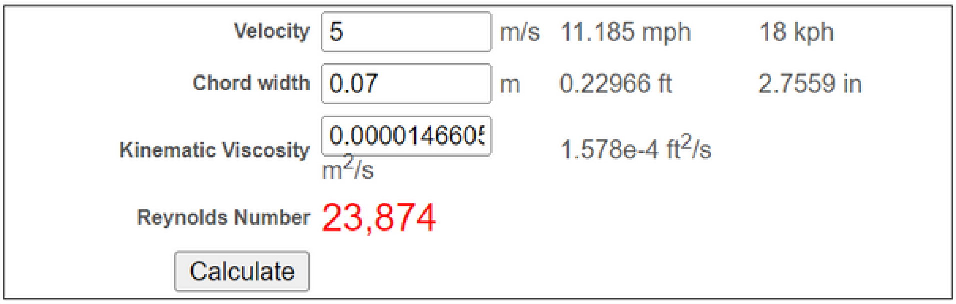
Low-Speed Aerodynamics: In certain aerospace applications, such as low-speed flight or small unmanned aerial vehicles (UAVs), airflow over airfoils or wings can occur at low Reynolds numbers. Understanding aerodynamic behavior at low Reynolds numbers is important for designing efficient and stable aircraft in these regimes.

REYNOLD NUMBER CALCULATION:

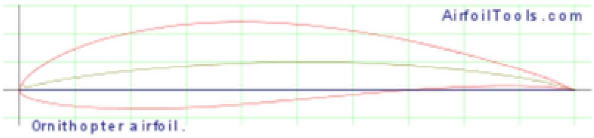




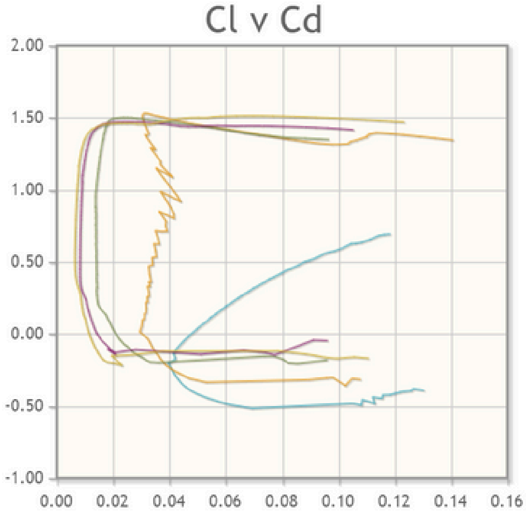


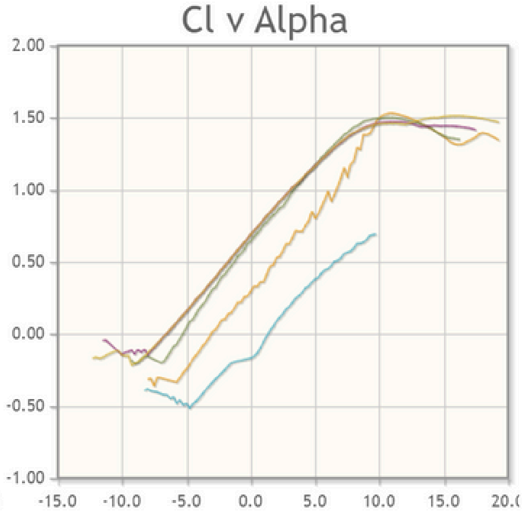


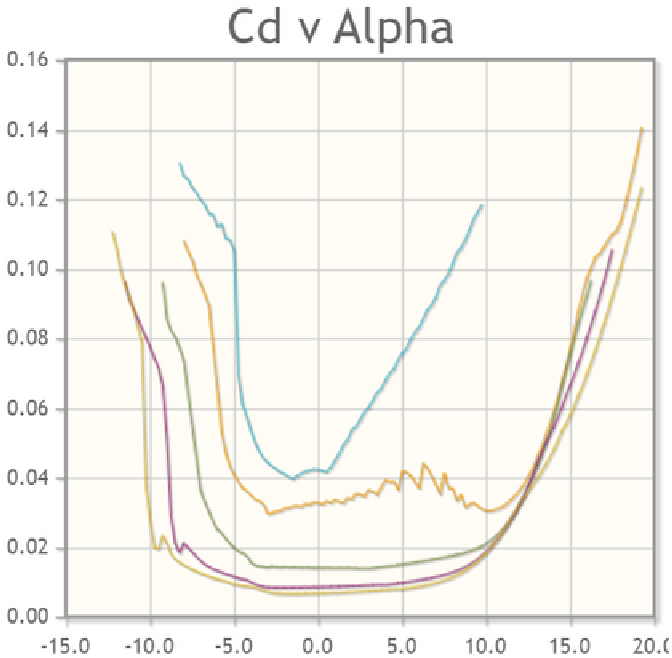
Based on these calculations it is certain that the reynolds number should be low as per our assumption and hence the most suitable airfoil was chosen based on this assumption (s1020-il) Ornithopter airfoil.



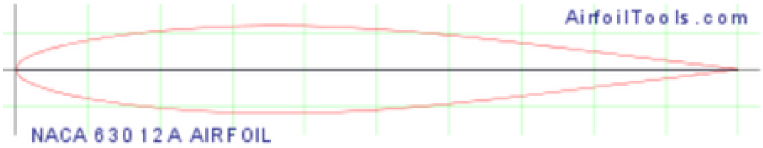
Selig S1020 ornithopter airfoil
Max thickness 15.1% at 33.8% chord
Max camber 4.6% at 57% chord
Max Cl/Cd 18.1 at Re# 50,000
Source [UIUC Airfoil Coordinates Database]



