

EU HORIZON 2020 PROJECT STEP2DYNA SEMINAR, TSINGHUA
UNIVERSITY



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LINCOLN

**DEVELOPMENT OF AN AUTONOMOUS
FLAPPING WING ROBOT LOCUST;
LINLOC**

Hamid Isakhani

21st May 2018

• Session Overview

✓ Introduction

- Self Introduction
- Problem Statement
- Objectives

✓ Literature Review

- Several Similar Prominent Projects
- National Projects



✓ Objective-1

- Aerodynamics Study
- Computational Fluid Dynamics (CFD)
- Stages Involved in CFD Studies

✓ Future Work

- Objective-1 Continuation
- Objective-2 Initialisation

• Self-Introduction



B.Eng.
Aeronautics

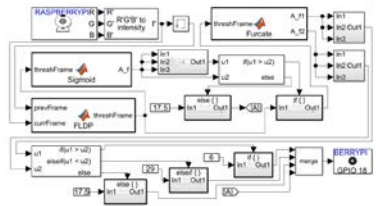


Biozopter

MRes.
Aerospace



FLDP



Ph.D.
Computer



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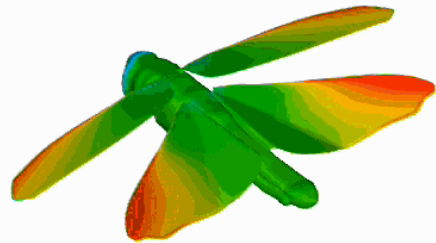
LinLoc

• Problem Statement

- ✓ **Problem at hand:** A fully bioinspired autonomous flapping unmanned aerial vehicle.

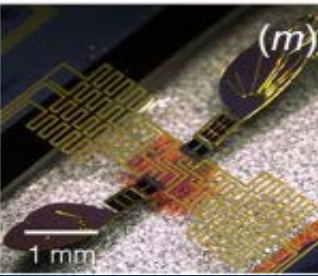
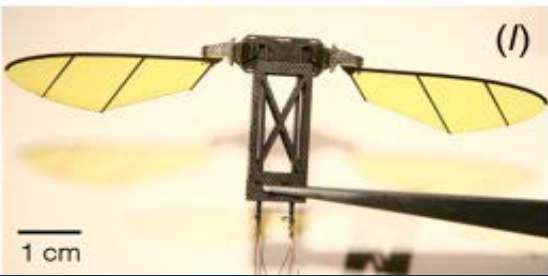
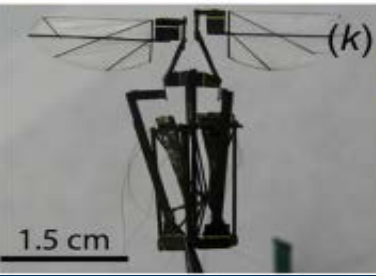
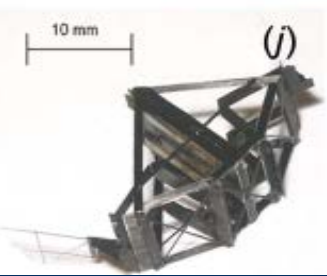
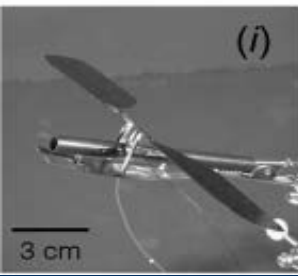
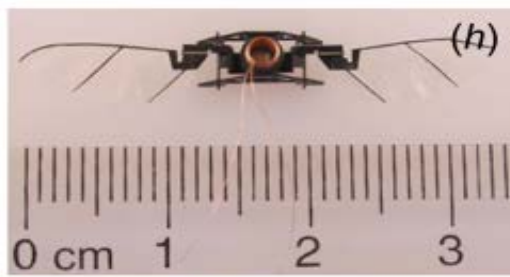
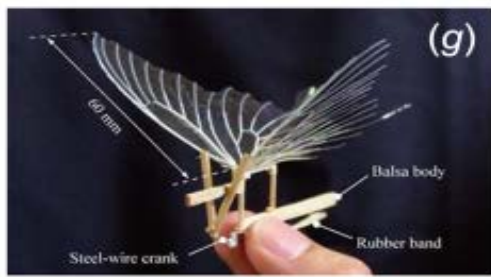
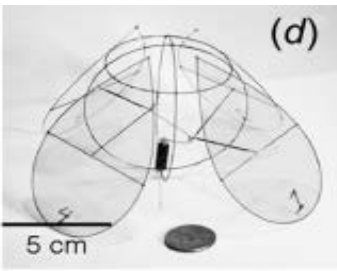
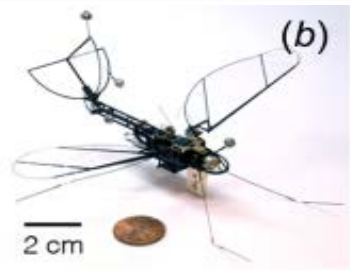
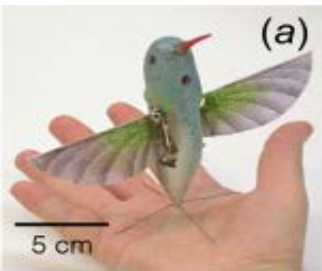


(Step2Dyna-WP4: Implementation of Collision detection and avoidance systems for mobile robots and unmanned aerial systems)









- ✓ **Subproblem-1 (Aerodynamics):** Numerical and experimental fluid dynamics study and rapid prototyping of locust wing.
- ✓ **Subproblem-2 (Mechanics):** Biomechanical properties (mechanical testing) and formulation of wing articulation mechanism of locust wing.
- ✓ **Subproblem-3 (Autonomous Control):** Integration of LGMD vision module onto the flapping flight control system (FCS).

• Literature: Several Similar Prominent Projects



Literature

✓ Several Prominent Projects

COUNTRY						
Research Institution	Konkuk University	DRDO	Delft University	University of Lincoln	Harvard University	Warsaw University
Project	LIPCA MAV	VTOL MAV	Delfly III	LinLoc	HMF/PARITy	Lissajous MAV
Bioinspired	Quasi	Quasi	Quasi	Fully (Aerodynamics + Mechanics + Control)	Quasi	Quasi
Topology	4-bar	4-bar	4-bar	4-bar	4-bar	Double Scotch Yoke
Actuator Type	LIPCA	DC Motor	DC Motor	DC Motor	PZT BiMorph	DC Motor
Wing Rotation	Passive	Active	Passive	Passive	Passive	Active

• Proposed Methodology

LinLoc: a novel fully-bioinspired aerial robotic platform that appreciates biological solutions

To address

1) Flapping wing flight

2) Collision avoidance and autonomous flight in complex cluttered environment



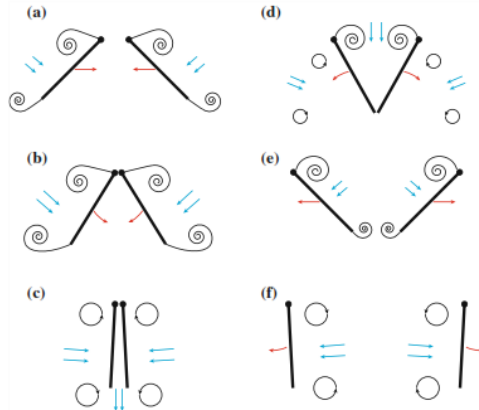
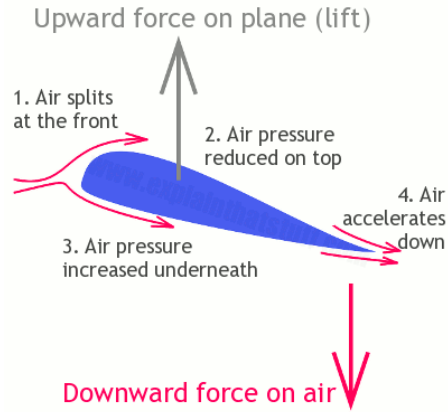
LinLoc



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Subproblem-1: Linloc Aerodynamics

✓ Fundamentals of Conventional and Flapping Flight



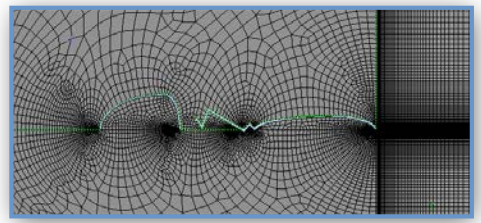
Locust in a wind-tunnel test, recorded using high-speed camera.

