EU HORIZON 2020 PROJECT STEP2DYNA SEMINAR, TSINGHUA UNIVERSITY

UNIVERSITY OF 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**

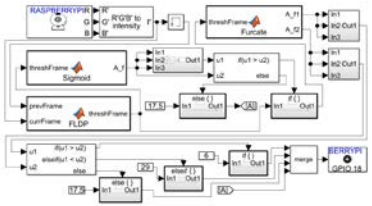
✓ **Future Work**

- **Objective-1 Continuation**
- **Objective-2 Initialisation**

# • Self-Introduction


**B.Eng.**
Aeronautics

**Biozopter**



**MRes.**
Aerospace

Cranfield University

**FLDP**

**Ph.D.**
Computer

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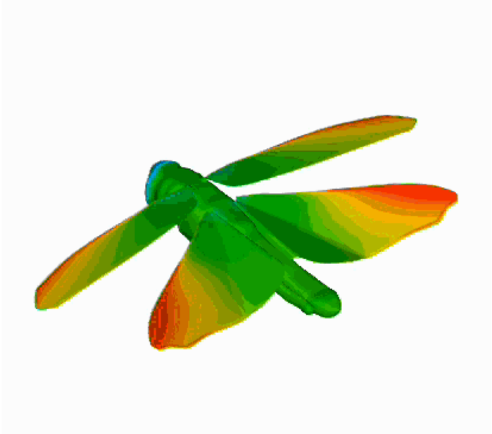
**LinLoc**

- ## Problem Statement

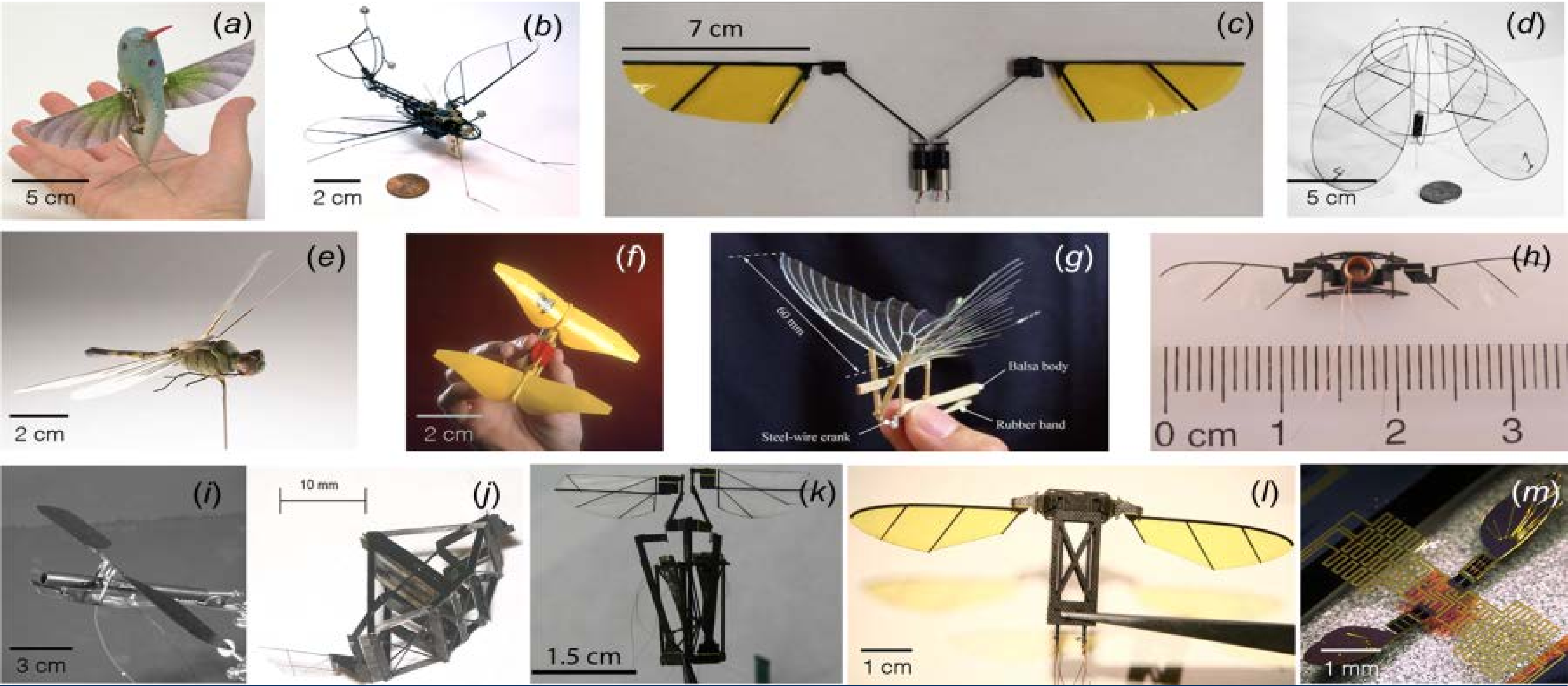
✓ **Problem at hand:** **A fully bioinspired autonomous flapping unmanned aerial vehicle.**

**(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

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# • 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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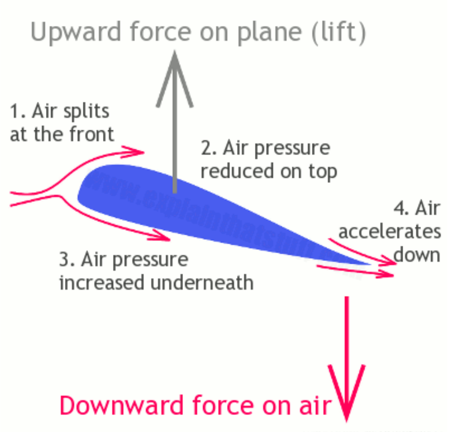
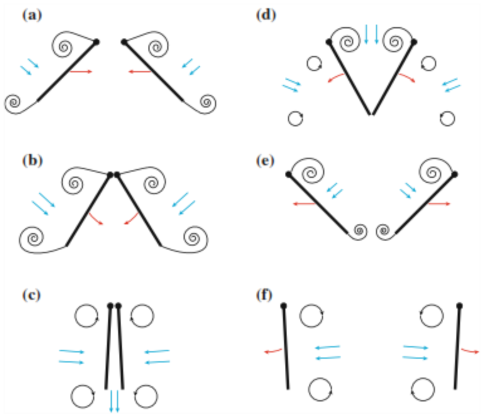
# • Subproblem-1: Linloc Aerodynamics

## ✓ Fundamentals of Conventional and Flapping Flight



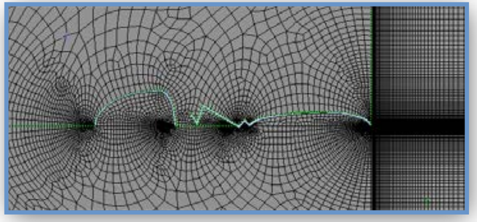

**Locust in a wind-tunnel test, recorded using high-speed camera.**

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

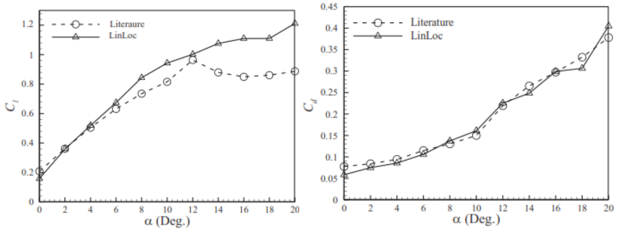
**Clap-and-peel motion by use of two rigid wing sections with the red arrows indicating the direction of the wing motion and the blue arrows indicating the direction of the induced flow, for the instroke (a–c) and outstroke (d–f ).**

