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Aerodynamics Prediction of Airfoil using Artificial Neural Network

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Abstract

In this study, an artificial neural network (ANN)-based method is proposed to predict the aerodynamic characteristics of NACA 0012 airfoil, approximating the flow around the airfoil as a function of Reynolds number (Re), angle of attack (α), airfoil coordinates (X , Y), and lift coefficient (C_L) and drag coefficient (C_D) without extensive software packages. Wind turbine data for C_L and C_D were obtained for α ($0^\circ \leq \alpha \leq 180^\circ$) and Re ($10^4 \leq Re \leq 10^7$). An ANN model was trained to have an MSE of 0.0144 and 0.00062 for C_L and C_D , respectively. The trained model used to evaluate new data had an MSE of less than 0.0081 for C_L and 0.0144 for C_D . The results were validated in a two-dimensional numerical domain using RANS-CFD simulations and experimental data, showing that the proposed ANN approach is in good agreement for predicting the stall shape and aerodynamic characteristics at an angle of attack (α) ranging from ($0^\circ \leq \alpha \leq 30^\circ$).

Background & Objectives

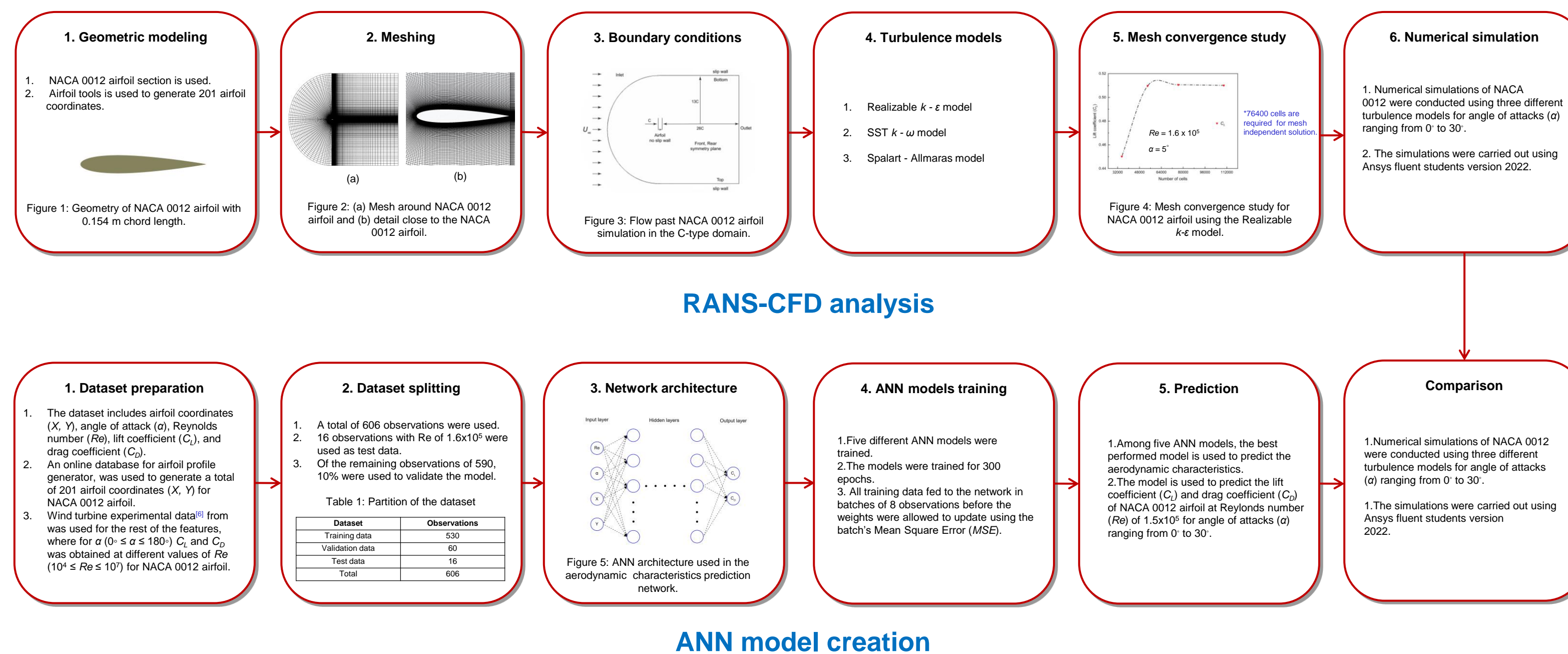
The airfoil shape is responsible for producing lift and drag for wind turbines, aircraft wings, and ship rudders. Therefore, the precision of the lift coefficient (C_L) and drag coefficient (C_D) has a significant impact on the airfoil design process. The analysis of the flow field tends to be the most computationally intensive and time-consuming part of the process. Because of

- massive computational resources needed, especially with the increased number of DOFs;
- for the final results, the machine experience gained during the simulation is lost.

Trained artificial neural network (ANN) models have recently gained attention for learning the responses of large, complex, and nonlinear systems^[1]. Previous studies that used ANN models to predict aerodynamic characteristics relied heavily on different CFD simulation software tools to generate training data^[2,3,4,5]. However, CFD simulation software tools have certain real-world limitations. Consequently, ANN models generated from these data will eventually mimic those limitations because the accuracy of the ANN is heavily dependent on the data quality during the training phase. Therefore, the goal of this study is

- to use reliable training data from wind turbine experiment^[6];
- to reduce extensive dependence on software packages;
- to reduce the time needed to solve.

Methodology



Conclusions

This study developed a neural network model to predict airfoil aerodynamic characteristics using experimental data to test the feasibility of deep learning in flow analysis. To validate the ANN model, RANS-based CFD simulations with three turbulence models in a two-dimensional domain were performed. Evidently, when compared with the experimental data, the ANN model easily outperformed each of the three turbulence models. More specifically, when the angle of attack (α) was in the range of 11° - 30° , the ANN model produced the most precise outcome or, in other words, had the least amount of error compared to all other turbulence models. When α was in 0° - 10° range, different turbulence models performed better. Even at α (0° - 10°), the ANN model outperformed all other turbulence models. Additionally, the ANN model successfully predicted the stall shape for airfoil, whereas the turbulence models failed to do the same. Also, The ANN model used much less computational power than RANS-based CFD analysis. Thus, the proposed ANN approach can accurately predict the aerodynamic characteristics of marine rudders and other airfoil-shaped geometries.

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Results & Discussion