Newton's 3rd Law of Motion; for a every action, there is an equal and opposite reaction.

Clap-and-peel motion by use of two rigid wing sections with the red arrows indicating the direction of the wing motion and the blue arrows indicating the direction of the induced flow, for the instroke (a-c) and outstroke (d-f).

Linloc Aerodynamics: Computational Fluid Dynamics (Major Stages)

1) Geometry Modeling and Meshing



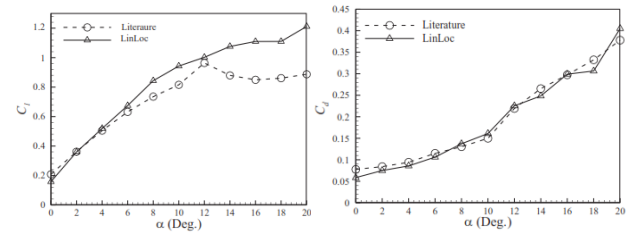
2) Governing equations and Solution parameters

The continuity equation: $\frac{\partial \bar{U}_j}{\partial x_j} = 0$

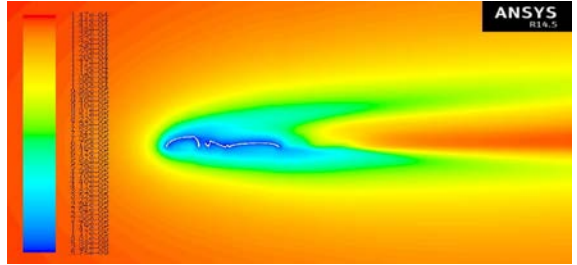
The momentum equation: $\frac{\partial}{\partial t}(\rho \bar{U}_i) + \frac{\partial}{\partial x_j}(\rho \bar{U}_i \bar{U}_j) - \frac{\partial \bar{P}}{\partial x_i} - \frac{\partial}{\partial x_j}(\bar{\tau}_{ij} + \rho u_j'' \bar{u}_i'')$

The energy equation: $\frac{\partial}{\partial t}(\rho \bar{h}) + \frac{\partial}{\partial x_j}(\rho \bar{U}_j \bar{h}) - \frac{\partial}{\partial x_j}(\bar{Q}_j + \rho u_j'' \bar{h}'')$

4) Observation & Comments



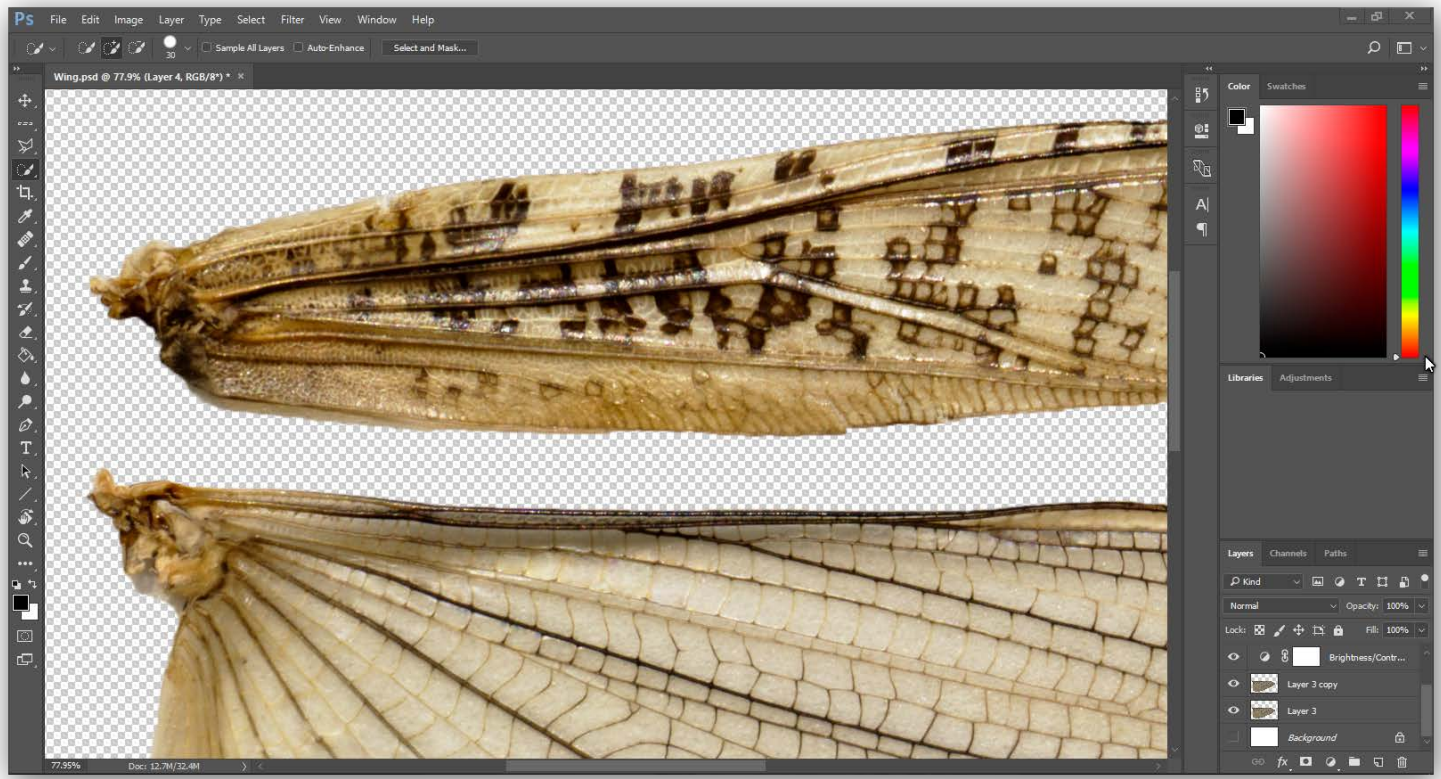
3) Results and discussions



- Stage-1: Taxidermy and Macro Photography



• Stage-2: Post-processing Images in Adobe Photoshop



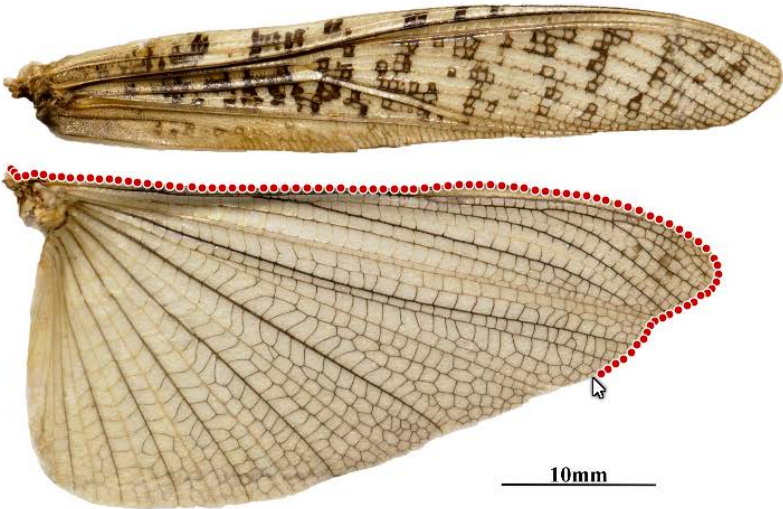
Stage-3: Digitizing Wing in WebPlotDigitizer

WebPlotDigitizer - Copyright 2010-2017 Ankit Rohatgi

File Help + - 100% Fit

Axes
Map
Datasets
Default Dataset
Measurements

Dataset
Axes: Map
Rename Dataset
Delete Dataset
View Data
Clear Data
Data Points: 92



[2.7174e+0, 7.2464e-3]

Manual Extraction
Add Point (A) Adjust Point (S)
Delete Point (D)

Automatic Extraction
Mask Box Pen Erase View
Color: Foreground Color
Distance: 120 Filter Colors
Algorithm: Averaging Window
 ΔX 10 Px
 ΔY 10 Px
Run

Stage-3: Exporting Wing Coordinates

WebPlotDigitizer - Copyright 2010-2017 Ankit Rohatgi

File Help + - 100% Fit

Axes
Map
Datasets
Default Dataset
Measurements

Dataset
Axes: Map
Rename
Delete
View
Clear
Data Poi

Acquired Data

Dataset: Default Dataset ▾

Variables: X, Y

```
0.20289855072463758, 1.2826086956521734
0.22463768115942018, 1.3043478260869559
0.2463768115942028, 1.333333333333326
0.2971014492753622, 1.3260869565217386
0.3550724637681158, 1.31159420289855
0.41304347826086935, 1.3189405797101443
0.47101449275362295, 1.333333333333326
0.5289855072463766, 1.333333333333326
0.5869565217391302, 1.3405797101449268
0.6521739130434779, 1.3405797101449268
0.7173913043478258, 1.3405797101449268
0.7753623188405793, 1.347826086956521
0.8405797101449272, 1.347826086956521
0.8985507246376807, 1.3550724637681153
0.9637681159420286, 1.3623188405797095
1.021739130434782, 1.3695652173913035
```

Copy to Clipboard Download .CSV Graph in Plotly* Close

*Plotly is a secure data analysis and graphing site with data sharing and access controls.
Visit <http://plot.ly> for details.