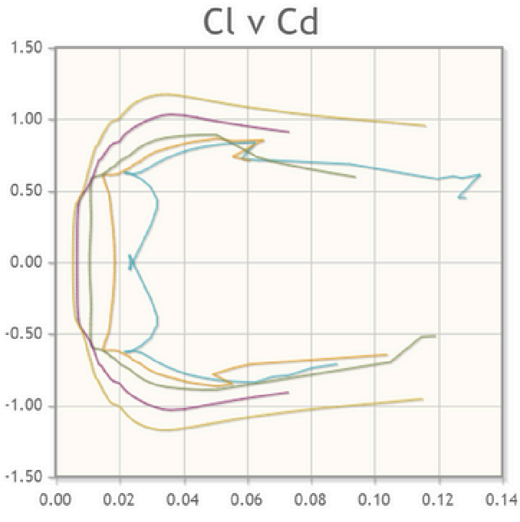


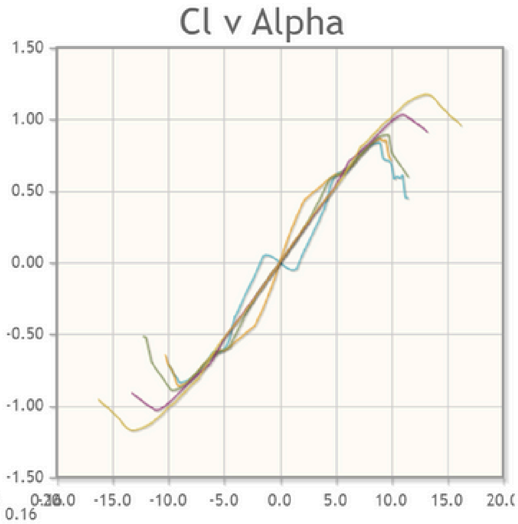


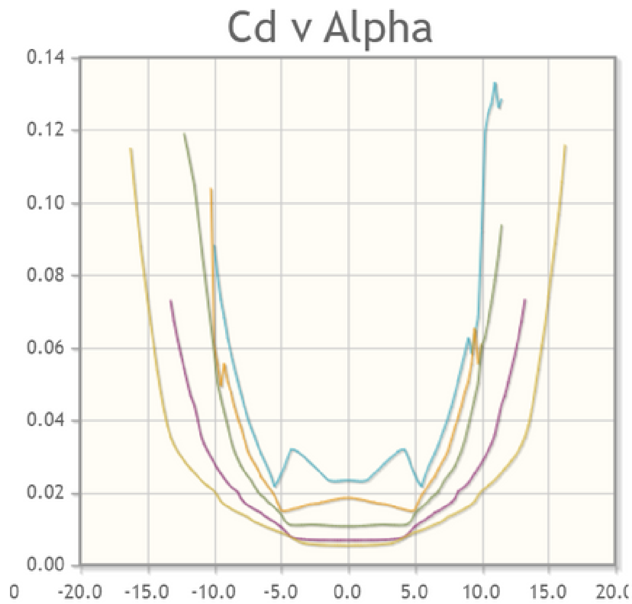
n63012a-il) NACA 63012A AIRFOIL



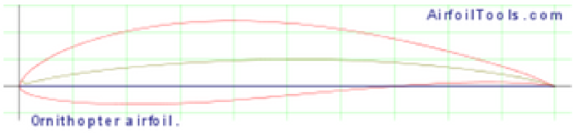
NACA 63-012A airfoil
Max thickness 12% at 35% chord
Max camber 0% at 0% chord
Source [UIUC Airfoil Coordinates Database](#)



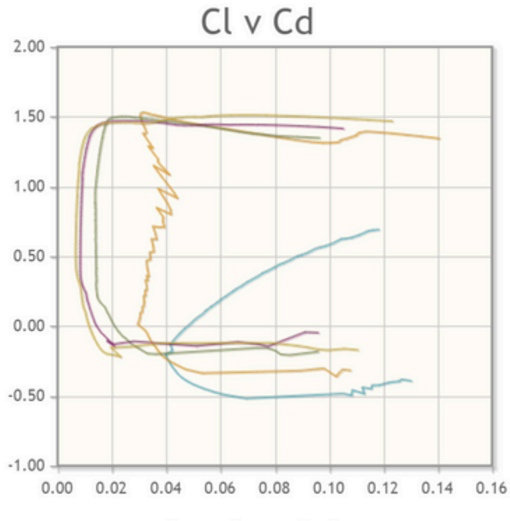


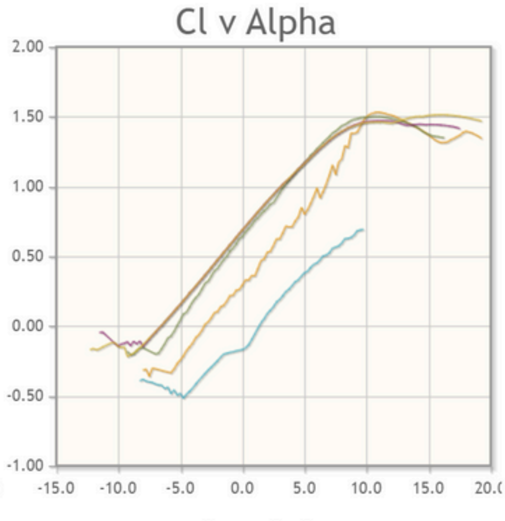


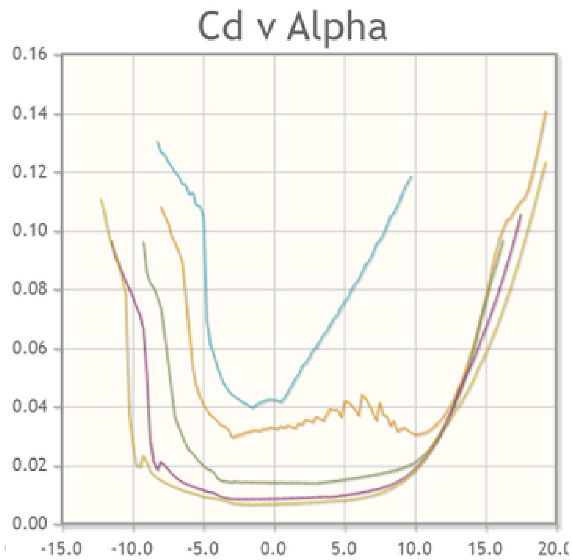
(s1020-il) Ornithopter airfoil.

