# Numerical optimization of foil shape and generic wing planform

Under the guidance of **Prof. Dr. Rajan Kumar**

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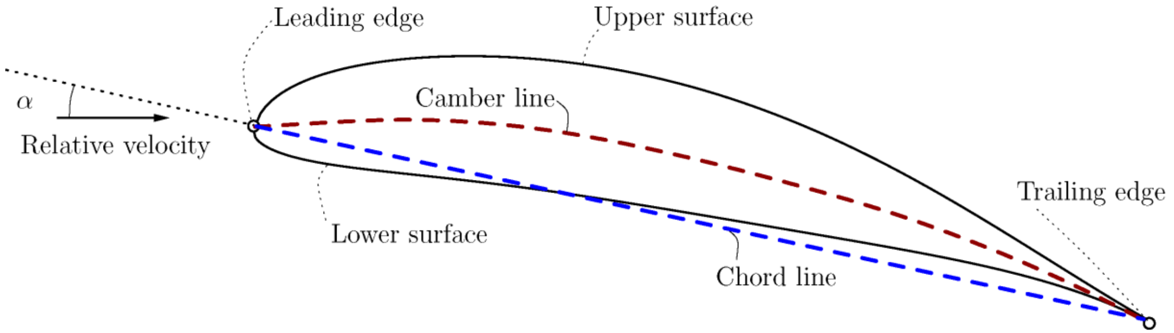
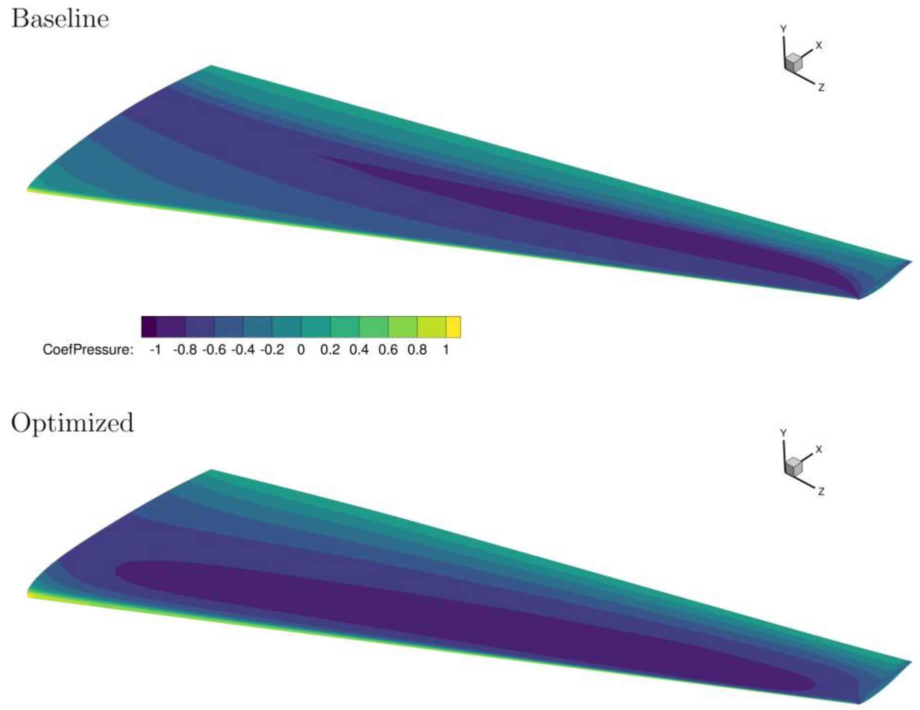


# Overview

## Aerodynamic Shape Optimization

*Aerodynamic shape optimization revolutionizes engineering by systematically refining object designs for fluid environments. Across aerospace, automotive, and marine sectors, it minimizes drag, enhances lift, and optimizes efficiency. Computational tools like Computational Fluid Dynamics (CFD) analyze flow patterns and pressure distributions. Objective functions guide optimization, aiming to minimize drag coefficients or maximize lift-to-drag ratios.*

*With gradient-based algorithms, evolutionary strategies, and surrogate models, engineers navigate complex design spaces. Challenges include computational costs and multidisciplinary considerations.*



