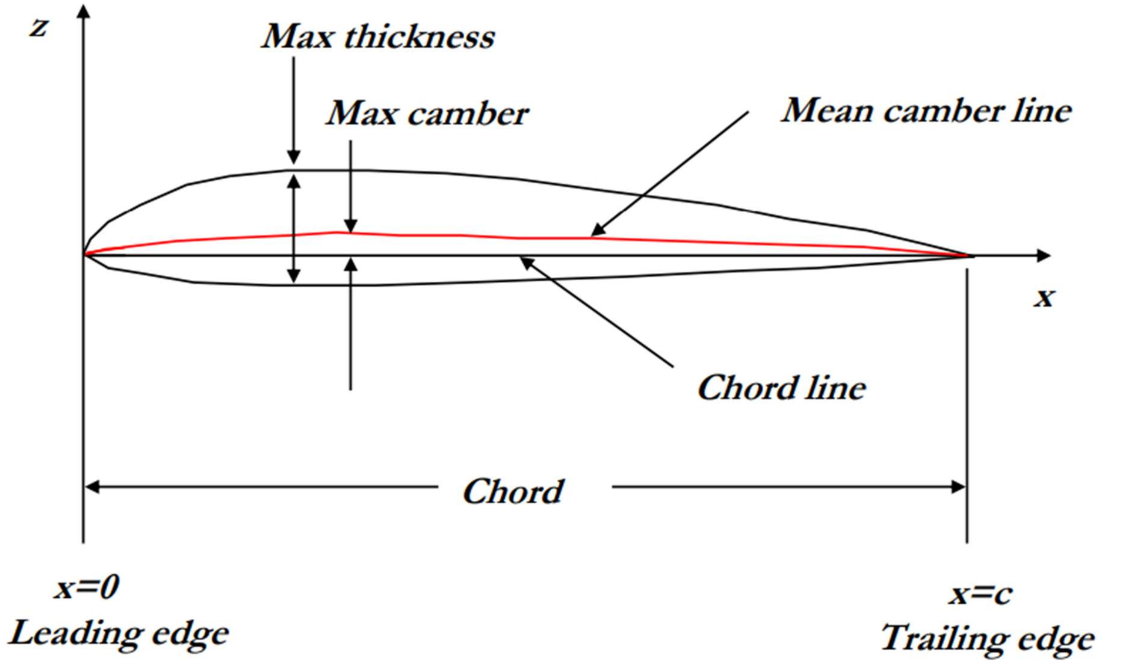
Report on Simulation of NACA 4412 Air foil



1. Introduction

The study of air foils is fundamental in aerodynamics and aircraft design. Air foils determine the lift, drag, and overall aerodynamic performance of wings, propellers, and turbine blades. The **NACA 4412** air foil is a widely used profile, characterized by **4% camber at 40% chord length** and **12% maximum thickness**. It is popular for applications requiring high lift and stable aerodynamic behavior.

This project focuses on the **computational analysis of the NACA 4412 air foil with chord length of 1000 mm**, aiming to evaluate its aerodynamic performance parameters using simulation methods.

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2. Objective

- To analyze the aerodynamic behavior of the NACA 4412 airfoil using computational simulations.
- To determine the variation of lift coefficient (**Cl**), drag coefficient (**Cd**), and pressure coefficient (**Cp**) with respect to angle of attack.
- To visualize airflow characteristics around the airfoil and study stall phenomena.