# • Linloc Aerodynamics: Computational Fluid Dynamics (Major Stages)

## 1) Geometry Modeling and Meshing



## 4) Observation & Comments



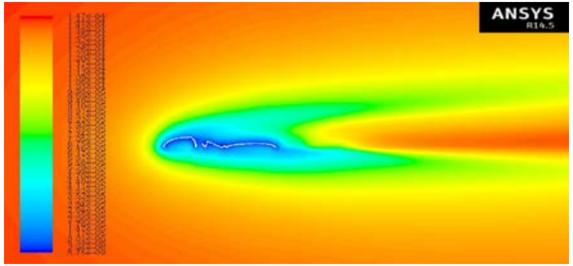

## 2) Governing equations and Solution parameters

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

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

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

## 3) Results and discussions

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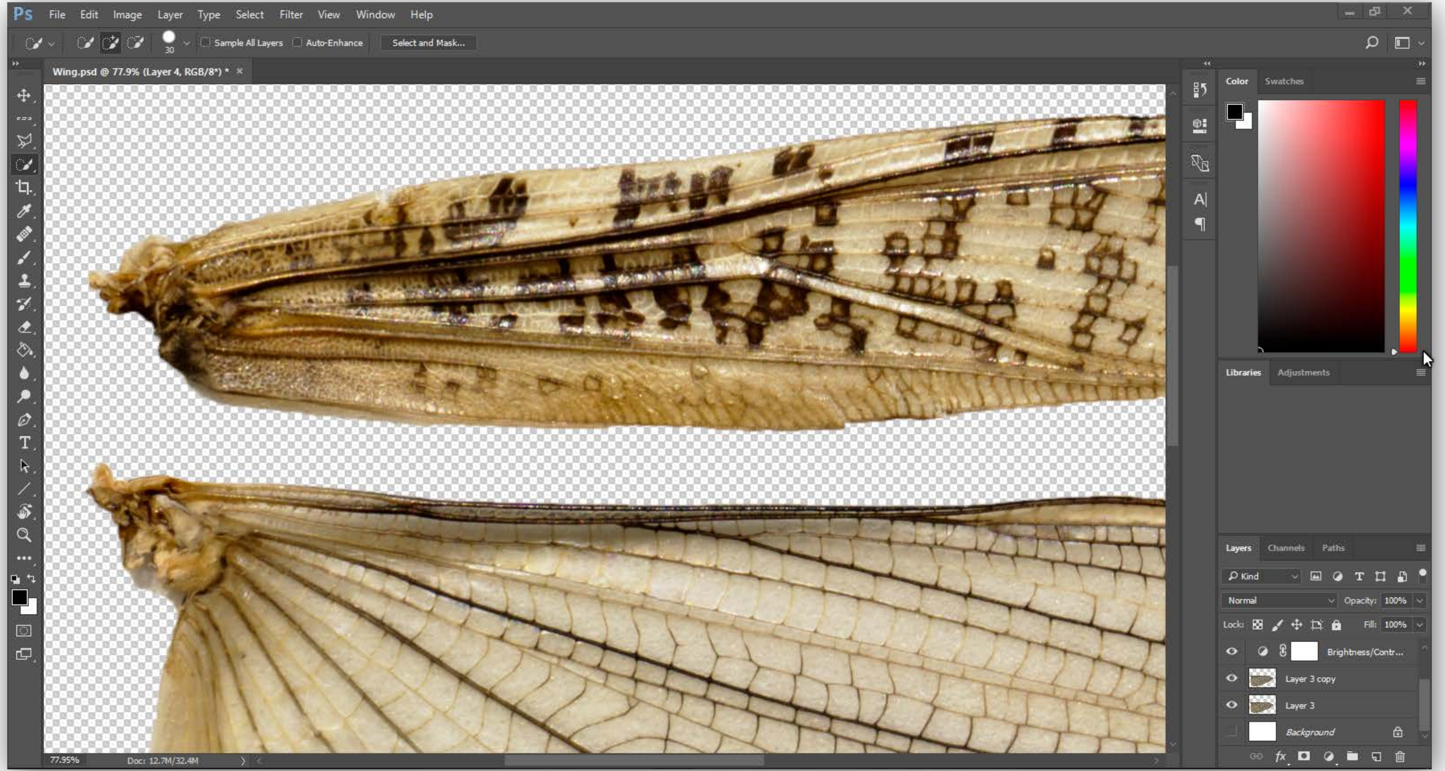
- <u>Stage-1: Taxidermy and Macro Photography</u>

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

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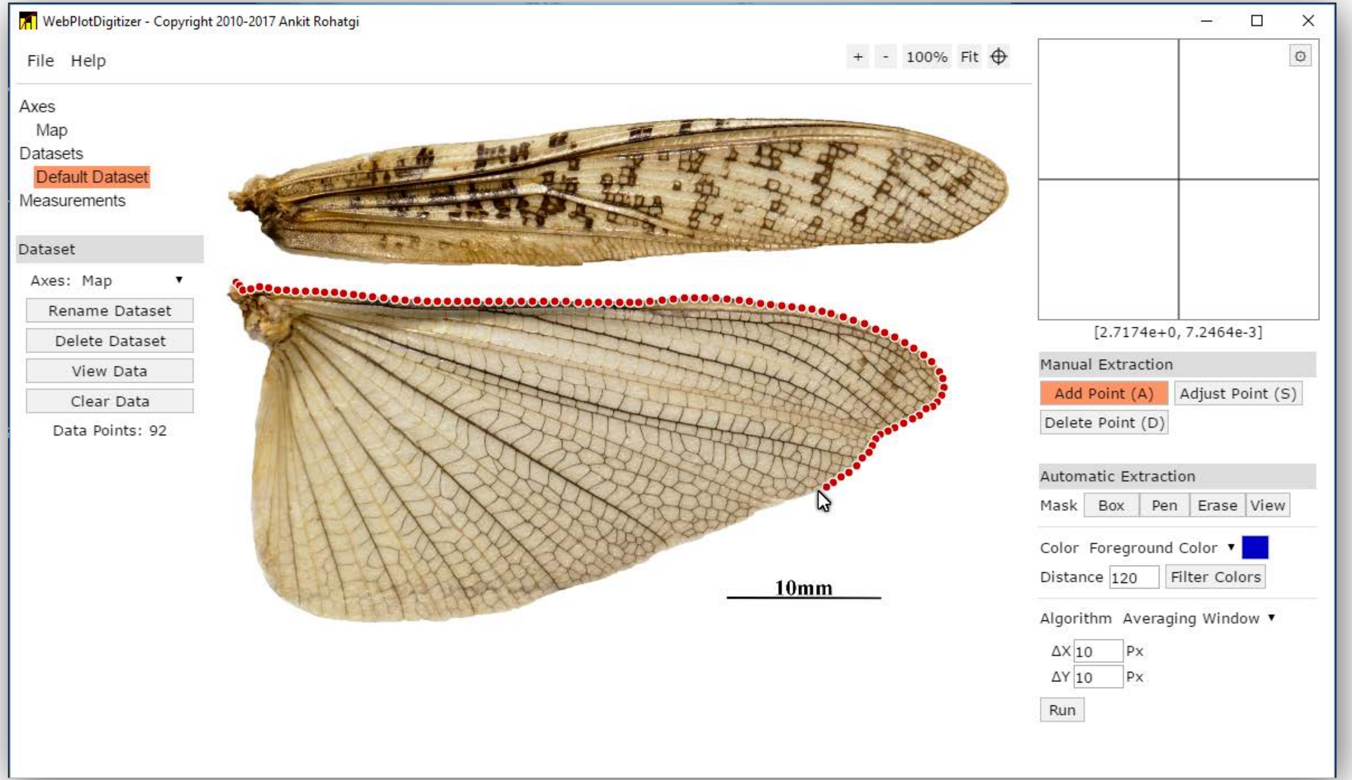
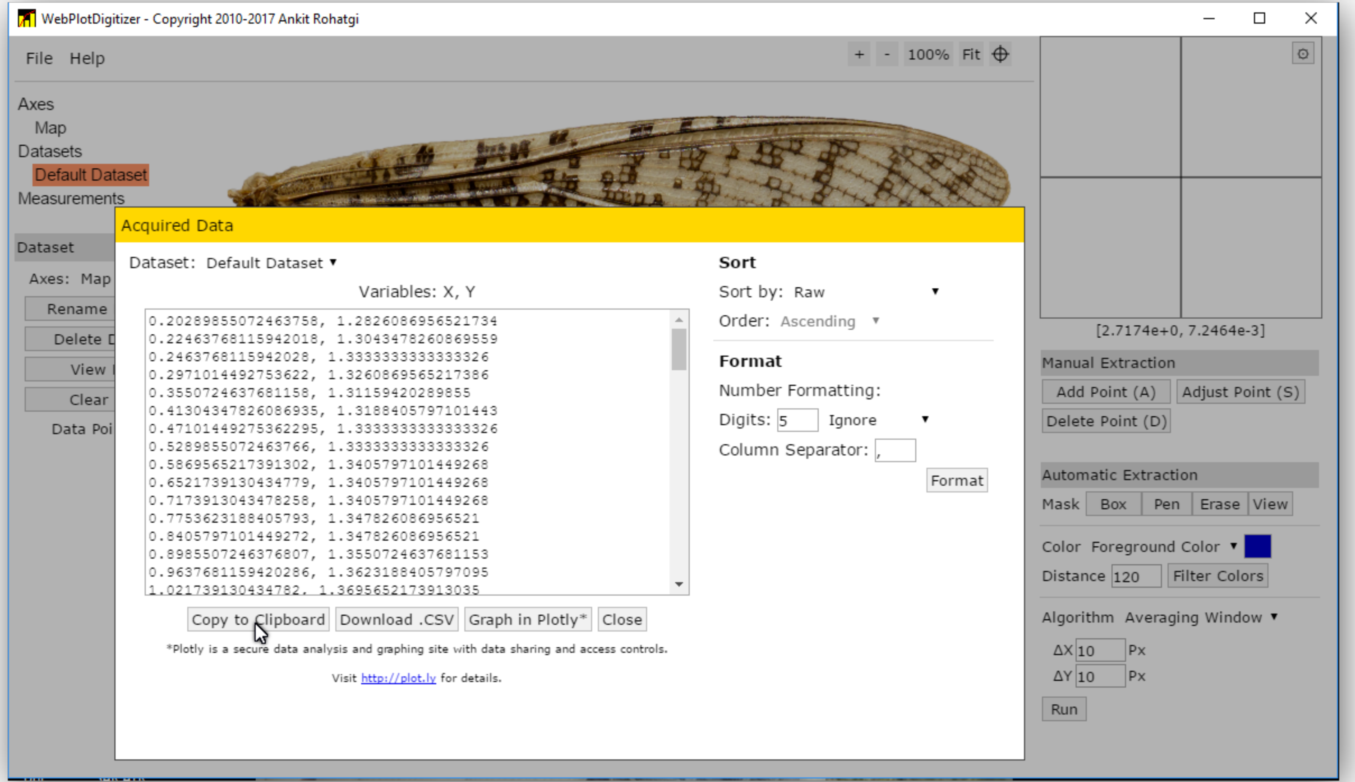
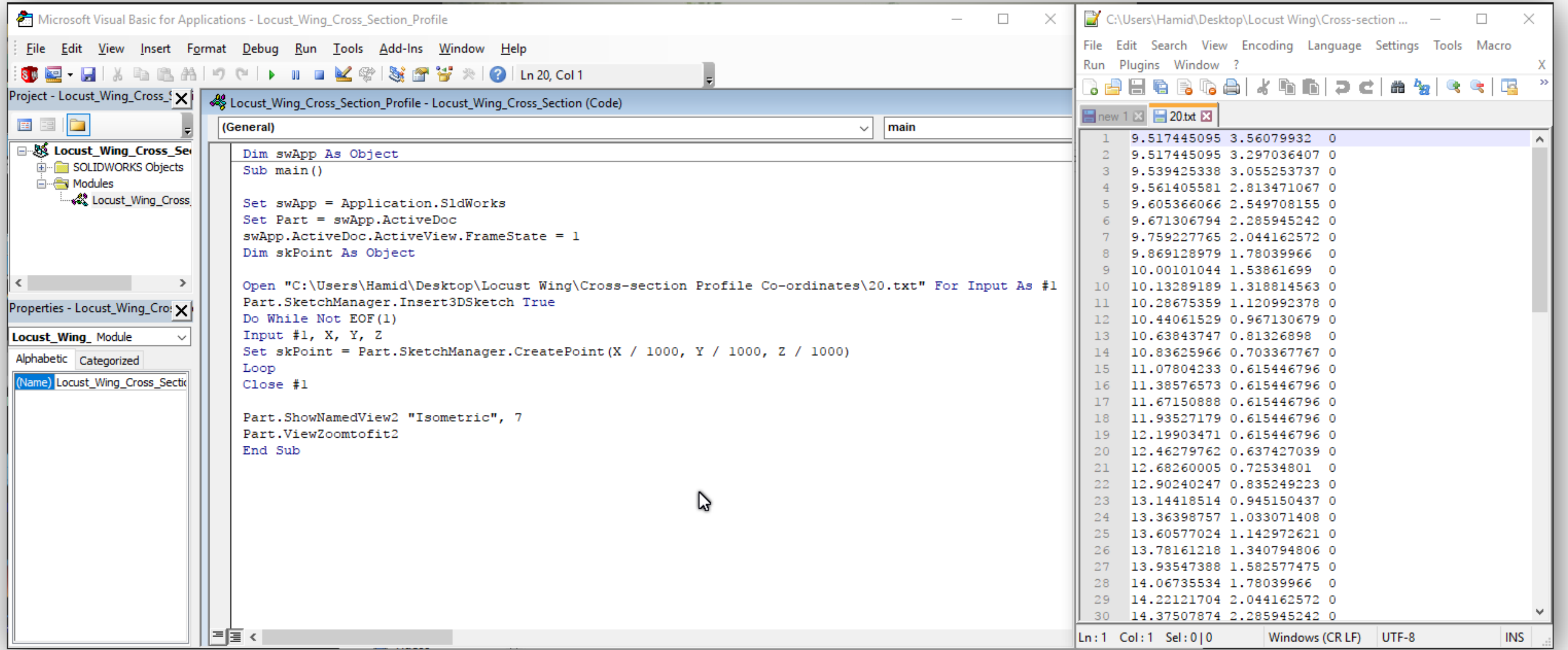
- Stage-3: Digitizing Wing in WebPlotDigitizer