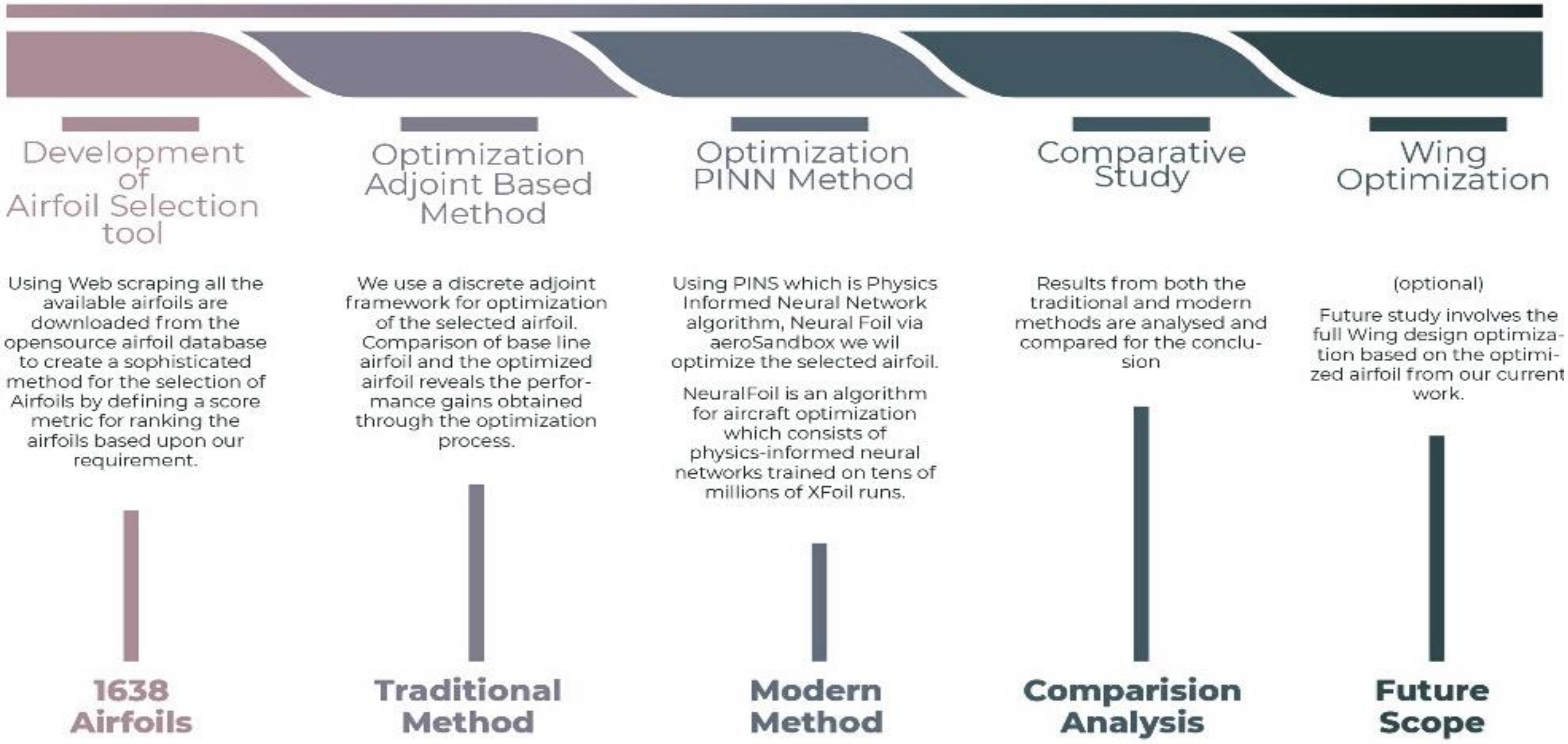
# Objective

1. *To methodically improve aerodynamic designs, apply numerical optimization tools such as gradient-based approaches, evolutionary strategies, and reinforcement learning techniques.*
2. *Investigate the impact of various design parameters, such as foil shape, wing geometry, and surface features, on aerodynamic performance using sensitivity analysis and parametric studies.*
3. *Validate optimized designs through comparison with experimental data or benchmark cases to assess accuracy and reliability.*
4. *Contribute to the advancement of aerodynamic engineering by proposing innovative solutions and best practices for optimizing foil shapes and generic wing platforms, with implications for enhancing efficiency, performance, and sustainability across industries.*

# Problem Statement

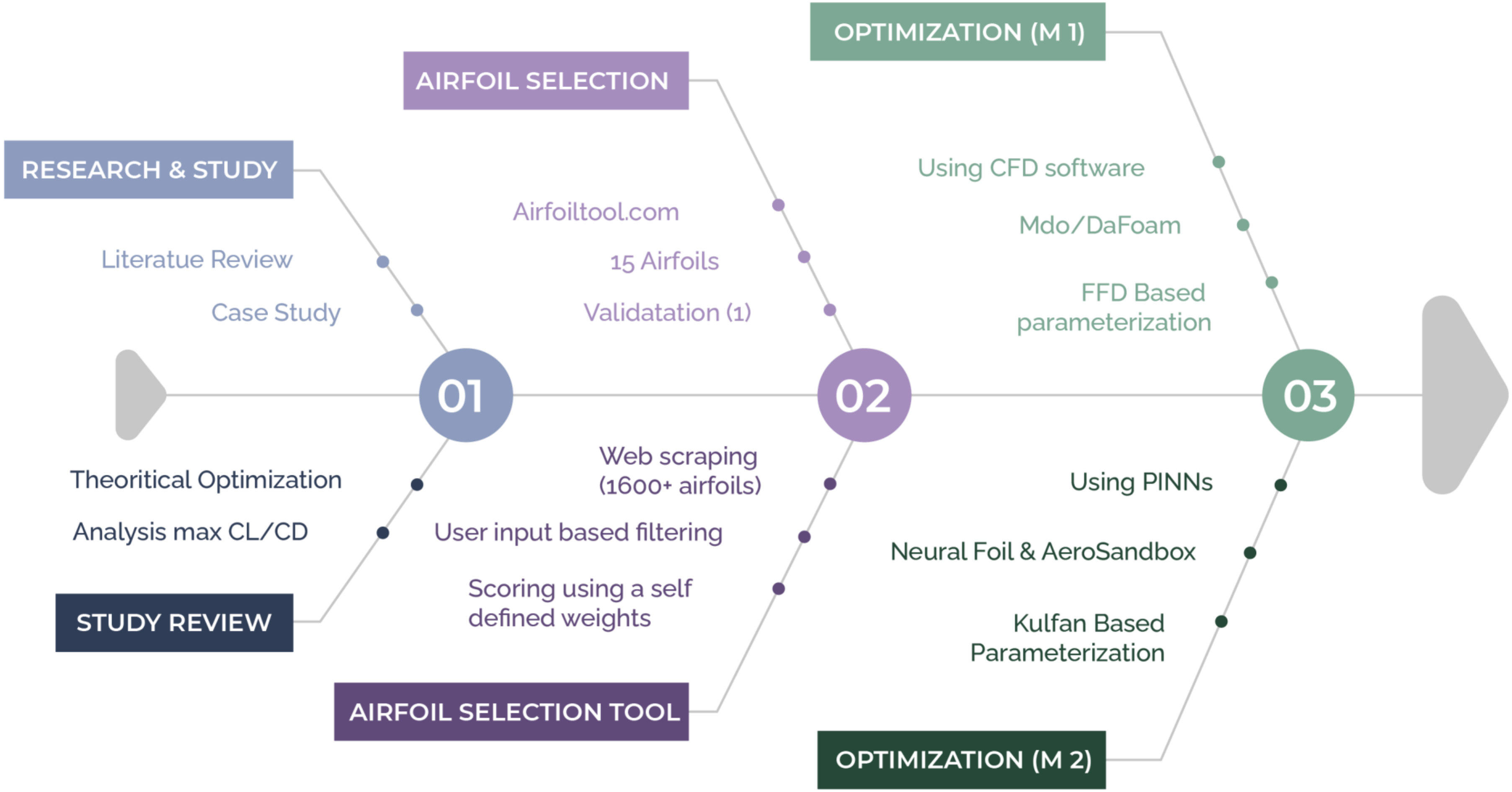
*The study aims to improve aerodynamic performance by addressing the difficulty of optimizing foil designs and generic wing planforms. The problem statement specifically revolves around the necessity of creating and utilizing sophisticated algorithms, numerical optimization approaches, and Computational Fluid Dynamics (CFD) simulations to methodically improve aerodynamic designs. To minimize drag, maximize lift, and enhance overall efficiency, it is necessary to navigate complicated design spaces while taking into account multidisciplinary constraints including structural integrity, material qualities, and manufacturing limits. The main goal is to push the limits of aerodynamic engineering to improve performance, efficiency, and sustainability in a variety of industries, such as the automotive, marine, and aerospace sectors.*

# Research Plan/ Methodology



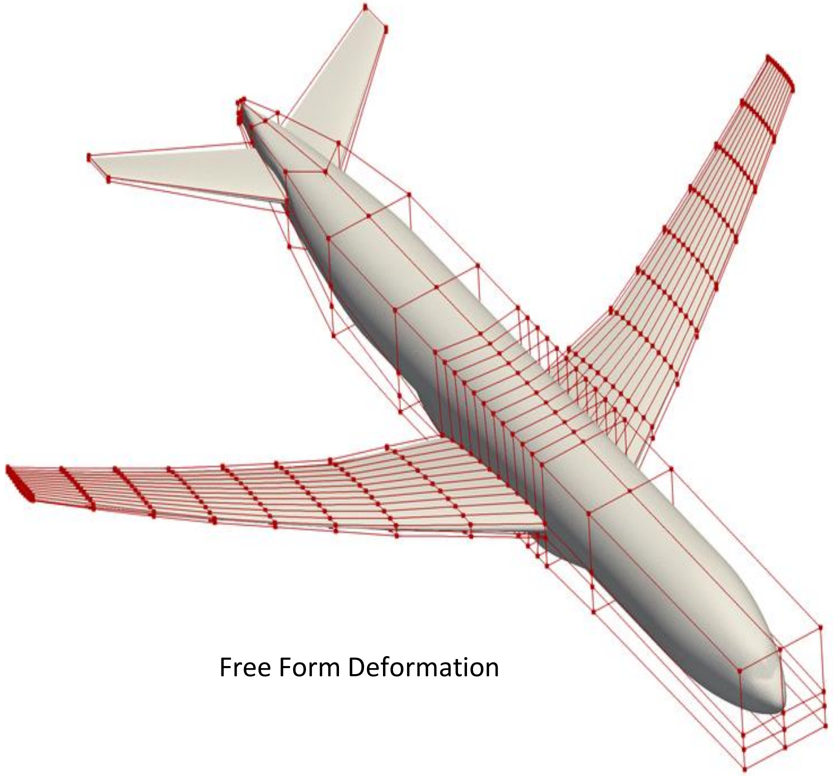
# Workflow

M1 : Method 1 (using Computatioinal Fluid Dynamics)
M2 : Method 2 (using neural network)