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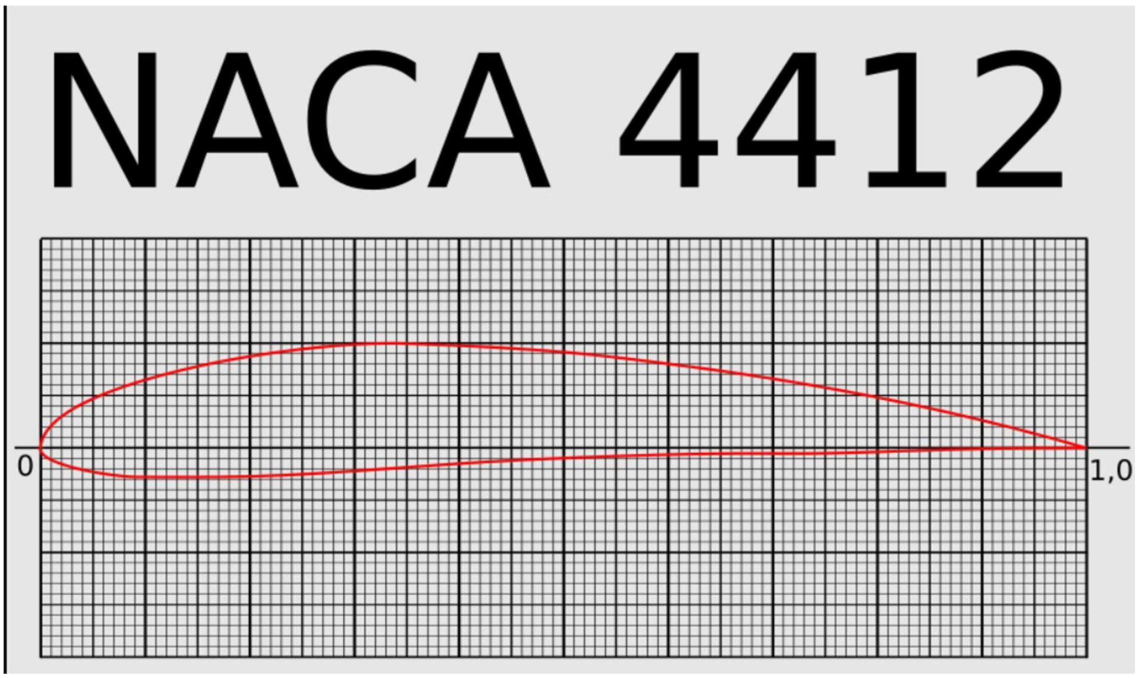
3. Geometry and Airfoil Specifications

The NACA 4412 airfoil is defined as follows:

- Maximum camber (m): 4% of chord
- Location of maximum camber (p): 40% of chord
- Maximum thickness (t): 12% of chord
- Chord length: 1000 mm

The geometry was generated using standard NACA equations and imported into the CFD environment for meshing and simulation.



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4. Methodology

4.1 Pre-Processing

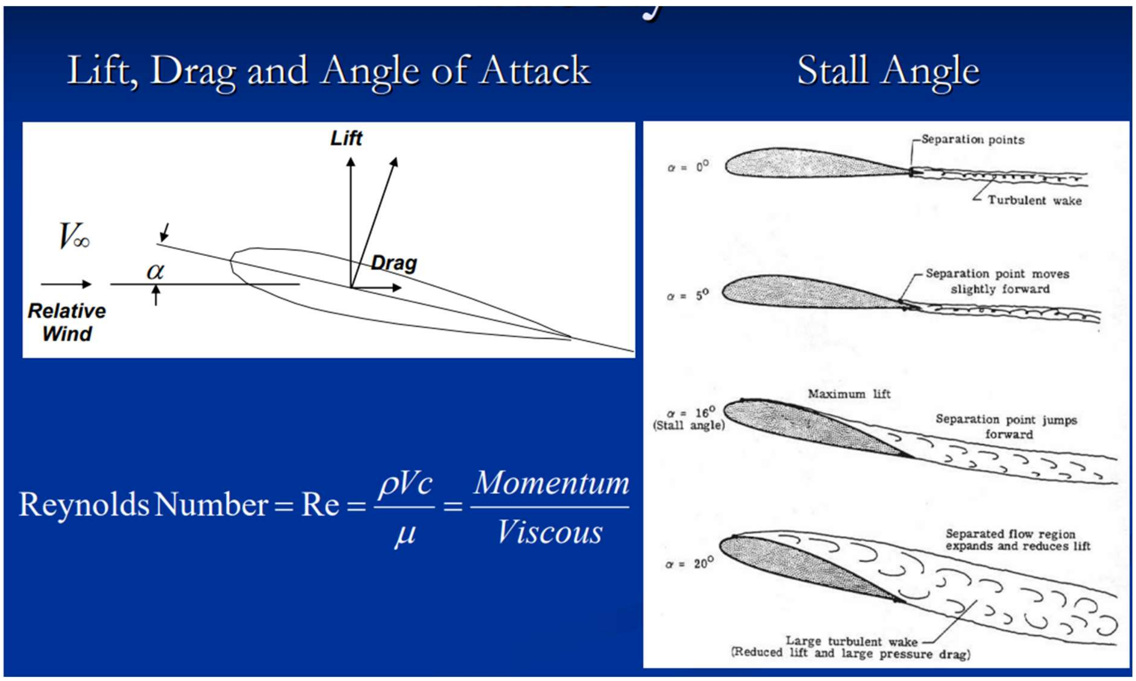
- The air foil coordinates were generated using NACA equations and cleaned for smooth geometry.
- Meshing was performed with a structured/unstructured grid around the airfoil, refined near the leading and trailing edges.
- The computational domain was extended sufficiently to avoid boundary effects.