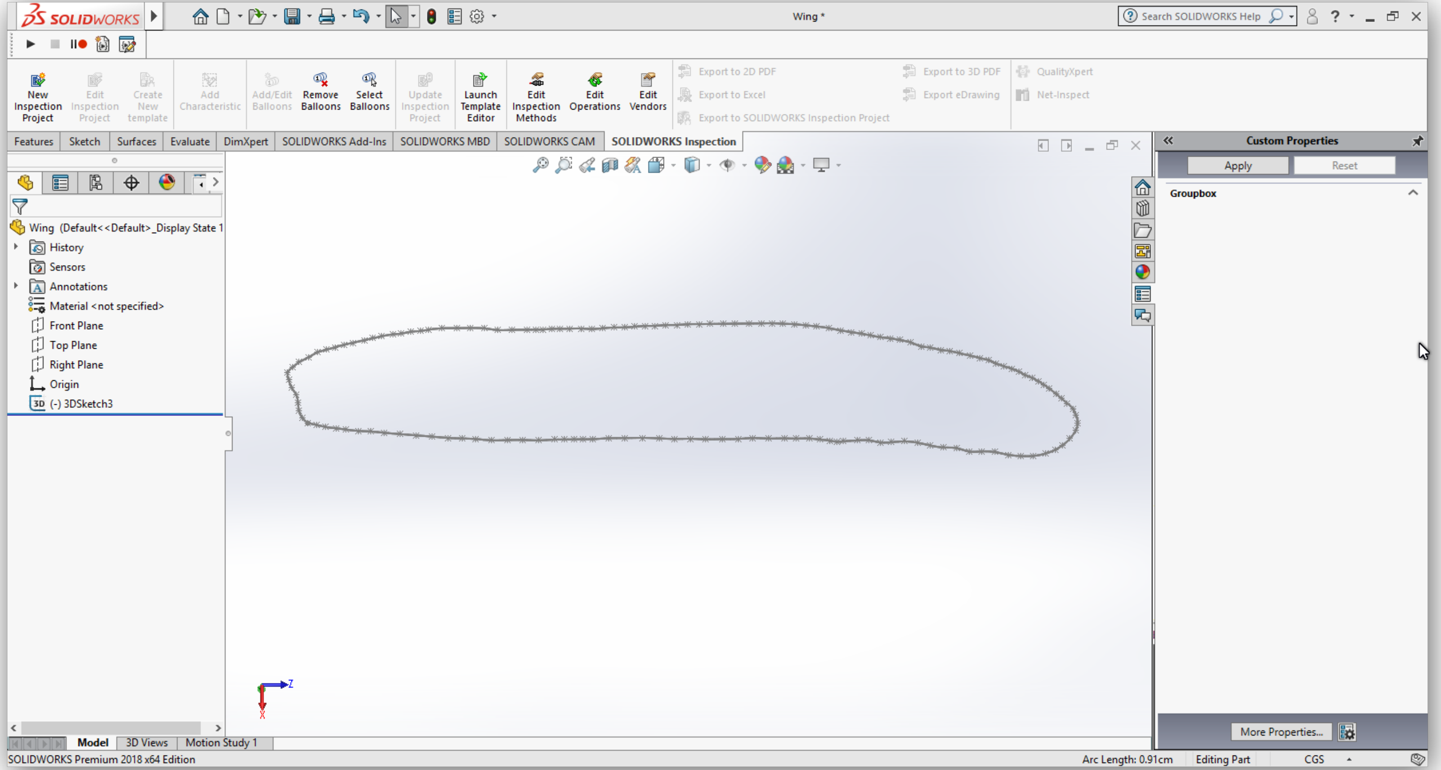
- Stage-3: Exporting Wing Coordinates



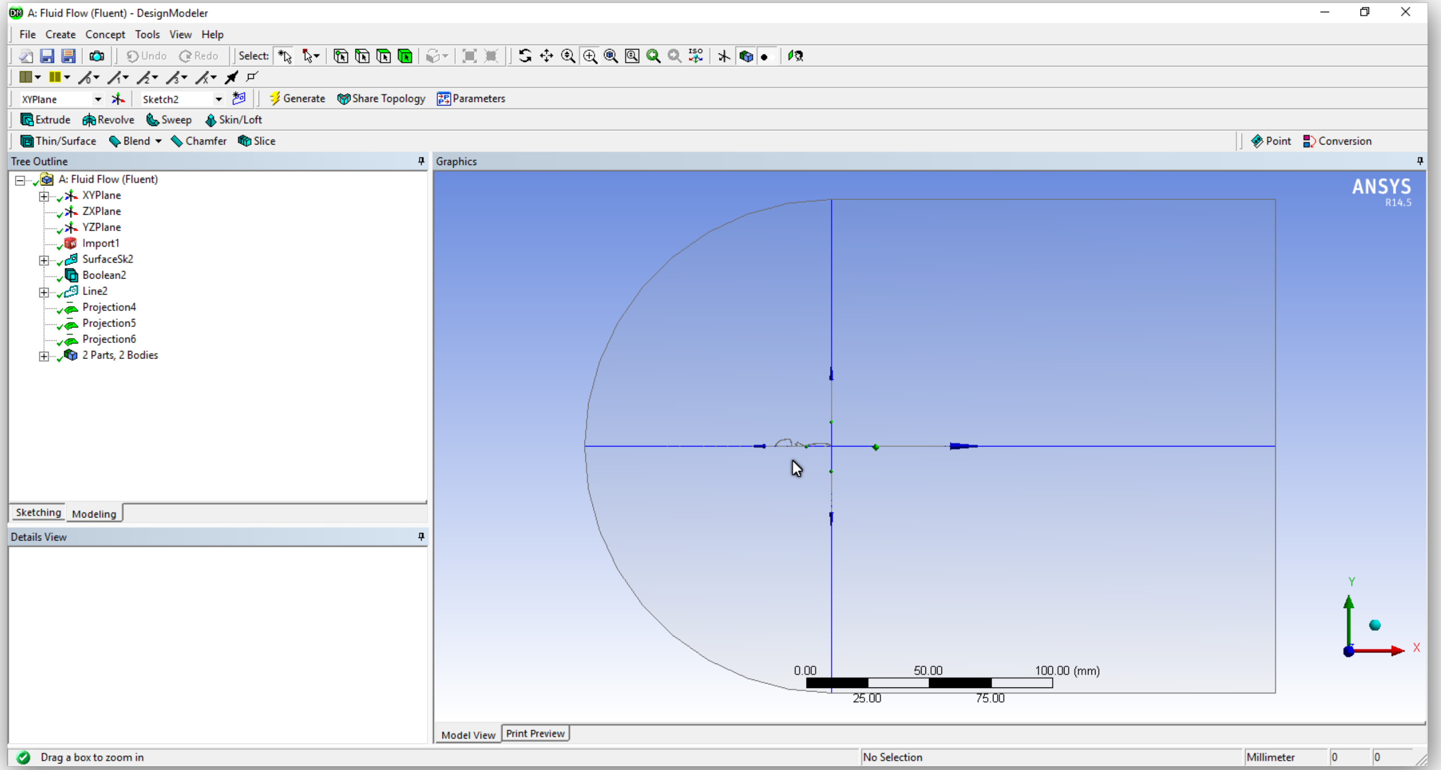
- # Stage-4: Writing the .swp Code in MS Visual Basic



- Stage-5: Running the Macro Code in SolidWorks



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



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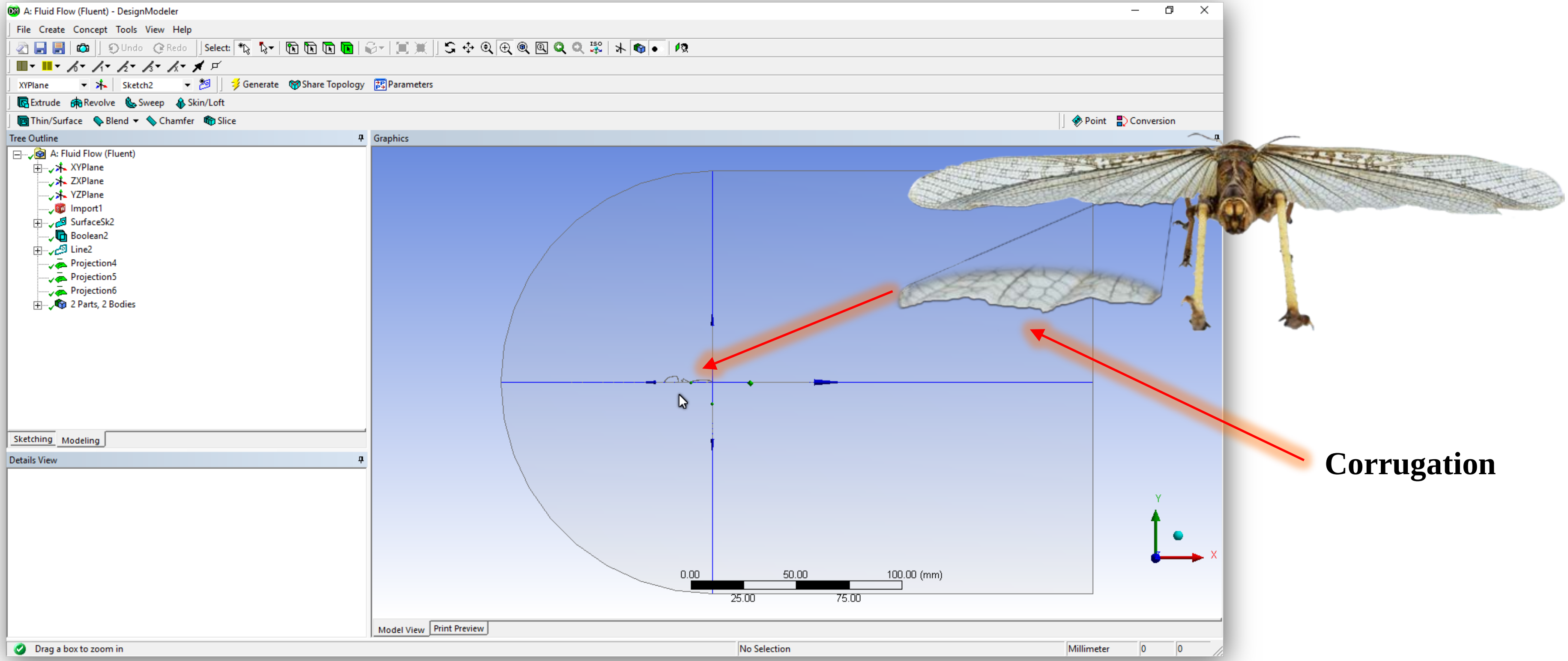
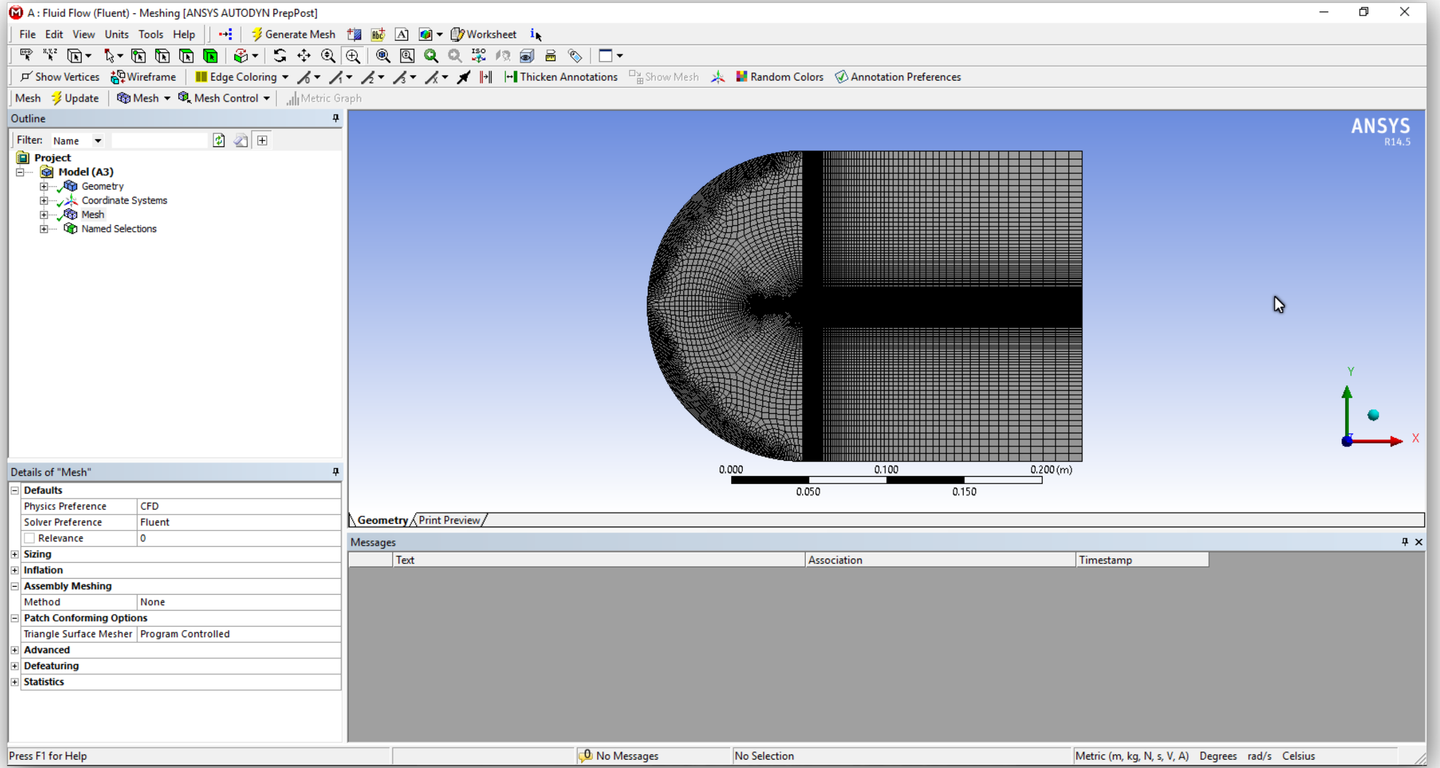