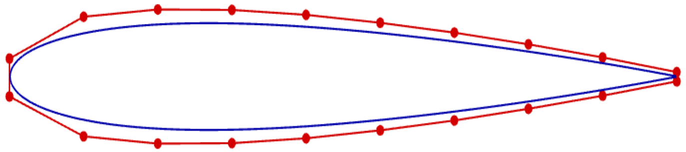


# Research Study/Case Study

1. Foil selection
2. Adjoint based generic wing optimization
3. Airfoil selection methodology for small wind turbine
4. Selection and analysis of an airfoil for fixed wing micro unmanned aerial vehicle
5. A conceptual study of airfoil performance enhancement using CFD
6. Study of airfoil shape optimization by using the evolutionary method
7. Data-based approach for fast airfoil analysis and optimization
8. Airfoil design and optimization methods: recent progress at NLR
9. Physics-informed neural networks modelling for systems with moving immersed boundaries: Application to an unsteady flow past a plunging foil



Free Form Deformation



# Data Collection Methods

Using open source library for airfoil dataset, such as Airfoiltools.com

*Also we developed a sophisticated tool for airfoil selection which makes it easy for user to choose the appropriate airfoil for his need.*

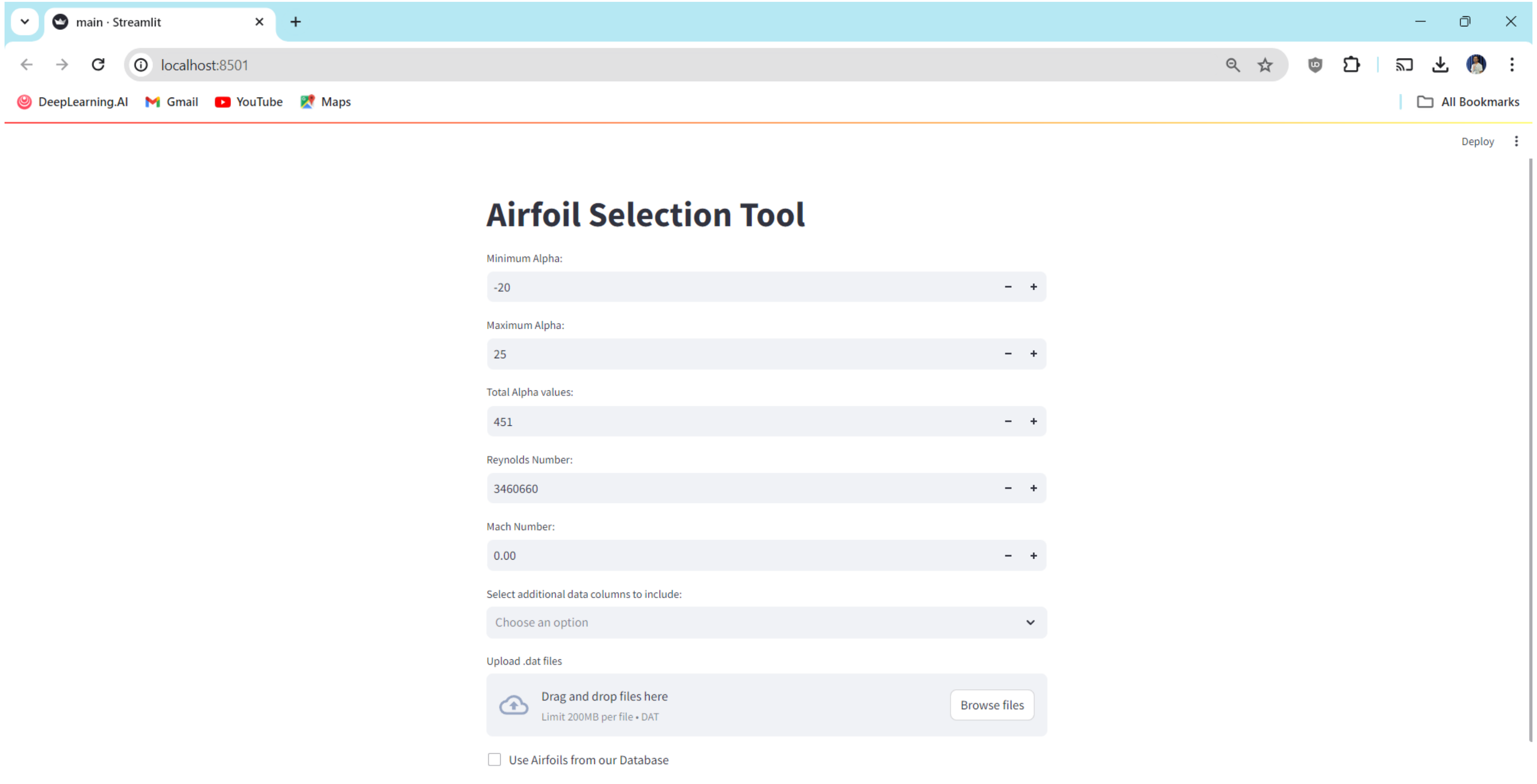
***Idea for developing this tool came during the Airfoil selection process for our project, which becomes to be a tedious task as one needs to plot the graphs and analyze the stall behavior for the various airfoils for selecting the best one.***

Using our developed tool:

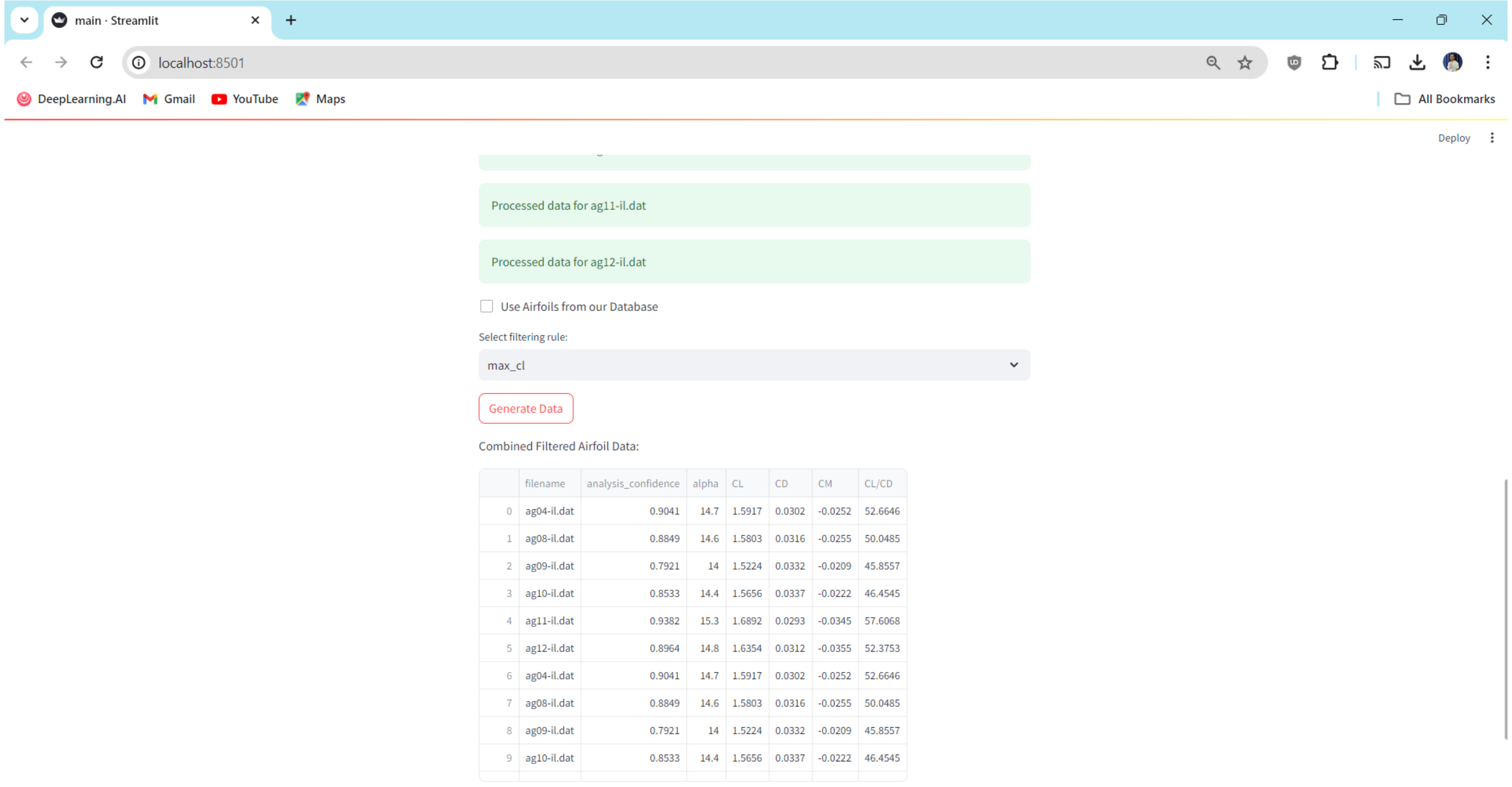
1. User can customize there selection process according to there need
2. User gets a wide range of airfoils to compare and score them for there requirement.

# Our Airfoil Selection Tool

Page 1



# Our Airfoil Selection Tool




| | filename | analysis_confidence | alpha | CL | CD | CM | CL/CD |
|---|---|---|---|---|---|---|---|
| 0 | ag04-il.dat | 0.9041 | 14.7 | 1.5917 | 0.0302 | -0.0252 | 52.6646 |
| 1 | ag08-il.dat | 0.8849 | 14.6 | 1.5803 | 0.0316 | -0.0255 | 50.0485 |
| 2 | ag09-il.dat | 0.7921 | 14 | 1.5224 | 0.0332 | -0.0209 | 45.8557 |
| 3 | ag10-il.dat | 0.8533 | 14.4 | 1.5656 | 0.0337 | -0.0222 | 46.4545 |
| 4 | ag11-il.dat | 0.9382 | 15.3 | 1.6892 | 0.0293 | -0.0345 | 57.6068 |
| 5 | ag12-il.dat | 0.8964 | 14.8 | 1.6354 | 0.0312 | -0.0355 | 52.3753 |
| 6 | ag04-il.dat | 0.9041 | 14.7 | 1.5917 | 0.0302 | -0.0252 | 52.6646 |
| 7 | ag08-il.dat | 0.8849 | 14.6 | 1.5803 | 0.0316 | -0.0255 | 50.0485 |
| 8 | ag09-il.dat | 0.7921 | 14 | 1.5224 | 0.0332 | -0.0209 | 45.8557 |
| 9 | ag10-il.dat | 0.8533 | 14.4 | 1.5656 | 0.0337 | -0.0222 | 46.4545 |

Final Scoring:
Airfoil with highest score is the best suited Airfoil

| | Airfoil | Score |
|---|---|---|
| 68 | ah94145-il | 0.889933 |
| 71 | ah95160-il | 0.883603 |
| 121 | ch10sm-il | 0.909798 |
| 148 | dae11-il | 0.901538 |
| 168 | drgnfly-il | 0.885037 |
| 299 | e58-il | 0.908403 |
| 312 | e61-il | 0.854933 |
| 441 | fx72150a-il | 0.874037 |
| 442 | fx72150b-il | 0.861935 |
| 443 | fx72ls160-il | 1.000000 |
| 445 | fx73170a-il | 0.894838 |
| 462 | fx76mp120-il | 0.914993 |
| 463 | fx76mp140-il | 0.868508 |
| 901 | goe804-il | 0.998615 |
| 906 | gu255118-il | 0.899252 |
| 975 | jn153-il | 0.904883 |
| 1300 | r1046-il | 0.879596 |
| 1455 | s831-nr | 0.855419 |
| 1456 | s832-nr | 0.869671 |
| 1551 | uag8814320-il | 0.905159 |

# Methods for Data Analysis & Optimization of Airfoil Design

python™

OpenFOAM

Aero Sandbox
by Peter Sharpe

mdolab/**dafoam**

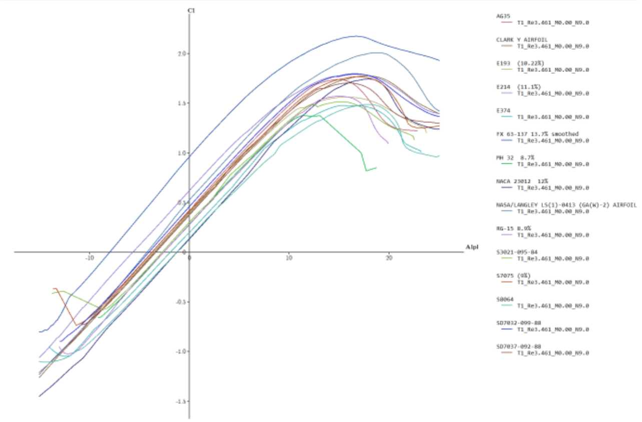
Neural Foil

# Data Analysis:
# Cl vs alpha, Cd vs alpha

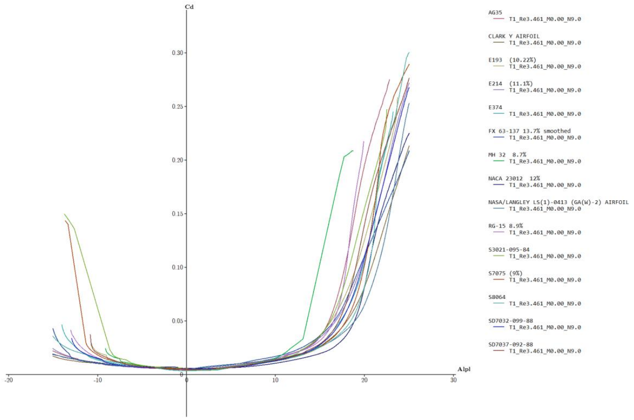
*From the initial results using Panel Method deployed in* XFLR5, *we were able to decide that* **FX63-317sm** *has the desired properties in terms of optimum lift and drag characteristics.*