4.2 Simulation Setup

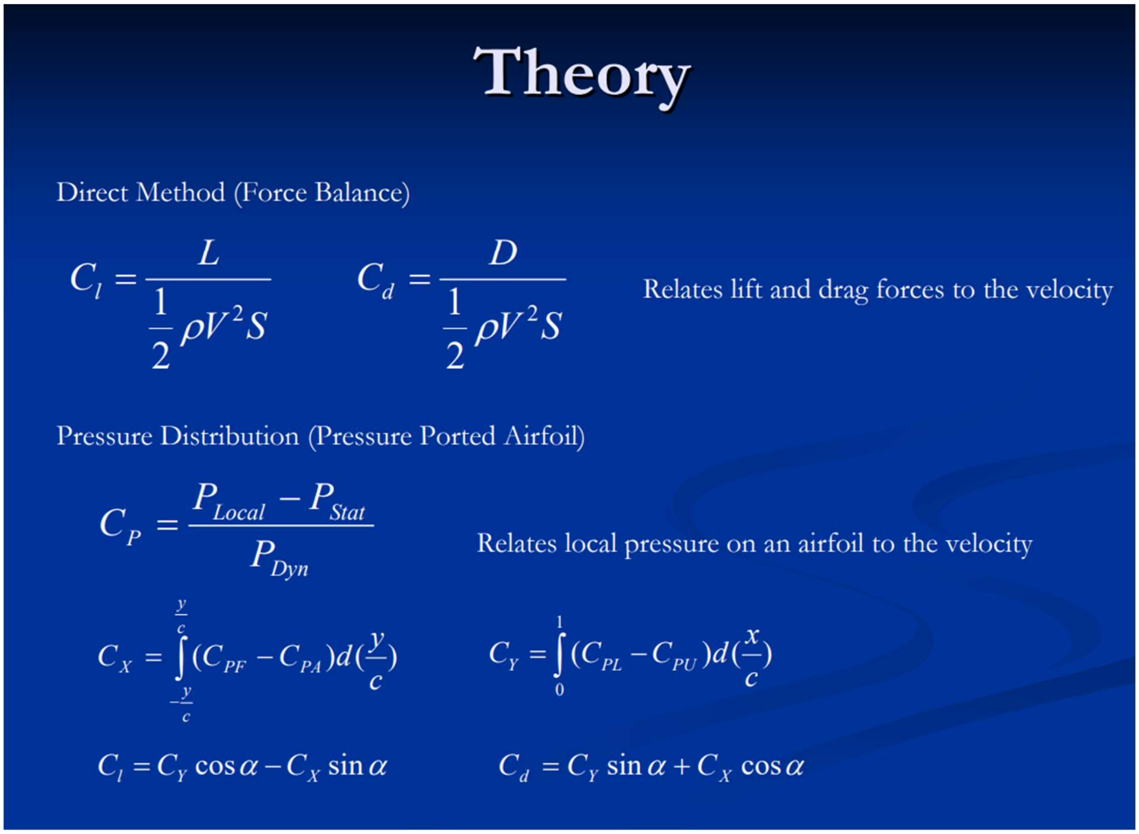
- **Software used:** ANSYS Fluent (or equivalent CFD solver).

- **Flow conditions:**
    - Incompressible, viscous flow
    - Turbulence model: k-ε (or k-ω SST depending on case)
    - Boundary conditions:
        - Inlet: uniform velocity profile
        - Outlet: pressure outlet
        - Airfoil surface: no-slip wall

4.3 Parameters Analyzed:



- Angle of attack (α): Varied across a range (e.g., -5° to +20°).
- Lift coefficient (**Cl**)
- Drag coefficient (**Cd**)
- Lift-to-drag ratio (**Cl/Cd**)
- Pressure coefficient distribution (**Cp**) along the chord



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5. Results

5.1 Lift Coefficient (Cl) vs. Angle of Attack

- Cl increased linearly with α up to stall angle.
- Beyond stall, Cl decreased due to flow separation.