- Stage-7: Generating Grids/Mesh and Evaluating its Resolution

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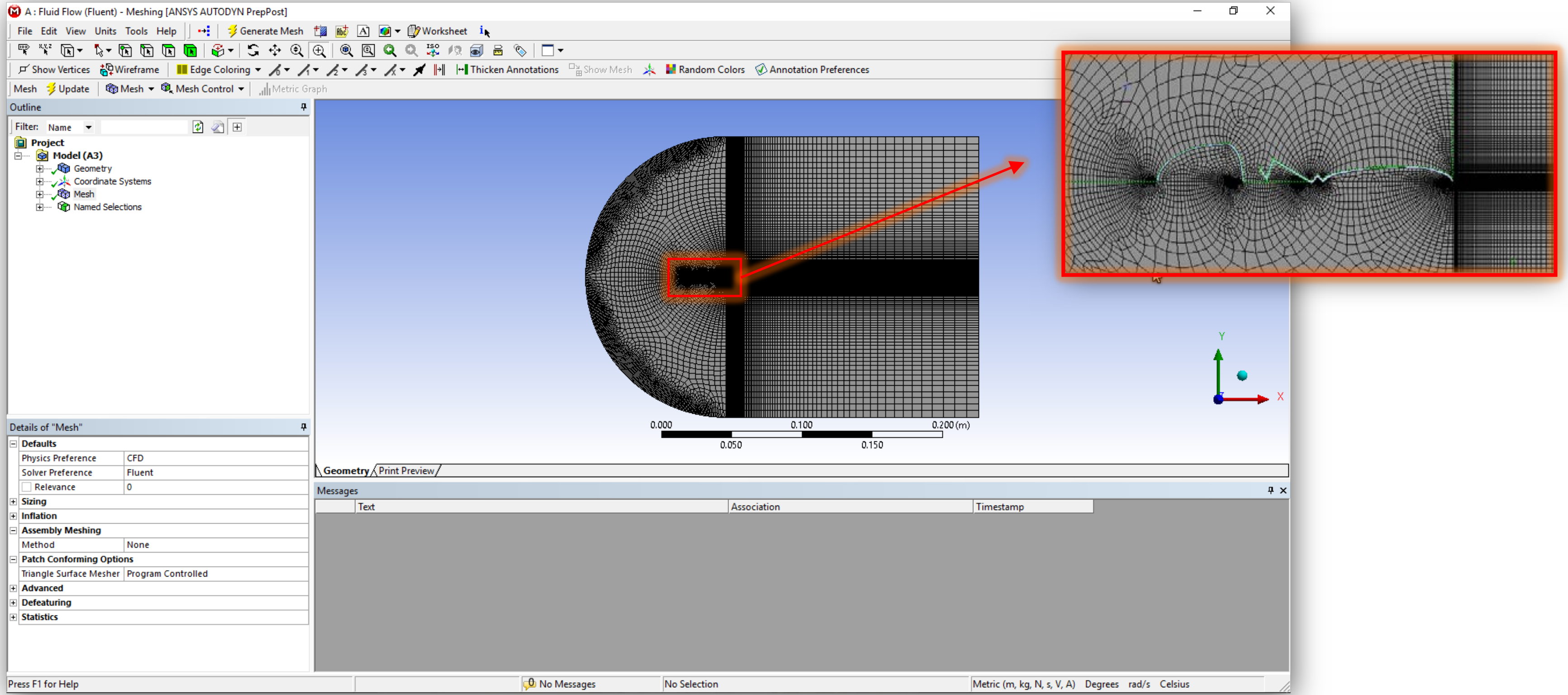
# • Stage-7: Generating Grids/Mesh and Evaluating its Resolution



# • LinLoc Aerodynamics: Governing Equations

➢ **Flow over aerofoil is described by Navier-Stokes equation;**

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

$$\nabla \cdot u = 0$$

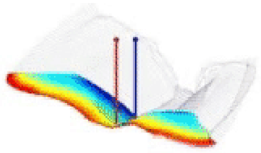
$u$– Fluid Velocity

$\rho$– Fluid Density

$f$– Body Force

$t$– Time

$p$– Pressure



➢ **Our turbulence model is described by Spalart-Allmaras equation;**

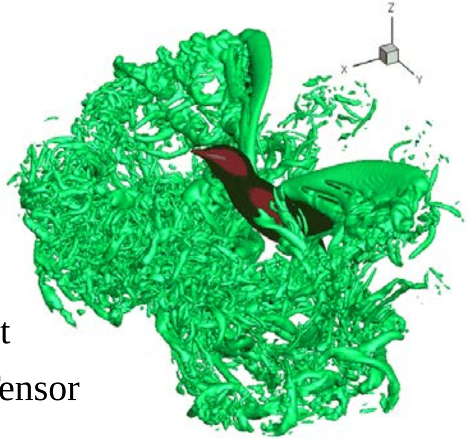
$$\frac{\overline{D}_{v_T}}{\overline{D}_t} = \nabla \cdot \left(\frac{v_T}{\sigma_v}\nabla vT\right) + Sv$$

$v_T$ – Turbulent Viscosity

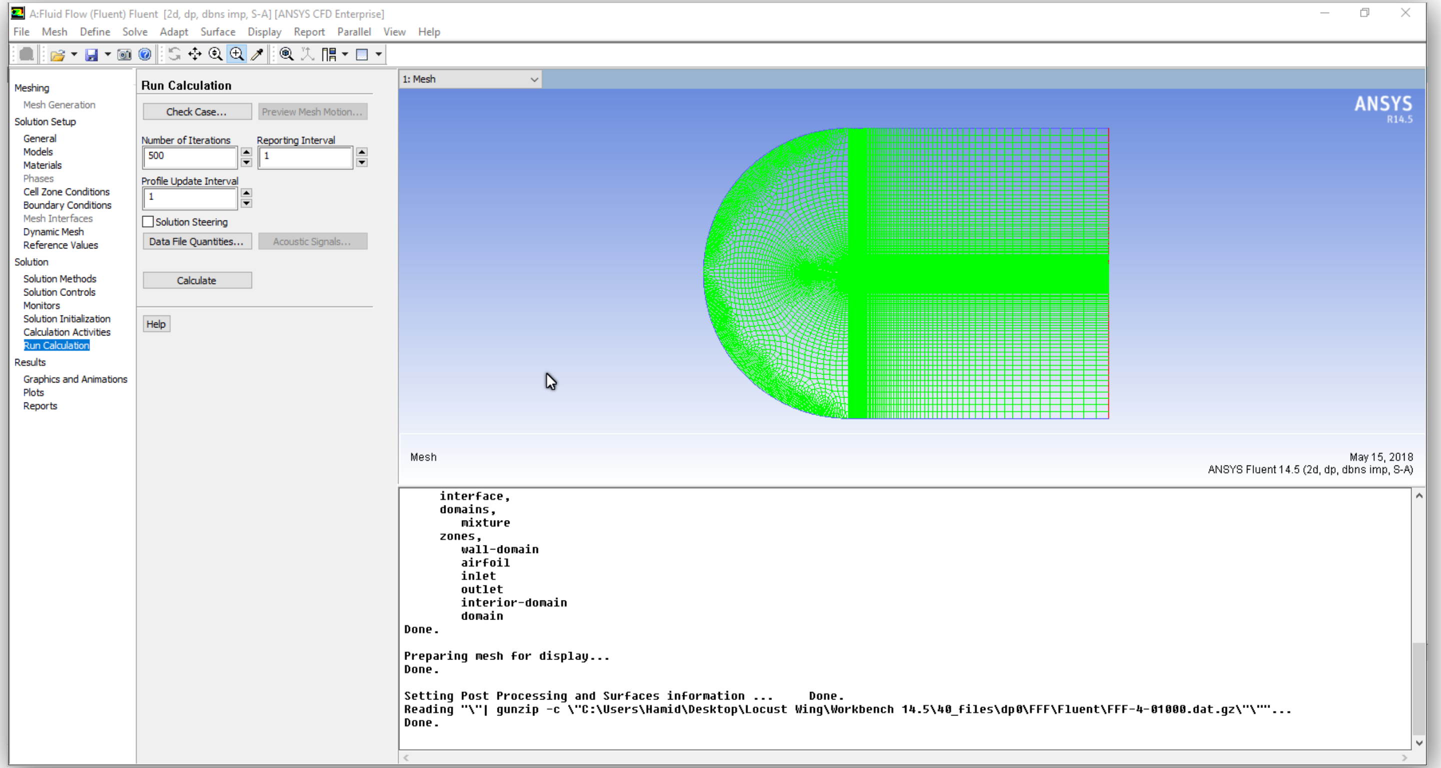
$\nabla vT$– Turbulent Viscosity Gradient

