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A Parameter Optimization of the γ-SST Transition Model for Moderate Reynolds Number Flows over Airfoils

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ABSTRACT

Accurate prediction of laminar-to-turbulent transition is critical for aerodynamic performance analysis in moderate Reynolds number applications, such as wind turbine blades and airfoils. While the Reynolds-averaged Navier-Stokes (RANS) framework with eddy viscosity models remains a widely used approach due to its computational efficiency, its capability to predict transition accurately often falls short compared to high-fidelity methods like Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES). This limitation is particularly pronounced in moderate Reynolds number flows, where transition phenomena are highly sensitive to flow conditions and model parameters.

This study focuses on modifying specific parameters within the γ-SST transition model to enhance its predictive accuracy for moderate Reynolds number flows. In this work, key parameters such as the transition onset criteria, intermittency production terms are systematically adjusted. A Monte Carlo targeting method is employed to explore the parameter space and identify optimal combinations that minimize discrepancies with high-fidelity data. The improved model is then rigorously validated by simulating transitional flows over NACA0018 and NLF416 airfoils at moderate Reynolds numbers, where transition is triggered by different mechanisms.

The results are evaluated based on their ability to capture key transition characteristics, such as transition onset location, boundary layer growth, and separation-induced transition. Comparative analyses against DNS and LES data for velocity profiles, displacement thickness, momentum thickness, and shape factors demonstrate significant improvements in predictive accuracy. The modified model shows enhanced capability in capturing the complex interplay between laminar, transitional, and turbulent regions, particularly in scenarios with adverse pressure gradients and mild separation. Sensitivity analyses reveal the relative importance of each parameter in influencing transition prediction, providing valuable insights for future model development.

This work establishes a refined transition modeling approach that bridges the gap between computational efficiency and predictive accuracy, offering a practical tool for engineering applications where moderate Reynolds number flows are prevalent. The findings also highlight the potential for further improvements by incorporating additional flow physics, such as receptivity to free-stream disturbances and non-local effects, into the RANS framework.