*As can be seen on the top-right fig., the* zero A.O.A. Coefficient of Lift *and* Maximum Lift *available are both maximum for* **FX63-317sm**

*Likewise, the* Drag Coefficient *against increasing* A.O.A. *can be seen on bottom-right fig., wherein the* Drag Coefficient *characteristics of* **FX63-317sm** *lies in between.*

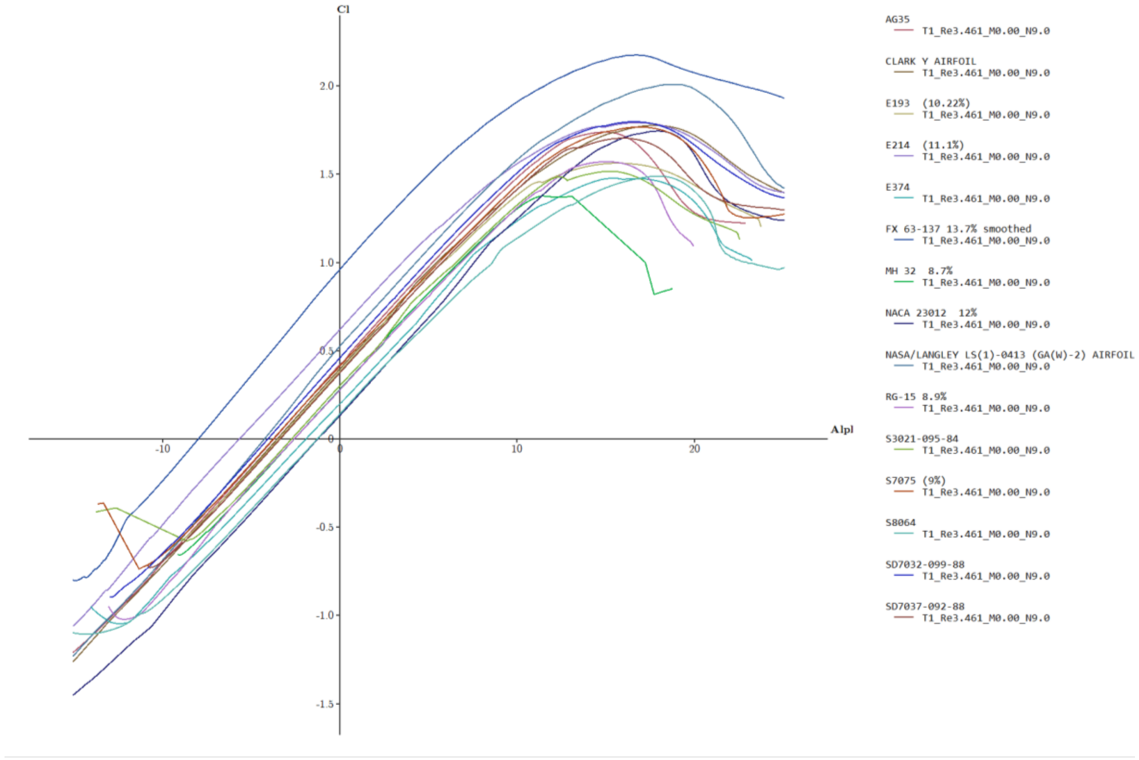


$C_l$ vs α

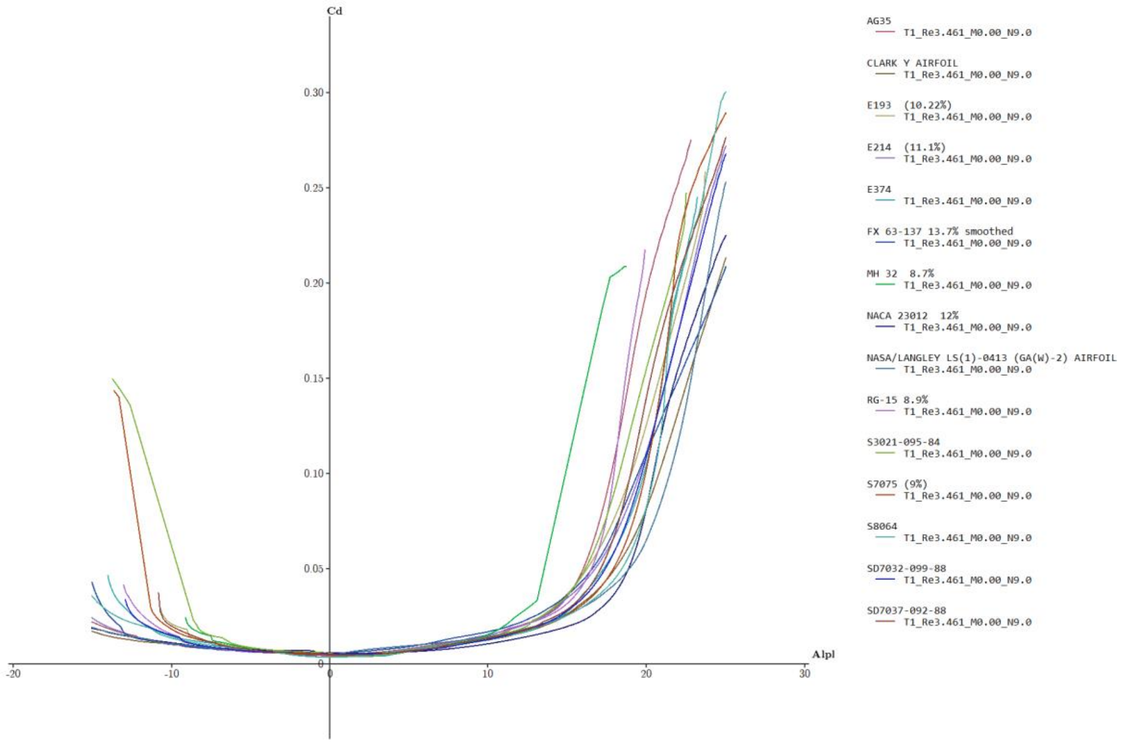


$C_d$ vs α

# Data (2D) Analysis




$C_l$ vs α



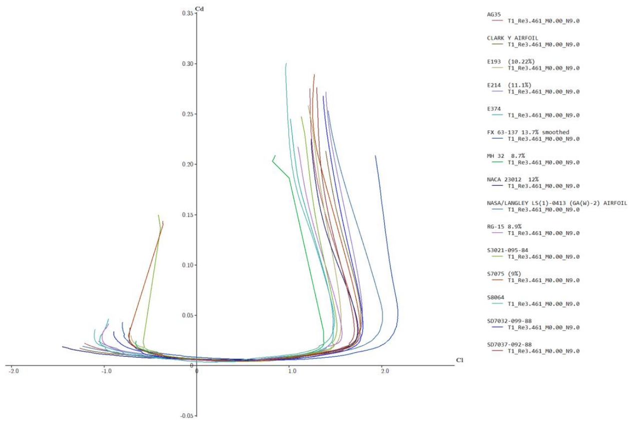

$C_d$ vs α

# Data Analysis :
# Drag polar, Cl/Cd vs alpha

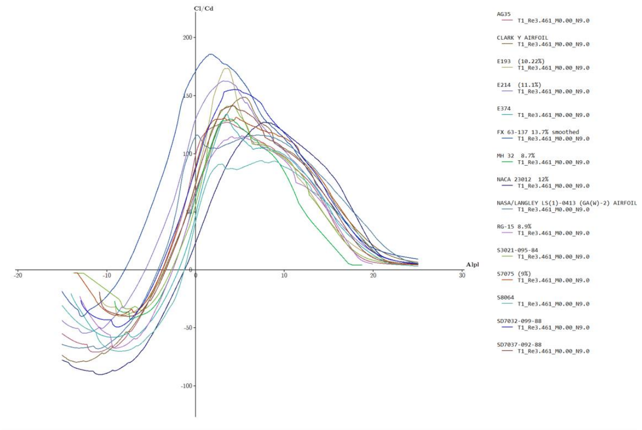
*For further tradeoff we look into drag polar curves and $C_l/C_d$ vs α curves as shown in the right column.*

