# OPTIMIZATION OF AIRFOIL BASED ON CAMBER LINE & ANGLE OF ATTACK

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## PROBLEM STATEMENT

Transportation is a fundamental aspect of every society. With many advances in the past century, a fundamental method of transportation in the 21st century is through the use of an airplane. This form of transportation is fast, however, not without a large environmental impact. The airfoil of a wing has a large impact on the efficiency of the airplane.

Determine the best of three airfoil designs based on the efficiency, a ratio of the lift and the drag coefficients.

$$Efficiency = \frac{Lift\ Coefficient}{Drag\ Coefficient}$$

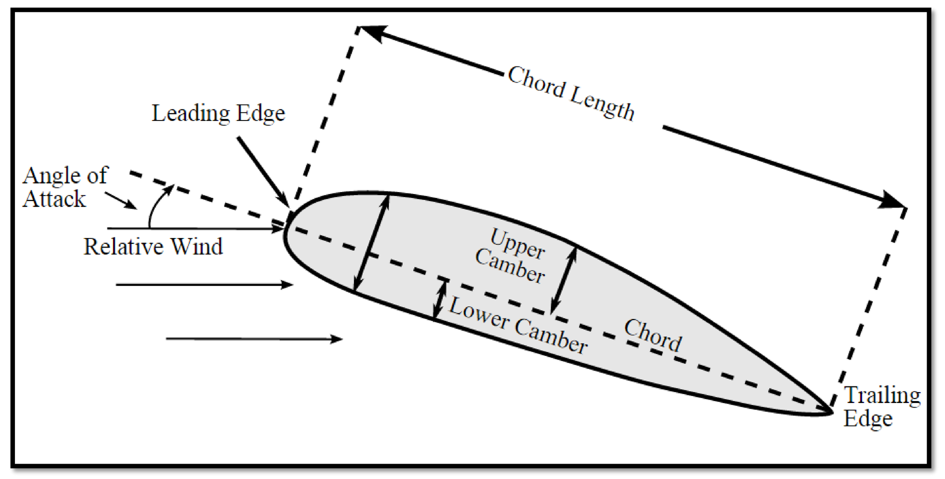


*Figure 1: A typical airfoil design with all geometric properties*

## DEVELOPMENT OF MATHEMATICAL MODEL

### Inviscid Flow Analysis

- Inertial forces, such as induced lift & drag was the primary focus of the analysis
- Flow over an airfoil is a high-Reynolds-number application—where viscous forces can be assumed to be negligible
- Therefore, inviscid flow was used to mathematically model the mesh around the airfoil to reduce the number of varying parameters

### Euler's Equations

- Used by ANSYS Fluent for inviscid flow; so viscosity is negligible for simulation [1]
- Thus, they are a simplification of the Navier-Stokes equation—in which viscous properties of the fluid are considered. [1]
- Euler's equations' results are an approximation of the real-life engineering application. [1]
- Euler's equations mathematically express:
  - Conservation of Mass (or Continuity)

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m$$

  - Conservation of Momentum (based on Newton's Second Law)

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + p)) = -\nabla \cdot \left(\sum_j h_j J_j\right) + S_h$$

  - Conservation of Energy

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v}\,\vec{v}) = -\nabla p + \rho \vec{g} + \vec{F}$$

## IMPLEMENTATION OF MATHEMATICAL MODEL

### Mesh Discretization

- Steady-state, two-dimensional analysis created a static mesh for the simulation
- Fine mesh was used to observe rapid changes in fluid velocity and pressure around the airfoil boundary