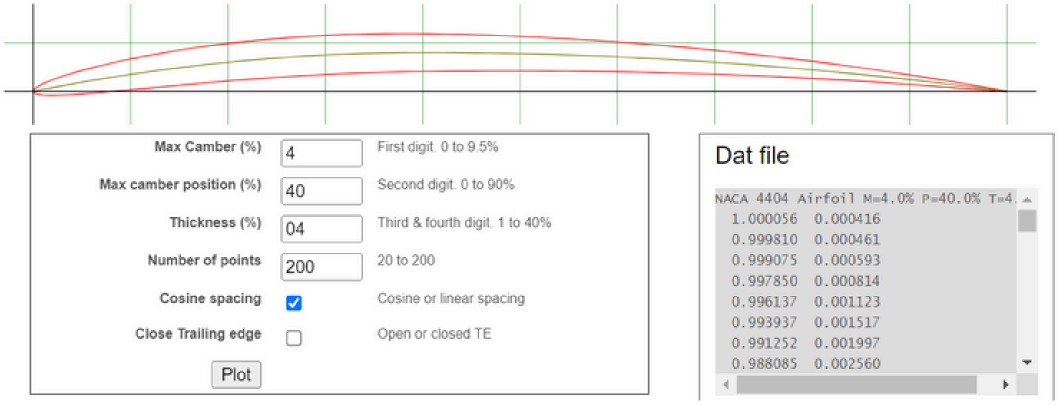


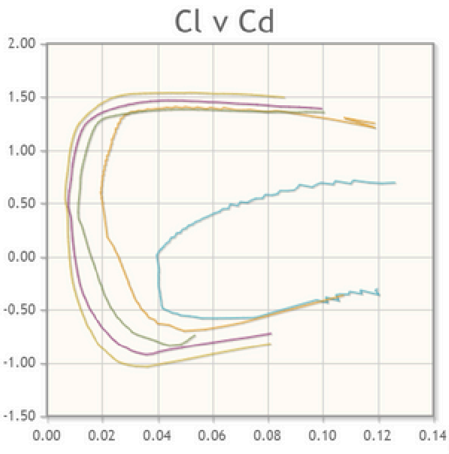
Selig S1020 ornithopter airfoil
Max thickness 15.1% at 33.8% chord
Max camber 4.6% at 57% chord
Max Cl/Cd 6 at Re# 50,000
Source UIUC Airfoil Coordinates Database