Sort
Sort by: Raw ▾
Order: Ascending ▾

Format
Number Formatting:
Digits: 5 Ignore ▾
Column Separator: ,
Format

[2.7174e+0, 7.2464e-3]

Manual Extraction
Add Point (A) Adjust Point (S)
Delete Point (D)

Automatic Extraction
Mask Box Pen Erase View

Color Foreground Color ▾
Distance 120 Filter Colors

Algorithm Averaging Window ▾
ΔX 10 Px
ΔY 10 Px
Run

Stage-4: Writing the .swp Code in MS Visual Basic

The screenshot displays two windows from Microsoft Visual Basic for Applications. The left window shows the VBA editor for a macro named 'main' in the 'Locust_Wing_Cross_Section_Profile' project. The code defines a sub 'main' that opens a text file '20.txt' for input, reads data into variables X, Y, and Z, and uses the SolidWorks API to create a point and show an isometric view.

```
Dim swApp As Object
Sub main()

Set swApp = Application.SldWorks
Set Part = swApp.ActiveDoc
swApp.ActiveDoc.ActiveView.FrameState = 1
Dim skPoint As Object

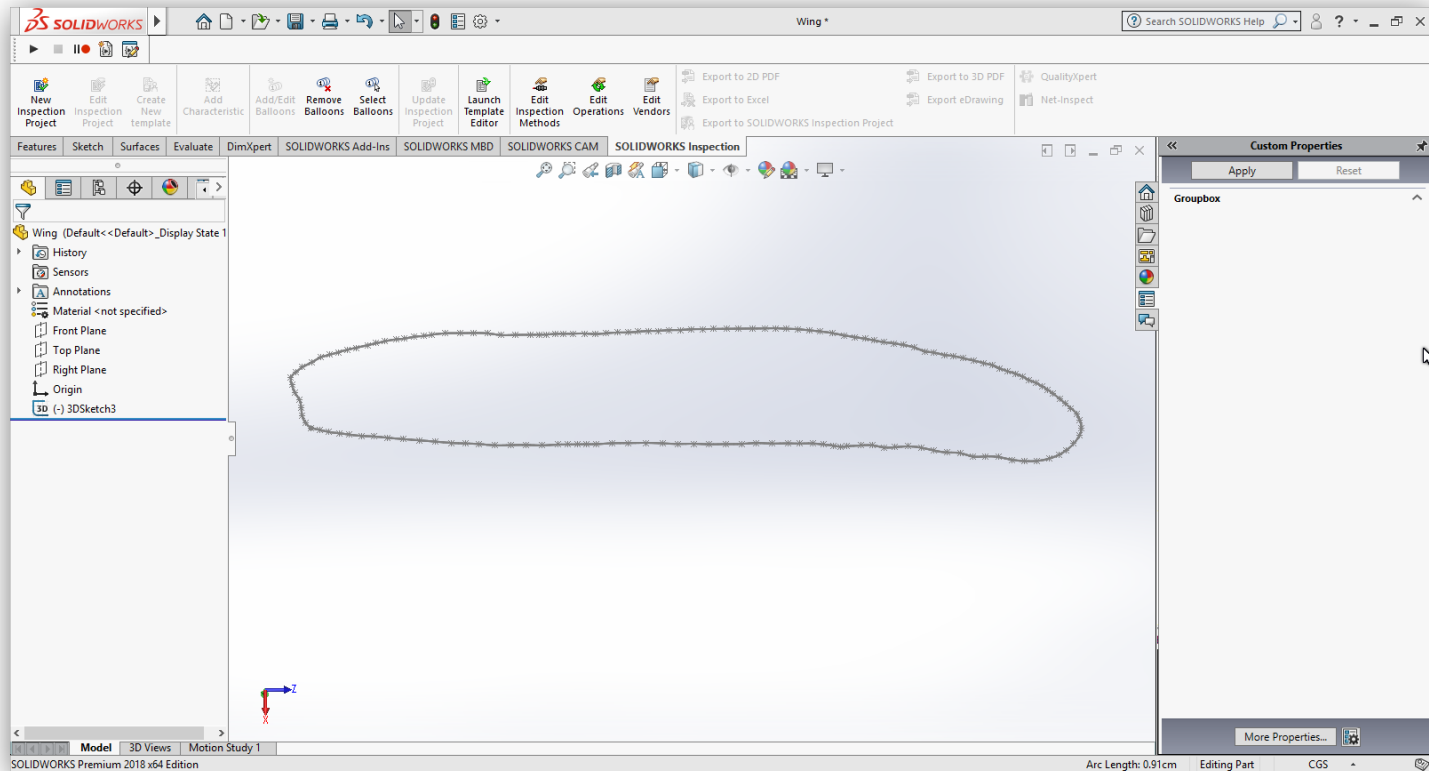
Open "C:\Users\Hamid\Desktop\Locust Wing\Cross-section Profile Co-ordinates\20.txt" For Input As #1
Part.SketchManager.Insert3DSketch True
Do While Not EOF(1)
Input #1, X, Y, Z
Set skPoint = Part.SketchManager.CreatePoint(X / 1000, Y / 1000, Z / 1000)
Loop
Close #1

Part.ShowNamedView2 "Isometric", 7
Part.ViewZoomtofit2
End Sub
```

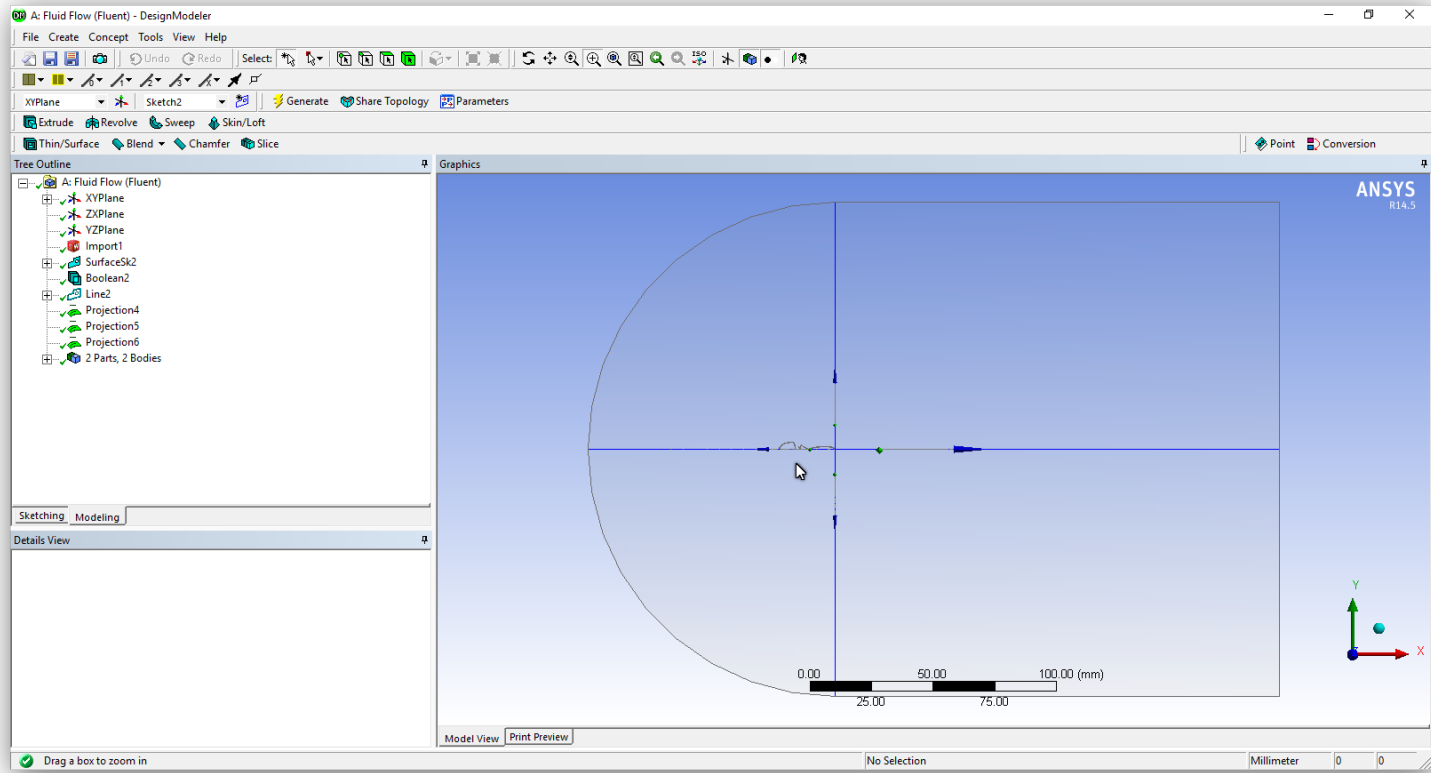
The right window shows a text file named '20.txt' containing a list of 30 rows of numerical data, likely representing cross-section coordinates.