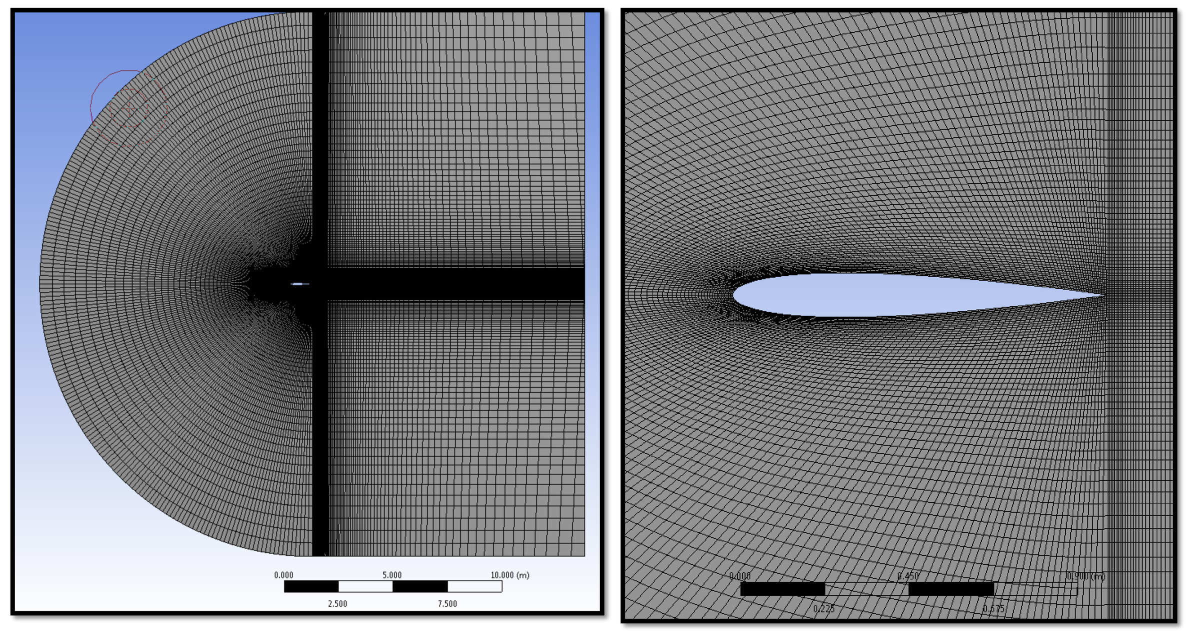

*Figure 2: a) A discretized mesh for 0012 airfoil with fine as mesh type b) Zoomed to the airfoil*

- Discretized using finite-volume method to create quadrilaterals, called cells [2]
- Finite-volume approach used the integral form of the conservation equations applied to the control volume defined to retrieve the discrete equations for the cell [2]

### Material Properties

- The materials are constant for the analysis: air for mesh & aluminum for airfoil

### Boundary Conditions

Convergence Criteria - 1*e^-6

| Boundary Condition | Value | Justification |
|---|---|---|
| Inlet Velocity Magnitude | 1 m/s | Constant, simple, subsonic velocity |
| Gauge Pressure | 0 Pa | The air is incompressible |
| Inviscid Flow | 0 Friction | To assume viscous properties to be negligible |

## PARAMETRIC STUDY

The parameters that were changed were camber of the airfoil and the angle of attack of the wing. These were selected because they the two distinct properties of the cross of the airfoil not the wing itself.