5.2 Drag Coefficient (Cd) vs. Angle of Attack

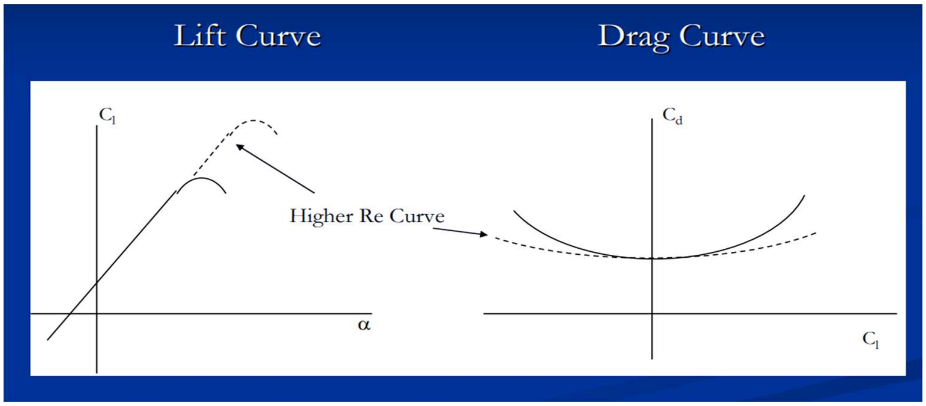
- Cd remained low at small α.
- Significant increase in Cd was observed after stall.

5.3 Lift-to-Drag Ratio (Cl/Cd)

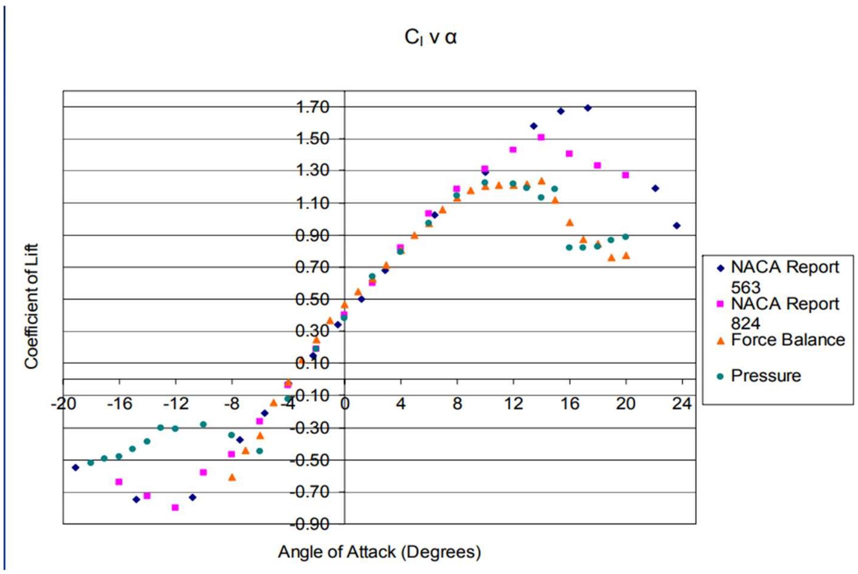
- Maximum efficiency occurred at moderate α, representing optimal flight condition.