*The drag polar curve depicts that the drag bucket for* **FX63-317sm** *again has the best possible configuration and even at high $C_l$ values, the $C_d$ values remain fairly low and hence provides maximum possible deliverable range values.*

*This can be further visualized in the $C_l/C_d$ vs α graph as shown in bottom right fig., wherein within the operational range of* A.O.A. **FX63-317sm** *has the best performance.*

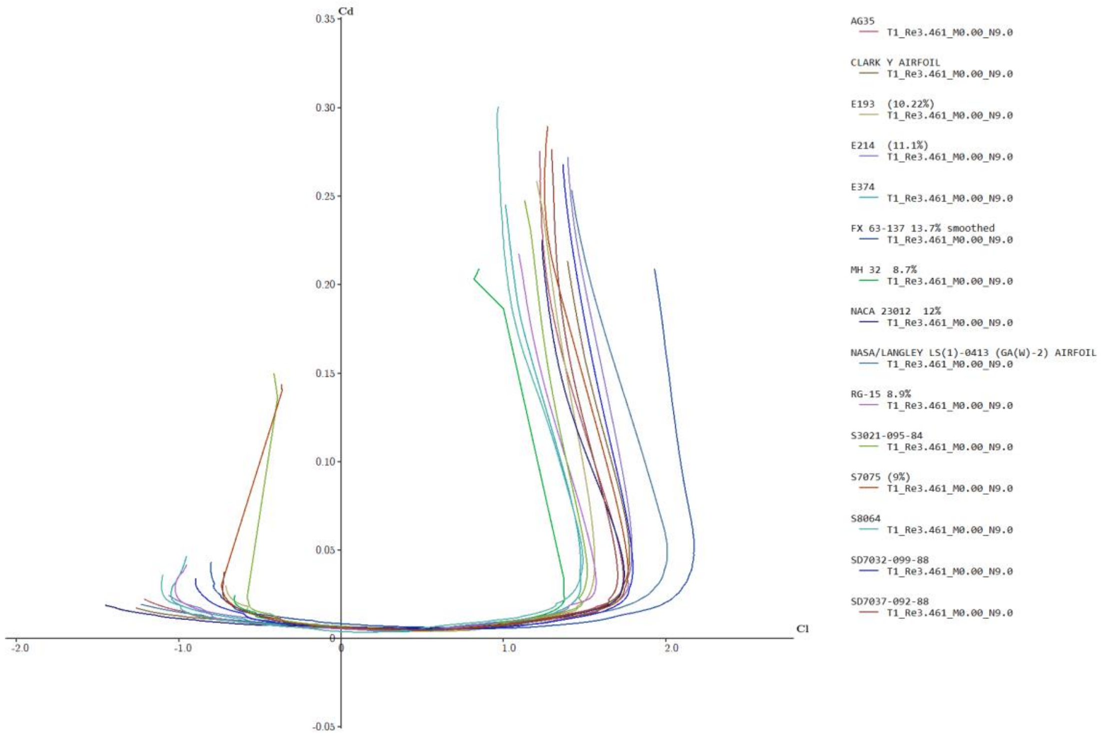


*Drag Polar Curve*

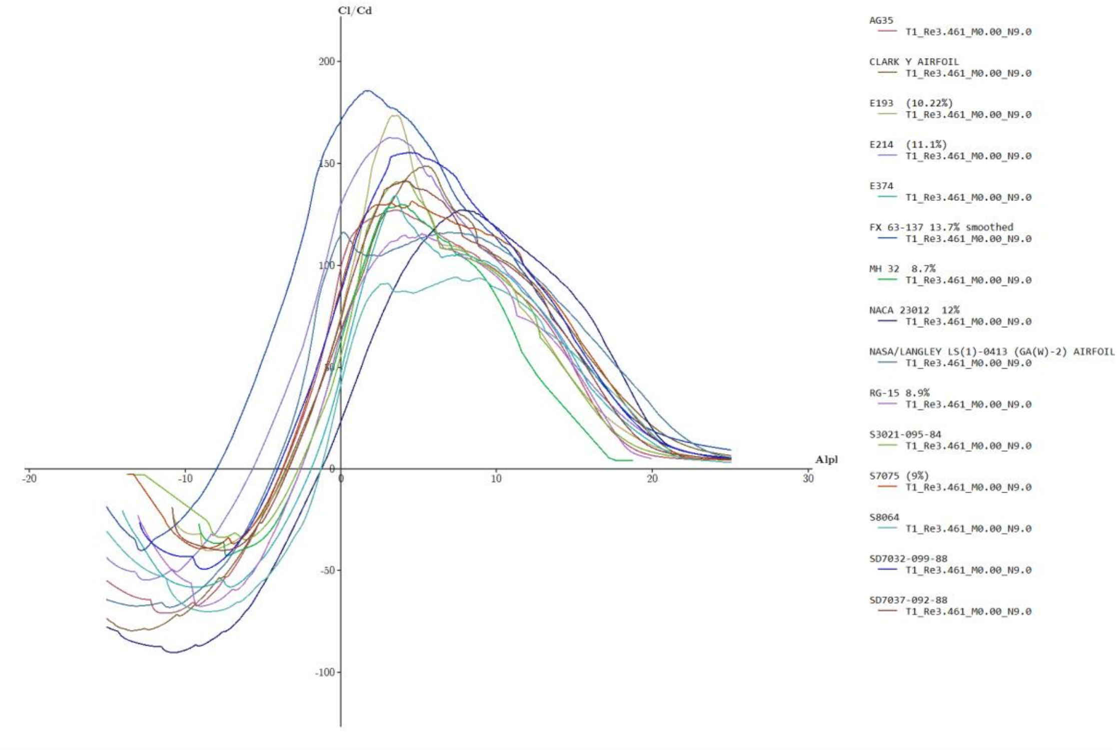


$C_l/C_d$ vs α

# Data (2D) Analysis




*Drag Polar Curve*