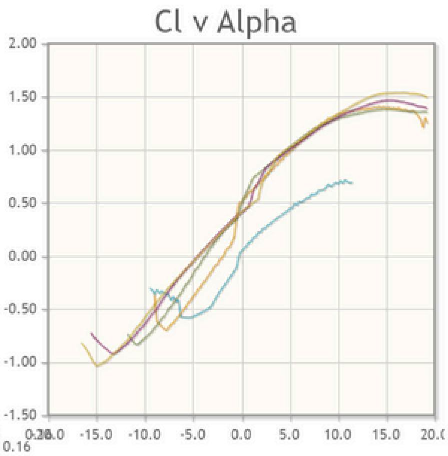


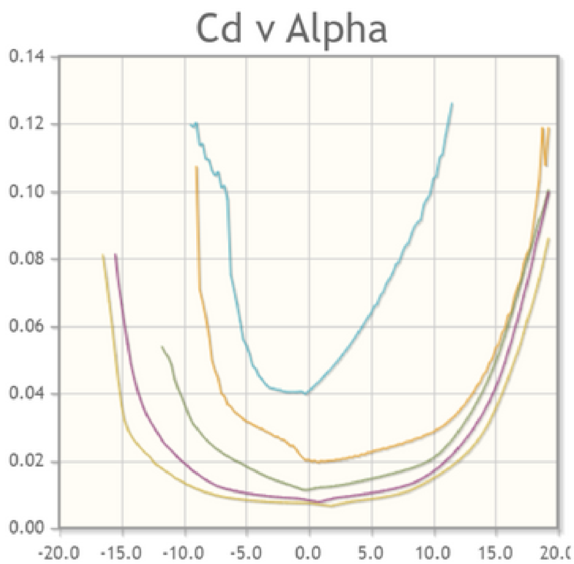





Max Camber (%)
4
First digit. 0 to 9.5%
Max camber position (%)
40
Second digit. 0 to 90%
Thickness (%)
04
Third & fourth digit. 1 to 40%
Number of points
200
20 to 200
Cosine spacing
Cosine or linear spacing
Close Trailing edge
Open or closed TE
Plot
Dat file
NACA 4404 Airfoil M=4.0% P=40.0% T=4.
1.000056 0.000416
0.999810 0.000461
0.999075 0.000593
0.997850 0.000814
0.996137 0.001123
0.993937 0.001517
0.991252 0.001997
0.988085 0.002560

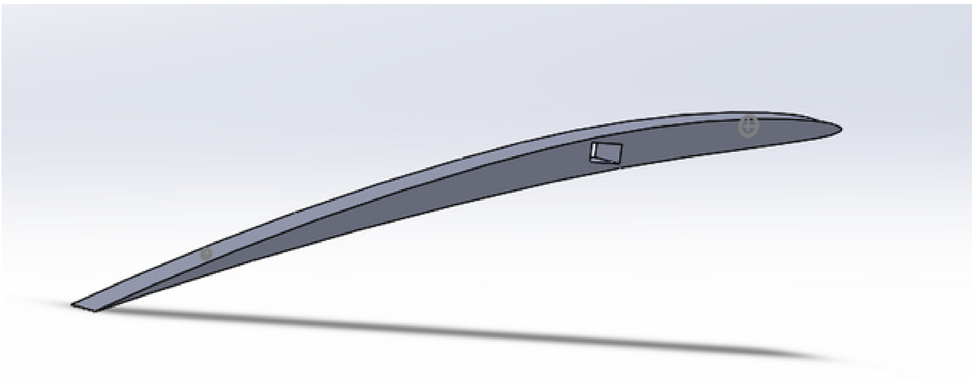

Cl v Cd
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16


Cl v Alpha
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-20.0 -15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0


Cd v Alpha
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-20.0 -15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0

Flow Separation

Instead of following the curvature they actually flow into each other making it more turbulent. This is called the Stall period. Flow separation is unwanted and hence the stall angle should be high which is given by cl versus alpha and hence NACA 4404 was chosen