1	9.517445095	3.56079932	0
2	9.517445095	3.297036407	0
3	9.539425338	3.055253737	0
4	9.561405581	2.813471067	0
5	9.605366066	2.549708155	0
6	9.671306794	2.285945242	0
7	9.759227765	2.044162572	0
8	9.869128979	1.78039966	0
9	10.00101044	1.53861699	0
10	10.13289189	1.318814563	0
11	10.28675359	1.120992378	0
12	10.44061529	0.967130679	0
13	10.63843747	0.81326898	0
14	10.83625966	0.703367767	0
15	11.07804233	0.615446796	0
16	11.38576573	0.615446796	0
17	11.67150888	0.615446796	0
18	11.93527179	0.615446796	0
19	12.19903471	0.615446796	0
20	12.46279762	0.637427039	0
21	12.68260005	0.72534801	0
22	12.90240247	0.835249223	0
23	13.14418514	0.945150437	0
24	13.36398757	1.033071408	0
25	13.60577024	1.142972621	0
26	13.78161218	1.340794806	0
27	13.93547388	1.582577475	0
28	14.06735534	1.78039966	0
29	14.22121704	2.044162572	0
30	14.37507874	2.285945242	0

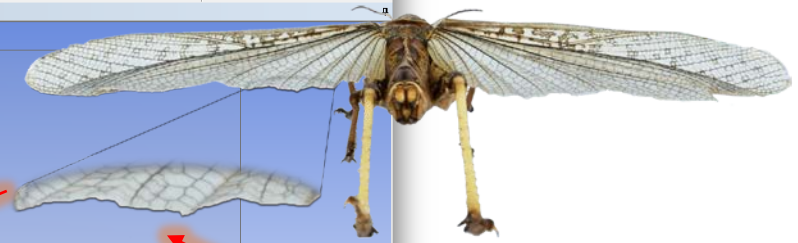
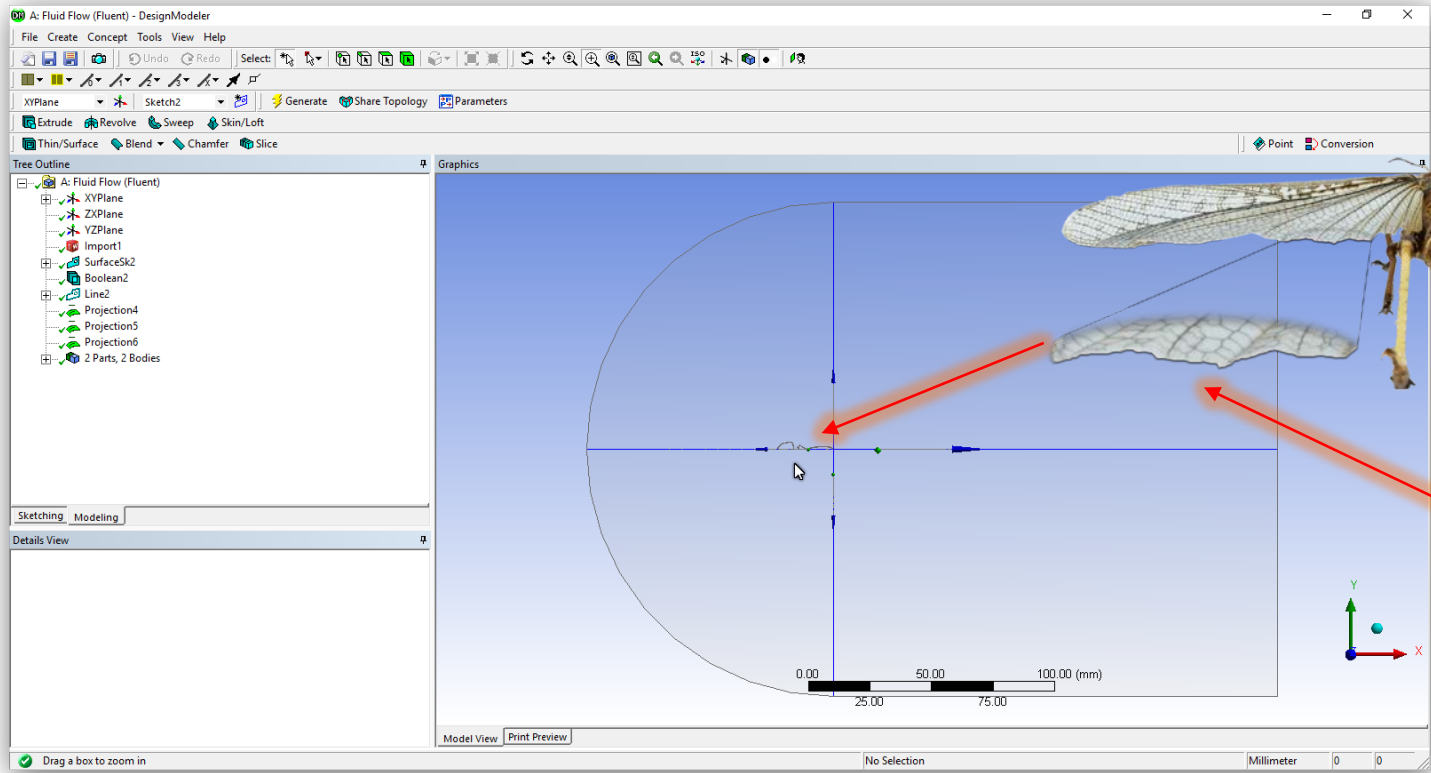
Stage-5: Running the Macro Code in SolidWorks