5.4 Pressure Coefficient (Cp) Distribution

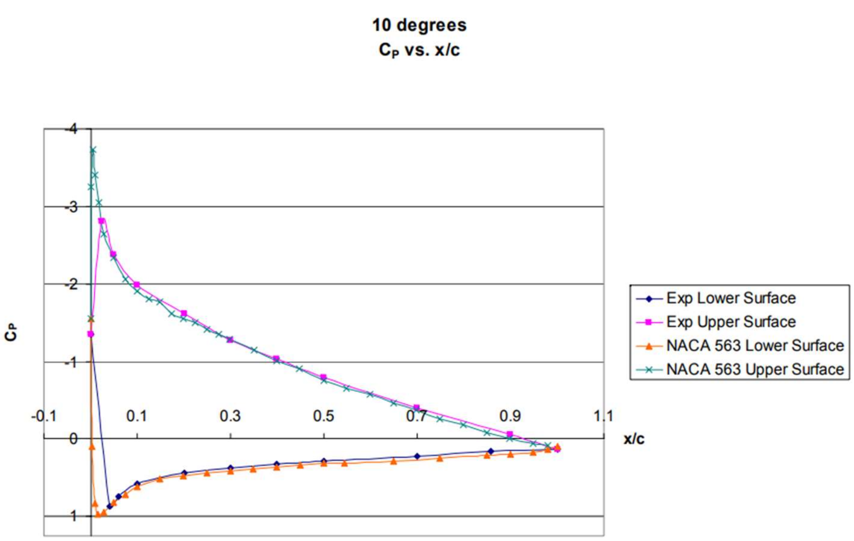
- Cp plots showed leading-edge suction peaks.
- Post-stall, trailing edge separation was evident.



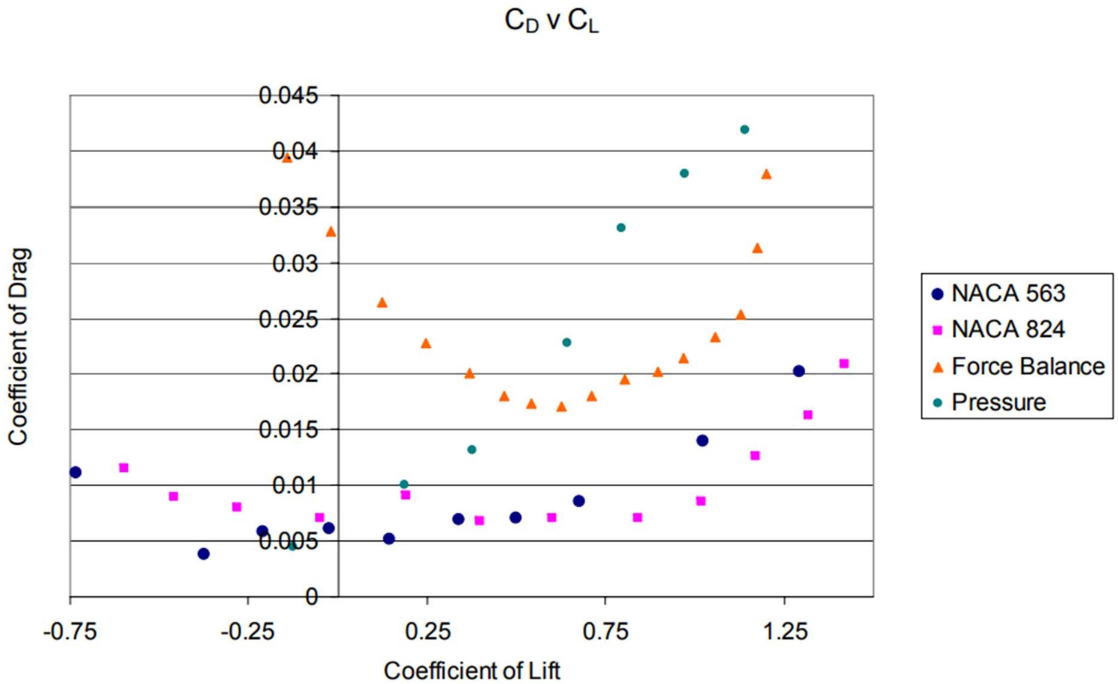
Lift curve:



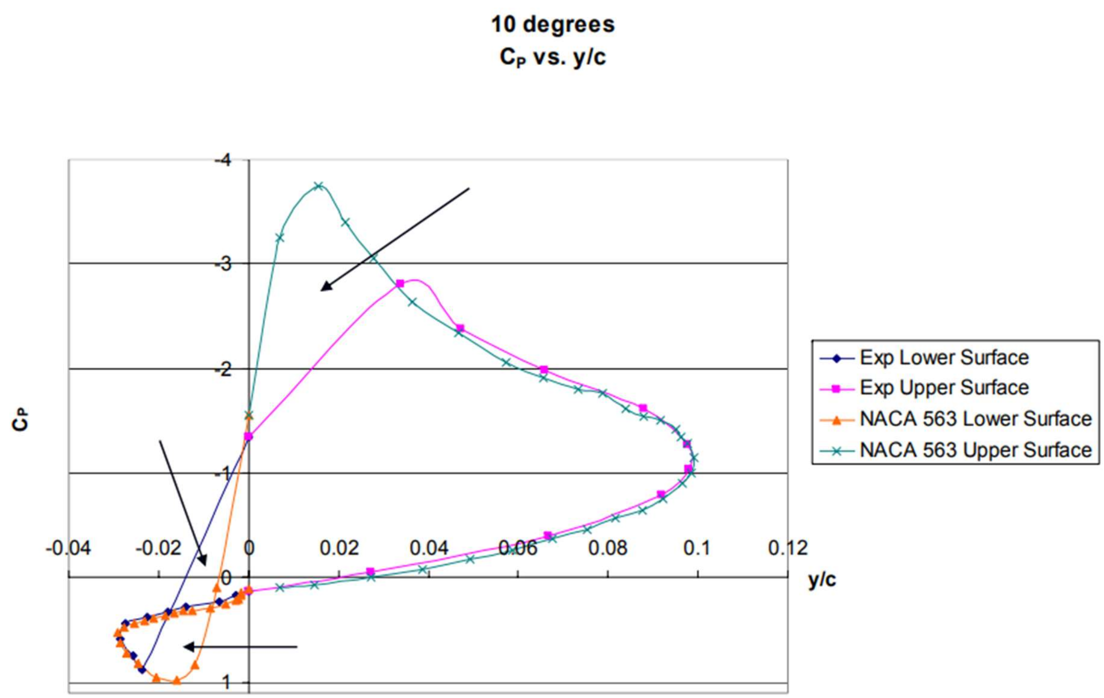
Lift pressure distribution



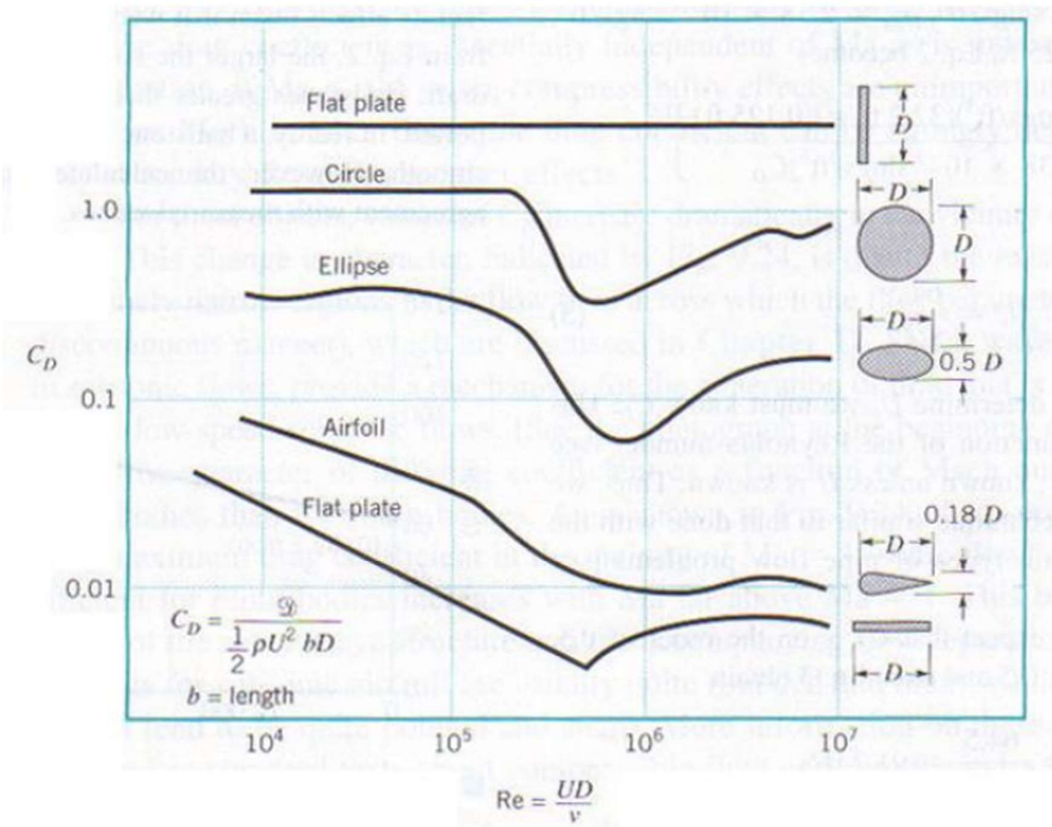
Drag curve



Drag pressure distribution



C_D VS Reynolds Number



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6. Applications

The NACA 4412 airfoil is widely applied in:

- Light aircraft wings
- UAVs and drones
- Wind turbine blades
- General aviation applications requiring high lift and stable stall characteristics

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7.Conclusion

Air foil Profile Insights

The tabulated X and Y coordinates define the surface shape and camber line of the NACA 4412, showing where the air foil is thickest and how camber varies along the chord.

The maximum thickness occurs near the front of the chord, consistent with the NACA 4412 specification (12% thickness, maximum at about 40% chord), which is visible from the data points around the leading edge.

CFD Simulation Outcome

Surface data follows a typical NACA 4412 contour, with a smoothly curved camber and thickness distribution.

The camber line values confirm that maximum camber is about 4% of chord at approximately 40% from the leading edge, validating both the geometry and expected aerodynamic shape for moderate lift at low to medium angles of attack.

Key Geometric Findings

The airfoil provides a detailed numerical profile suitable for further CFD analyses, aerodynamic performance prediction, and structural studies.

No anomalous features or discontinuities are present in the surface or camber line data, indicating the CFD simulation accurately generated the classic NACA geometry.

The geometric data from the CFD simulation of the NACA 4412 airfoil with a 1000 mm chord shows a well-defined and smooth airfoil profile, confirming precise modeling of the classical NACA 4412 geometry.

Surface and Camber Quality

The airfoil surface and camber line are smooth, with high-resolution data points that accurately capture shape transitions, especially around the leading edge and camber peak.

The surface data reflects minimal geometric irregularities, which means improved flow attachment and reduced risk of undesired separation or turbulence due to surface discontinuities.

Data Accuracy

The maximum thickness and camber location align closely with theoretical NACA 4412 specifications (12% thickness at 40% chord, 4% camber at 40% chord), confirming that the simulation precisely reproduced the intended geometry without distortion.

The full set of coordinates, including both surface and camber lines, provides greater flexibility for further shape optimization or manufacturing precision, facilitating aerodynamic performance improvements and efficient structural analysis.

Innovations and Improvements

The continuity and fine resolution of the points along both upper and lower surfaces allow computational optimization algorithms to work more effectively, supporting future geometric refinements or custom airfoil adaptations for specific performance targets.

The data structure (explicit surface and camber lines) supports the implementation of advanced analysis techniques, such as thickness and curvature distribution optimization—key to enhancing lift-to-drag ratio and structural efficiency for modern applications.

Key Aerodynamic Findings

The stall angle increases with Reynolds number*, with experimental stall observed at 11° for Re = 150,000 (Baylor setup) and at 15° for Re = 3,000,000 (NACA data), showing that higher Reynolds numbers delay stall.

The coefficient of lift (Cl) measured in the Baylor experiment matches published NACA data within 2%*, indicating reliable experimental accuracy for lift prediction.

The drag coefficient (Cd) measurements exhibited greater inaccuracies and strong dependence on Reynolds number*, mainly due to limited pressure port resolution in Baylor's wind tunnel model.

Experimental Limitations and Recommendations

The pressure port configuration in the Baylor experiment (18 ports) was insufficient for detailed drag mapping; increasing to more ports (as in NACA studies with 54 ports) is advised for future tests.

Recommendations include conducting further experiments with a NACA 0012 airfoil using more pressure ports and advanced fabrication (such as 3D printing) to improve measurement and geometric fidelity.

Practical Implications

The study confirms that NACA air foil data is reproducible experimentally for lift, but drag is sensitive to measurement setup and model resolution.

The geometric and Reynolds number sensitivity insights are valuable for aerodynamics research, air foil optimization, and experimental design.

Conclusion

The investigation validates canonical NACA air foil theory for lift, exposes challenges in drag measurement fidelity, and highlights the importance of experimental refinement—especially for drag analysis—via increased pressure port density and advanced fabrication techniques.