$S_v$– Measure of the Deformation Tensor

$\sigma_v$– Turbulent Prandtl Number



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

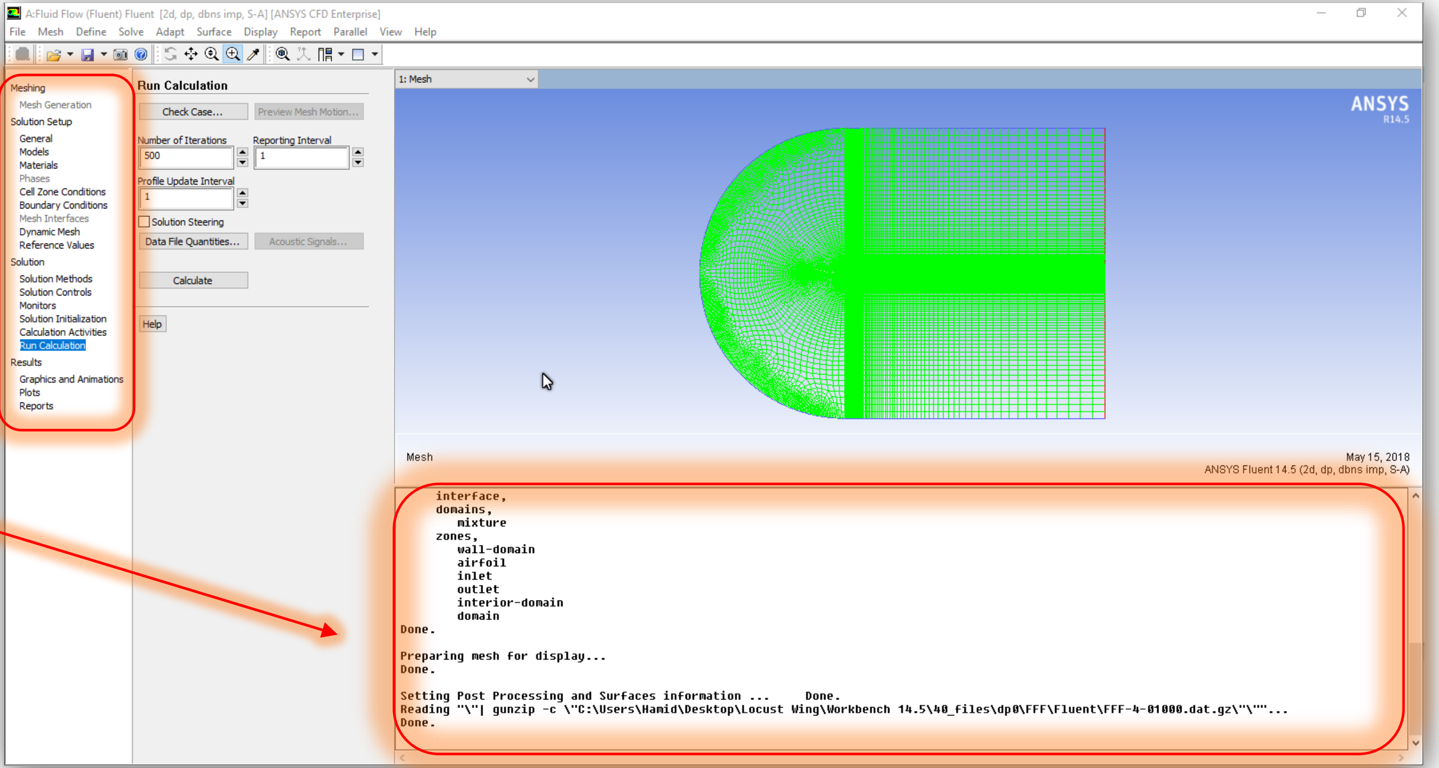


# • Stage-8.1: Setting Up Solver Model, Boundary Conditions, and Flow Problem

**Define;**

**Material, Boundary Conditions, Reference Values, Solution Method, Initialization, and Calculation**

**Processes Window**