Stage-6: Importing the Wing Geometry and Creating Fluid Volume in ANSYS

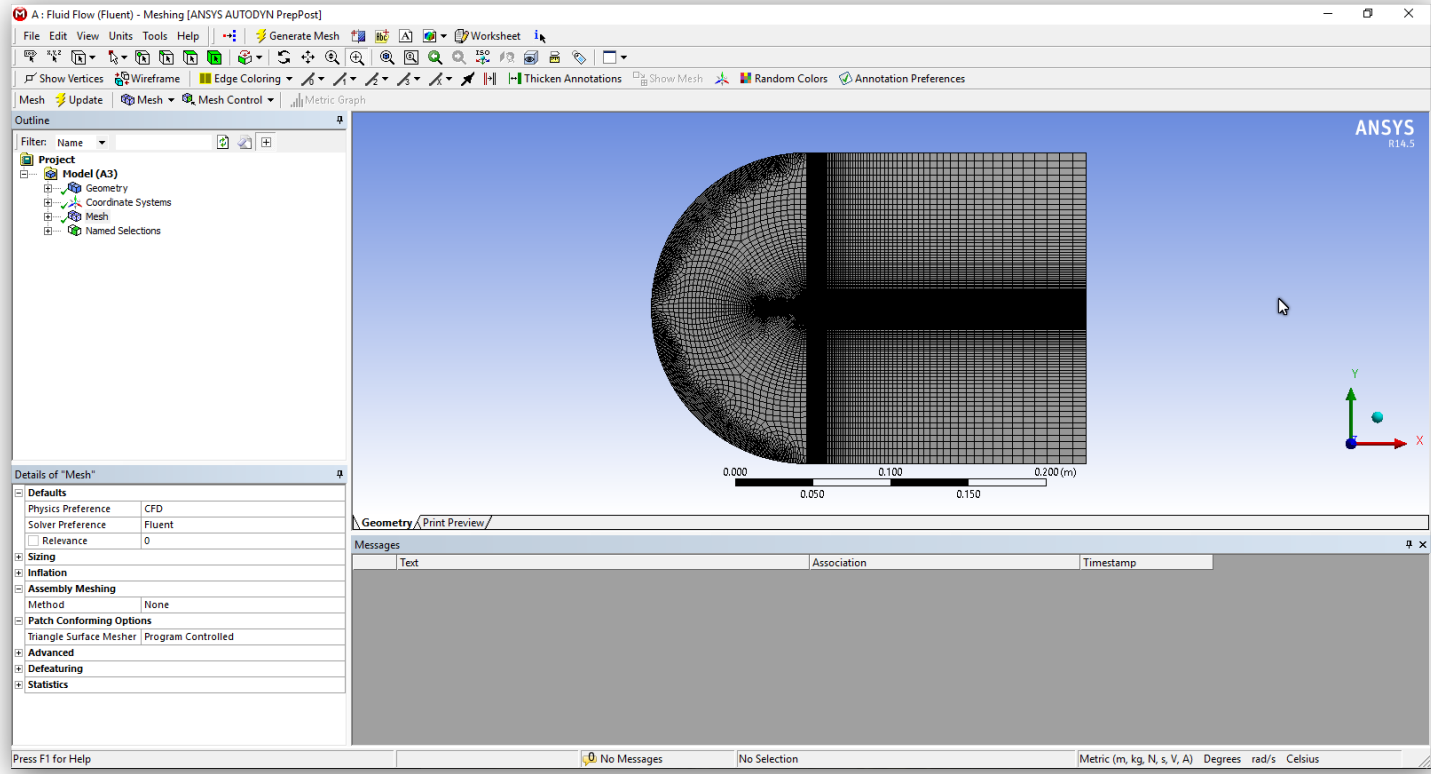


Stage-6: Importing the Wing Geometry and Creating Fluid Volume in ANSYS

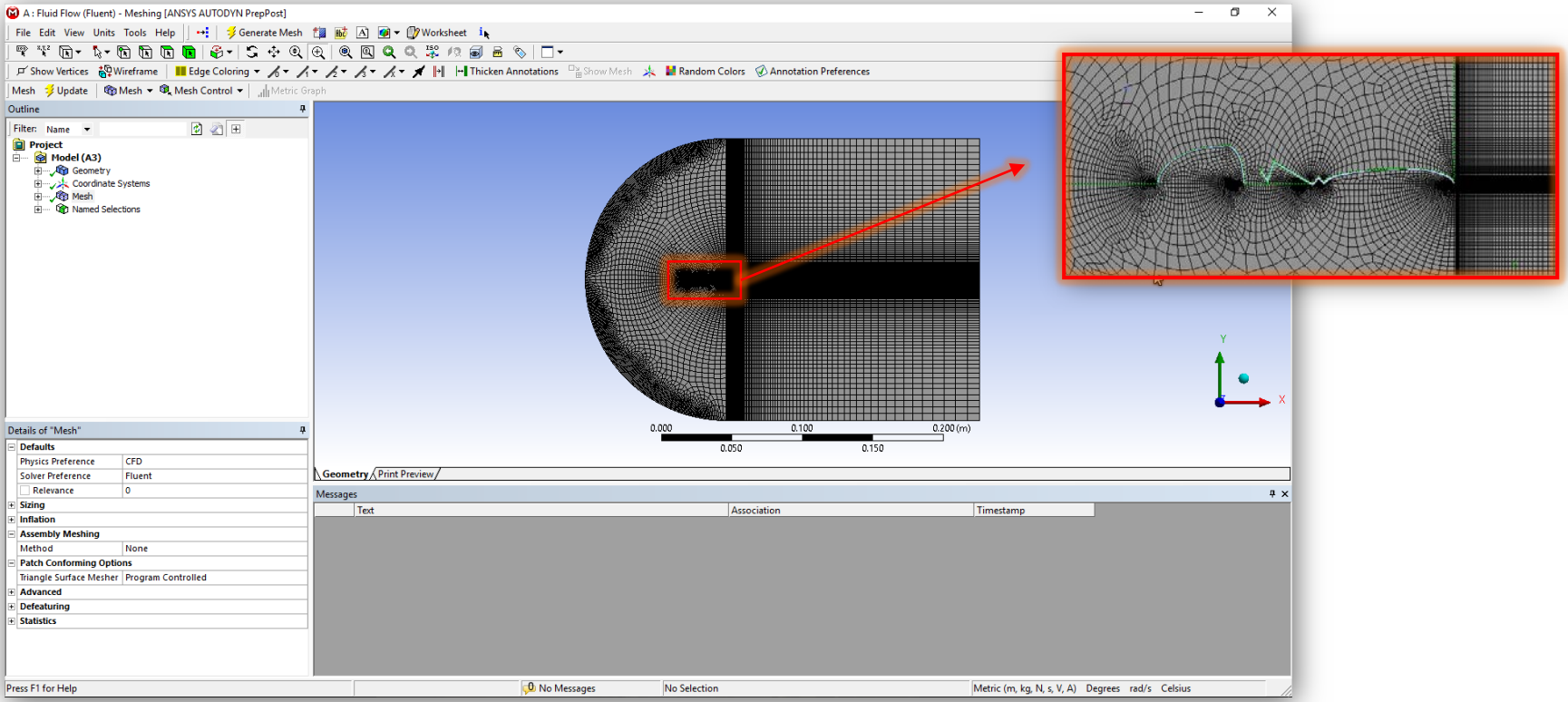


Corrugation

Stage-7: Generating Grids/Mesh and Evaluating its Resolution



Stage-7: Generating Grids/Mesh and Evaluating its Resolution



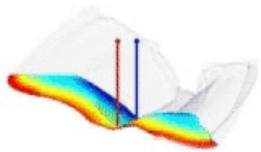
• LinLoc Aerodynamics: Governing Equations

➤ Flow over aerofoil is described by Navier-Stokes equation;

$$\frac{\partial u}{\partial t} + \rho(u \cdot \nabla)u - \nabla \sigma(u \cdot p) = \rho f$$

$$\nabla \cdot u = 0$$

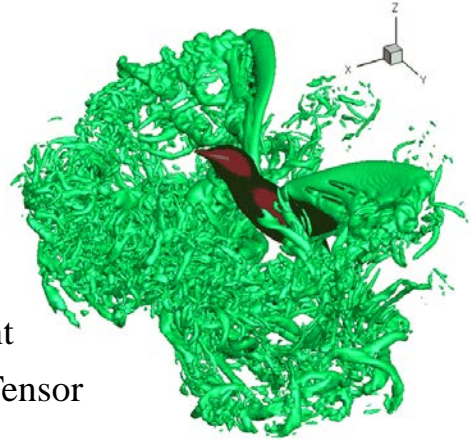
- u – Fluid Velocity
- ρ – Fluid Density
- f – Body Force
- t – Time
- p – Pressure