SOLIDOWRKS MODEL OF NACA 4404

4.CHOOSING A MOTOR

A DC motor was chosen based upon the weight of the ornithopter which was approximately 2 kg and hence the motor chosen ran at 48 rpm providing a torque of 5-nm

```
const int button1 = 9;
const int button2 = 8;
const int button3 = 7;
int en = 10;
int i1 = 11;
int i2 = 12;
int a = 100;

// Debounce variables
unsigned long lastDebounceTime = 0;
unsigned long debounceDelay = 5; // Debounce time in milliseconds

void setup() {

  pinMode(button1, INPUT_PULLUP);
  pinMode(button2, INPUT_PULLUP);
  pinMode(button3, INPUT_PULLUP);
  pinMode(en, OUTPUT);
  pinMode(i1, OUTPUT);
  pinMode(i2, OUTPUT);
  Serial.begin(9600);
  analogWrite(en, a);
  digitalWrite(i1, HIGH);
  digitalWrite(i2, LOW);
}

void loop() {

  int b1 = digitalRead(button1);
  int b2 = digitalRead(button2);
  int b3 = digitalRead(button3);
  int read1 = digitalRead(i1);
  int read2 = digitalRead(i2);

  // Check if button 1 is pressed with debounce
  if (b1 == LOW && millis() - lastDebounceTime > debounceDelay) {
    lastDebounceTime = millis();
    a += 50;
    if (a > 255) {
      a = 255;
    }
     // lcd.print("hello world hi");
```

```
  Serial.print("The pwm value is ") ;
    Serial.print(a);
    int a1 = (200*a/255) ;
    Serial.print("\n");
    Serial.print("The speed of the motor in rpm is ");
    Serial.print(a1);


    analogWrite(en, a);
}

// Check if button 2 is pressed with debounce
else if (b2 == LOW && millis() - lastDebounceTime > debounceDelay) {
  lastDebounceTime = millis();
  a -= 50;
  if (a < 0) {
   a = 0;
  }

   Serial.print("The pwm value is ") ;
    Serial.print(a);
    int a1 = (200*a/255) ;
    Serial.println("\n");
    Serial.println("The speed of the motor in rpm is ");
    Serial.print(a1);

    analogWrite(en, a);
}

// Check if button 3 is pressed with debounce
else if (b3 == LOW && millis() - lastDebounceTime > debounceDelay) {
  lastDebounceTime = millis();
  if (read1 == HIGH && read2 == LOW) {
      digitalWrite(i1, LOW);
   delay(500);
        analogWrite(en, a);

   digitalWrite(i2, HIGH);

  } else if (read1 == LOW && read2 == HIGH) {
      digitalWrite(i2, LOW);
   delay(100);
        analogWrite(en, a);

   digitalWrite(i1, HIGH);

  }
```

```
Serial.print("The pwm value is ") ;
      Serial.print(a);
      int a1 = (200*a/255) ;
      Serial.println("\n");
      Serial.println("The speed of the motor in rpm is ");
      Serial.print(a1);

  }
  // Delay before next loop iteration
  delay(1000); // Adjust as needed
}
```

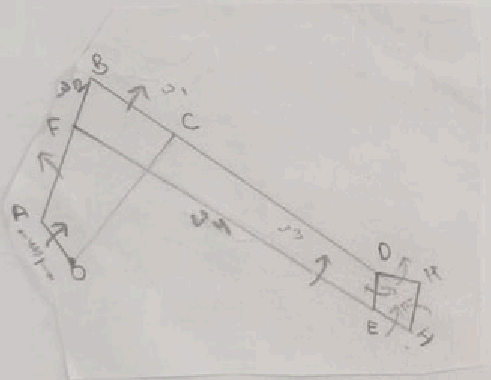
5.VELOCITY ANALYSIS

Ornithopter

Velocity Analysis

-TANISH GOYAL
-SUMIT YADAV

1cm in dia. ⇒ 2.5cm in real dimensions in Ornithopter



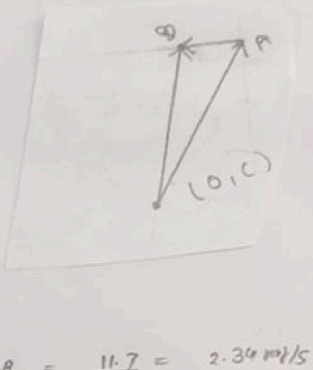
Scale diagram of Ornithopter (on-site)

4-Bar Mechanism (OABC)

Fixed link OC
Crank → OA

1cm in diagram ⇒ 3.25 cm/s velocity

- N = 50rpm
- $\omega = \frac{2\pi 50}{60} = 5.23$ rad/s
- $V_{OA} = \omega \times r_{OA} = 13.075$ cm/s



- $V_{CB} = 3.6$ cm ⇒ $3.6 \times 3.25 = 11.7$ cm/s
- $V_{BA} = 1.4 \times 3.25 = 4.55$ cm/s

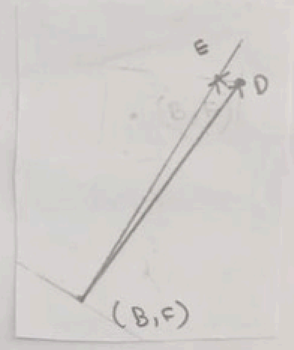
- $\omega_{CB} = \frac{V_{CB}}{CB} = \frac{11.7}{5} = 2.34$ rad/s
- $\omega_{AB} = \frac{V_{AB}}{AB} = \frac{4.55}{7.75} = 0.58$ rad/s

