Department of Mechanical and Mechatronics Engineering

University of Waterloo

ME 597 – Machine Learning for Mechanical Engineers

Project Proposal: Airfoil Performance Prediction Model

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1.0 Motivation

Airfoil design plays a critical role in the performance of aircraft, wind turbines, and other aerodynamic systems. Traditionally, the development of new airfoils requires either extensive computational fluid dynamics (CFD) simulations or costly wind tunnel experiments to evaluate lift, drag, and the angle of stall for various angles of attacks with any given geometry. The relation between the coefficient of lift and angle of attack for any given airfoil geometry is linear and can be predicted through theoretical models. As the angle of attack increases, the airfoil will eventually reach the angle of stall. This angle of stall cannot be found through any theoretical model and needs to be observed empirically. While databases of existing airfoil geometries and analysis tools already exist, the process of predicting the angle of stall for a newly designed airfoil remains resource-intensive and time-consuming.

With the growing need for rapid design cycles, optimization, and exploration of unconventional geometries, there is a strong motivation to create predictive tools that can provide accurate performance estimates without the full computational or experimental overhead. By leveraging machine learning techniques and existing airfoil datasets from websites like *AirFoil Tools*, this project objective is to build a predictive modeling framework capable of estimating the angle of stall for new airfoils prior to experimental simulation. Such a tool would not only accelerate the design and iteration process but also lower computational costs, enabling engineers and researchers to focus on refining promising designs rather than spending resources on trial-and-error evaluations.

Ultimately, this approach will bridge the gap between airfoil geometry data and aerodynamic performance prediction, paving the way for faster innovation in aerodynamics research and industry applications.

2.0 Objectives

The objective of this project is to develop a machine learning–based predictive model capable of estimating the aerodynamic characteristics of newly designed airfoils prior to performing full CFD simulations or physical testing. Specifically, the project aims to:

1. Leverage existing airfoil databases to extract geometric features and aerodynamic performance metrics including the linear relation between the coefficient of lift and angle of attack.
2. Design and train predictive models that can accurately forecast the angle of stall of new airfoil geometries based on the geometric feature inputs.
3. Validate model accuracy against benchmark simulation results to ensure reliability and generalizability across diverse airfoil designs.
4. Provide a scalable framework that accelerates the airfoil design process by reducing reliance on computationally expensive simulations during early-stage development.

By meeting these objectives, the project will create a tool that enhances design efficiency, supports rapid iteration, and broadens the exploration of innovative aerodynamic solutions.

3.0 Approach

The starting point for this project is to convert airfoil geometry into an input vector. This vector will consist of features representing measurable geometric attributes relevant to the stall angle. Examples of such features include chord length, thickness distribution, and leading-edge radius. All features will be normalized to ensure that different airfoil geometries can be compared within the same feature space for model development.

The output of the model will be the stall angle, treated as a continuous variable rather than a categorical one. Since accurately estimating stall angle requires numerical precision, classification would not provide the necessary accuracy. Therefore, this task will be approached as a regression problem, allowing the model to predict stall values directly.

With the inputs, outputs, and problem type defined, the next step is to develop a predictive model for the stall angle. Three model types covered in this course will be tested to determine which yields the most accurate predictions:

- Linear regression, to assess whether a linear relationship exists between geometry and stall angle.
- k-Nearest Neighbors (kNN) regression, to group geometrically similar airfoils and predict stall angle based on the average of the most similar examples.
- Decision tree regression, to capture potential nonlinear relationships by splitting data based on feature thresholds and assigning predictions through the tree's leaves.

The dataset will be divided into training and test sets. Model hyperparameters will be tuned using the training data and validated with the test data. Parameter tuning will focus on minimizing loss to maximize the model's predictive accuracy.