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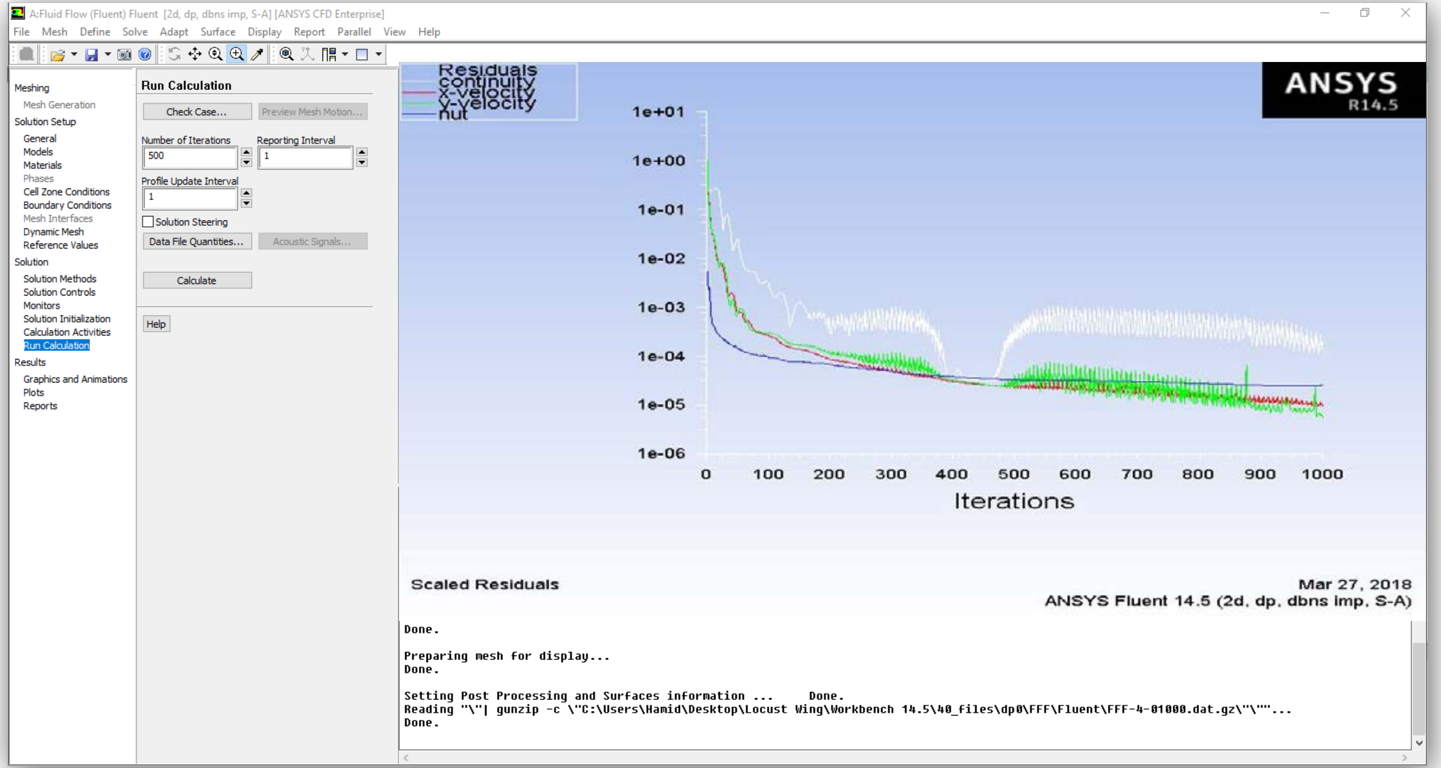
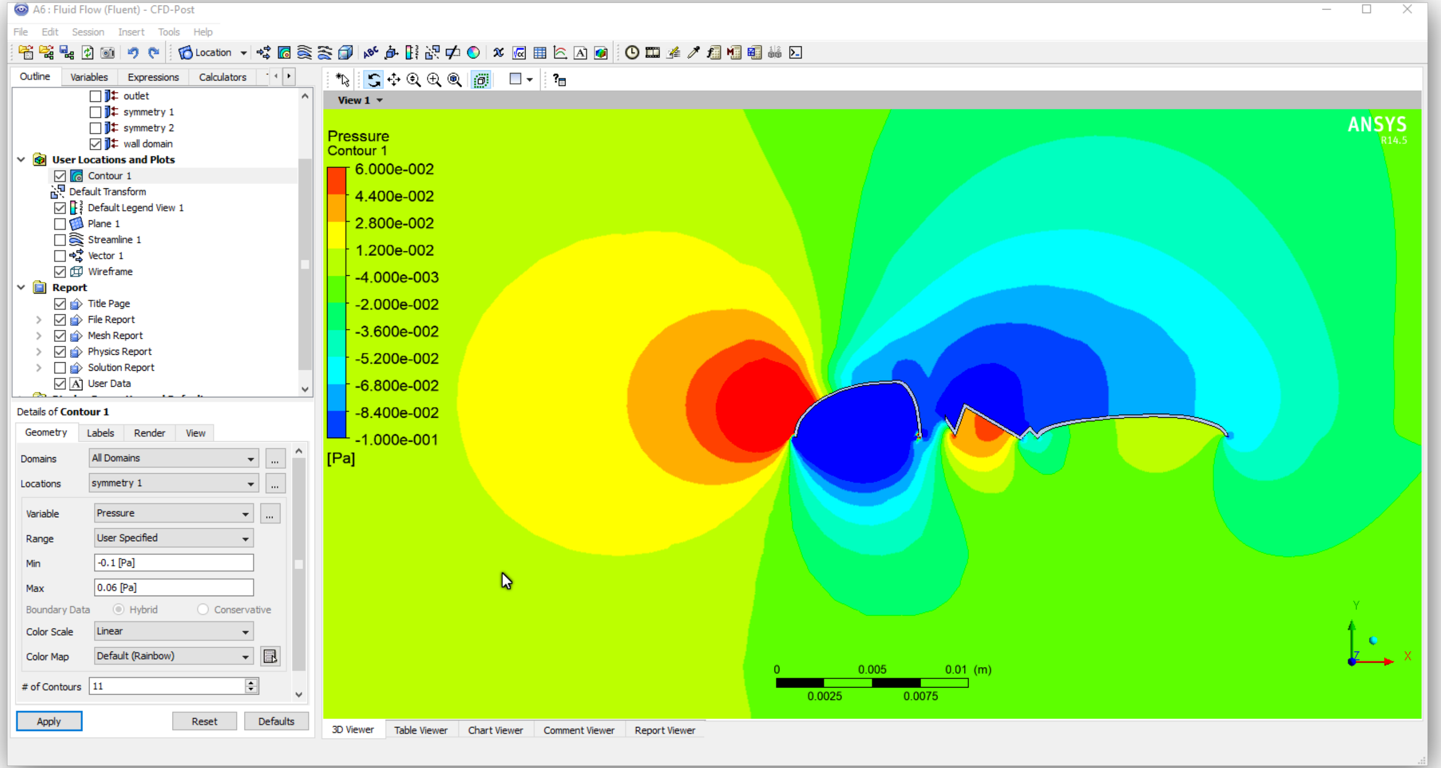
- Stage-8.2: Iterating Towards a Solution



- # Stage-9.1: Post-Processing Result- Pressure Contour

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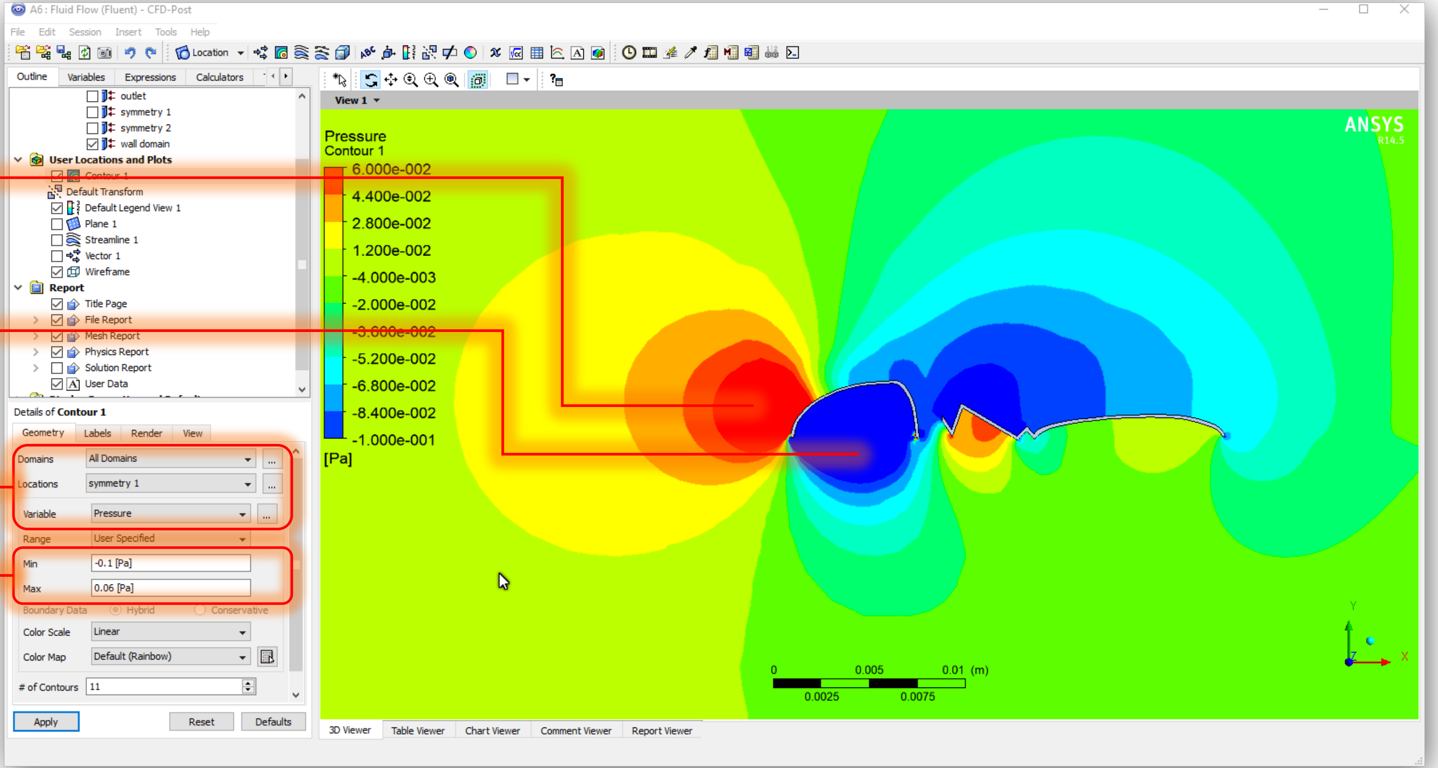
# • Stage-9.1: Post-Processing Result- Pressure Contour