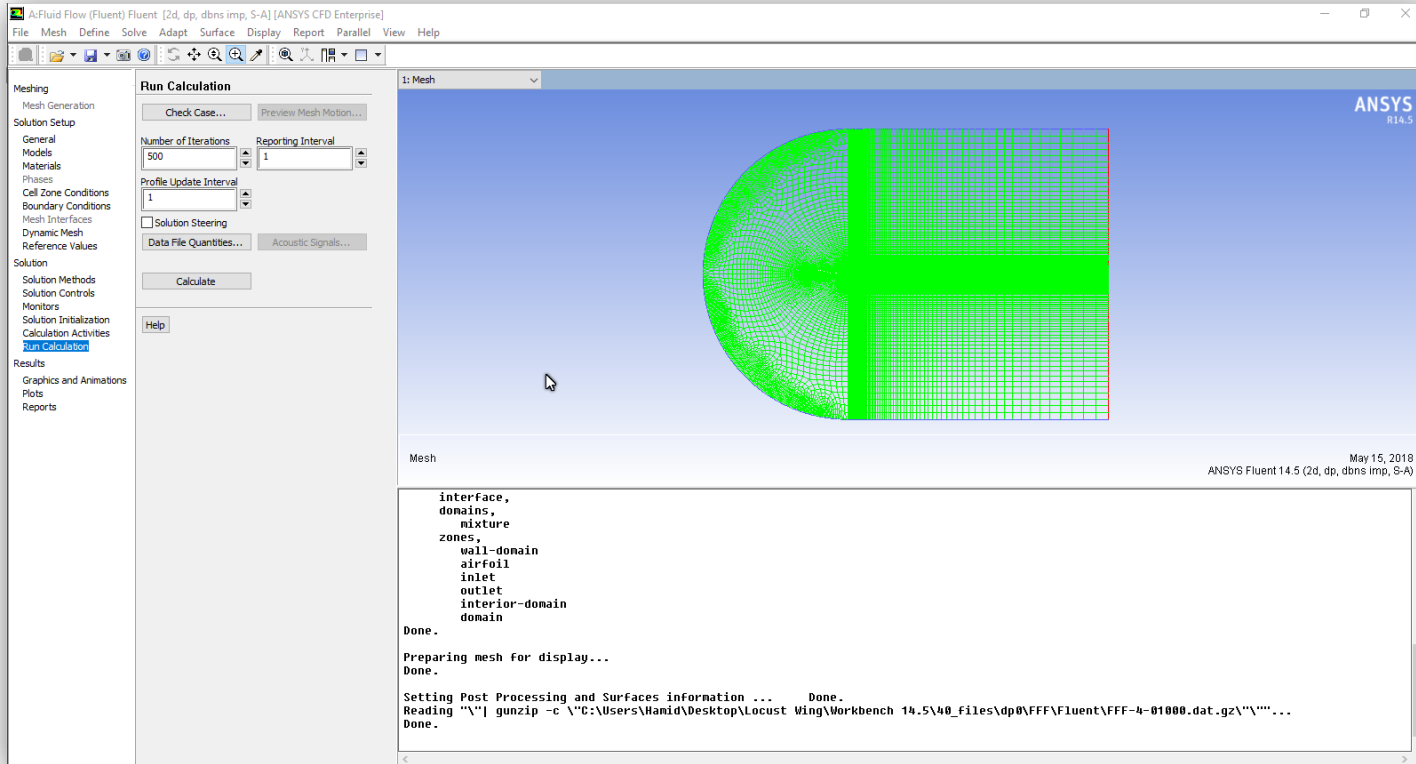
➤ Our turbulence model is described by Spalart-Allmaras equation;

$$\frac{\overline{D} v_T}{\overline{D}_t} = \nabla \cdot \left(\frac{v_T}{\sigma_v} \nabla v_T \right) + S v$$

- v_T – Turbulent Viscosity
- ∇v_T – Turbulent Viscosity Gradient
- S_v – Measure of the Deformation Tensor
- σ_v – Turbulent Prandtl Number



Stage-8.1: Setting Up Solver Model, Boundary Conditions, and Flow Problem



The screenshot displays the ANSYS Fluent interface. The 'Run Calculation' dialog box is open, showing the following settings:

- Number of Iterations: 500
- Reporting Interval: 1
- Profile Update Interval: 1
- Solution Steering
- Data File Quantities... Acoustic Signals...

The 'Calculate' button is visible. The main window shows a green meshed airfoil model. The bottom panel displays the following text:

```
interface,  
domains,  
mixture  
zones,  
wall-domain  
airfoil  
inlet  
outlet  
interior-domain  
domain  
Done.  
Preparing mesh for display...  
Done.  
Setting Post Processing and Surfaces information ... Done.  
Reading "\\\\" gunzip -c \\\"C:\Users\Hamid\Desktop\Locust Wing\Workbench 14.5\40_files\dp0\FFF\Fluent\FFF-4-01000.dat.gz\"\\\"...  
Done.
```

Stage-8.1: Setting Up Solver Model, Boundary Conditions, and Flow Problem

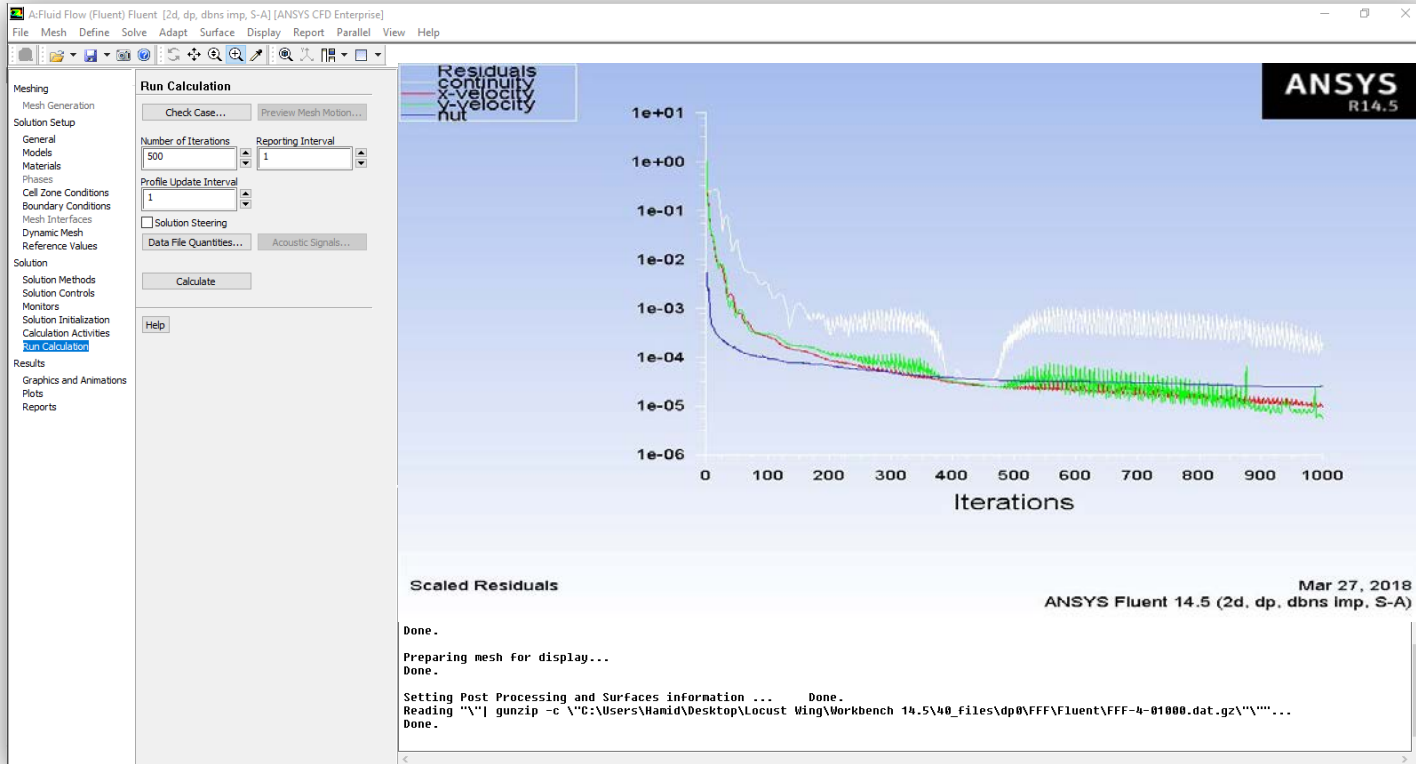
Define;
Material,
Boundary Conditions,
Reference Values,
Solution Method,
Initialization, and
Calculation