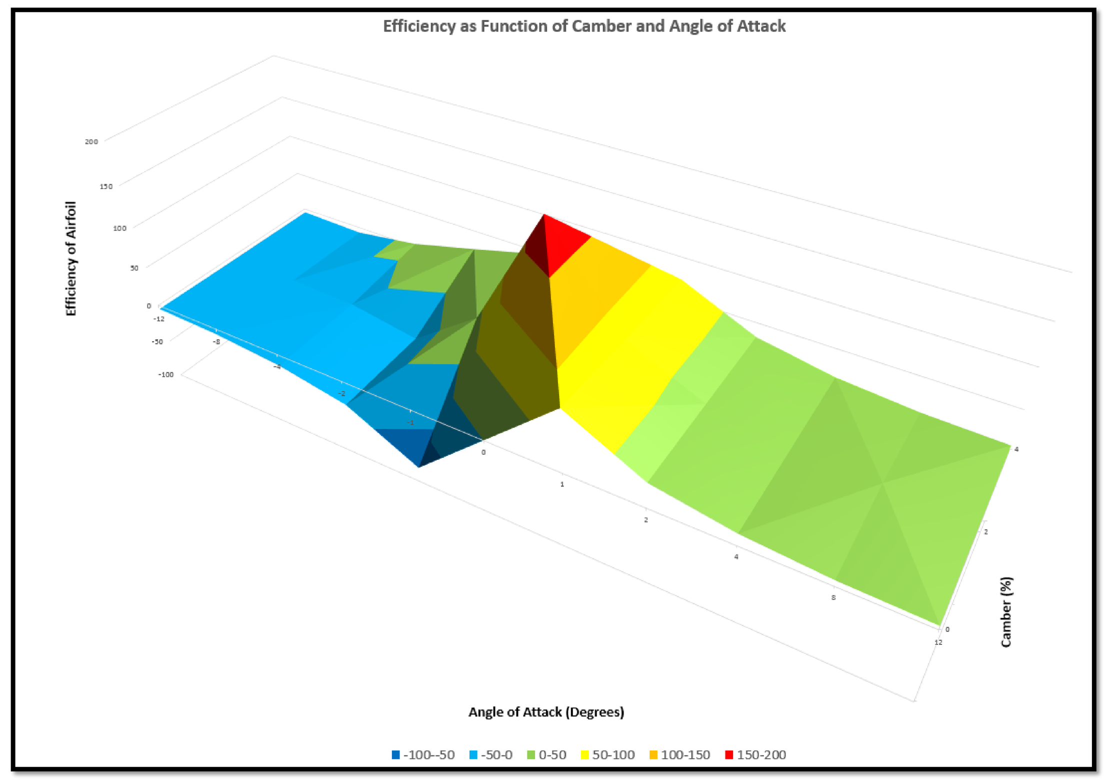


*Figure 3: Comparing the Efficiency with varying camber line & angle of attack*

## RESULTS

From the data we can see that:

- The most efficient angle of attack for each occurs at an angle of attack of approximately 0o, due to a rapid decrease in drag at approximately that angle
- There is no noticeable relationship between camber and efficiency due to the fact that the coefficient of lift at 0o increasing linearly, while the coefficient of drag does not