$C_l/C_d$ vs α

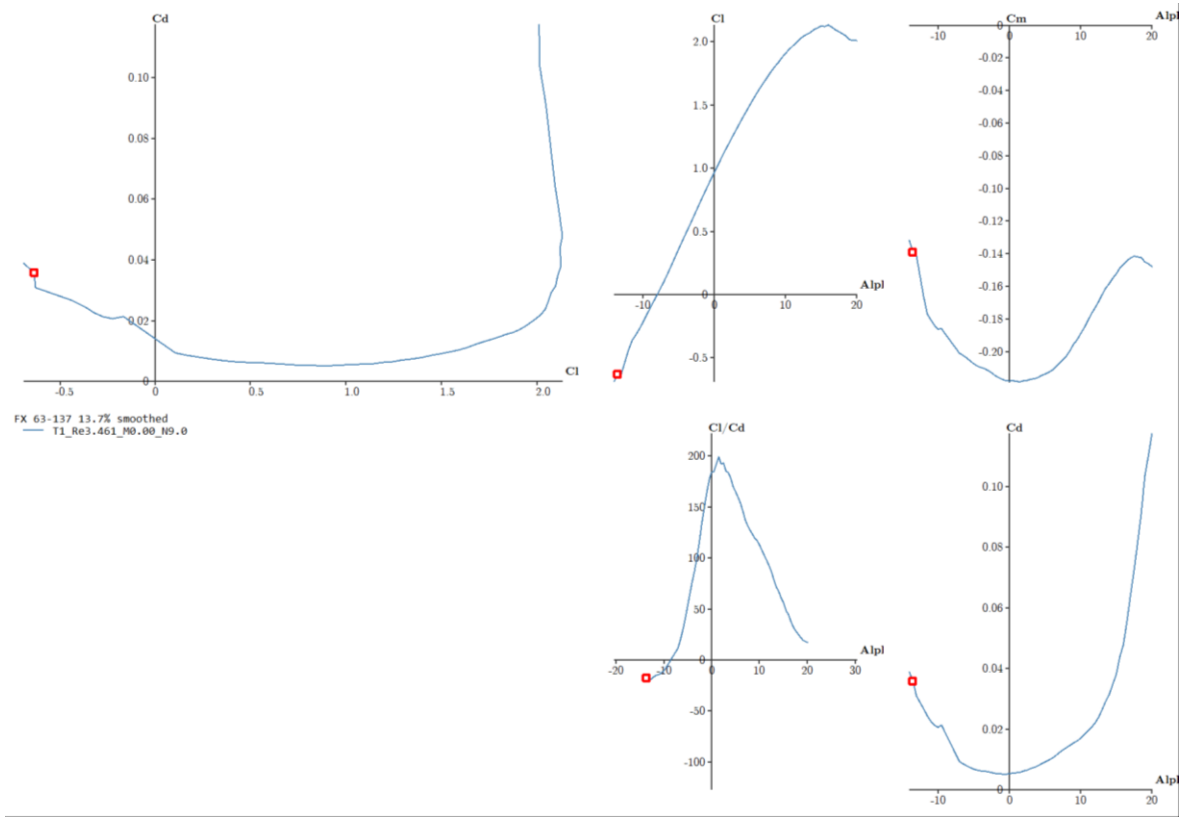
# Results : Data Analysis

*After visualizing the set of all the airfoils we finalized that* **FX63-317sm** *was the best suit for the purpose.*

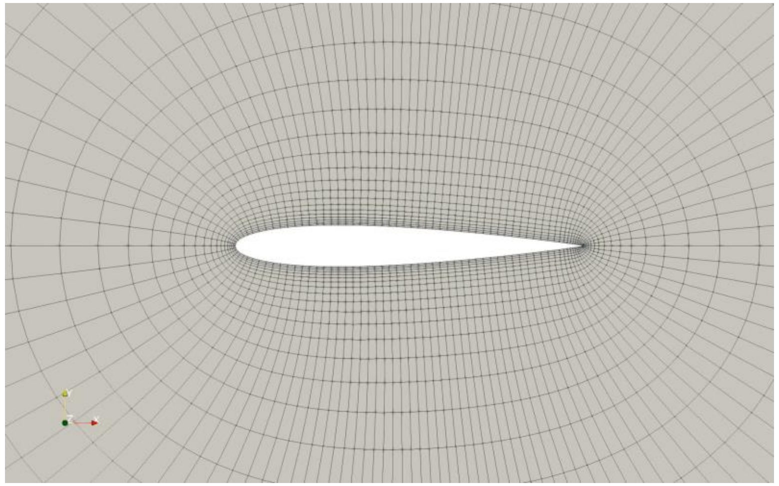
*It has*

- *Highest $C_l$ at 0 degree A.O.A.*
- *Highest possible $C_l$.*
- *Widest possible drag bucket.*
- *Benign stall Characteristics*
- *Stable Moment Characteristics*

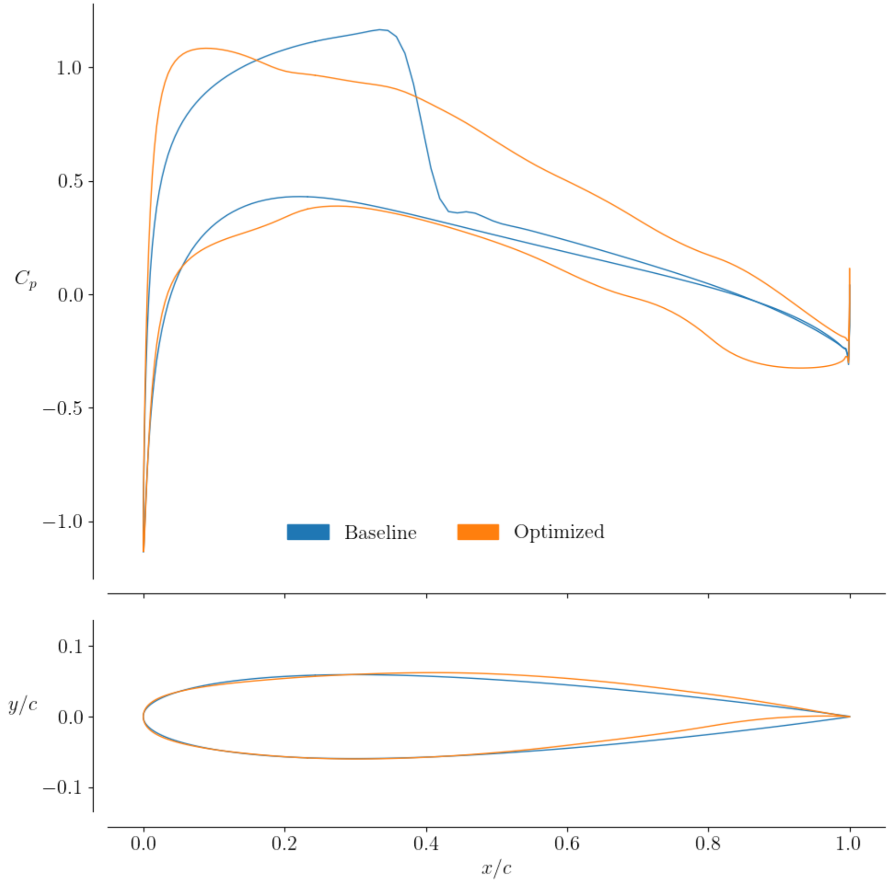
*Next we have visualization for $C_p$ vs Chord normalized x-distance for* **FX63-317sm** *airfoil.*



