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Exploring new models for Explicit Algebraic Reynolds Stress Modelling using Multi-Expression Programming

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While eddy-viscosity two-equation Reynolds averaged turbulence models are still more popular in industrial applications, models based on the transport of the Reynolds stresses, such as the explicit algebraic Reynolds stress models (EARSM), have the potential for dealing with complex flows and geometries [1]. These models replace the eddy-viscosity relation in the two-equation models, but present non-trivial complexities when forming algebraic approximations of the anisotropy transport equations. The present work, performed in the framework of the HiFi-TURB project (grant agreement no. 814837), proposes a framework for machine learning (ML) based on a five-term EARSM. Several previous proposals in this direction have based their expression on tensors formed by the strain- and rotation rate tensors, normalized by the turbulence time scale $\tau = K/\varepsilon$. Under this formulation, the tensors and their invariants are all dependent on the dissipation rate ε, and are not limited in the rapid limit when normalized by τ. Hence, when introduced as a framework for ML, the optimization problem is not well posed and realizability of the anisotropy cannot easily be preserved. This work introduces an alternative novel normalization based on s, the L2 norm of the velocity gradient tensor. With this scaling, the tensor terms and their invariants are limited for all parameter values and also independent of ε, except for the equilibrium parameter, $\sigma = sK/\varepsilon$. This framework is then applied to a high-fidelity direct numerical simulation of the 3D Standford diffuser at Reynolds number of 10,000 using the code Alya. This case is well documented with complex internal corner flow and 3D separation while having a relatively simple geometry, thus considered appropriate for EARSM modeling.

The high-fidelity data is then extracted by means of a variational autoencoder (VAE), which enables to cherry pick the data where the EARSM model is acting on the diffuser and feed it to a multi-expression programming (MEP) tool, a genetic programming algorithm that is able to extract analytical expressions from numerical data in a multi-variate regression fashion [2]. MEP has been successfully applied in a number of different scientific applications to obtain analytical regressions of complex datasets. The obtained expressions are further fine-tuned in terms of their coefficients using the data embeddings.

Preliminary results are very promising and show an improvement with respect to the models available in the literature [3]. Firstly, due to the novel formulation, realizability can then more easily be preserved, and data can be explored even with some uncertainties in the derivation of ε. The obtained models, validated a priori, respect the fixed point of homogeneous shear, the log-layer as well as the limits of the EARSM formulation even though some polishing is still needed.

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