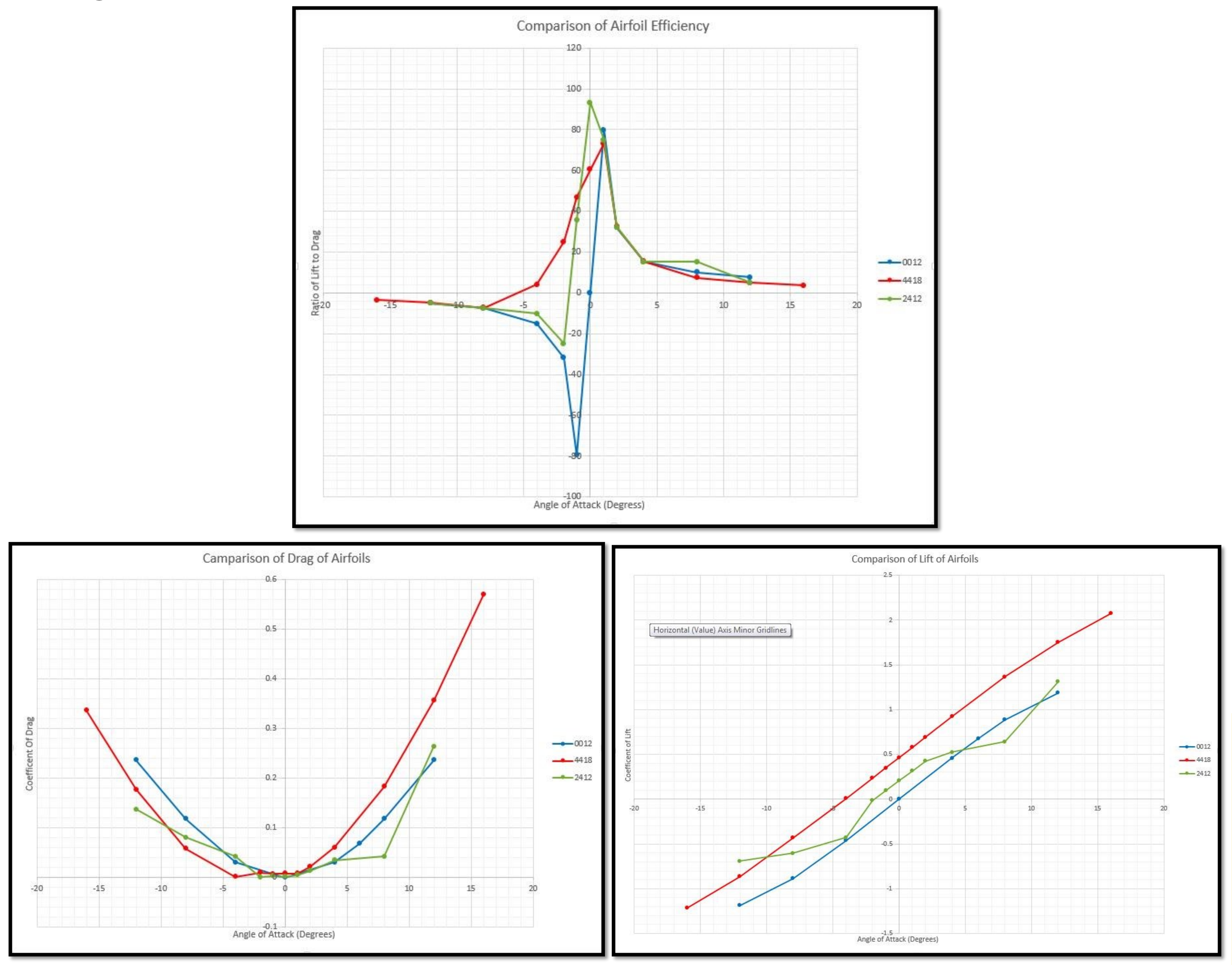


*Figure 4: a) Comparing Lift-to-drag ratio of different airfoils b) Comparing Drag Coefficient of different airfoils c) Comparing Lift Coefficient of different airfoils*

## CONCLUSIONS & ANALYSIS

Each airfoil can be made approximately equal in efficiency by optimizing the angle of attack. The calculation of exact angle of optimum efficiency for each airfoil requires very precise calculations as the values are minuscule and small values have large impacts on the values. In this study the computational tools to calculate values accurately enough to determine exact angles were not available. The model used also had intrinsic error as the angle of the air was being changed , as opposed to the angle of the wing.

## FUTURE RECOMMENDATIONS

- Run more simulations in inviscid flow by varying the other geometric properties of the airfoil, such as thickness and length, and analysing the change effects
- Run simulations in laminar flow rather than using inviscid flow to analyse the fluid viscous properties

## REFERENCES

[1] (April 2009). ANSYS Fluent 12.0 (Release 15.0) [PDF]. Available: http://orange.engr.ucdavis.edu/Documentation12.0/120/FLUENT/flth.pdf

[2] B. Ray, R. Bhaskaran, L. R. Collins. (February 7 2012). Introduction to CFD Basics [PDF]. Available: https://confluence.cornell.edu/display/SIMULATION/FLUENT+-+Introduction+to+CFD+Basics?preview=/90736159/197689659/mae423_notes_update_feb7_12.pdf

[3] I. H. Abbott, Theory of Wing Sections. New York, NY: Dover Publications, 1959.