4. Bar Mechanism (BDEF):-

Take Fixed Link → BF

$\omega_{BD} = \omega_{BC} = 2.34$
$\omega_{BA} = \omega_{BF} = 0.58$

$\omega_{rel, BC, BF} = \omega_{BD} + \omega_{BF} = 2.34 + 0.58 = 2.92$ rad/s



• $V_{BD})_{rel} = 2.92 \times 18 = 52.56$ cm/s

•

⇒ 1cm ⇒ 8.75

$V_{EF})_{rel} = 5.8$ cm $= 5.8 \times 8.75$
$= 50.75$ cm/s

$V_{ED})_{rel} = 0.5$cm $= 4.375$cm/s

$\omega_{DE})_{rel} = \dfrac{V_{DE}}{DE} = \dfrac{4.375}{2} = 2.1875$ rad/s

$\omega_{EF})_{rel} = \dfrac{V_{EF}}{EF} = \dfrac{50.75}{18} = 2.81$ rad/s

$\omega_{EF})_{rel} = \omega_4 - \underbrace{\omega_2}_{0.58} = 2.81$ rad/s

$\omega_4 = 3.39$ rad/s (ACW)

$\omega_{DE})_{rel} = \omega_3 + (\omega_4 - \omega_2) = 2.187$ rad/s

$\omega_3 + 2.81 = 21875$

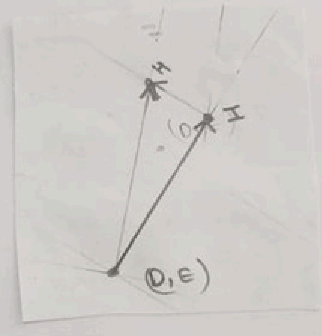
$\omega_3 = -2.81 + 2.1875 = -0.6225$ rad/s (ACW)

4 - Bar Mechanism (EDHI) :-

Fixed link · DE

$\omega_{rel})_{EI,DE} = \omega_{EI} - \omega_{DE} = 3.39 - 0.6225 = 2.76$ rad/s

$V_{EI})_{rel} = 2.76 \times 2 = 5.52$ cm/s



1cm → 1.38

$\omega_{DH})_{rel} = \frac{V_{DH}}{DH} = \frac{5.934}{2.5} = 2.3$ rad/s

$\omega_{HI})_{rel} = \frac{V_{HI}}{HI} = \frac{2.2}{2.5} = 0.88$ rad/s

$V_{DH})_{rel} = 4.3 \times 1.38 = 5.934$ cm/s

$V_{HI})_{rel} = 1.6$ cm $= 1.6 \times 1.38 = 2.2$ cm/s

- $\omega_{DE} = 0.6225$ rad/s (ACW)
- $\omega_{EI} = 3.39$ rad/s

$\omega_{DH})_{rel} = \omega_{DH} - \underset{0.6225}{\omega_{DE}} = 2.3$ rad/s

$\omega_{DH} = 2.9225$ rad/s

$\boxed{V_{DH} = 7.30625 \text{ cm/s}}$

$\omega_{HI})_{rel} = \omega_{HI} - \underset{2.76}{\omega_{EI})_{rel}} = 0.88$

$\omega_{HI} = 3.64$ rad/s

$\boxed{V_{HI} = 9.1 \text{ cm/s}}$

CONSTRAINTS FACED

1) Changing length of links and distance between 2 links multiple times to enhance the flapping mechanism which was found to be tedious and laborious

2) The two linkages in velocity analysis weren't fixed and were considered to be fixed to produce right results for velocity analysis.

3)Airfoil was 3-D printed but due to poor structural integrity it would've collapsed, had it been attached to the frame.

4) Unavailability of 3d printer and screws and nuts.