# Results:
# Foil Optimization Test Case – NACA 0012 (DaFoam)

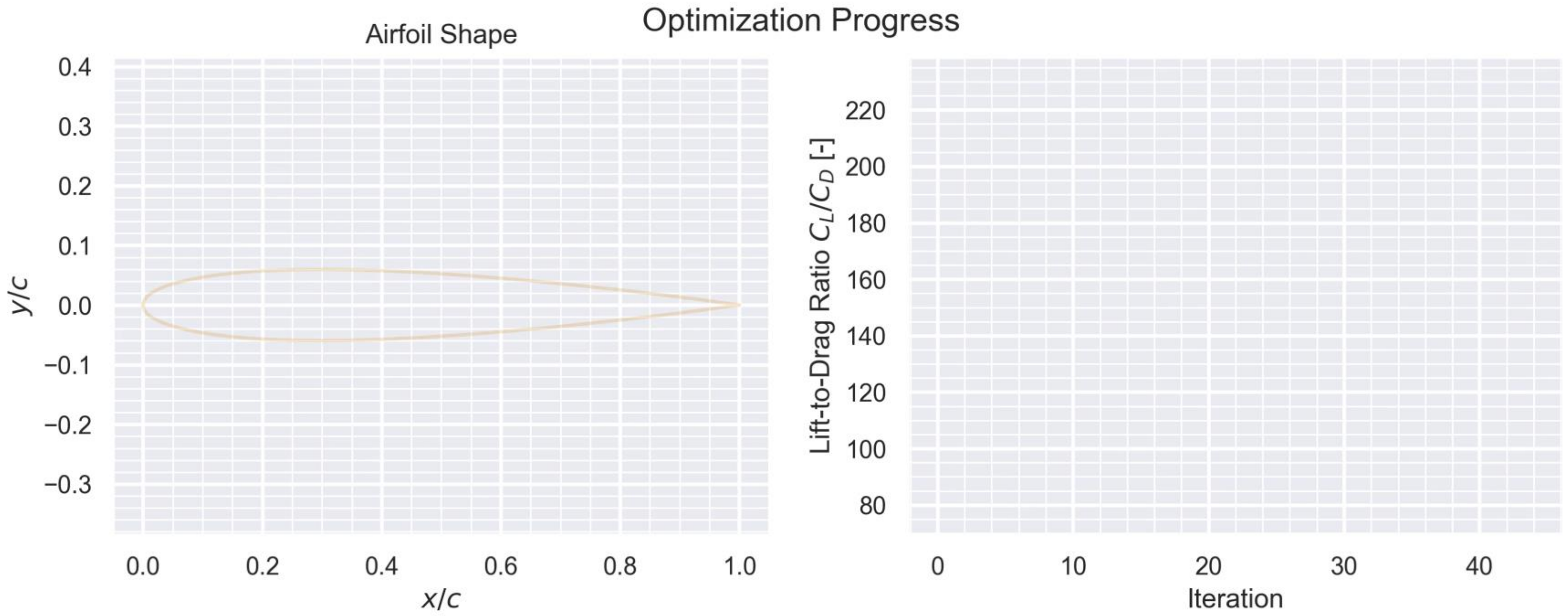


*FFD based Optimization using DaFoam*




*The results for Coefficient of pressure for Baseline and Optimized airfoils are shown in the figure alongside. For further analysis of aerodynamic properties, the generated foil can be further analyzed using XFOIL.*

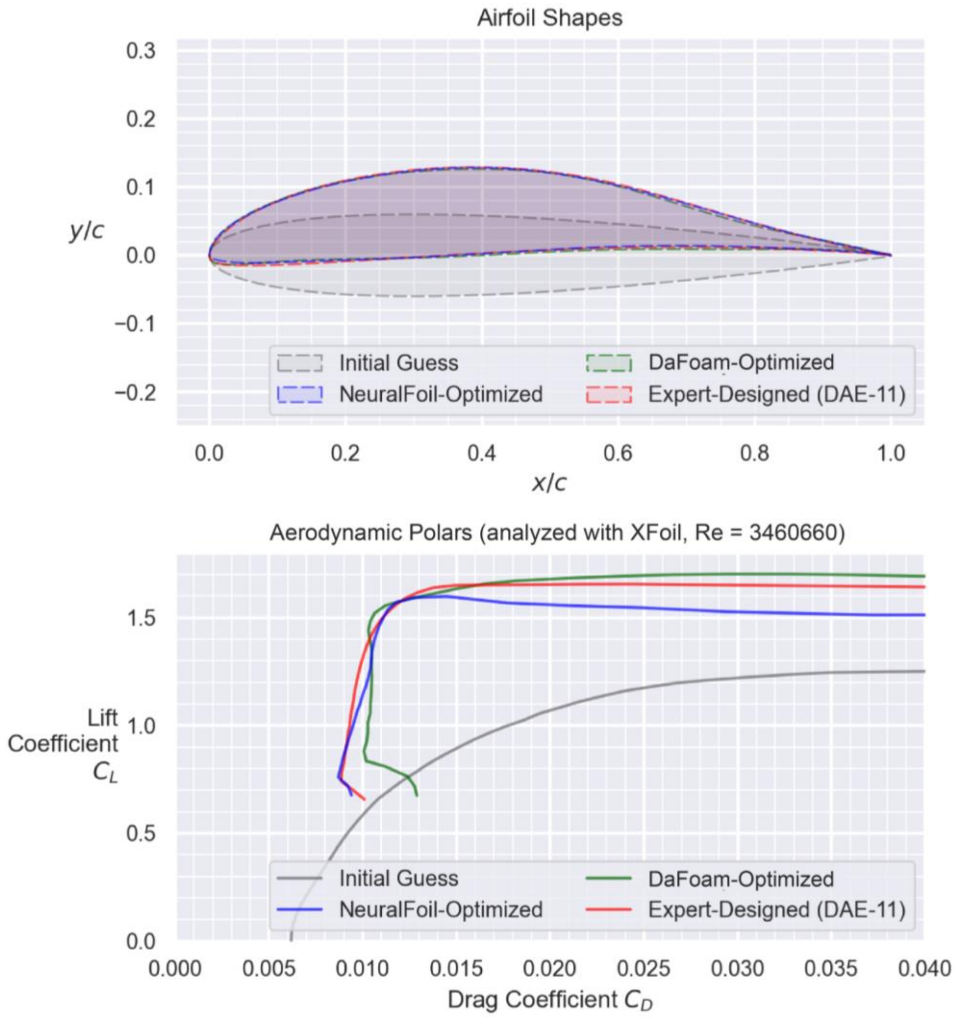
# Foil Optimization Test Case – NACA 0012  (NeuralFoil)




*The results for max Cl/Cd for different iterations for the Optimized airfoils are shown in the figure alongside gif. For further analysis of aerodynamic properties, the generated foil can be further analyzed.*

*Kulfan based Optimization using NeuralFoil*

# Conclusion



Airfoil Shapes
0.3
0.2
0.1
y/c
0.0
−0.1
−0.2
Initial Guess
NeuralFoil-Optimized
DaFoam-Optimized
Expert-Designed (DAE-11)
0.0
0.2
0.4
0.6
0.8
1.0
x/c
Aerodynamic Polars (analyzed with XFoil, Re = 3460660)
1.5
Lift Coefficient $C_L$
1.0
0.5
0.0
Initial Guess
NeuralFoil-Optimized
DaFoam-Optimized
Expert-Designed (DAE-11)
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
Drag Coefficient $C_D$

# Conclusion

| Parameter | Framework |
|---|---|
| Time | Neural Foil |
| Performance | DaFoam |

*NeuralFoil excels in time efficiency for optimization, prioritizing swift iterations. Conversely, DaFoam outperforms NeuralFoil in delivering slightly superior aerodynamic performance results. While NeuralFoil's speed is advantageous for meeting tight deadlines, DaFoam's precision in aerodynamic simulations provides a competitive edge. The choice between the two depends on the project's emphasis on time constraints versus performance optimization.*

# Thank You