**Maximum pressure at the leading edge**

**Minimum pressure at the bottom of aerofoil**

**Domain Selection**

**Range Selection**

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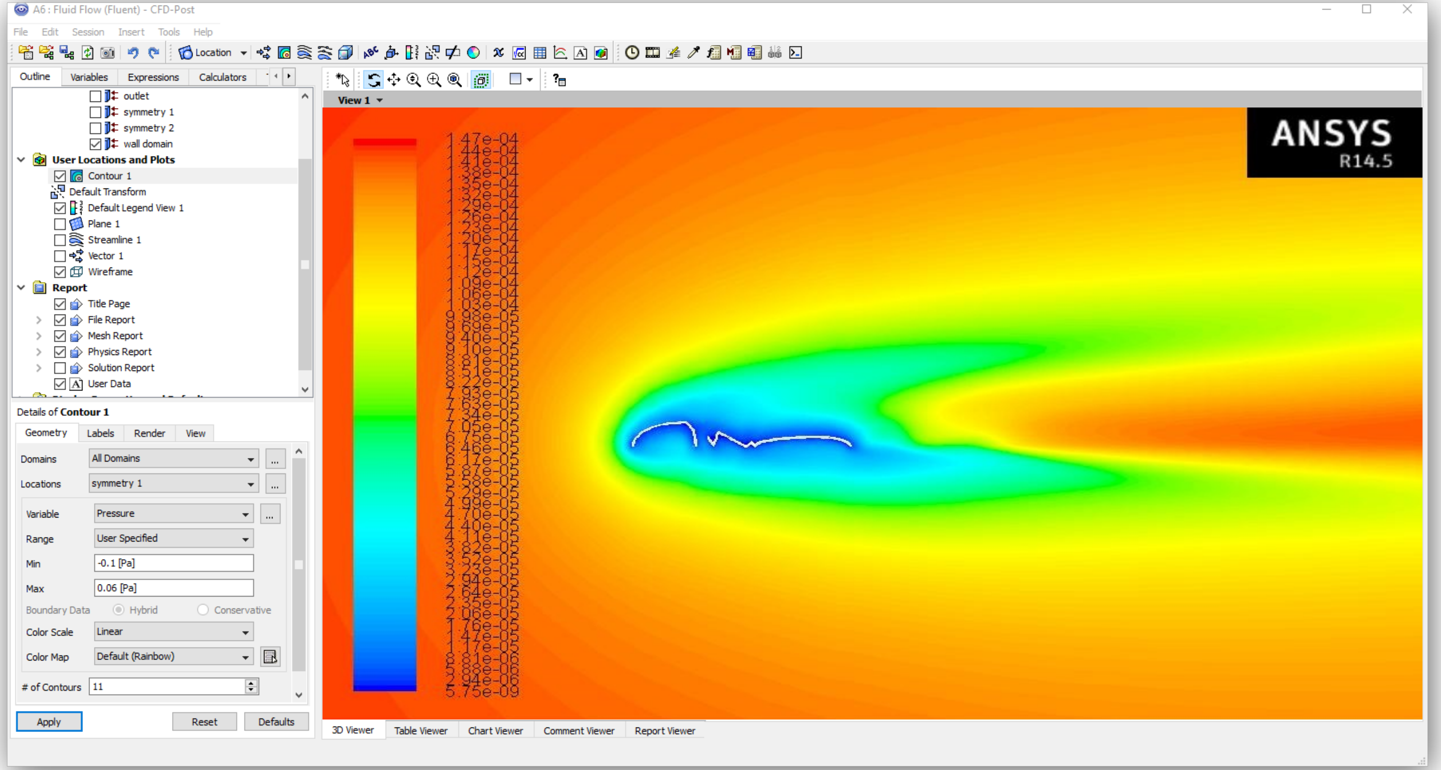
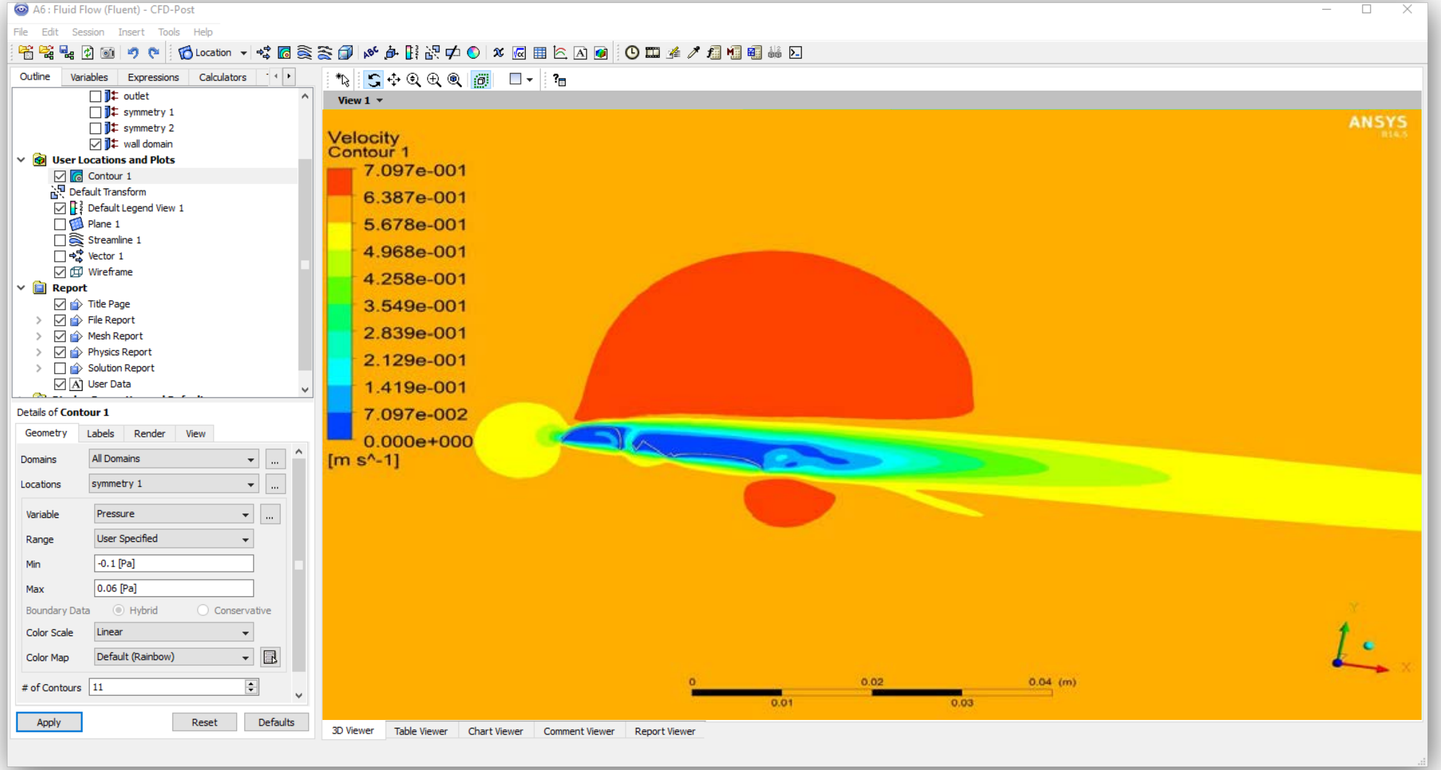
# • Stage-9.2: Post-Processing Result- Turbulence Contour



# • 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

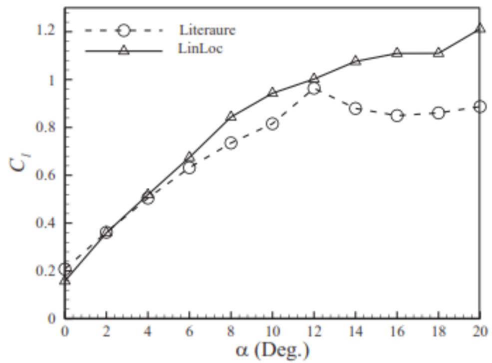
$\rho$ – Air Density

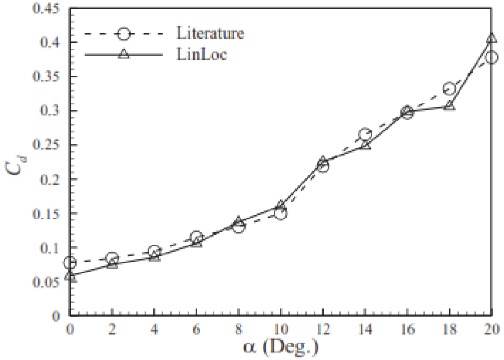
$l$ – Characteristic length

$v_\infty$ – 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 |

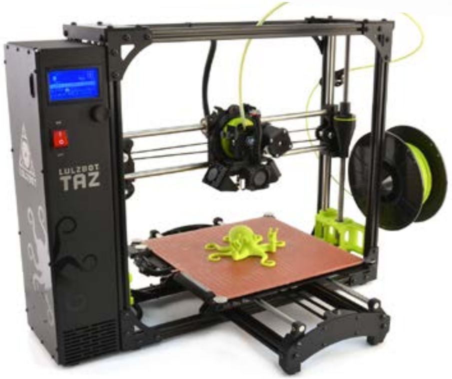


- # Subproblem-1: Linloc Aerodynamics (Continuation)

✓ **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.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**“Those who are inspired by a model other than Nature, a mistress above all masters, are labouring in vain”.**

**Leonardo da Vinci**