Processes Window

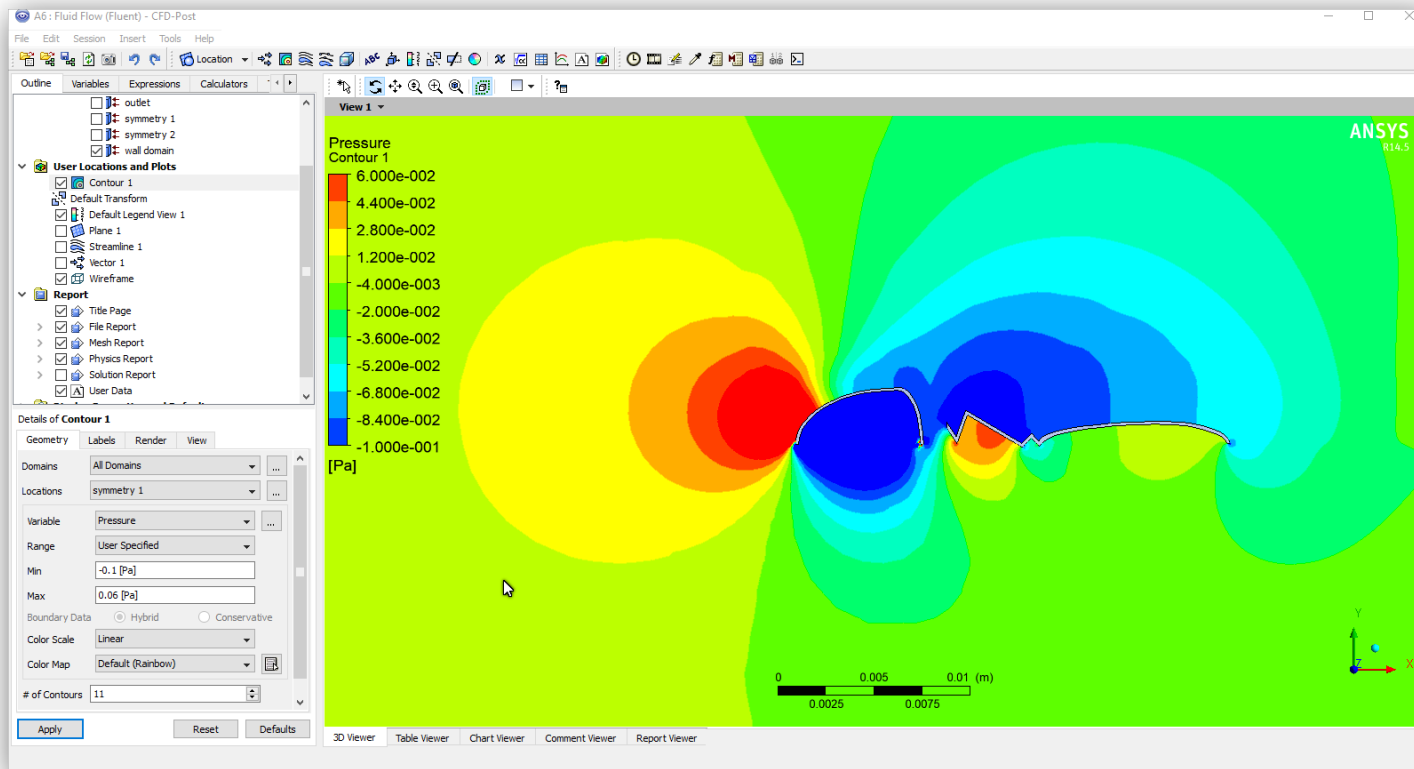
The screenshot shows the ANSYS Fluent interface. On the left is a tree view with 'Run Calculation' selected. The 'Run Calculation' panel is active, showing 'Number of Iterations' set to 500 and 'Reporting Interval' set to 1. The 'Calculate' button is visible. The main window displays a green mesh of a circular domain with a vertical slit. At the bottom, the 'Processes' window shows the following text:

```
interface,  
domains,  
mixture  
zones,  
wall-domain  
airfoil  
inlet  
outlet  
interior-domain  
domain  
Done.  
Preparing mesh for display...  
Done.  
Setting Post Processing and Surfaces information ... Done.  
Reading "\ | gunzip -c \"C:\Users\Hamid\Desktop\Locust Wing\Workbench 14.5\files\dp0\FFF\Fluent\FFF-4-01000.dat.gz\" ...  
Done.
```


Stage-8.2: Iterating Towards a Solution



Stage-9.1: Post-Processing Result- Pressure Contour



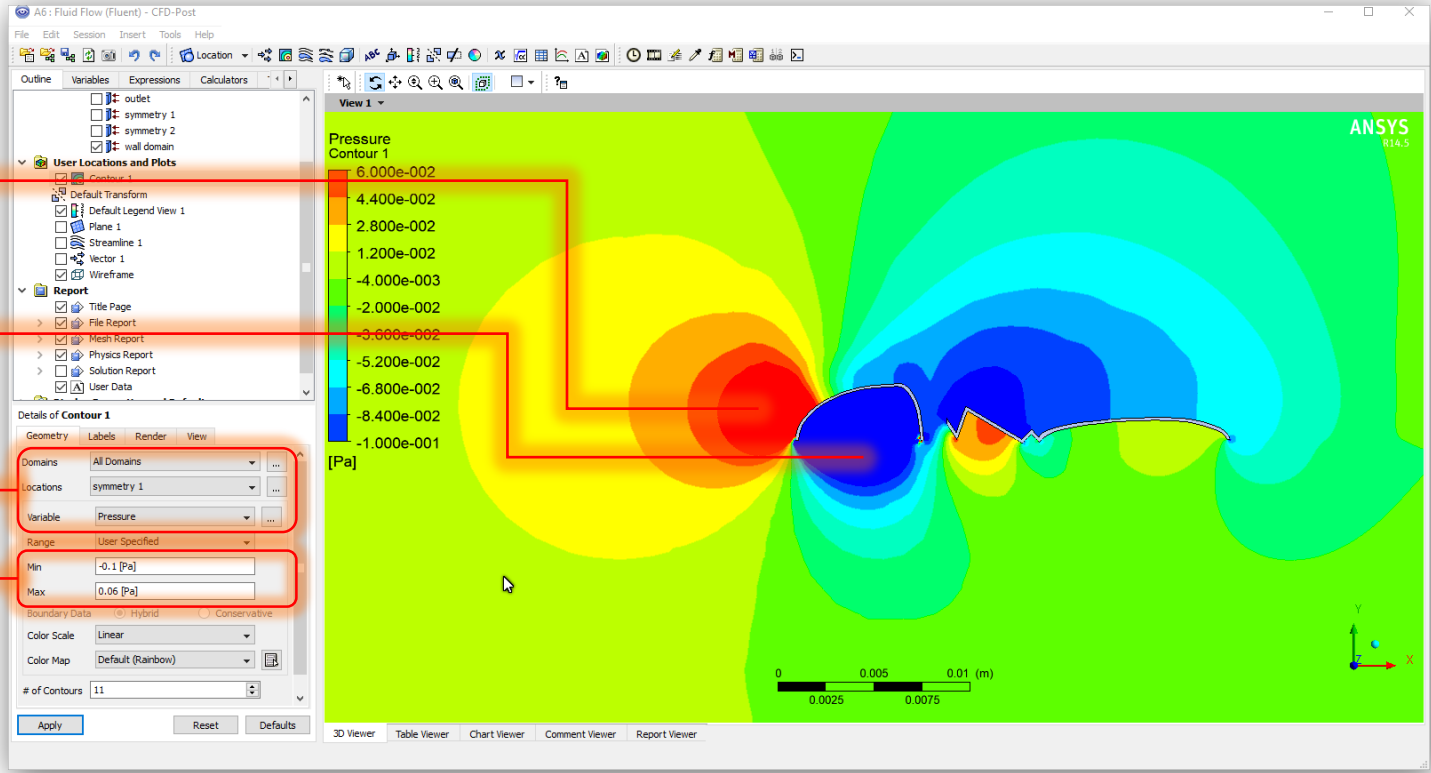
Stage-9.1: Post-Processing Result- Pressure Contour

