Master’s thesis

Classification/Regression Hybrid Approaches for Data-Driven RANS Modelling

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Preface

This is my master's thesis the final piece to complete my studies in Computational Sciences in Engineering at the TU Braunschweig. The thesis allowed me to dive into two fascinating fields of research: turbulence and machine learning. Turbulence describes a chaotic phenomena which combines the natural beauty of fluid flow with an intricate complexity that keeps stimulating my curiosity. In machine learning, computers search for patterns in data and learn to predict these. In combining both fields, I had the chance to conduct captivating research and gather a rich learning experience.

Throughout this thesis I have received much support and assistance. I would first like to thank my supervisor Dr. Richard Dwight for giving me the opportunity to join his research group at the TU Delft and for providing me with the freedom to creatively explore my research topic, thank you for numerous meetings and inspiring discussions.

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Finally, I want to thank my family and friends for wise counsel and an open ear whenever I needed it. You have helped me to disconnect from the work for a while. I am very grateful for your support throughout the last years of my studies and, especially, the last months.

Henrik Wüstenberg
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Abstract

Reynolds-averaged Navier-Stokes (RANS) turbulence models have a narrow range of applicability and low predictive accuracy. The SST model improves the range and overall accuracy with a smooth boundary layer identification. The identification allows blending of two turbulence models. The present work explores the possibility of more versatile identifications based on machine learning algorithms. The identification locally detects either high or low uncertainty in RANS predictions. High uncertainty is presumed when assumptions in RANS eddy-viscosity models are violated due to either anisotropic turbulence or negative eddy viscosity. The machine learning algorithms train identifier models to predict high uncertainty using local mean flow quantities based on high-fidelity simulation data. To provide challenging flow physics, the high-fidelity data includes a variety of flows with strong separation and adverse pressure gradients. The selected algorithms train algebraic identifier models with a simple mathematical form that enables direct insight into the identification. It is shown that algebraic models of higher complexity show significant improvements. They correctly identify most violations with mean true-positive rate of 88 % for anisotropy and 77 % for negative eddy viscosity. Qualitatively, the identifier models detect wall-blocking induced anisotropy and negative eddy viscosity in strongly accelerated flows. However, the effect of complexer flow physics on the identification including the convection of turbulence and influence of strong adverse pressure gradients are not adequately identified by the models.

Übersicht

Reynolds-averaged Navier-Stokes (RANS) Turbulenzmodelle haben einen eingeschränkten Anwendungsbereich und geringe Vorhersagegenauigkeit. Das SST Modell verbessert den Anwendunsbereich und die Genaugikeit, indem es zwei Turbulenzmodelle kombiniert. Diese Kombination basiert auf einer Grenzschichterkennung, welche einen glatten Übergang zwischen den Modellen ermöglicht. Die vorliegende Arbeit untersucht die Möglichkeit einer umfassenderen Erkennung und verwendet dafür Algorithmen für maschinelles Lernen. Die Erkennung sagt lokal eine entweder hohe oder niedrige Unsicherheit in RANS Modellen vorher. Dabei wird hohe Unsicherheit erkannt, wenn die Annahmen von Wirbelviskositätsmodellen durch entweder anisotrope Turbulenz oder negative Wirbelviskosität verletzt werden. Die Algorithmen trainieren Erkennungsmodelle, um hohe Unsicherheit auf Grundlage von mittleren Strömungsgrößen vorherzusagen. Zum Training werden Strömungsdaten aus skalenauflösenden Simulationen mit starker Ablösung oder positiven Druckgradienten verwendet. Da die gewählten Algorithmen Modelle mit einfachen mathematischen Termen trainieren, gewähren diese Einblick in die Erkennung. Die Auswertung zeigt, dass interpretierbare Modelle mit höherer Komplexität deutlich bessere Erkennungen durchführen. Sie detektieren den Großteil der verletzten Modellannahmen mit mittlerer Richtig-Positiv Rate von 88 % für Anisotropie und 77 % für negative Wirbelviskosität. Dabei identifizieren die Modelle Anisotropie in Wandnähe und negative Wirbelviskositäten in stark beschleunigten Strömungen. Jedoch wird der Einfluss komplexer Strömungsphänomene auf die Erkennung, einschließlich des Transports von Turbulenz und dem Effekt positiver Druckgradienten, nicht verlässlich identifiziert.