Maximum pressure at the leading edge

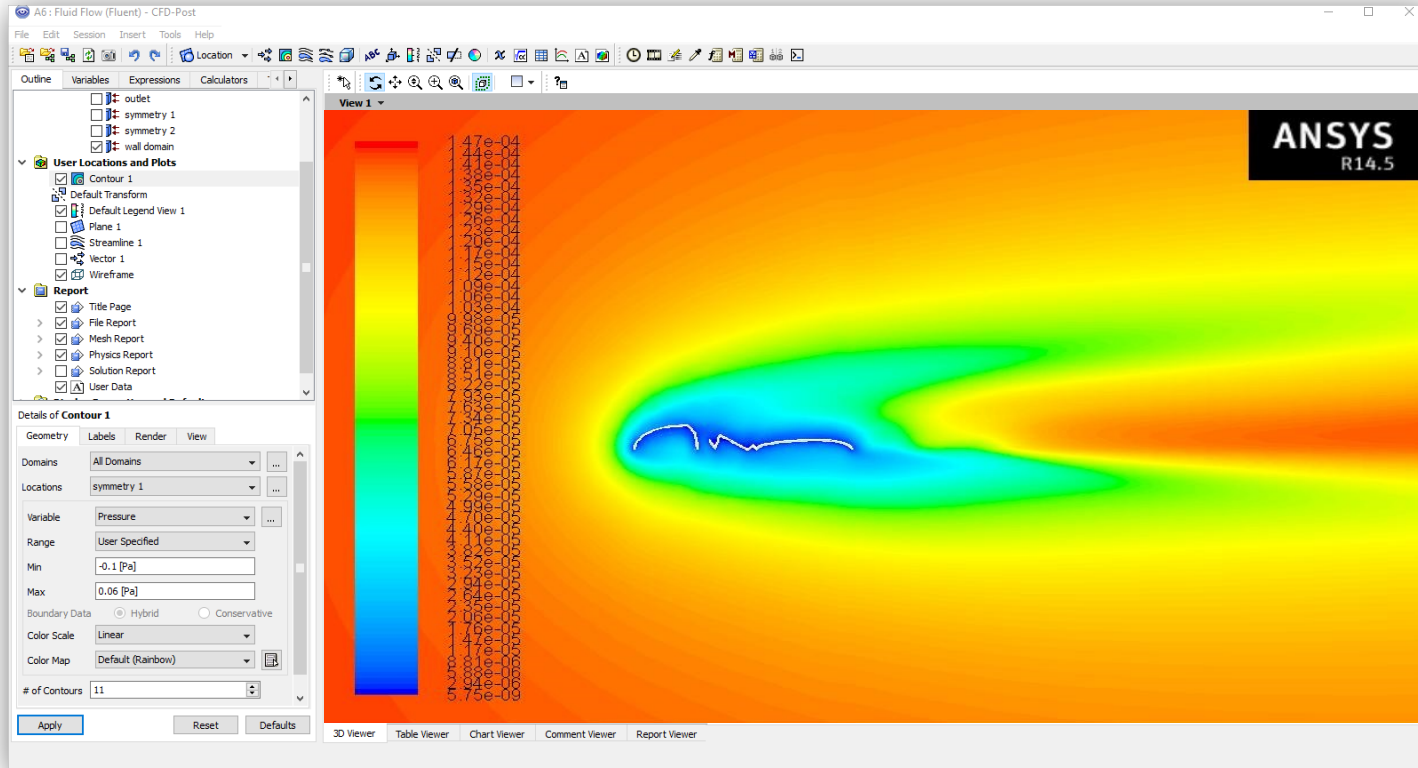
Minimum pressure at the bottom of aerofoil

Domain Selection

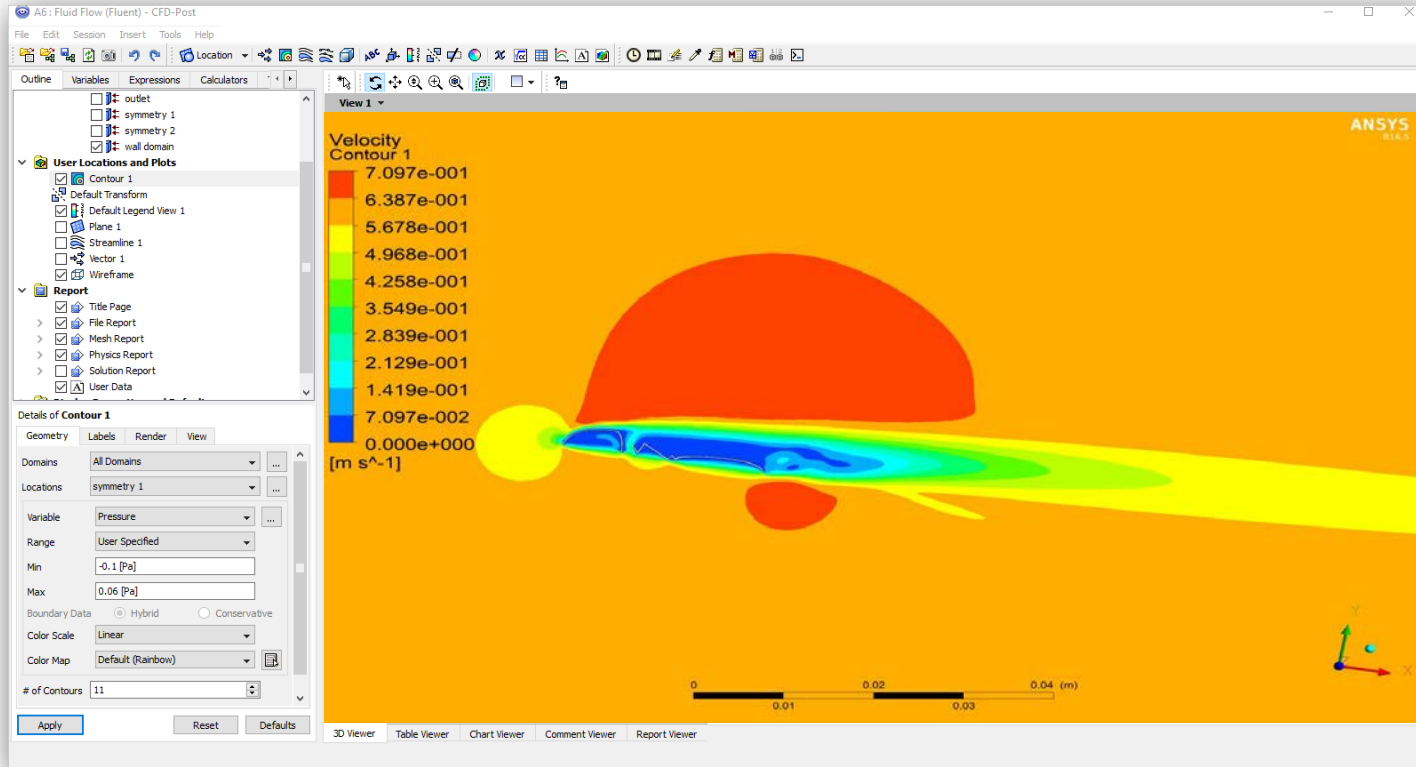
Range Selection



Stage-9.2: Post-Processing Result- Turbulence Contour



Stage-9.3: Post-Processing Result- Velocity Contour



Results for Publication

Reynolds Number, $R_e = ul/v_\infty$

Strouhal Number, $St = fl/u$

Lift Coefficient, $C_L = L/(0.5\rho u^2 S)$

Drag Coefficient, $C_D = D/(0.5\rho u^2 S)$

L – Lift

D – Drag

S – Area

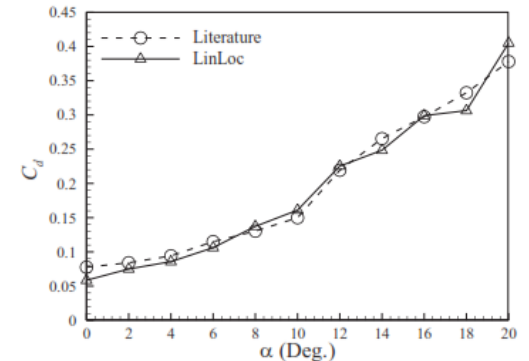
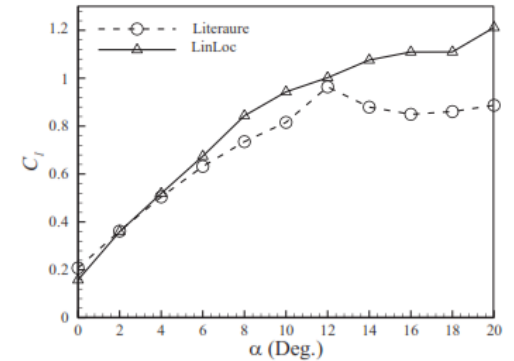
ρ – Air Density

l – Characteristic length

v_∞ – Kinematic Viscosity

f – Frequency of Vortex Shedding

Profile	C_L	C_D
Locust-1	0.452	0.230
Locust-2	0.385	0.240
Locust-3	0.495	0.241
Locust-4	0.505	0.243
Locust-5	0.419	0.248
Locust-6	0.643	0.238
Locust-7	0.861	0.260
Locust-8	0.264	0.240
Locust-9	0.259	0.241
Locust-10	0.427	0.260



• Subproblem-1: Linloc Aerodynamics (Continuation)

✓ Wind tunnel testing

The manufactured wing is then subjected to low-speed (subsonic) wind-tunnel testing to obtain its **real-world aerodynamic characteristics** and flow-field structures. Finally, the results are compared to the simulation results, and the available literature, to determine its contribution to the knowledge.

✓ Rapid prototyping (3D Printing/Injection moulding)

The final wing design concept is 3D printed through additive manufacturing using **long chain crystalline polymer** (closest material to insect wing). Furthermore, the wings are prototyped through injection moulding to compare the two manufacturing processes for optimisation purposes.



